december 1959
the
institute
of
radio
engineers

# Proceedings of the IRE

in this issue



Electronic Scanning of Infrared Images: Page 2069

# FILTERS FOR ALL APPLICATIONS FROM STOCK

**HERMETICALLY SEALED TO MIL-T-27A & MIL-F-18327 SPECS.**

Write For NEW Catalog

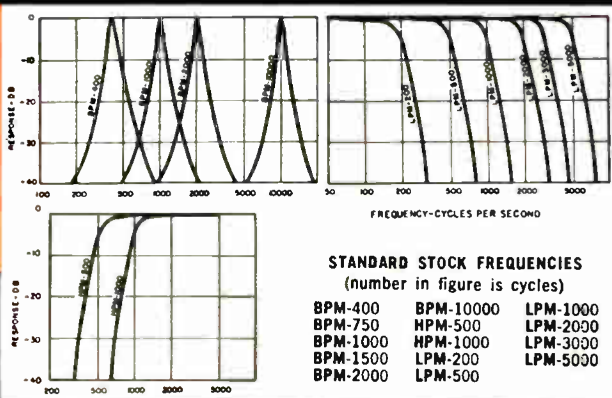
## MINIFILTERS

New Minifilters provide almost the same characteristics (with attenuation only slightly less) as the industry's standard interstage and line filters immediately below.

**BPM** band pass units are 10K input, output to grid; 2:1 gain. Attenuation is approximately 2 db ±3% from center frequency, then 35 db per octave.

**HPM** high pass units; loss of less than 6 db at cut-off frequency; attenuation of 30 db at .67 cut-off frequency, 40 db at .6 cut-off frequency. Input and output 10K.

**LPM** low pass units; loss of less than 6 db at cut-off frequency; attenuation of 30 db at 1.5 cut-off frequency, 40 db at 1.65 cut-off frequency. Input and output 10K.




**STANDARD STOCK FREQUENCIES**
(number in figure is cycles)

| | | |
|---|---|---|
| BPM-400 | BPM-10000 | LPM-1000 |
| BPM-750 | HPM-500 | LPM-2000 |
| BPM-1000 | HPM-1000 | LPM-3000 |
| BPM-1500 | LPM-200 | LPM-5000 |
| BPM-2000 | LPM-500 | |

BPM case (MIL AF)
¾ x ¾ x 1⅛"
Weight 1 oz.

HPM and LPM case (MIL AG)
1 x 1 x 1⅜"
Weight 2¼ oz.

## INTERSTAGE & LINE

These six basic types cover most popular filter applications and frequencies.

**BMI** band pass units are 10K input, output to grid; 2:1 gain. Attenuation is approximately 2 db at 3% from center frequency, then 40 db per octave.

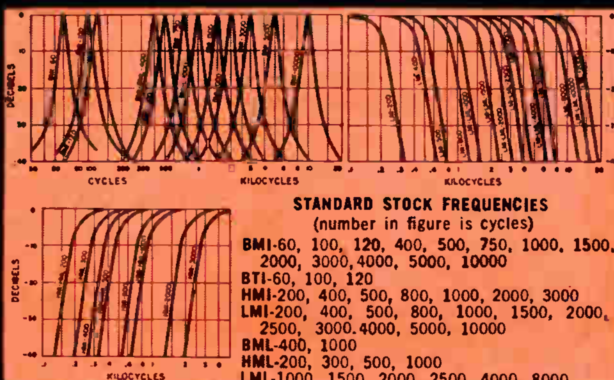
**HMI** high pass units are 10K in and out. Attenuation is less than 6 db at cut-off frequency and 35 db at .67 cut-off frequency.

**LMI** low pass units are 10K in and out. Attenuation is less than 6 db at cut-off frequency and 35 db at 1.5 cut-off frequency.

**HML** high pass filters are same as HMI but 500/600 ohms in and out.

**LML** low pass filters are same as LMI but 500/600 ohms in and out.

**BML** band pass units are same as BMI but 500/600 ohms input, output to grid, 9:1 gain.




**STANDARD STOCK FREQUENCIES**
(number in figure is cycles)

BMI-60, 100, 120, 400, 500, 750, 1000, 1500, 2000, 3000, 4000, 5000, 10000
BTI-60, 100, 120
HMI-200, 400, 500, 800, 1000, 2000, 3000
LMI-200, 400, 500, 800, 1000, 1500, 2000, 2500, 3000, 4000, 5000, 10000
BML-400, 1000
HML-200, 300, 500, 1000
LML-1000, 1500, 2000, 2500, 4000, 8000, 10000, 12000

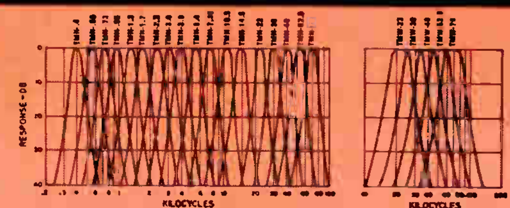
Base ........................ 1⁵⁄₁₆ x 1¹¹⁄₁₆"
Height, BMI, LMI, BML ...... 1⅝"
Height, HMI, HML, LML ...... 2½"
Weight ............... 6 oz. and 9 oz.

## TELEMETERING BAND PASS

UTC standard telemetering filters provide extreme miniaturization with maximum stability, a complete set of 18 filters taking 19 cubic inches. They are 100K in and out and have an insertion loss of less than 6 db, 4 pin header for small Winchester socket.

**TMN** units are within 3 db at ± 7.5% of center frequency . . . down more than 18 db at ± 25% . . . more than 40 db beyond 1.75 and .58 center frequency.

**TMW** are within 3 db at ± 15% of center frequency . . . down more than 20 db at ± 50% . . . more than 40 db beyond 2.5 and .4 center frequency.




**STANDARD STOCK FREQUENCIES**
(number in figure is KC)

| | | | | |
|---|---|---|---|---|
| TMN- .4 | TMN-1.7 | TMN- 5.4 | TMN-30 | TMW-22 |
| TMN- .56 | TMN-2.3 | TMN- 7.35 | TMN-40 | TMW-30 |
| TMN- .73 | TMN-3.0 | TMN-10.5 | TMN-52.5 | TMW-40 |
| TMN- .96 | TMN-3.9 | TMN-14.5 | TMN-70 | TMW-52.5 |
| TMN-1.3 | | TMN-22 | | TMW-70 |

TMN-2.3 thru TMW-70
[illegible] x 25/32 x [illegible]"
Weight 1 2 oz.

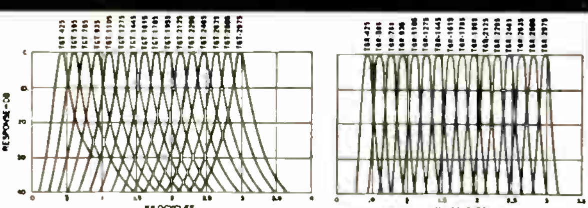
TMN-.4 thru TMN-1.7
[illegible] x 1[illegible] x 2"
Weight 3 5 oz.

## TELEGRAPH TONE CHANNEL

These band pass filters for multiplex transmitting and receiving provide maximum stability in miniature sizes. Both receiving and transmitting types are 600 ohms in and out, and employ 7 terminal header for sub-miniature 7 pin socket.

**TGT** transmitting filters are within 3 db at ± 42.5 cycles from center frequency . . . down more than 16 db at ± 170 cycles . . . down more than 7.5 db at adjacent channel crossover.

**TGR** receiving filters are within 3 db at ± 42.5 cycles from center frequency . . . down more than 30 db at ± 170 cycles . . . down more than 15 db at adjacent channel crossover.




**STANDARD STOCK FREQUENCIES**
(number in figure is cycles)

| TRANSMITTING | | RECEIVING | |
|---|---|---|---|
| TGT-425 | TGT-1785 | TGR-425 | TGR-1785 |
| TGT-595 | TGT-1955 | TGR-595 | TGR-1955 |
| TGT-765 | TGT-2125 | TGR-765 | TGR-2125 |
| TGT-935 | TGT-2295 | TGR-935 | TGR-2295 |
| TGT-1105 | TGT-2465 | TGR-1105 | TGR-2465 |
| TGT-1275 | TGT-2635 | TGR-1275 | TGR-2635 |
| TGT-1445 | TGT-2805 | TGR-1445 | TGR-2805 |
| TGT-1615 | TGT-2975 | TGR-1615 | TGR-2975 |

TGT CASE
1½ x 1½ x 2½"
Weight....8 oz.

TGR CASE
1½ x 1½ x 4¼"
Weight....15 oz.

*And Special Units to Your Specifications*

**UNITED TRANSFORMER CORP.**
150 Varick Street, New York 13, N. Y.

PACIFIC MFG. DIVISION: 4008 W. JEFFERSON BLVD., LOS ANGELES 16, CALIF.
EXPORT DIVISION: 13 EAST 40th STREET, NEW YORK 16, N. Y. CABLES: "ARLAB"

VOLUME 47, NUMBER 12

**December, 1959**

*published monthly by The Institute of Radio Engineers, Inc.*

# Proceedings of the IRE®

*contents*



**COVER**

An infrared "window" made of silicon can be made locally opaque by bombarding it with electrons. This phenomenon has been utilized by the Philco Corp. in a novel system for scanning infrared images electronically. The image is dissected by producing a moving opaque spot on the window by means of a scanning electron beam, as described on page 2069.

DECEMBER

*published monthly by The Institute of Radio Engineers, Inc.*

# Proceedings of the IRE®

*continued*



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# 1959 IRE SHOW REGISTRATION:

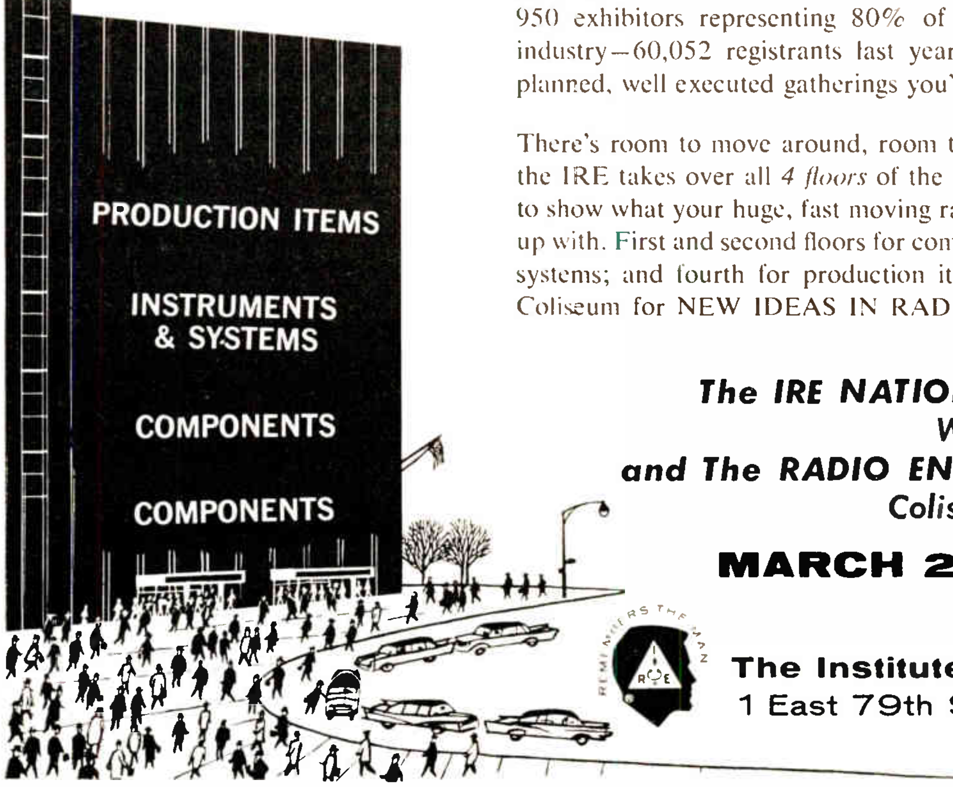
# 60,052

*and we're set to handle even more of you in 1960 looking for*

## NEW IDEAS *in* RADIO-ELECTRONICS!

Yes, the IRE NATIONAL CONVENTION and RADIO ENGINEERING SHOW is growing bigger every year, and drawing more people—950 exhibitors representing 80% of the productive capacity of your industry—60,052 registrants last year! Yet, it's one of the most well planned, well executed gatherings you'll ever see!

There's room to move around, room to see all you want to see because the IRE takes over all *4 floors* of the giant Coliseum in New York City to show what your huge, fast moving radio-electronics industry is coming up with. First and second floors for components; third for instruments and systems; and fourth for production items. Follow the engineers to the Coliseum for NEW IDEAS IN RADIO-ELECTRONICS, 1960!




***The IRE NATIONAL CONVENTION***
*Waldorf-Astoria Hotel*
***and The RADIO ENGINEERING SHOW***
*Coliseum, New York City*

**MARCH 21, 22, 23, 24**

REMEMBERS THE MAN

**The Institute of Radio Engineers**
1 East 79th St., New York 21, N. Y.

**Winthrop Sullivan and Alan Swanson, members of our Department of Medical and Biological Physics recently demonstrated a new device to physicians attending the Convention of the American Physiological Society. This device, an ingestible pressure transensor, will be of great value to the medical researcher.**

# Ingestible Medical Pressure Transensor

For years research workers have sought a painless method for obtaining data concerning the activity of the patient's gastrointestinal tract. Until recently, the only methods available necessitated the patient's swallowing a combination of tubes and wires that led to an external instrument. The passage of this paraphernalia into the gastrointestinal tract frequently caused the patient considerable discomfort. In many cases, the discomfort caused by the tubes and wires reflected itself in the recorded data.

The obvious need for a method of measuring gastrointestinal activity led to development of the Pressure Transensor, a miniature ingestible pressure-sensitive telemetry capsule.

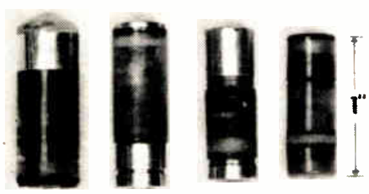



Figure 1. Progressive miniaturization of transensor

Developed from earlier work done by RCA and by the Rockefeller Institute for Medical Research, the capsule contains a pressure transducer that modulates the frequency of an internal transistor oscillator that is powered by a tiny mercury battery. The signal transmitted from the ingested capsule is received by an antenna located outside the body and is demodulated by an FM receiver that produces a voltage proportional to the internal pressure.

A great advantage of the Pressure Transensor is that its small size enables it to pass easily through the gastrointestinal tract and to be recovered and used again. Earlier models have been used in an experimental test program carried out during the last two years by Dr. John Farrar and his associates at the Veterans Administration Hospital in New York; all results indicate that the Transensor causes no discomfort to the patient.

Data obtained from Dr. Farrar's experiments are quite promising.* From records similar to those in the accompanying diagrams, it has been found that most pressures in the gastrointestinal tract range from 0 to 3 psi. Furthermore, the testing of subjects with certain intestinal diseases has resulted in records that appear to be markedly different from those obtained from normal subjects as can be seen in Figure 2. The importance of the data obtained by the Pressure Transensor will be known only after more extensive clinical investigation. Only then will the frequencies and amplitudes of the pressure waves recorded by the Transensor in the gastrointestinal tract come to be meaningful.

The Pressure Transensor is only the first in a series of instruments using telemetry that our Department of Medical and Biological Physics plans to produce. To gain a complete picture of gastrointestinal activity, variables other than pressure must be recorded. At present, we are experimenting with a Transensor capable of measuring temperature, and we are interested in designs to monitor acidity and to detect the presence of blood in the gastrointestinal tract.

The telemetering sensor may not be limited entirely to the study of the gastrointestinal tract. The development of small, short-range telemetering sensors that can be either swallowed or attached inconspicuously to the subject's clothing or person could be used in the field of space medicine to monitor a number of physiological variables. These sensors would not require a complexity of wires and tubes leading to the subject, and the data obtained could provide a key to the behavior of human beings under stress.

***A complete bound set of our third series of articles is available on request. Write to Harold Hechtman at AIL for your set.***

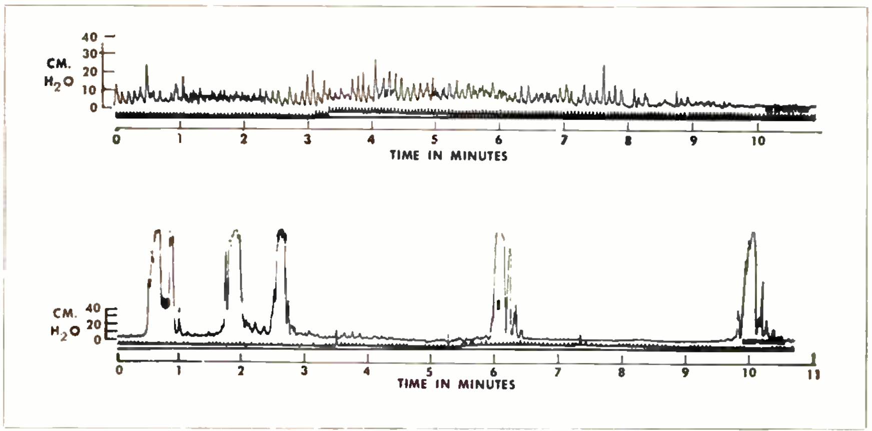



Figure 2. Upper record, example of the normal intraluminal pressure of the jejunum. Lower record, intraluminal pressure of the ileum in a patient with the malignant carcinoid syndrome.

*"Recording of Intraluminal Gastrointestinal Pressures By a Radiotelemetering Capsule," by John T. Farrar, M.D., and James S. Bernstein, M.D.

**Airborne Instruments Laboratory**

**A DIVISION OF CUTLER-HAMMER, INC.**

**OLD COUNTRY ROAD, MINEOLA, L. I., N. Y.**

**Phone MYrtle 2-6100**

# SPRAGUE® RELIABILITY
## in these two dependable wirewound resistors

### MINIATURE Blue Jacket®
**VITREOUS-ENAMEL POWER RESISTORS**

Sprague's new improved construction gives even greater reliability and higher wattage ratings to famous Blue Jacket miniature axial lead resistors.

A look at the small *actual sizes* illustrated, emphasizes how ideal they are for use in miniature electronic equipment with either conventional wiring or printed wiring boards.

Get complete data on these dependable minified resistors, **write for Engineering Bulletin 7410.**

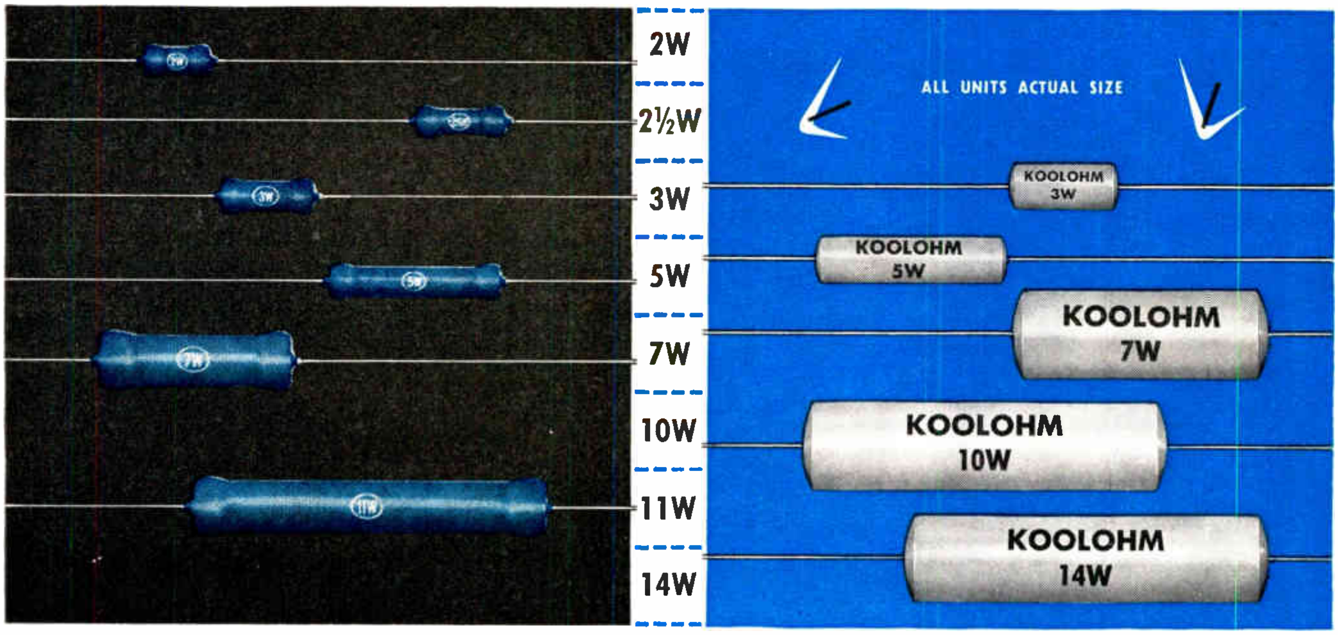
**TAB-TYPE BLUE JACKETS:** For industrial applications, a wide selection of wattage ratings from 5 to 218 watts are available in Sprague's famous Tab-Type Blue Jacket close-tolerance, power-type wirewound resistors. Ideal for use in radio transmitters, electronic and industrial equipment, etc. **For complete data, send for Engineering Bulletin 7400A.**

### NEW SMALLER SIZE KOOLOHM®
**INSULATED-SHELL POWER RESISTORS**

New Koolohm construction features include welded leads and winding terminations—Ceron ceramic-insulated resistance wire, wound on special ceramic core—multi-layer non-inductive windings or high resistance value conventional windings—sealed, insulated, non-porous ceramic outer shells—*aged-on-load* to stabilize resistance value.

*You can depend upon them to carry maximum rated load for any given physical size.*

**Send for Engineering Bulletin 7300 for complete technical data.**

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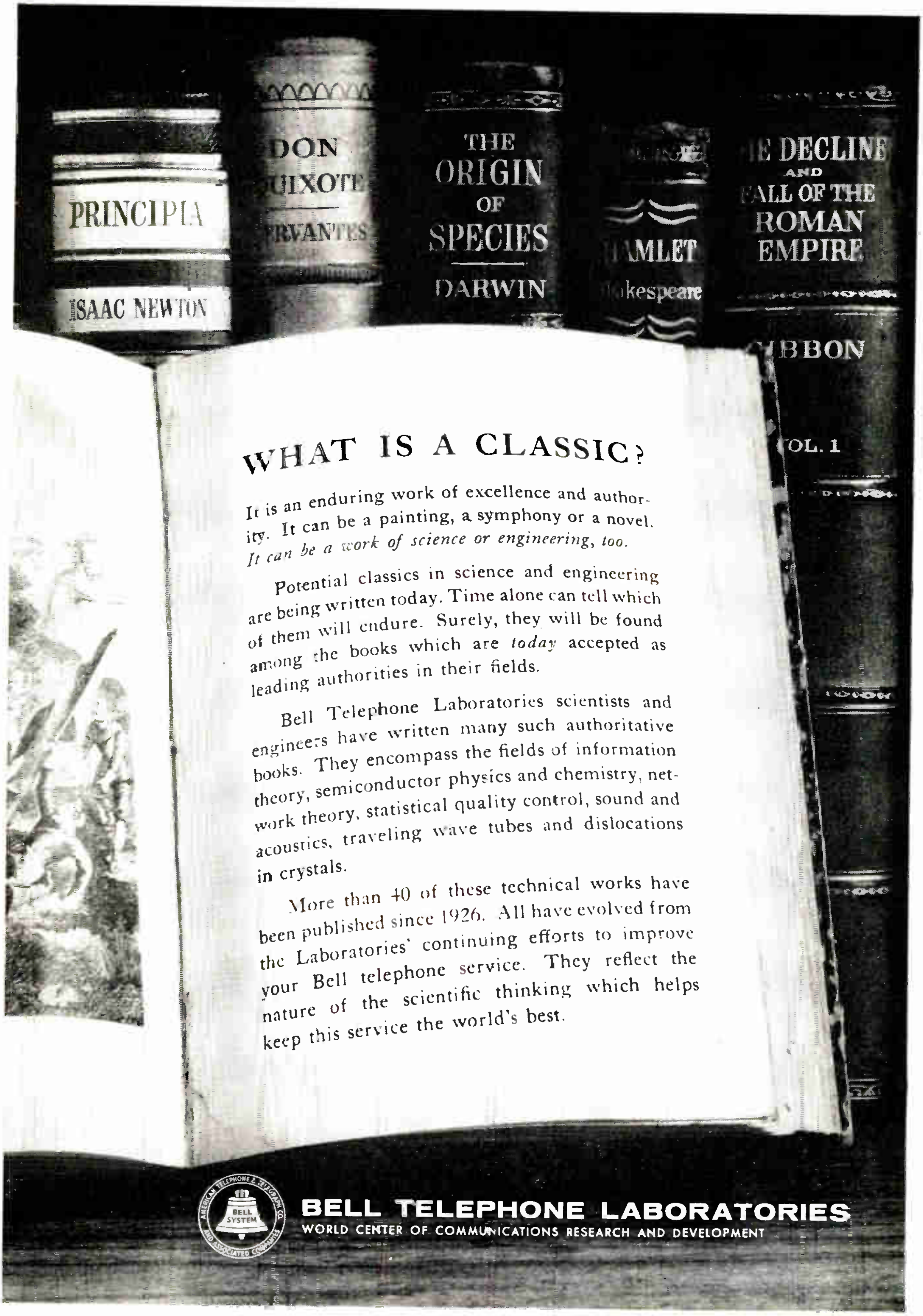
*THE MARK OF RELIABILITY*

**SPRAGUE COMPONENTS:** RESISTORS • CAPACITORS • MAGNETIC COMPONENTS • TRANSISTORS
INTERFERENCE FILTERS • PULSE NETWORKS • HIGH TEMPERATURE MAGNET WIRE • PRINTED CIRCUITS


PRINCIPIA
ISAAC NEWTON
DON
THE
ORIGIN
OF
SPECIES
DARWIN
AND
ROMAN
EMPIRE
WHAT IS A CLASSIC?
It is an enduring work of excellence and authority. It can be a painting, a symphony or a novel. *It can be a work of science or engineering, too.*
Potential classics in science and engineering are being written today. Time alone can tell which of them will endure. Surely, they will be found among the books which are *today* accepted as leading authorities in their fields.
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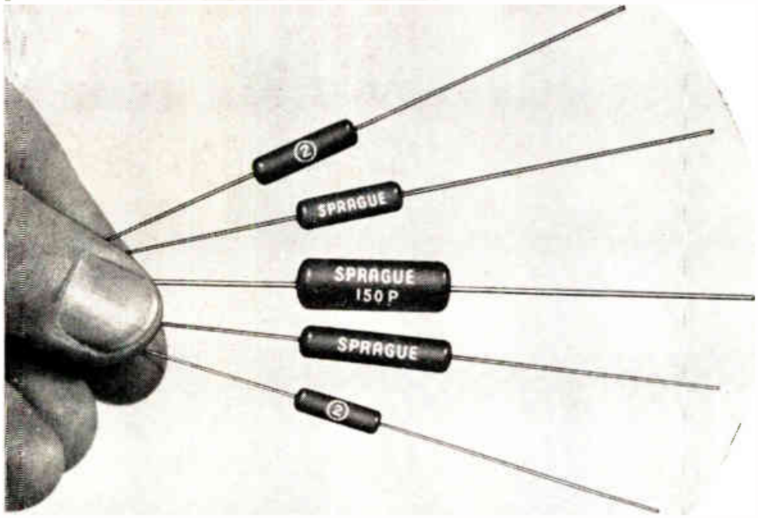


**Miniature**

# PROKAR® 'D' Molded Capacitors

## —with improved moisture resistance and a new dual dielectric for 125 C operation without voltage derating

Sprague's new and improved PROKAR 'D' Molded Tubular Capacitors meet the need for *ever smaller* molded capacitors capable of withstanding 125 C operation in military, commercial, and industrial electronics.

Key to the new design is an improved processing technique which greatly increases moisture resistance. The new dual dielectric used in Type 150P Capacitors combines the dielectric strength of the highest grade capacitor tissue with the effective moisture resistance of plastic film, giving these miniature units high insulation resistance plus extended life at 125 C. The impregnant used is still the same exclusive high temperature organic material which marked a milestone in molded capacitor development for the original Prokar series.

The improved performance of PROKAR 'D' Capacitors is worth investigating—greater resistance to humidity, high insulation resistance (minimum of 10 megohm-microfarads at 125 C), moderate capacitance change with temperature, longer life, and improved reliability.

*For complete specifications on Type 150P PROKAR 'D' Molded Tubular Capacitors, write for Engineering Bulletin 2300 to Technical Literature Section, Sprague Electric Company, 235 Marshall St., North Adams, Mass.*

**SPRAGUE®**
**THE MARK OF RELIABILITY**

SPRAGUE COMPONENTS:

CAPACITORS • RESISTORS • MAGNETIC COMPONENTS • TRANSISTORS • INTERFERENCE FILTERS • PULSE NETWORKS
HIGH TEMPERATURE MAGNET WIRE • CERAMIC-BASE PRINTED NETWORKS • PACKAGED COMPONENT ASSEMBLIES

## Meetings with Exhibits

● As a service both to Members and the industry, we will endeavor to record in this column each month those meetings of IRE, its sections and professional groups which include exhibits.

*February 3-5, 1960*
**PGMIL Winter Meeting,** Biltmore Hotel, Los Angeles, Calif.
*Exhibits:* Mr. Einer Ingebretson, Summers Gyroscope Co., Santa Monica, Calif.

*March 21-24, 1960*
**Radio Engineering Show and IRE National Convention,** Waldorf-Astoria Hotel and New York Coliseum, New York, N.Y.
*Exhibits:* Mr. William C. Copp, Institute of Radio Engineers, 72 West 45th St., New York 36, N.Y.

*April 3-8, 1960*
**Sixth Nuclear Congress,** New York Coliseum, New York, N.Y.
*Exhibits:* Mr. F. M. Howell, c/o EJC, 29 W. 39th St., New York 18, N.Y.

*April 20-22, 1960*
**SWIRECO, Southwestern IRE Regional Conference & Electronics Show,** Shamrock-Hilton Hotel, Houston, Texas.
*Exhibits:* Mr. A. D. Seixas, SWIRECO, P.O. Box 22331, Houston, Texas.

*May 2-4, 1960*
**National Aeronautical Electronics Conference,** Dayton Biltmore Hotel, Dayton, Ohio.
*Exhibits:* Mr. Edward M. Lisowski, General Precision Lab., Inc., Suite 452, 333 West First St., Dayton 2, Ohio.

*May 2-6, 1960*
**Western Joint Computer Conference,** Fairmont Hotel, San Francisco, Calif.
*Exhibits:* Mr. H. K. Farrar, Pacific Tel. & Tel. Co., 140 New Montgomery St., San Francisco 5, Calif.

*May 23-25, 1960*
**Seventh Regional Technical Conference & Trade Show,** Olympic Hotel, Seattle, Wash.
*Exhibits:* Dr. Frank Holman, Boeing Airplane Co., 10708 39th Ave., S.W., Seattle 66, Wash.

*May 24-26, 1960*
**Armed Forces Communications & Electronics Association Convention and Exhibit,** Sheraton-Park Hotel, Washington, D.C.
*Exhibits:* Mr. William C. Copp, 72 West 45th St., New York 36, N.Y.

*June 27-29, 1960*
**National Convention on Military Electronics,** Sheraton-Park Hotel, Washington, D.C.
*Exhibits:* Mr. L. David Whitelock, BuShips, Electronics Div., Dept. of Navy, Washington, D.C.

(continued on page 10A)

KAY KAY KAY

# For High Accuracy—Broad Band Noise-Figure Measurement


# KAY
# *Therma-Node*

**Basic Noise Source**
**CAT. NO. 770**

## Available Noise
Accurate to ± 0.1 db

## 3 Noise Heads
Cover 1 kc to 1000 mc

## Portable
Can be Operated from
117 V, 60 cycles or 24 V dc

### SPECIFICATIONS

STANDARD NOISE HEAD: (Head A furnished with **Therma-Node**), covers 2 to 1000 mc; output impedance 50 ohms, unbalanced. N type connectors.
Max. VSWR, variable tuned, 1.1 from 10 to 1000 mc.
Max. VSWR, fixed tuned, 1.1 from 10 to 100 mc; 1.2 from 6 to 300 mc; 1.4 from 4 to 400 mc; 2 from 2 to 500 mc.

INTERCHANGEABLE LOW FREQUENCY NOISE HEAD: (Head B), covers 1 kc to 400 mc; output impedance 50 ohms, unbalanced.
Max. VSWR 1.1 from 3 kc to 100 mc; 1.2 from 2 kc to 250 mc; 1.4 from 1 kc to 400 mc.

AMBIENT SOURCE PROBE for use with A and B Noise Heads:
Frequency range—0 to 1000 mc.
Output impedance—50 ohms, unbalanced.
Max. VSWR—1.1
Accuracy of indicated temperature—±1%.

SELECTABLE-IMPEDANCE NOISE HEAD: (Head C) covers 0.25 to 400 mc, balanced or unbalanced output. Selectable output impedances of 50, 100 and 200 ohms are provided.
Max. VSWR—1.1 from 1 to 75 mc; 1.2 from 0.5 to 100 mc; 1.4 from 0.25 to 400 mc.
Max. VSWR difference between ambient and hot source is 0.05 (hot and ambient sources contained in same probe).

**Weight:** 8 pounds in carrying case.
**Dimensions:** 11.5 x 8 x 4.75 inches.
Operates on 117 V, 60 cps, or 24 V dc
**Price: $495.00,** f.o.b. factory.
Low Frequency Noise Head (B): $125.00.
Selectable Impedance Head (C): $125.00.

Through refinement of a basic noise generation technique—thermal noise from a heated resistive element—the new Kay *Therma-Node* achieves high accuracy over an extremely wide range of frequencies. *Therma-Node's* resistive element, contained in the noise head, is heated to a normal 2200° K, generating adequate noise-power for accurate noise figure measurements to 10 db. Nominal fixed available noise temperature ranging between 2000 and 2400° K may be read directly on the panel meter to 2% accuracy. A single tuning element, contained in the noise head, provides a fixed range of 2 to 500 mc, and may be tuned to extend the range to 1000 mc. An optional, interchangeable head extends measurement down to 1 kc. Ambient termination is supplied. Both heads have output impedances of 50 ohms, unbalanced. Both heads can be used without connecting coaxial cables, thus eliminating cable errors.

A selectable-impedance noise head, covering the range .25 to 400 mc, and furnishing output impedances of 50, 100 and 200 ohms, balanced and unbalanced, is available as an accessory.

The inexpensive resistive element in the *Therma-Node* noise head has a life expectancy of 10,000 hours in either intermittent or continuous service. Because the few active components in the *Therma-Node* are solid state devices, its inherent stability results in long term accuracy and freedom from maintenance.

**OTHER KAY NOISE GENERATORS**

| Instrument & Cat. No. | Frequency Range (mc) | Noise Figure Range (db) | Output Impedance (ohms) | Price f.o.b. factory |
|---|---|---|---|---|
| *Mega-Node* 240-B | 5-220 | 0-16 at 50 ohms<br>0-23.8 at 300 ohms | unbal.—50, 75, 150, 300, ∞<br>bal.—100, 150, 300, 600, ∞ | $365.00 |
| *Mega-Node* 175-A | 50-500 | 0-19 | balanced 300 | $365.00 |
| *Mega-Node* 403-A | 3-500 | 0-19 | unbalanced 50 | $365.00 |
| *Mega-Node-Sr.* 250-B | 10-3000 | 0-20 | unbalanced 50 | $790.00 |
| *Rada-Node* 600-A | 5-400 | 0-23.8 depending on impedance | unbalanced as specified | $1495.00 |
| | 10-3000 | 0-20 | unbal. nom. 50 | $1965.00 |
| | 1120-26,500 | 15.28 or 15.8 | waveguide | † |
| *Micro-Node* 1080-A | 3700-4200 | 0-15.8 | waveguide | $795.00 |
| *Microwave Mega-Nodes** | 1120-26,500 | 15.28 or 15.8 | waveguide | $175.00 to $595.00 |

† Price varies with Microwave Mega-Node discharge tube used as accessory.
* Ideally suited for noise figure measurement in radar communication

*WRITE FOR*
*KAY CATALOG 1959-A*


**KAY ELECTRIC COMPANY**
Dept. I-12 Maple Avenue, Pine Brook, N.J. CApital 6-4000


KAY KAY KAY

## Meetings with Exhibits

(Continued from page 8A)

*August 23-26, 1960*

**WESCON, Western Electronic Show and Convention,** Ambassador Hotel & Memorial Sports Arena, Los Angeles, Calif.

*Exhibits:* Mr. Don Larson, WESCON, 1435 LaCienega Blvd., Los Angeles, Calif.

*September 19-21, 1960*

**National Symposium on Space Electronics & Telemetry,** Shoreham Hotel, Washington, D.C.

*Exhibits:* John Leslie Whitlock Associates, 6014 Ninth St., North, Arlington 5, Va.

*October 3-5, 1960*

**Sixth National Communications Symposium,** Hotel Utica & Utica Memorial Auditorium, Utica, N.Y.

*Exhibits:* Mr. W. R. Roberts, 102 Fort Stanwix Park N., Rome, N.Y.

*October 10-12, 1960*

**National Electronics Conference,** Hotel Sherman, Chicago, Ill.

*Exhibits:* Mr. Arthur H. Streich, National Electronics Conference, 184 E. Randolph St., Chicago, Ill.

*October 24-26, 1960*

**East Coast Aeronautical & Navigational Electronics Conference,** Lord Baltimore Hotel & 7th Regiment Armory, Baltimore, Md.

*Exhibits:* Mr. R. L. Pigeon, Westinghouse Electric Corp., Air Arm Div., P.O. Box 746, Baltimore, Md.

*November 14-16, 1960*

**Mid-America Electronics Convention (MAECON),** Municipal Auditorium, Kansas City, Mo.

*Exhibits:* Mr. John V. Parks, Bendix Aviation Corp., P.O. Box 1159, Kansas City 41, Mo.

*November 15-17, 1960*

**Northeast Electronics Research & Engineering Meeting (NEREM),** Boston Commonwealth Armory, Boston, Mass.

*Exhibits:* Miss Shirley Whitcher, IRE Boston Office, 73 Tremont St., Boston, Mass.

*December 1-2, 1960*

**PGVC Annual Meeting,** Sheraton Hotel, Philadelphia, Pa.

*Exhibits:* Mr. E. B. Dunn, Atlantic Refining Co., 260 S. Broad St., Philadelphia 1, Pa.

Δ

Note on Professional Group Meetings: Some of the Professional Groups conduct meetings at which there are exhibits. Working committeemen on these groups are asked to send advance data to this column for publicity information. You may address these notices to the Advertising Department and of course listings are free to IRE Professional Groups.

Ingenious, ultra-convenient...

# NEW (hp) 196A OSCILLOSCOPE CAMERA

## combines every feature you've wanted

**FULL-SIZE, DISTORTION-FREE PICTURES.** Full picture area may be scaled.

**SHARP, CLEAR PICTURES, JUST LIKE CRT ITSELF.** New f/1.9 lens has a flat field.

**ADJUST CAMERA ON SCOPE.** Not necessary to remove camera to set f-stop and shutter.

**SIMPLE, ONE-HAND MOUNTING.** Easy clamp mounts camera on scope with "quick-lock" tab.

**MULTIPLE EXPOSURES ARE EASY.** With one hand, move lens through 11 detented positions.

**EASY TAB PULLING.** Polaroid® Land Camera back is securely fastened.

**INSURED AGAINST LIGHT LEAKS;** uses professional camera bellows.

**WEAR GLASSES?** Keep 'em on while viewing image with both eyes.

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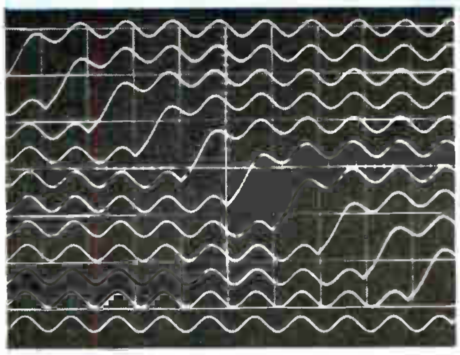
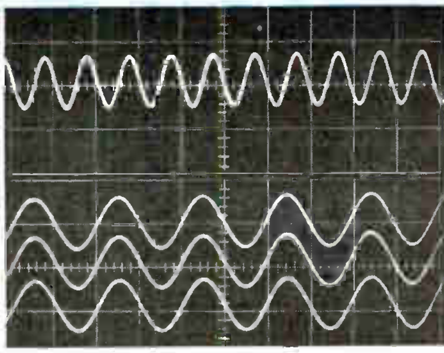


Up to 11 equally spaced exposures available



Two 4 x 10 cm field exposures. No overlapping

New -hp- 196A Camera on -hp- 120A Oscilloscope

The new (hp) 196A Oscilloscope Camera is the most convenient means yet devised for recording oscilloscope traces. Operation is extremely simple and swift; loss of film from light leakage is eliminated; mounting and unmounting takes just seconds; the entire unit is light weight, rugged, compact, yet a precision instrument in every respect.

*Check the specifications below, and ask your (hp) representative for demonstration on your oscilloscope.*

| | | | |
|---|---|---|---|
| **Object/Image Ratio:** | 1 to 0.9. (Adjustable to 1:1 ratio) | **Film:** | Polaroid ® Land types 42, 44, 46, 46-L. |
| **Lens:** | Wollensak 3" (75 mm) f/1.9 Oscillo-Raptar | **Size:** | 13½" long, 9¼" high, 10" wide Weight 9 lbs. |
| **Shutter:** | Alphax #3. Time, Bulb, 1/100, 1/50, 1/25, 1/10, 1/5, 1/2, 1 second | **Accessories Available:** | Carrying case, Tektronix adapter |
| **Print Size:** | 2-7/8" x 3-13/16" | **Price:** | $425.00 |

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

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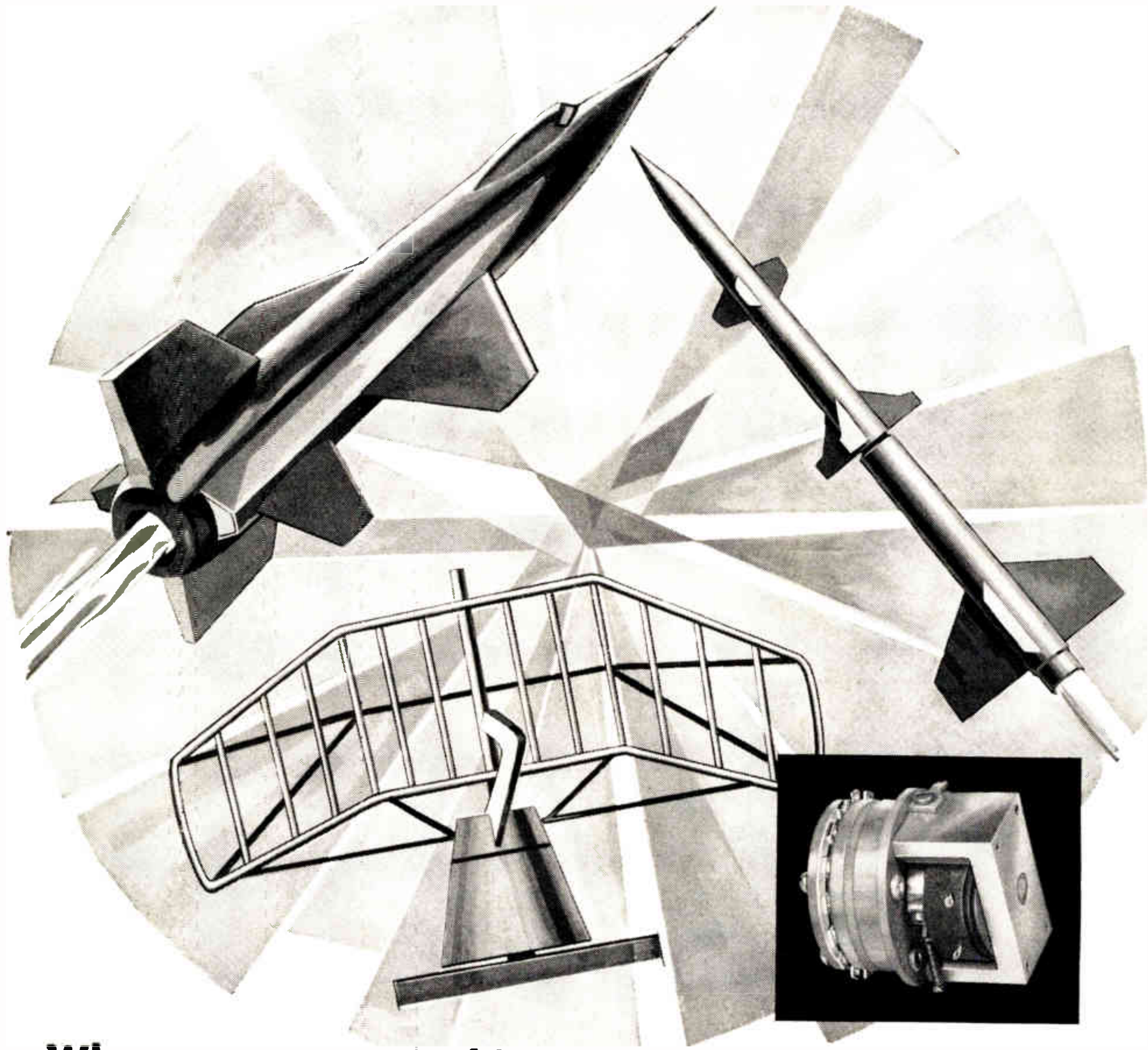

# Where can you use this versatile HI-SHOCK SWITCH?

Military missiles, mines, shipboard antennas, or industrial and commercial equipment wherever rigorous vibration, shock or constant acceleration is present, this new Hi-Shock Switch offers distinct advantages.

**Engineered and custom-packaged.** The Hi-Shock Switch can be used for remote power switching (mounted directly on moving members) . . . changeover from primary to auxiliary power source, AC or DC . . . rapid stepping of power distribution.

**Hermetically Sealed.** Use in remotely controlled, power operated units or as a sequence exciter for auxiliary prime movers.

**100% Rotary Action, Counter Balanced.** The actuator, a rotary solenoid, is counter balanced in all axes. Standard coil voltages range from 6 to 48 volts, but other ranges can be furnished as required. High-speed stepping—30 per second—is one feature; higher speeds are available for specific designs.

**Positive Stopping, Positive Locking.** The ratchet mechanism prevents overshooting of the switch contacts—which will not move except during actual stepping. This mechanism is simple, reliable, virtually fatigue-proof.

**Knife-Edge Contacts.** On rotary switch contacts are strong and simple, provide positive connections to prevent chattering under acceleration and other vibration-producting conditions.

**Environmental Ratings.** The Hi-Shock Switch withstands non-operating impacts of 1000 g for one millisecond parallel to its rotating axis, and 100 g for one millisecond perpendicular to its rotating axis. The stepping switch operates under vibration, in three mutually perpendicular axis, of 0.5″ double amplitude 5—17.5 cps., and 10 g 17.5—2000 cps. Constant operating acceleration may be as high as 100 g, in axis parallel to rotation. Operating temperature range may exceed —65°F. and +165°F., and could be extended under special conditions.

Other models also developed with varying configurations and contact arrangements with higher current rating. Write for complete details. *Hi-Shock, Singer Military Products Division, Singer-Bridgeport, 915 Pembroke Street, Bridgeport 8, Conn.*

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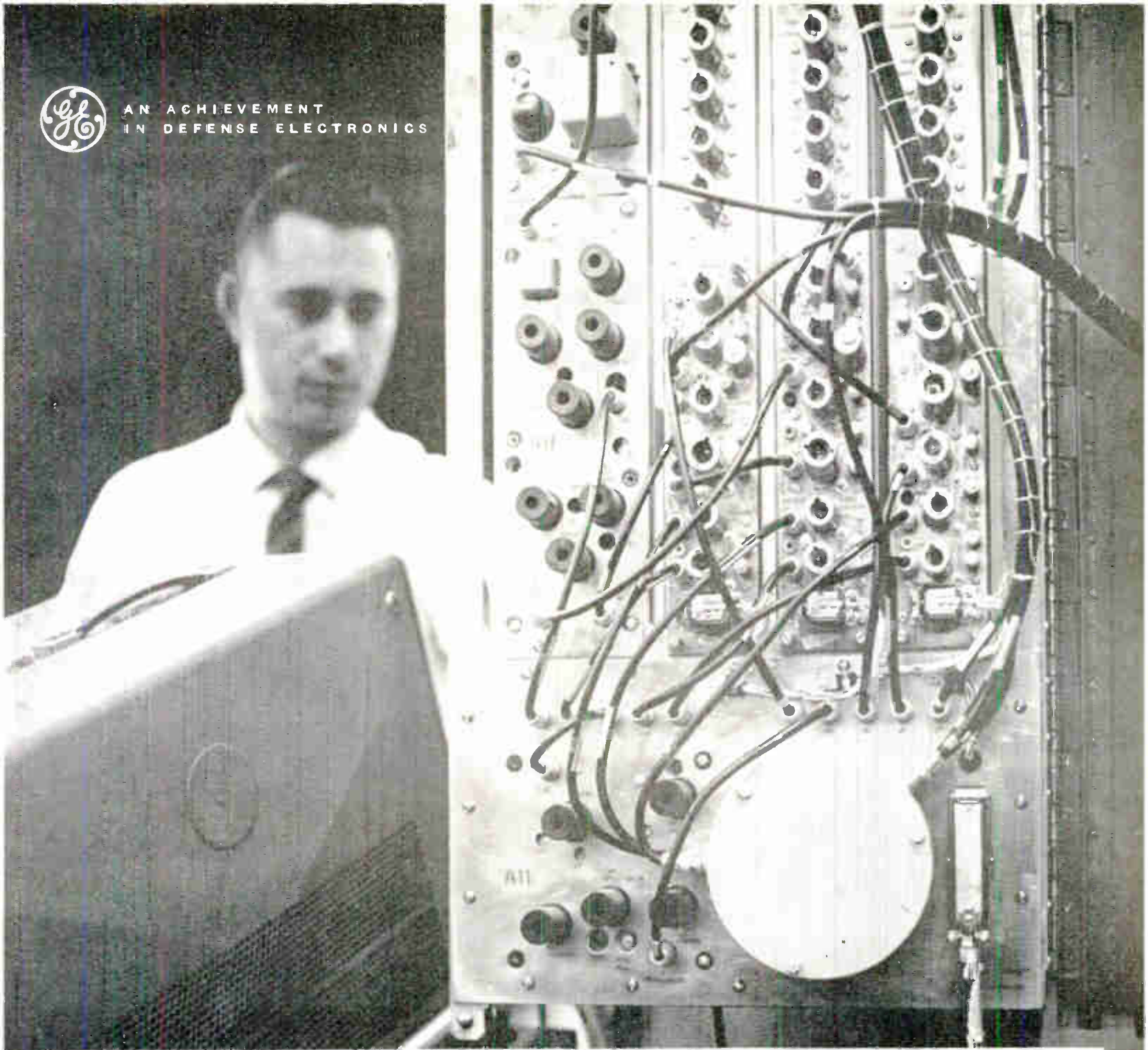


# NEW SONAR SIGNAL PROCESSOR DOES WORK OF 1,000 UNITS

The first sonar signal processors to utilize time compression are being produced by General Electric. These new processors were developed in cooperation with the United States Navy. Extracting only critical bits of transmitted and received signals in series, one unit can perform as many correlating operations on a continuous signal—in the same time—as a parallel processor with thousands of units.

Excellent improvement in signal-to-noise ratio also makes these new processors effective against background levels which have formerly made certain signals undetectable by any other practical means. The new equipment is also designed to handle signals from more than one transducer.

This advance in sonar signal processing is typical of General Electric's many achievements in defense electronics. 227-3

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## Calendar of Coming Events and Authors' Deadlines*

**1959**

Eastern Joint Comp. Conf., Hotel Statler, Boston, Mass., Dec. 1–3.

4th Midwest Symp. on Circuit Theory, Brooks Mem. Union, Marquette Univ., Milwaukee, Wis., Dec. 1–2.

PGVC Annual Meeting, St. Petersburg, Fla., Dec. 3–4.

Institute of Mathematical Statistics Mtg., Washington, D.C., Dec. 27–30.

**1960**

6th Natl. Symp. on Reliability and Quality Control, Statler-Hilton Hotel, Wash., D.C., Jan. 11–13.

PGMIL Winter Mtg., Biltmore Hotel, Los Angeles, Calif., Feb. 3–5.

1960 Solid State Circuits, Conf., Sheraton Hotel, Phila., Pa., Feb. 10–12.

IRE National Conv., N. Y. Coliseum and Waldorf-Astoria Hotel, New York, N. Y., Mar. 21–24.

First Natl. Symp. on Human Factors in Electronics, New York, N. Y., Mar. 24–25.

Scintillation Counter Symp., Washington, D.C., Mar.

6th Nuclear Congress, N. Y. Coliseum, New York, N. Y., Apr. 4–8.

Conf. on Automatic Tech., Sheraton-Cleveland Hotel, Cleve., Ohio, Apr. 18–19.

SWIRECO (Southwestern Regional Conference), Houston, Texas, Apr. 20–22.

Natl. Aeronautical Electronics Conf., Dayton, Ohio, May 2–4.

Western Joint Computer Conf., San Francisco, Calif, May 2–6.

PGMTT Natl. Symp., San Diego, Calif., May 9–11. (DL*: Jan. 15, D.B. Medved, CONVAIR, Div. of Gen. Dynamics Corp., Mail Zone 6-172, San Diego, Calif.

Electronic Components Conf., Washington, D. C., May 10–12.

7th Reg. Tech. Conf. & Trade Show, Olympic Hotel, Seattle, Wash., May 23–25.

Natl. Conv. on Mil. Elec., Sheraton Park Hotel, Washington, D. C., June 27–29.

* DL = Deadline for submitting abstracts.

*(Continued on page 15A)*

## PGMTT Symposium Calls for Papers

The 1960 annual symposium of the PGMTT will be held May 9–11 at the Hotel del Coronado, Coronado, Calif. Papers in the field of microwave components, systems and physics, are being solicited for presentation at the meeting. One hundred word abstracts in triplicate and 500 word summaries in triplicate should be submitted before January 15, 1960 to Dr. D. B. Medved, Chairman, Technical Program Committee, 1960 PGMTT Symposium, CONVAIR, Div. of General Dynamics Corp., Mail Zone 6-172, San Diego 12, Calif.

All papers are to be submitted in English. Authors should advise the Technical Program Committee if any paper will have been presented elsewhere or published prior to the symposium.

## D. B. Sinclair Attends Hungarian Colloquium

Donald B. Sinclair attended a Colloquium on Microwave Communication sponsored by the Hungarian Academy of Sciences, held in Budapest, Hungary, November 10–13, 1959, as a representative of the IRE, of which he is past president, and is now a vice president and director. He is chief engineer, vice president and director of the General Radio Co., West Concord, Mass.

Last year he was a delegate to a similar meeting held in the USSR at which representatives from six Western nations and six Iron Curtain countries were invited guests.

Preliminary information on the Budapest meeting indicated that special consideration would be given to system analysis (with emphasis on long-distance transmission), microwave electronics (including circuits and antennas) and general electronic circuitry. The papers are delivered in Hungarian, English, German and Russian, and provision is made for simultaneous translation so that all representatives can follow each talk as delivered.

## H. P. Kalmus Awarded Prize at Army Symposium

Henry P. Kalmus (A'39–SM'45–F'56), Associate Director for Advanced Research at the Diamond Ordnance Fuze Laboratories, Washington, D. C., was awarded a certificate of commendation and a cash prize of $500.00 for his first place entry in in the field of electronics at the National Military Science Symposium. The meeting was conducted by the Department of the Army, at West Point, N. Y. The award-winning paper concerned Mr. Kalmus' invention entitled "Cigarette Fuze."

## PGHFE Will Conduct First Annual Symposium

The IRE Professional Group on Human Factors in Electronics will hold its first annual symposium in New York, N. Y., the evening of March 24 and all day March 25, 1960.

Those interested in presenting papers or in suggesting symposia should correspond as soon as possible with either R. R. Riesz, Chairman of the Papers Procurement Committee, c/o Bell Telephone Labs., Murray Hill, N. J.; or J. E. Karlin, Chairman of the Meetings Committee, at the same address.

Chairman George E. Hagerty (left) presenting the Scott Helt Award of the PG on Broadcasting to Professor Alfred H. La Grone of the University of Texas. The plaque was awarded at the Ninth Annual Broadcast Symposium.

## A. J. Buxton and M. O. Felix Receive NEC Annual Award

A. J. Buxton and M. O. Felix (SM'55), both of Canadian Westinghouse Company, Ltd., received the National Electronics Conference Award for their joint paper, "The Performance of FM Scatter Systems Using Frequency Compression." The NEC award, consisting of $500 and certificates, was presented to them on October 12, 1959, during the 15th Annual NEC. The paper was adjudged the best in terms of scholarship, originality, significance and clarity among the 100 papers presented October 13–15, 1958, at the 14th Annual NEC.

Mr. Buxton and Mr. Felix are co-inventors of a method to improve scatter communications systems by significantly reducing undesirable noise. The scatter system is used for long-range, beyond-the-horizon transmission of voice, television, teletype, facsimile, telemetering and data signals over hops of 100 to 200 miles. They are currently working on scatter projects for the RCAF, U. S. Air Force, and Supreme Headquarters Allied Powers in Europe.

## J. J. Lamb Receives ARRL Merit Award

The Merit Award of the American Radio Relay League for 1959 went to James J. Lamb (A'28–SM'48–F'54) for his significant contributions to the welfare of amateur radio. He was presented the award at the New England Division Convention of the League, at Hartford, Conn.

The plaque is inscribed: "For his contribution to amateur communication techniques, especially in the development of methods for achieving high selectivity and noise reduction in radio reception."

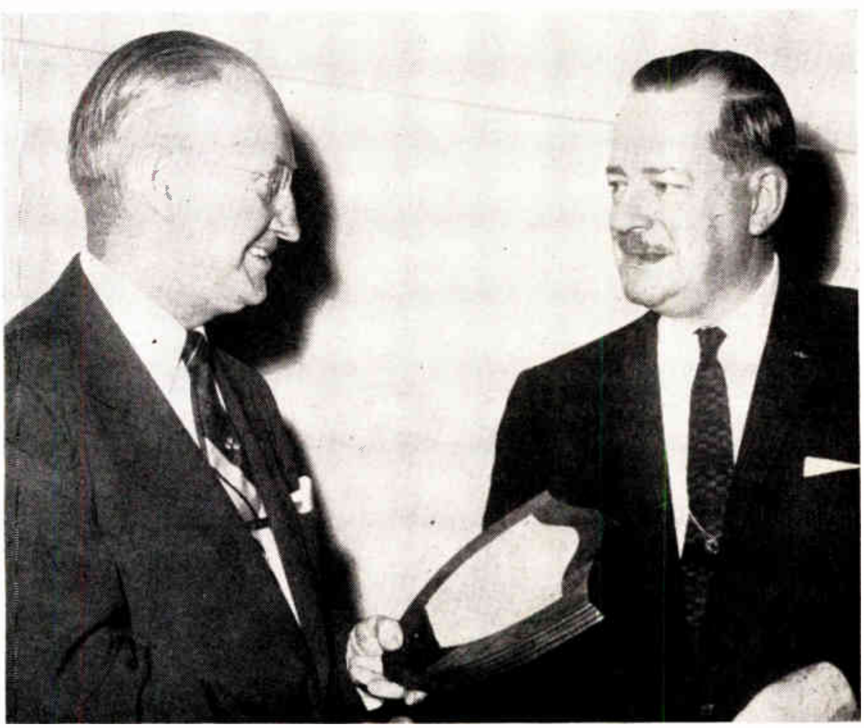
The work which the ARRL Merit Award commemorates was done during his tenure as technical editor of the League's monthly publication, QST, and exercised a profound influence on the course of development of radio receivers for communications applications. The Lamb crystal filter, an integral part of the receiving system developed by him, has been a standard feature of communications receivers for more than 25 years.

Born in Michigan, N. D., Mr. Lamb received the E.E. degree from Catholic University of America, Washington, D. C., in 1922, operated a standard broadcast station in Grand Forks, N. D. in the early 1920's and joined the technical staff of the ARRL in 1928. He was technical editor from 1929 until 1939 and in 1940 was a research engineer with the League working on special projects. In 1941, he was chosen to organize and head the newly-formed Electronic Division of Remington-Rand, Inc. (now Sperry-Rand) to develop military airborne television equipment. In recent years he has specialized in digital data developments, and in 1959 became an independent consulting engineer, concentrating on communications and industrial electronics.

## Three Honored in Italy for Outstanding Achievement in Telecommunications

The Christopher Columbus International Award for outstanding achievement in telecommunications was presented in Genoa, Italy, on October 12, to Brig. General David Sarnoff, Chairman of the Board of RCA; Dr. E. W. Engstrom, Senior Executive Vice President of RCA; and Dr. V. K. Zworykin, Honorary Vice President of RCA.

The presentation was made by President Giovanni Gronchi of Italy at the closing session of the Seventh International Congress on Communications. General Sarnoff and Dr. Engstrom received the award, which consists of a purse and gold medal, in person.



James J. Lamb (*left*) receiving the ARRL Merit Award for 1959 from G. L. Dosland, President of the League.

### Calendar of Coming Events and Authors' Deadlines*

(*Continued from page 14A*)

**Cong. Intl. Federation of Automatic Control, Moscow, USSR, June 25–July 9.**

**WESCON, Los Angeles Mem. Sports Arena, Los Angeles, Calif., Aug. 23–26.**

**Space Electronics and Telemetry Conv. and Symp., Shoreham Hotel, Washington D.C., Sept. 19–22.**

**Industrial Elec. Symp., Sept. 21–22.**

**Sixth Natl. Communications Symp., Hotel Utica and Utica Memorial Aud., Utica, N. Y., Oct. 3–5.**

**Natl. Elec. Conf., Chicago, Ill., Oct. 10–12.**

**East Coast Conf. on Aero & Nav. Elec., Baltimore, Md., Oct. 24–26.**

**Electron Devices Mtg., Hotel Shoreham, Washington, D. C., Oct. 27–29.**

**Radio Fall Mtg., Hotel Syracuse, Syracuse, N. Y., Oct. 31, Nov. 1–2.**

**Mid-Amer. Elec. Conv., Kansas City, Mo., Nov. 14–16.**

**1960 NEREM (Northeast Electronics Res. & Engrg. Mtg.), Boston, Mass., Nov. 15–17.**

**13th Ann. Conf. on Elec. Tech. in Med. and Bio., Washington, D. C., Nov.**

**PGVC Ann. Mtg., Sheraton Hotel, Philadelphia, Pa., Dec. 1–2.**

**Eastern Joint Computer Conf., New Yorker Hotel, New York, N.Y., Dec.**

**1961**

**IRE National Conv., N.Y. Coliseum and Waldorf-Astoria Hotel, New York, N.Y., Mar. 20–23.**

**Electronic Computer Conf., West Coast, May 9–11.**

**WESCON, San Francisco, Calif., Aug. 22–25.**

**Natl. Symp. on Space Elec. and Telemetry, Sept.**

**Industrial Elec. Symp., Sept. 20–21.**

**National Elec. Conf., Chicago, Ill., Oct. 9–11.**

**1961 NEREM (Northeast Electronics Res. & Engrg. Mtg.), Nov. 14–16.**

**1961 Electron Devices Mtg., Shoreham Hotel, Washington, D. C., Nov. 20–21.**

**Mid-America Elec. Conv. (MAECON), Kansas City, Mo., Nov. 14–16.**

**Eastern Joint Computer Conf., Sheraton Park Hotel, Washington, D. C., Dec.**

* DL = Deadline for submitting abstracts.

## Current IRE Standards

Please order by number from IRE Headquarters, 1 E. 79 St., N. Y. 21, N. Y. A 20 per cent discount will be allowed on order for 100 or more copies mailed to one address.

| | *Standard* | *Cost* |
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| 48 | **IRE 2., 11., 15.S1 Standards on Antennas, Modulation Systems, and Transmitters: Definitions of Terms, 1948** | $0.75 |
| 53 | **IRE 2.S1 Standards on Antennas and Waveguides: Definitions of Terms, 1953. Adopted by ASA. (ASA C16.21-1954.)** Reprinted from the December, 1953, Proceedings | $0.75 |
| 55 | **IRE 2.S1 Standards on Antennas and Waveguides: Definitions for Waveguide Components, 1955.** Reprinted from the September, 1955, Proceedings | $0.25 |
| 59 | **IRE 2.S1 Standards on Antennas and Waveguides: Waveguide and Component Measurements, 1959** Reprinted from the April, 1959, Proceedings | $0.75 |
| 48 | **IRE 2.S2 Standards on Antennas: Methods of Testing, 1948. Adopted by ASA. (ASA C16.11-1949.)** | $0.75 |
| 54 | **IRE 3.S1 Standards on Audio Techniques: Definitions of Terms, 1954.** Reprinted from the July, 1954, Proceedings | $0.50 |
| 56 | **IRE 3.S1 Standards on Audio Systems and Components: Methods of Measurement of Gain, Amplification, Loss, Attenuation and Amplitude-Frequency-Response, 1956. Adopted by ASA. (ASA C16.29-1957.)** Reprinted from the May, 1956, Proceedings | $0.80 |
| 58 | **IRE 3.S1 Standards on Audio Techniques: Definitions of Terms, 1958.** Reprinted from the December, 1958, Proceedings | $0.60 |
| 53 | **IRE 3.S2 Standards on American Recommended Practice for Volume Measurements of Electrical Speech and Program Waves, 1953. Adopted by ASA. (ASA C16.5-1954.)** Reprinted from the May, 1954, Proceedings | $0.50 |
| 50 | **IRE 4.S1 Standards on Circuits: Definitions of Terms in Network Topology, 1950.** Reprinted from the January, 1951, Proceedings | $0.50 |
| 53 | **IRE 4.S1 Standards on Circuits: Definitions of Terms in the Field of Linear Varying Parameter and Nonlinear Circuits, 1953.** Reprinted from the March, 1954, Proceedings | $0.25 |
| 51 | **IRE 6.S1 Standards on Electroacoustics: Definitions of Terms, 1951.** Reprinted from the May, 1951, Proceedings | $1.00 |
| 52 | **IRE 7.S1 Standards on Magnetrons: Definitions of Terms, 1952.** Reprinted from the May, 1952, Proceedings | $0.25 |
| 54 | **IRE 7.S1 Standards on Electron Devices: Definitions of Terms Related to Phototubes, 1954.** Reprinted from the August, 1954, Proceedings | $0.25 |
| 56 | **IRE 7.S1 Standards on Electron Devices: Definitions of Terms, Related to Microwave Tubes (Klystrons, Magnetrons, and Traveling Wave Tubes), 1956.** Reprinted from the March, 1956, Proceedings | $0.50 |
| 57 | **IRE 7.S1 Standards on Electron Tubes: Physical Electronics Definitions, 1957.** Reprinted from the January, 1957, Proceedings | $0.50 |
| 50 | **IRE 7.S2 Standards on Electron Tubes: Methods of Testing, 1950.** Part I Reprinted from August, 1950, Proceedings. Part II Reprinted from September, 1950, Proceedings | $1.25 |
| 52 | **IRE 7.S2 Standards on Gas-Filled Radiation Counter Tubes: Methods of Testing, 1952. Adopted by ASA. (ASA C60.11-1954.)** Reprinted from the August, 1952, Proceedings | $0.75 |
| 54 | **IRE 7.S2 Standards on Electron Devices: Definitions of Semiconductor Terms, 1954.** Reprinted from the October, 1954, Proceedings | $0.50 |
| 56 | **IRE 7.S2 Standards on Electron Devices: Definitions of Terms Related to Storage Tubes, 1956.** Reprinted from the April, 1956, Proceedings | $0.25 |
| 57 | **IRE 7.S2 Standards on Electron Tubes: Definitions of Terms, 1957.** Reprinted from the July, 1957, Proceedings | $1.00 |
| 52 | **IRE 7.S3 Standards on Gas-Filled Radiation Counter Tubes: Definitions of Terms, 1952.** Reprinted from the August, 1952, Proceedings | $0.50 |
| 56 | **IRE 7.S3 Standards on Electron Tubes: TR and ATR Tube Definitions, 1956.** Reprinted from the August, 1956, Proceedings | $0.50 |
| 56 | **IRE 8.S1 Standards on Electronic Computers: Definitions of Terms, 1956.** Reprinted from the September, 1956, Proceedings | $0.60 |
| 59 | **IRE 8.S1 Standards on Static Magnetic Storage: Definition of Terms, 1959.** Reprinted from the March, 1959, Proceedings | $0.50 |
| 43 | **IRE 9.S1 Standards on Facsimile: Temporary Test Standards, 1943** | $0.20 |
| 56 | **IRE 9.S1 Standards on Facsimile: Definitions of Terms, 1956. Adopted by ASA. (ASA C16.30-1957.)** Reprinted from the June, 1956, Proceedings | $0.60 |
| 55 | **IRE 10.S1 Standards on Industrial Electronics: Definitions of Industrial Electronics Terms, 1955.** Reprinted from the September, 1955, Proceedings | $0.50 |
| 53 | **IRE 11.S1 Standards on Modulation Systems: Definitions of Terms, 1953.** Reprinted from the May, 1953, Proceedings | $0.50 |
| 58 | **IRE 11.S1 Standards on Information Theory: Definitions of Terms, 1958.** Reprinted from the September, 1958, Proceedings | $0.50 |
| 54 | **IRE 12.S1 Standards on Radio Aids to Navigation: Definitions of Terms, 1954. Adopted by ASA. (ASA C16.26-1955.)** Reprinted from the February, 1955, Proceedings | $1.00 |
| 59 | **IRE 12.S1 Standards on Navigation Aids: Direction Finder Measurement, 1959.** Reprinted from the August, 1959, Proceedings | $1.00 |

(*Continued on page 18A*)

## MIL-E-CON Issues Call for Papers

The 4th National Convention on Military Electronics—1960 (MIL-E-CON) will be held at the Sheraton-Park Hotel, Washington, D. C., on June 27–29, 1960, under the sponsorship of the Professional Group on Military Electronics. Robert H. Cranshaw, Manager, Advanced Space Projects, General Electric Company, Utica, N. Y., is Convention President for MIL-E-CON.

Papers presenting original work in military electronics are invited for this meeting. Suggested topics include, but are not limited to the following: Current Problems of Space Technology, Space Electronics, Ranging and Tracking, Electronic Propulsion, Data Handling Systems, Guidance and Control, Inertial Systems, Reconnaissance Systems, Communication Systems, Operational Analysis, and Reliability.

The technical program will include both classified (limited to confidential) and unclassified sessions, with the Air Research and Development Command sponsoring the classified sessions. An unclassified and bound *Proceedings* of the convention will be available at the meeting.

Prospective authors are requested to furnish the following information, *not later than February 1, 1960;* Three copies of a 250-word unclassified abstract of the proposed paper, plus the name and position of the author and the name and address of his company or organization. Each author must obtain the appropriate military and company clearances for his abstract.

Send abstracts to: Dr. Craig M. Cranshaw, Dept. of Army, Office of the Chief Signal Officer, R & D Div., SIGRD-2, Washington 25, D. C.

## Army MARS Announces December Schedule

The First U. S. Army Military Affiliate Radio System (MARS) Single Side Band Technical Net has scheduled five speakers for December. The net can be heard each Wednesday at 9 P.M. EST on 4030 kilocycles upper sideband. The schedule includes:

December 2—"Technical Aspects of Satellite Communications," L. Smilen, Res. Associate, Microwave Res. Inst., Brooklyn Polytechnical Institute.

December 9—"The Trans-Atlantic Submarine Telephone Cable," H. West, Plant Design Engineer, Long Lines Dept., American Telephone & Telegraph Co.

December 16—"Determination of Percent Success Expectable in High Frequency Radio Transmission," G. Krause, Project Engineer, Analysis Engineering Div., U. S. Army Signal Radio Propagation Agency, Fort Monmouth.

December 23—"FM Forward Scatter Tropospheric Communications Systems," J. Lesmez, Project Engineer, Radio Engineering Labs. Inc.

December 30—"Coaxial Cable," M. Ferber, Sales Engineer, Times Wire & Cable Co.

# George at the Forge

*The day the mobile radar was delivered to Washington at Valley Forge, it was so cold a man's shadow froze to the ground. Nevertheless, the Father of his Country managed to work up a good head of steam when he saw the unit.*

*"Idiots!" he stormed. "Why do they send me radar when we need food and shelter and clothing? What good is it? Does it have Bomac tubes?"**

*"No sir," his orderly shivered. "It doesn't seem to have any tubes at all. But it might make a nice warm fire."*

*"I was thinking the same," Washington said. And, without another word, he went and got a little hatchet and chopped and chopped.*

*The wind blew and the chips flew. Soon, the installation was reduced to kindling.*

*"That's more like it," the General said when he was done. "Now, if someone will hand me a match . . ."*

*But he never finished the sentence. The ice on which he was standing suddenly gave way, and he disappeared into the frigid water.*

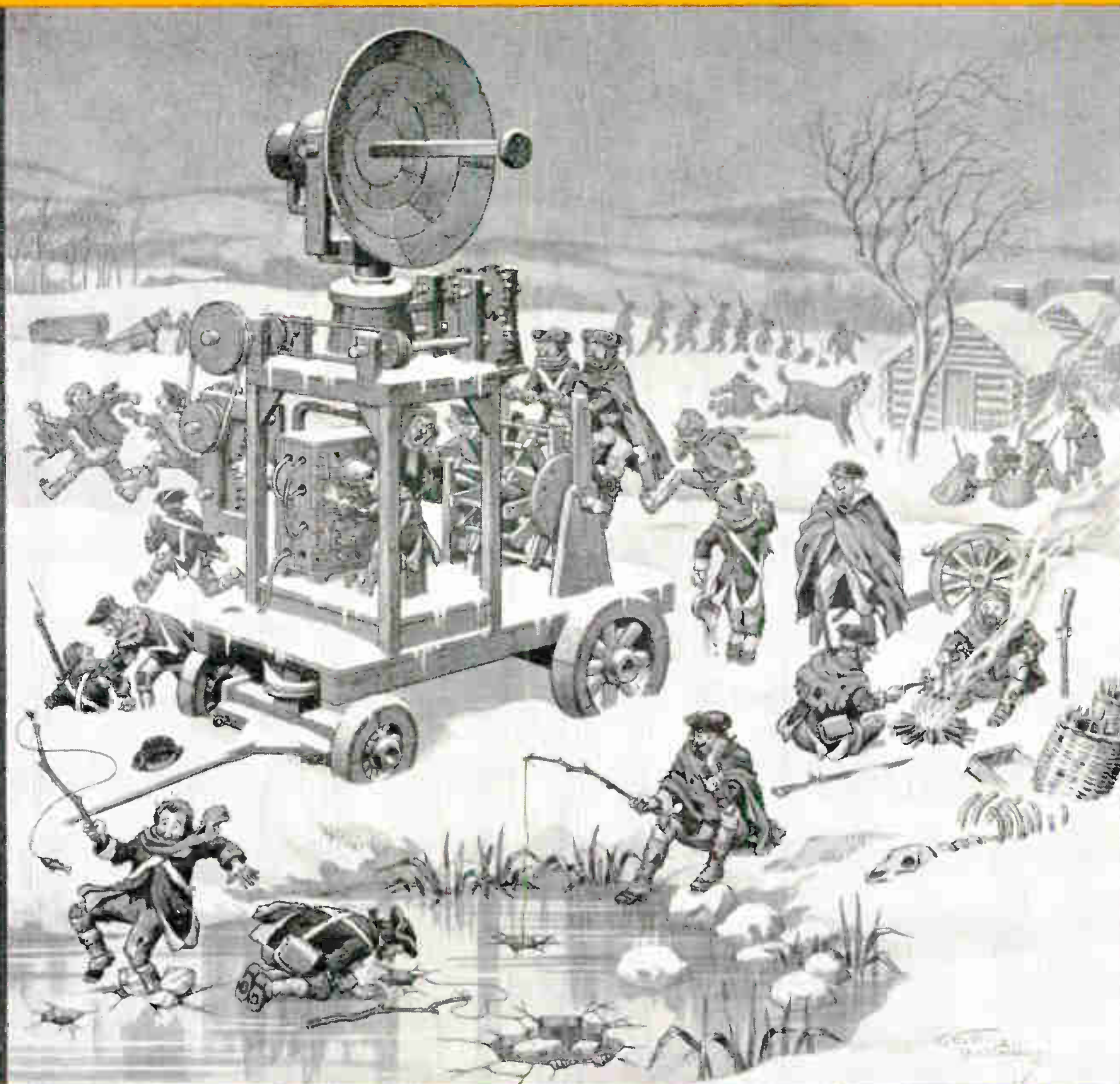
*"General, general are you all right?" the orderly asked as he fished him out.*

*"I'm afraid so," Washington said. "But you'd better put a sign here to warn the others."*

*So, that was why the famous sign was put up — the sign you can see today when you visit Valley Forge. You know the one.*

*It reads "George Washington slipped here."*

*No. 17 of a series . . .* BOMAC LOOKS AT RADAR THROUGH THE AGES



* *Bomac makes the finest microwave tubes and components either side of Valley Forge*

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The Executive Committee of the Benelux Section at the Rotterdam meeting—Mr. C. B. Broersma, Membership; Dr. V. Belevitch, Vice-Chairman; Mr. B. B. Barrow, Secretary-Treasurer; Mr. H. Rinia, Chairman; Mr. J. M. L. Janssen, Meetings and Papers; and Dr. H. P. Williams, Publicity.

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| **57 IRE 14.S1 Standards on Piezoelectric Crystals—The Piezoelectric Vibrator: Definitions and Methods of Measurement, 1957.** Reprinted from the March, 1957, PROCEEDINGS | $0.60 |
| **58 IRE 14.S1 Standards on Piezoelectric Crystals: Determination of the Elastic, Piezoelectric, and Dielectric Constants—The Electromechanical Coupling Factor, 1958.** Reprinted from the April, 1958, PROCEEDINGS | $0.75 |
| **55 IRE 15.S1 Standards on Pulses: Methods of Measurements of Pulse Quantities, 1955. Adopted by ASA. (ASA C16.28-1956.)** Reprinted from the November, 1955, PROCEEDINGS | $0.60 |
| **58 IRE 15. TRI IRE Technical Committee Report: Methods for Testing Radiotelegraph Transmitters (Below 50 MC).** Reprinted from the January, 1959, PROCEEDINGS | $0.60 |
| **49 IRE 16.S1 Standards on Railroad and Vehicular Communications: Methods of Testing, 1949.** Reprinted from the December, 1949, PROCEEDINGS | $0.50 |
| **47 IRE 17.S1 Standards on Radio Receivers: Methods of Testing Frequency-Modulation Broadcast Receivers, 1947. Adopted by ASA. (ASA C16.12-1949.)** | $0.50 |
| **48 IRE 17.S1 Standards on Radio Receivers: Methods of Testing Amplitude-Modulation Broadcast Receivers, 1948** | $1.00 |
| **49 IRE 17.S1 Tests for Effects of Mistuning and for Downward Modulation. 1949 Supplement to 47 IRE 17.S1.** Reprinted from the December, 1949, PROCEEDINGS | $0.25 |
| **51 IRE 17.S1 Standards on Radio Receivers: Open Field Method of Measurement of Spurious Radiation from Frequency Modulation and Television Broadcast Receivers, 1951.** Reprinted from the July, 1951, PROCEEDINGS | $0.50 |
| **52 IRE 17.S1 Standards on Receivers: Definitions of Terms, 1952.** Reprinted from the December, 1952, PROCEEDINGS | $0.60 |
| **54 IRE 17.S1 Standards on Receivers: Methods of Measurement of Interference Output of Television Receivers in the Range of 300 to 10,000 KC, 1954. Adopted by ASA. (ASA C16.25-1955.)** Reprinted from the September, 1954, PROCEEDINGS | $0.60 |
| **55 IRE 17.S1 Standards on Radio Receivers: Method of Testing Receivers Employing Ferrite Core Loop Antennas, 1955.** Reprinted from the September, 1955, PROCEEDINGS | $0.50 |
| **53 IRE 19.S1 Standards on Sound Recording and Reproducing: Methods of Measurement of Noise, 1953.** Reprinted from the April, 1953, PROCEEDINGS | $0.50 |
| **58 IRE 19.S1 Standards on Recording and Reproducing: Methods of Calibration of Mechanically-Recorded Lateral Frequency Records, 1958.** Reprinted from the December, 1958, PROCEEDINGS | $0.60 |
| **53 IRE 19.S2 Standards on Sound Recording and Reproducing: Methods for Determining Flutter Content, 1953. Adopted by ASA. (ASA Z57.1-1954.)** Reprinted from the March, 1954, PROCEEDINGS | $0.75 |
| **51 IRE 20.S1 Standards on Pulses: Definitions of Terms—Part I, 1951.** Reprinted from the June, 1951, PROCEEDINGS | $0.50 |
| **52 IRE 20.S1 Standards on Pulses: Definitions of Terms—Part II, 1952.** Reprinted from the May, 1952, PROCEEDINGS | $0.50 |
| **58 IRE 20.S1 Index to IRE Standards on Definitions of Terms, 1942–1957.** Reprinted from the February, 1958, PROCEEDINGS | $1.00 |
| **51 IRE 20.S2 Standards on Transducers: Definitions of Terms, 1951.** Reprinted from the August, 1951, PROCEEDINGS | $0.50 |
| **51 IRE 21.S1 Standards on Abbreviations of Radio-Electronic Terms, 1951.** Reprinted from the April, 1951, PROCEEDINGS | $0.50 |
| **54 IRE 21.S1 Standards on Graphical Symbols for Electrical Diagrams, 1954.** Reprinted from the June, 1954, PROCEEDINGS | $1.25 |

*(Continued on page 20A)*

### BENELUX SECTION HOLDS INITIAL MEETING

On October 3, 1959, the newly-formed Benelux Section of the IRE held its first meeting at the Rotterdam Offices of Radio-Holland, N. V. Talks were given on the radio and navigational equipment of the new *S. S. Rotterdam* by C. B. Broersma, Managing Director of Radio-Holland, H. T. Hylkema, Chief Engineer of Radio-Holland, and A. Webster, Assistant Nautical Superintendent of the Holland-America Line. The meeting was opened by the Section Chairman, H. Rinia, Director of Research at Philips Laboratories in Eindhoven.

Radio-Holland was host during the lunch which followed, at which Dr. L. V. Berkner, President of URSI and a Director of the IRE, presented the good wishes of the Board of Directors and emphasized the international character of the Institute and its interest in promoting contact among radio engineers from all lands. Mr. Rinia reported that Dr. Balthasar van der Pol was prevented from attending by his serious illness, and the group sent a telegram of greetings which was the last message of the IRE to one of its most respected and senior Fellows.

In the afternoon the party went aboard the Rotterdam, new flagship of the Holland-America Line, where they visited the radio station and the navigational equipment on the bridge. Many other parts of this fascinating ship were also visited, so that the occasion was a memorable one for the 77 members and guests who attended the meeting.

### NYU INSTITUTE OFFERS TEMPORARY MEMBERSHIPS

The Institute of Mathematical Sciences at New York University, N. Y., is offering temporary memberships to mathematicians and other scientists holding the Ph.D. degree who intend to study and do research in the fields in which the Institute is particularly active. These fields include Functional Analysis, Function Theory, Differential Equations, Mathematical Physics, Fluid Dynamics and Magnetohydrodynamics, Electromagnetic Theory and Numerical Analysis and Digital Computing.

The temporary membership program is designed primarily to alleviate the present critical shortage of scientists trained in mathematical physics, applied mathematics, and mathematical analysis. The program is being supported by the National Science Foundation and also by funds contributed by industrial firms to New York University.

Temporary members may participate freely in the research projects, the advanced graduate courses, and the research seminars of the Institute, and they will have the opportunity of using the computational facilities. They will receive a grant commensurate with their status.

Temporary memberships are awarded for one year, but may be renewed in special cases. Appropriate arrangements can be made for applicants who expect to be on leave of absence from their institutions.

Requests for information and for application blanks should be addressed to the Membership Committee, Institute of Mathematical Sciences, 25 Waverly Place, New York 3, N. Y.

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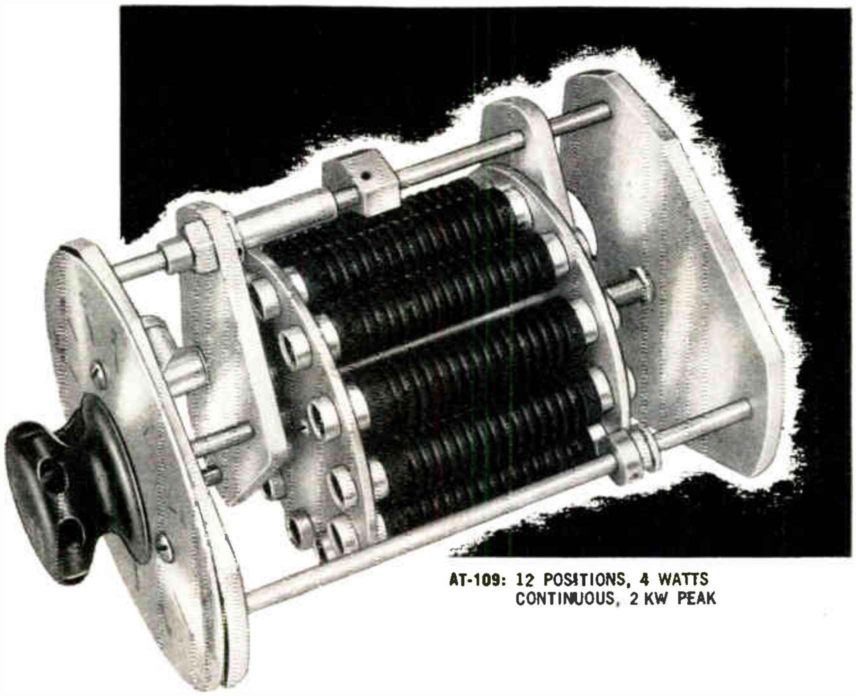

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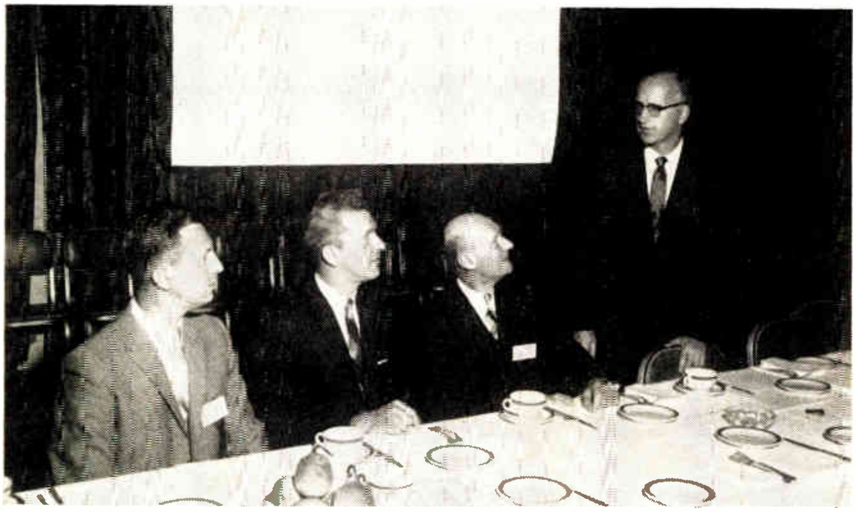

E. W. Pappenfus (*standing*), toastmaster at the banquet of the Cedar Rapids Symposium on Antennas and Propagation, with (*seated left to right*) E. L. Martin, Symposium Chairman, Dr. R. C. McCreary, Chairman of the Cedar Rapids Section, and Dr. Ernst Weber, President of the IRE.

## CURRENT IRE STANDARDS

**Please order by number from IRE Headquarters, 1 E. 79 St., N. Y. 21, N. Y. A 20 per cent discount will be allowed on order for 100 or more copies mailed to one address.**

| *Standard* | *Cost* |
|---|---|
| **57 IRE 21.S1 Standards on Letter Symbols and Mathematical Signs, 1948. (Reprinted 1957.)** | |
| Reprinted from the August 1957, PROCEEDINGS | $0.60 |
| **57 IRE 21.S2 Standards on Reference Designations for Electrical and Electronic Equipment, 1957.** | |
| Reprinted from the November, 1957, PROCEEDINGS | $0.70 |
| **57 IRE 21.S3 Standards on Graphical Symbols for Semiconductor Devices, 1957.** | |
| Reprinted from the December, 1957, PROCEEDINGS | $0.60 |
| **48 IRE 22.S1 Standards on Television: Methods of Testing Television Receivers, 1948. Adopted by ASA. (ASA C16.13-1949.)** | $1.00 |
| **55 IRE 22.S1 Standards on Television: Definitions of Color Terms, 1955.** | |
| Reprinted from the June, 1955, PROCEEDINGS | $0.60 |
| **50 IRE 23.S1 Standards on Television: Methods of Measurement of Television Signal Levels. Resolution, and Timing of Video Switching Systems, 1950.** | |
| Reprinted from the May, 1950, PROCEEDINGS | $0.70 |
| **54 IRE 23.S1 Standards on Television: Methods of Measurement of Aspect Ratio and Geometric Distortion, 1954. Adopted by ASA. (ASA C16.23-1954.)** | |
| Reprinted from the July, 1954, PROCEEDINGS | $0.60 |
| **55 IRE 23.S1 Standards on Television: Definitions of Television Signal Measurement Terms, 1955.** | |
| Reprinted from the May. 1955, PROCEEDINGS | $1.00 |
| **58 IRE 23.S1 Standards on Television: Measurement of Luminance Signal Levels, 1958. (ASA C16.31-1959.)** | |
| Reprinted from the February, 1958, PROCEEDINGS | $0.60 |
| **50 IRE 23.S2 Standards on Television: Methods of Measurement of Time of Rise, Pulse Width, and Pulse Timing of Video Pulses in Television, 1950.** | |
| Reprinted from the November, 1950, PROCEEDINGS | $0.75 |
| **50 IRE 23.S3 Standards on Television: Methods of Measurement of Electronically Regulated Power Supplies, 1950.** | |
| Reprinted from the January, 1951, PROCEEDINGS | $0.75 |
| **45 IRE 24.S1 Standards on Radio Wave Propagation: Definitions of Terms Relating to Guided Waves, 1945.** | $0.20 |
| **50 IRE 24.S1 Standards on Wave Propagation: Definitions of Terms, 1950.** | |
| Reprinted from the November, 1950, PROCEEDINGS | $0.60 |
| **55 IRE 26.S1 Standards on Graphical and Letter Symbols for Feedback Control Systems, 1955.** | |
| Reprinted from the November, 1955, PROCEEDINGS | $0.25 |
| **55 IRE 26.S2 Standards on Terminology for Feedback Control Systems, 1955.** | |
| Reprinted from the January, 1956, PROCEEDINGS | $0.50 |
| **56 IRE 27.S1 Standards on Methods of Measurement of the Conducted Interference Output of Broadcast and Television Receivers in the Range of 300 KC to 25 MC, 1956. Adopted by ASA. (ASA C16.25a-1957.)** | |
| Reprinted from the August, 1956, PROCEEDINGS | $0.50 |
| **58 IRE 27.S1 Supplement to "IRE Standards on Receivers: Methods of Measurement of Interference Output of Television Receivers in the Range of 300 to 10,000 KC 1954" (Standard 54 IRE 17.S1). (ASA C16.25b-1959.)** | |
| Reprinted from the July, 1958, PROCEEDINGS | $0.50 |
| **56 IRE 28.S1 Standards on Letter Symbols for Semiconductor Devices, 1956.** | |
| Reprinted from the July, 1956, PROCEEDINGS | $0.50 |
| **58 IRE 28.S1 Standards on Solid-State Devices: Methods of Testing Point-Contact Transistors for Large, Signal Applications, 1958.** | |
| Reprinted from the May, 1958. PROCEEDINGS | $0.70 |
| **56 IRE 28.S2 Standards on Solid-State Devices: Methods of Testing Transistors, 1956.** | |
| Reprinted from the November, 1956, PROCEEDINGS | $0.80 |

### CEDAR RAPIDS PGAP HOLDS SYMPOSIUM

The Symposium on Antennas and Propagation held by the Cedar Rapids, Iowa, Section, September 18 and 19, 1959, brought to more than 165 members of the section authorities in their fields who delivered papers reviewing the current state of the art. The papers by Dr. A. D. Wheelon and Dr. J. D. Dyson were of particular interest since they presented material never before published. Dr. Wheelon, who reviewed scatter propagation theory, had just completed a two-week session at the National Bureau of Standards, Boulder, Colo., with proponents of the various scattering theories. His paper reflected the results of this meeting. Dr. Dyson described another class of frequency independent antennas having characteristics similar to the logarithmic-periodic antennas and derived from equiangular spiral shapes.

### MICROWAVE TUBES CONGRESS ISSUES CALL FOR PAPERS

The International Congress on Microwave Tubes, to be held in Munich, Germany, June 7–11, 1960, has announced that the deadline for papers is December 30, 1959. The subjects for discussion at the convention will be treated in the following groups: Diode and Grid Controlled Fields, Velocity-Modulation Tubes, Traveling-Wave Tubes, O- and M-Type Backward-Wave Oscillators, Magnetrons and M-Type Amplifier Tubes, Cavities and Slow-Wave Structures, Space-Charge Waves, Noise, Electron Guns and Beam Focusing, Parametric Amplifiers—Masers, Gas-Discharge Tubes, Generation of Electromagnetic Energy by Radiation (Undulator, Cerenkov Effect, etc.), Measuring Techniques, and Technology.

Papers may be read in German, English or French. The maximum time allocated to each paper is 20 minutes. Three copies of a short summary (less than 50 lines) should be enclosed with the form and sent to:

Vortragsausschuss der Internationalen Tagung, "Mikrowellenrohren," z. Hd. Herrn Prof. Dr. W. Kleen, Munchen 8, Balanstrasse 73, Germany.

The program committee will inform the authors by about February 15, 1960, whether their papers have been accepted. The summaries of accepted papers will be printed and made available on or before the date of the Congress.

### AIR FORCE ANNOUNCES MARS DECEMBER SCHEDULE

The December schedule of the Air Force MARS Eastern Technical Net, to be heard Sundays from 2 to 4 P.M., EST at 3295 kc, 7540 kc, and 15,715 kc, is as follows:

December 6 "UHF Air-Sea Rescue Communications," T. C. Nehrbas, Ch. Eng., and J. E. Richter, Proj. Eng., Telephonics, Inc.

December 13 "Underwater Sound Detection," G. D. Cummings and W. Love, Proj. Engs., Telephonics, Inc.

December 20 "Reinforced Plastics," W. H. Greenberg, Ch. Eng., Riverside Plastics Corp.

December 27 Recess date.

January 3 Recess date.

# NEW

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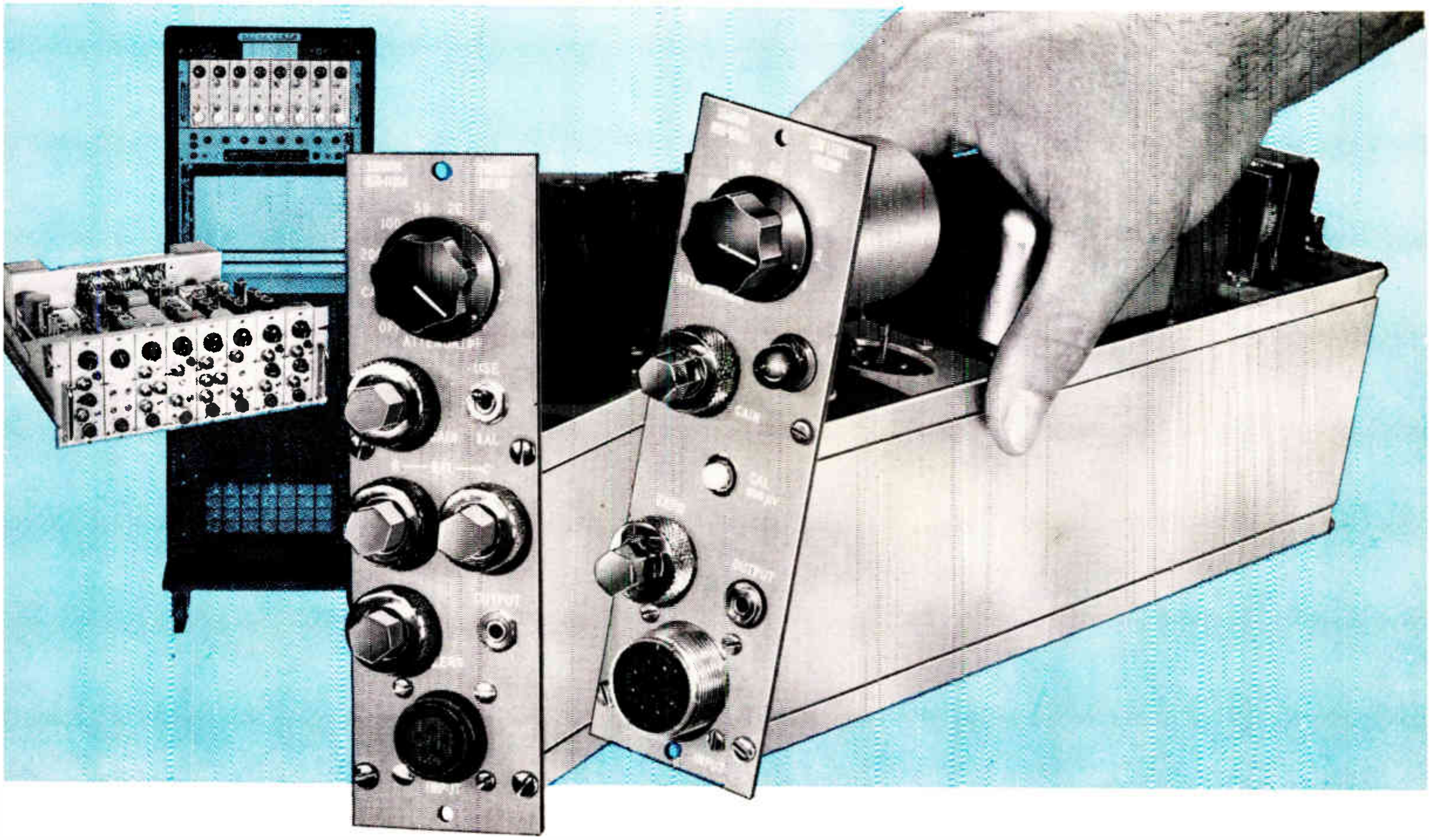

WITH the availability of these two new plug-in preamplifiers and associated MOPA, Sanborn 6- and 8-channel "850" oscillographic recording systems can now record an even *wider* variety of inputs — wherever *many channels* are needed in *minimum panel space*, with *no* sacrifice in system accuracy or reliability. The 850-1100A is a carrier amplifier-demodulator unit designed to work with resistance bridge, variable reluctance and differential transformer transducers. Attenuator, smooth gain, position and balancing controls are on the 2" x 7" front panel; input and output connections are provided at both front and rear. The 850-1500A is a chopper amplifier with floating input isolated from a floating output, capable of measuring low level DC-100 cps signals such as those from thermocouples and strain gage bridges. Design provides low noise operation, greater freedom from ground loop interference and high common mode rejection ratio. Required carrier excitation (2400 cps standard, 600, 1200 and 4800 cps optional) and chopper drive (440 cps) voltages are supplied by the 850-1900 MOPA, a dual-oscillator unit which can handle up to eight of each preamplifier.

### SPECIFICATIONS

| | 850–1100A | 850–1500A |
|---|---|---|
| Sensitivity | 100 µv in gives 1 v at output | |
| Input impedance | approx. 2500 ohms | approx. 100,000 ohms |
| Output | ±2.5v across 3300 ohms | ±2.5 volts across 2500 ohms |
| Freq. response | −3 db at 20% of carrier freq. | 0–100 cps, −3db |
| Linearity | ±0.5% of full scale | ±0.1% of full scale |
| Common mode performance | | 120 db for 60 cps, 160 db for DC with 5000 ohms unbalance in input |
| Noise | | 2 µv p-p over 100 cps bandwidth |

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Ask your Sanborn Sales-Engineering representative for complete facts on all "850" system units — or write the main office in Waltham.

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## Eta Kappa Nu Presents Awards to Young Engineers

Dr. Edgar A. Sack, Jr. (S'49–A'55–M'56) of Pittsburgh, Pa. has been named the Outstanding Young Electrical Engineer of 1959 in the annual nationwide talent search conducted by Eta Kappa Nu, national electrical engineering honor society. Willard B. Groth, Chairman of the Award Organization Committee of the society, also announced today that Honorable Mention awards in the national competition had been made to William O. Fleckenstein (A'52–M'57) of Whippany, N. J., Kenneth H. Olsen (S'48–A'53), of Bedford, Mass., and John W. Wentworth (S'48–A'50–M'55) of Haddonfield, N. J.

The 1959 competition is the twenty-fourth in the series which began in 1936. Formal presentation of the awards will be made at a banquet to be held during the Winter General Meeting of the AIEE in New York, N. Y., in February.

At 29 years of age, the 1959 Outstanding Young Electrical Engineer has a record of accomplishment in the field of solid state device research and development. Initially, Dr. Sack contributed to the understanding of dielectric amplifiers through his doctoral research in connection with ferroelectric materials and their use in resonant dielectric amplifiers. Most recently, he has been responsible for advances in electroluminescence and the application of this principle to practical solid state display mechanisms. His efforts have made possible an electroluminescent alpha-numeric and digital indicator as well as high resolution microcircuit structures for flat panel mural television displays valuable for Navy command information centers. He supervised the design and installation of the first full installation of electroluminescent panels for room lighting in 1956.

He received his education at the Carnegie Institute of Technology, being awarded the B.S., M.S., and Ph.D. degrees in 1951, 1952, and 1954, respectively. He joined the Research Laboratories of Westinghouse Electric Corporation in 1954 as a member of the television section of the Electronics and Nuclear Physics Department. At present he is Manager, Dielectric Devices Section, responsible for the direction of research on special dielectric devices such as electroluminescent displays.

William O. Fleckenstein, one of the Honorable Mention citation recipients, is 34 years of age. A native of Scranton, Pa., he was graduated from Lehigh University as the highest ranking senior in electrical engineering in 1949. He joined the Bell Telephone Laboratories, Inc., immediately upon graduation and participated in their communication Development Training Program. Upon completion of the program he began a telephone career which has been marked by creative accomplishment.

His principal contributions have been made in the areas of electronic switching systems, high speed magnetic core memory systems, and data transmission and record communication systems. He has taught extensively in the Laboratories' Communication Development Training Program.

Kenneth H. Olsen, another Honorable Mention recipient, at 33, is a specialist in the development of solid state components and circuitry for digital computation equipment in addition to being the founder and president of a corporation that has annual sales in excess of a million dollars within two years of its organization.

Mr. Olsen, a native of Bridgeport, Conn., received the B.S. and M.S. degrees in electrical engineering from the Massachusetts Institute of Technology in 1950 and 1952. As a graduate student, he invented a magnetic matrix switch for use with coincident current magnetic memories. Following graduation, as a staff member of the Digital Computer Laboratory of M.I.T. he supervised the group responsible for the first digital computer to use the magnetic core random-access memory. Later he was one of the first to build a high performance digital computer using transistors. In 1957 he founded and became president of Digital Equipment Corporation, a concern that has enjoyed remarkable financial success in the creation and marketing of transistorized building blocks for the computer industry.

The field of electronics also contributed the third winner of an Honorable Mention citation in the 1950 competition. John W. Wentworth, 33, is Manager of Television Terminal Engineering in RCA's Industrial Electronic Products Division. A native of Greenville, Maine, he was graduated from the University of Maine with a bachelor's degree in electrical engineering in 1949. He joined RCA shortly after graduation, and has been a major contributor to that organization's important advances in color television.

He has taught and lectured extensively on the subject of color television. His book, *Color Television Engineering*, was published in 1955.

The Eta Kappa Nu award is given to an electrical engineer who on May 1 of each year has not been graduated more than ten years from a regular course in electrical engineering from an American college or university, and who is not more than 35 years of age. Selection is made on the basis of the candidate's record of achievement in his chosen work, in his service in behalf of his community, state or nation; in his cultural or aesthetic development; and for his professional activities.

## Professional Group News

The following Chapters were approved by the IRE Executive Committee at its meeting held on October 7th: PG on **Automatic Control**—New York Chapter; PG on **Electron Devices**—Syracuse Chapter; PG on **Reliability and Quality Control**—Joint Metropolitan New York, North New Jersey and Long Island Chapter.

## OBITUARIES

**Roscoe Kent,** a Senior Member of the IRE, died recently at the age of 74. A pioneer in the field of radio, he was one of the early members of the IRE.

Mr. Kent was born in St. Paul, Minn., on February 22, 1885. After attending school in St. Paul, he enlisted in the U. S. Navy in 1902. From 1902 to 1906, while in the Navy, he studied the radio field, through correspondence courses, special courses, and handbooks. In 1906 he became Chief Engineer of the Radio Telephone and Telegraph Co., where he worked with the design, fabrication, and installation of wireless telephone and telegraph equipment, and motor generators and wood and steel towers and buildings. He sold and installed the first radio telephones to the U. S. Navy. In 1910 he joined the Mathews Gravity Conveyor Co., Ellwood City, Pa., and in 1912 he became a consulting engineer, developing and building small railroads and ships. During World War I he acted in undercover service for the U. S., and also was Superintendent of the George B. Curd Car and Locomotive Shops, Cincinnati, Ohio. For the next ten years he was Vice President of Florida Associated Engineers, Orlando, Fla., where he helped to design, sell, and install road machinery and equipment. In 1929 he developed a police radio which was produced by the DeForest Radio Co., Passaic, N. J., and for the next few years he did consulting work again. In 1935 he became Assistant General Manager of Wired Radio, Newark, N. J., developing such equipment as high fidelity phonograph records and pick ups, water cooled radio tubes, and carrier current systems. He also had charge of introducing these items to trade and selling patent licenses. Later, he designed, equipped, and put into operation the plant of Tools, Inc., Newark, N. J. During World War II he was in charge of War Contracts Div., Gemex Co., Union, N. J., and after the war he became consultant and patent adviser at Radio Inventions, Inc., New York, N. Y. For the past several years he had been the Florida Representative for Industrial Instruments, Inc., Cedar Grove, N. J.

Mr. Kent was a member of the Society of American Military Engineers and the American Society of Mechanical Engineers. He was a founder of Radio Pioneers.

**Thomas E. Goldup** (SM'52–F'55), Director of Mullard Ltd., London, England, died recently at the age of 65. He was head of the research and development work at Mullard, and directed its technical policy.

T. E. Goldup

He was born on April 30, 1894, in London, Eng., and attended the Royal Naval College, Greenwich, from 1910 to 1914, where he majored in Applied Electrical Engineering and Applied Physics. From 1913 to 1914 he was on the staff of the college.

In 1914 he was appointed to the research staff of Signal School, Portsmouth, and in 1918 he became Senior Experimental Officer at the school. While there he designed and developed the early 2.5 kw silica tubes for the British Navy. In 1923 he joined Mullard Radio Valve Co. as assistant in the Valve Laboratory. Five years later he was appointed Head of the Technical Service Department, and in 1938 he became Director of Mullard Equipment Ltd. In 1940 he became Director of Mullard Radio Valve Co. Ltd., and in 1951 he was appointed Director of Mullard Ltd., encompassing both the Radio Valve and Equipment Companies.


## WITH ARC's NEW TYPE T-25A 360 CHANNEL TRANSMITTER

As air traffic becomes heavier, pilots are busier with more frequent ground communications. To meet this growing need in traffic control, ARC designed the Type T-25A 360 Channel Transmitter with the widest range of frequencies — more than adequate for today or years to come. Weighing only 7.7 pounds including shock mounting, the T-25A provides complete coverage of 360 channels at 50 kc spacing between 118.00-135.95 megacycles. It is a 6-10 watt unit (nominal 8 watts), providing ample range for planning approaches in congested air traffic areas. Power consumption of only 2.0 amperes during transmission on the 28 volt model, plus the 2.0 amps input to the receiver dynamotor that supplies high voltage. This means little added power drain on the electrical system.

This transmitter is recommended for use with ARC's line of tunable receivers, (R-13B and R-19) for a primary communication system on small aircraft or as a "back-up" to ARC Type 210 Transmitter-Receiver on larger aircraft.

Certified to CAA TSO C-37 Category A and FCC Requirements

*Engineers: Investigate Career Opportunities at ARC*

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***Dependable Airborne Electronic Equipment Since 1928***

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# Sixth National Symposium on Reliability and Quality Control in Electronics

STATLER-HILTON HOTEL, WASHINGTON, D. C., JANUARY 11–13, 1960

The Sixth National Symposium on Reliability and Quality Control in Electronics, sponsored by the PGRQC, AIEE, ASQC and EIA, will be held January 11–13, 1960, at the Statler-Hilton Hotel, Washington, D. C.

Registration fees for members of the IRE, AIEE or ASQC are $20.00 in advance, and $24.00 at the door. The fee for nonmembers is $22.00 or $24.00.

### Monday Morning, January 11
### Session 1—Keynote address

"Reliability—Responsibility," *J. K. Sprague, Sprague Electric Co.*

### Session 2A—Military Requirements and Specifications

Chairman: *J. Allen, Space Technology Labs., Inc.*

"Reliability in Contracts," *J. L. Burnside, Lockheed Aircraft Corp.*

"Improved Component Specifications," *R. E. Moe, General Electric Co.*

"New Quality Assurance Techniques in Specifications," *H. G. Romig, Hoffman Electronics Corp.*

### Session 2B—New Production Techniques

Chairman: *A. W. Rogers, U. S. Army Signal Res. and Dev. Lab.*

"New Production Techniques on Filters and Capacitors," *S. Sonobe, Nippon Elec. Co.*

"Audio-Visual Aids to Human Reliability," *D. A. Hill, Hughes Aircraft Co.*

"Decentralized Reliability Education," *J. M. Wuerth, North American Aviation, Inc.*

### Monday Afternoon
### Session 3A—New Mathematical Techniques

Chairman: *G. Levenbach, Bell Tel. Labs.*

"Random Balance Designs for Reliability," *G. H. Sandler, Sylvania Elec. Prods., Inc.*

"Sequential Qualification: A Reliability Countdown," *D. R. Howes, Army Chemical Center.*

"Analog Computers for Statistical Procedures," *M. H. Norton, Booz-Allen Applied Res., Inc.*

"Accelerated Testing as a Problem of Modeling," *R. E. Thomas, Battelle Mem. Inst.*

### Session 3B—Cost Considerations

Chairman: *Rear Admiral R. Mandelkorn (USN, Ret.) Philco Div., Lansdale Tube Co.*

"A Reliability Economic Decision Method," *H. W. Price, Diamond Ordnance Fuze Lab.*

"The Cost of Reliability Versus Maintenance Cost," *Lt. Col. W. F. Stevens, Wright Air. Dev. Center.*

"Rework Costs Related to Reliability Requirements," *W. R. Kuzmin, Packard Bell Electronics.*

"An Information Theory Approach to Diagnosis," *R. A. Johnson, Syracuse, Univ.*

### Monday Evening
### Session 4—Round Table Discussion

Chairman: *J. M. Bridges, Office of Electronics, ODDR&E.*

Participating: *Advisory Board Members.*

### Tuesday Morning, January 12
### Session 5A—Training Session

Chairman: *R. Fitzgibbons, Raytheon Co.*

"Mathematics of Reliability," *J. M. Weisen, Sandia Corp.*

"Circuit Design Concept for High Reliability," *F. E. Dreste, Motorola, Inc.*

"Prediction of Reliability," *J. Conners, Hughes Aircraft Co.*

"Design Review," *G. J. Armbruster, RCA.*

### Session 5B—Failure Modes

Chairman: *G. Neuschaefer, New York Naval Material Lab.*

"Resistor Reliability—Capability Analysis," *B. R. Schwartz, RCA.*

"Failure Modes in Electronic Components," *M. L. Granberg, Sperry Rand Corp.*

"Modes of Failure of Component Parts," *C. D. Jeffcoat, Westinghouse Electric Corp.*

"Part Improvement in Missile Guidance Applications," *J. Hepp, General Motors Corp.*

### Session 5C—Advanced Mathematical Theory

Chairman: *G. M. Cox, Research Triangle Inst.*

"Negative Moments and the Evaluation of Reliability," *W. Mendenhall, Bucknell Univ.*

"Multi-factor Experiments in Life Testing," *M. Zelen, Nat. Bur. of Stand.*

"A Summary of Some New Techniques on Failure Analysis," *J. K. Kao, Cornell Univ.*

"Estimation of Reliability from Incomplete Data," *G. R. Herd, Booz-Allen Applied Res., Inc.*

### Tuesday Afternoon
### Session 6A—Training Session

Chairman: *R. Fitzgibbons, Raytheon Co.*

"Reliability Testing," *J. H. Hershey, Bell Tel. Labs.*

"Failure Reporting," *E. Gould, Hughes Aircraft Co.*

"Manufacturing Aspects of Reliability," *T. Wos, Westinghouse Electric Corp.*

"Field Reliability," *J. C. Burns, ARINC Corp.*

### Session 6B—Reliability Prediction

Chairman: *J. A. Connors, Hughes Aircraft Co.*

"Correlation of Laboratory and Field Reliability, *C. M. Bird, IBM Corp.*

"Reliability Prediction—A Proven Method," *W. T. Tier, General Electric Co.*

"The Practicality of Predicting Reliability Numbers," *W. E. Boyes, Sandia Corp.*

"Prediction of MTBF Bounds in Early Design," *B. Tiger, United Aircraft Corp.*

### Session 6C—Information Exchange Panel

Chairman: *R. H. DeWitt, Office of Electronics, ODDR&E.*

"The Tri-Service and NOL Program," *M. Barbe, Space Technology Labs., Inc.*

"Battelle Memorial Institute Data Pool," *C. R. Deeter, Battelle Mem. Inst.*

"ODD Ad Hoc Committee on Component Reliability," *J. Glass, Hughes Aircraft Co.*

"Inland Testing HELPER Program," *L. L. Schneider, Inland Testing Labs.*

"Information Exchange Mechanics," *R. M. Jacobs, Sylvania Electronic Systems Div.*

"Product Standardization and Technical Data Exchange," *E. F. Howrey, Attorney and partner with Law Firm of Howrey and Simon.*

### Tuesday Evening
### Session 7—Banquet

"Research and Development Aspects of Reliability," *Vice Admiral J. T. Hayward, USN, Assistant Chief of Naval Operations.*

### Wednesday Morning, January 13
### Session 8A—New Maintainability Techniques

Chairman: *Gen. F. L. Ankenbrandt (USA, Ret.), RCA.*

"Maintenance Planning During Equipment Development, *R. I. Moeller, IBM.*

"Maintainability Study on Shipboard Electronics," *J. Schechtel, Fed. Elec. Corp.*

"Practical Maintainability Numerics," *M. P. Feyerherm, RCA.*

"RADC Maintainability Program," *M. P. Forte, Rome Air. Dev. Center.*

### Session 8B—Life Tests

Chairman: *W. Sumerlin, Philco Corp.*

"Life Test Acceptance Plans," *B. Epstein, Stanford Univ.*

"High Temperature Burn-In for Silicon Diodes," *D. Cowan, Continental Device Corp.*

"The Selection of Components for Test Purposes," *W. G. Madow, Stanford Res. Inst.*

"Surface Barrier Transistor Life Characteristics," *J. Drennan, Battelle Mem. Inst.*

### Wednesday Afternoon
### Session 9A—System Aspects

Chairman: *P. S. Darnell, Bell Tel. Labs.*

"Design Reliability Analysis—A Proven Technique," *H. Wuerffel, RCA.*

"Some Effects of Redundancy on System Reliability," *H. S. Balaban, ARINC Corp.*

"Reliability, The Engineer, and the Mathematician," *G. W. Holtzman and W. E. Marshall, Minneapolis-Honeywell Reg. Co.*

"Reliability Measurement Applicable to Vigilante," *W. M. Roberts, U. S. Army Ordnance & Proof Services.*

### Session 9B—Programs and Management

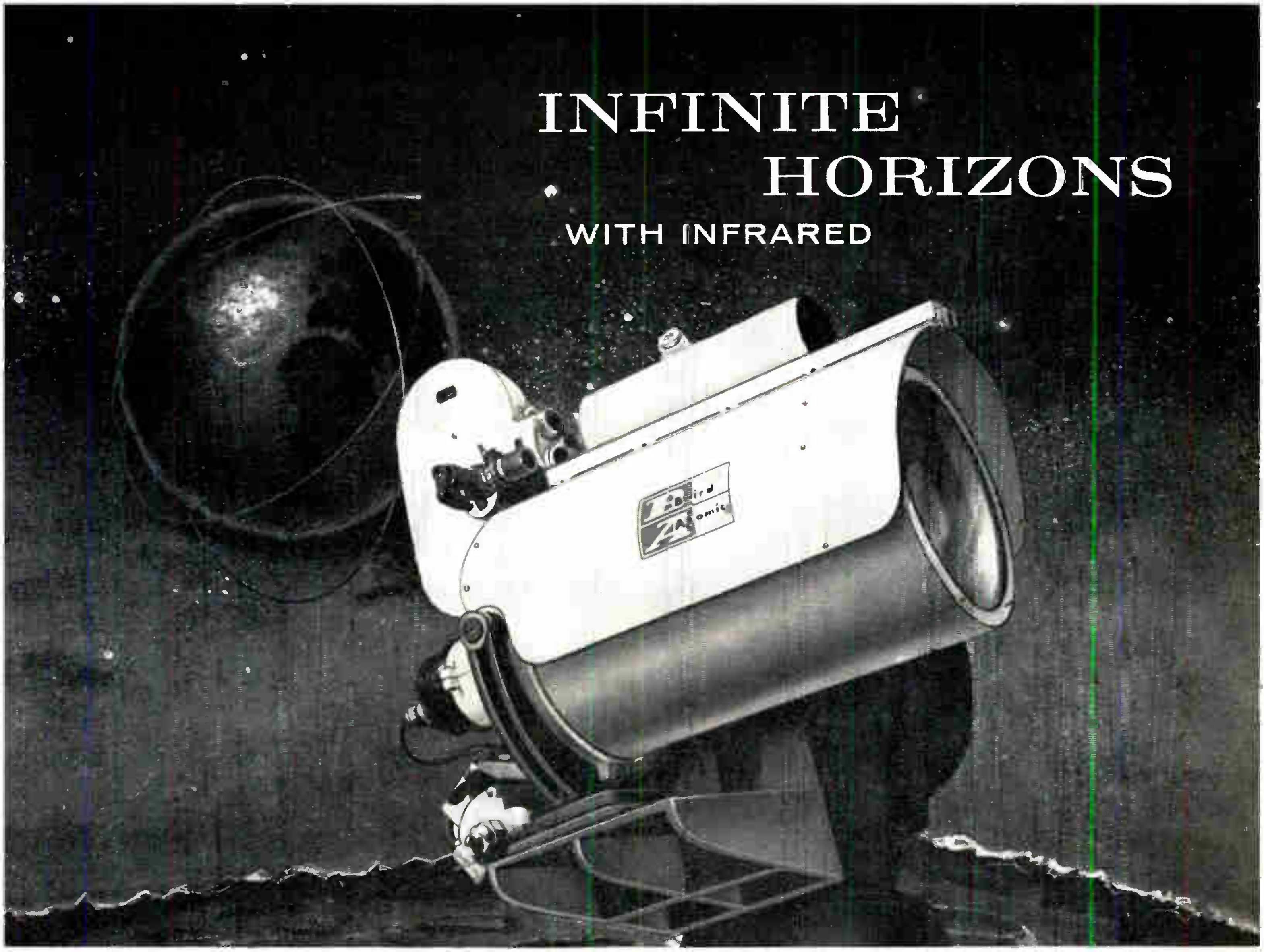
Chairman: *Col. R. O. Mitterling, Hdqtrs., Air Material Command.*

"A Field Reliability Data Program," *J. R. Holmes, IBM.*

"Designing in the Dark," *J. M. Farrier, ARINC Corp.*

"Small Samples are Significant," *S. J. Wilson, The Martin Co.*

"Supplier Reliability Assurance Program," *M. H. Saltz, Hughes Aircraft Co.*




## Airborne Search

The B/A transistorized "ROYAL FLUSH" Airborne Scanning, Detecting and Spectral Systems evaluate infrared radiation from airborne targets — also used to study radiation transmission at extremely high altitudes . . .

## Spectrophotometers

Baird-Atomic has also been a pioneer in commercial infrared instrumentation — first to market a double-beam recording spectrophotometer. B/A's development program continues to pace the field in infrared analysis.

## Optical Trackers

B/A tracking telescopes, as shown above, are in regular use at several locations. These unique systems can use visible, near or far infrared signals.

With a background of many years of advanced scientific and engineering effort in infrared, Baird-Atomic has developed and delivered a number of ground-based and airborne systems for special government requirements. B/A's backlog in this field has risen sharply, with major new commitments for the Missiles and Space Division of Lockheed Aircraft Corporation. Baird-Atomic's responsibilities include the development and delivery of specialized systems for important new applications in space programs. Other programs for infrared system development for the government show continued growth.

***The expansion of infrared projects at B/A*** and the continued growth of national and world markets have created new openings for scientists, designers and production engineers. Unusual opportunities are yours, if you qualify. For details, write to: Personnel, Baird-Atomic, Department Y.

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Main Office: **Baird-Atomic, Inc.**
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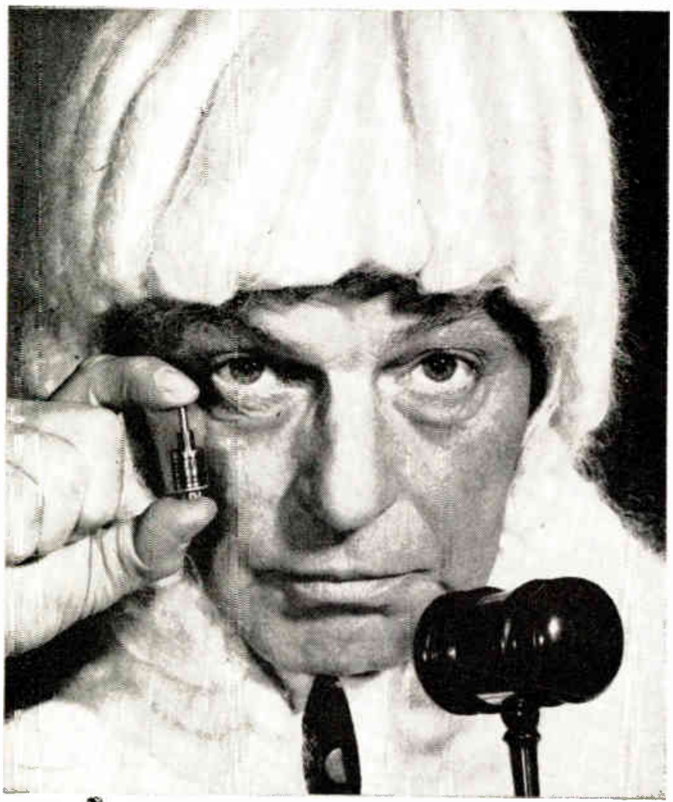
Cambridge 38, Massachusetts

### Other B/A Products

Emission Spectrographic Equipment — The Atomic Line of Radioactivity Measuring Instruments — Electronic and Special Products — Infrared Interference Filters — Periscopic Sextants

# Waters has a watertight case!



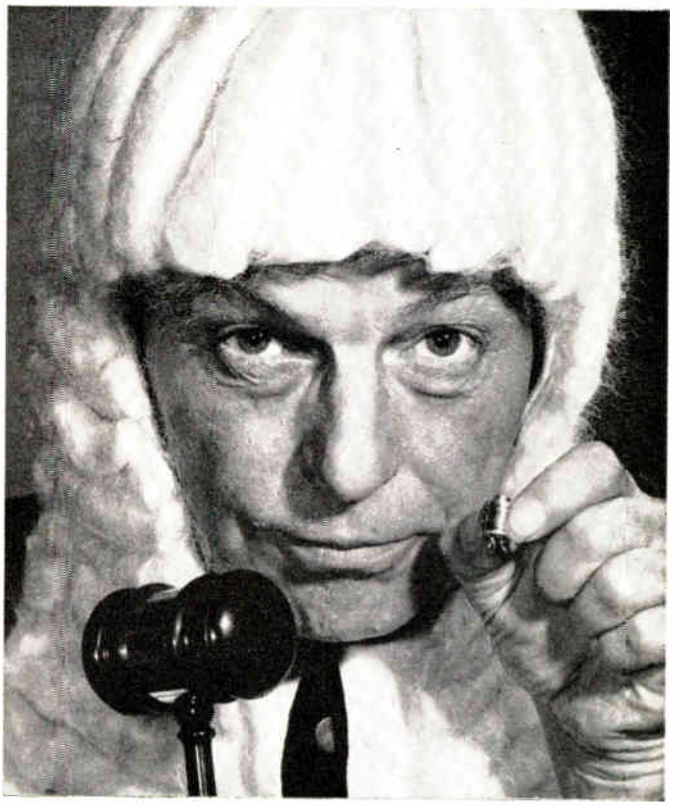
APW½
½" dia.

Waters APW½ Sealed Potentiometer is so watertight and so heat resistant that it operates reliably even in boiling water! The APW½ is completely unaffected by humidity and water vapor, the two common causes of potentiometer failures in aircraft and missiles, where pressure and altitude changes allow equipment "to breathe". Naturally, the watertight construction of the APW½ also seals out dust and other minute particles which might cause failure. Meets MIL-E-5272A immersion specifications by means of a double "O" ring shaft seal. The glass-to-metal terminal board is solder-sealed to the case. Available with 125°C or 150°C construction, mechanical rotation stops, special winding angles, values to 100K and tighter linearity tolerances. Can be supplied with optional split bushings and various shaft lengths. (Waters WPW½ Sealed Potentiometer features the same construction as the APW½, but with a servo face.) Write for Bulletin APW-359.

**Waters**
MANUFACTURING, INC.
WAYLAND, MASS.

POTENTIOMETERS
SLUG TUNED COIL FORMS
RF COILS
CHOKES
POT HOOK® PANEL MOUNTS
TORQUE WATCH® GAUGES
C'TROL METER/CONTROLLER
INSTRUMENTS

# Waters has an airtight case!



APH½
½" dia.

Waters APH½ hermetically sealed precision potentiometer, in addition to maintaining the hermetic seal behind the panel, is itself tightly sealed against outside atmosphere and salt spray by means of a double "O" ring shaft seal. The entire potentiometer passes Liquid Immersion Tests per MIL-E-5272A, par. 4.12.1, and, excluding the shaft, passes the Mass Spectrometer Test with leak rate less than $10^{-7}$ CC/sec. N.T.P. Pre-tinned, it can be easily soldered into the panel. Its terminal lugs are installed with a glass to metal seal, and are positioned for easy wiring. The brass case is plated in conformance with military requirements. Waters APH½ HT Potentiometer also has high temperature operating characteristics. It derates to zero watts at 150°C; ¾ watts may be safely dissipated at 125°C. Available with mechanical rotation stops, special winding angles, resistance values to 100K ohms and tighter linearity tolerances. Write for Bulletin APH.

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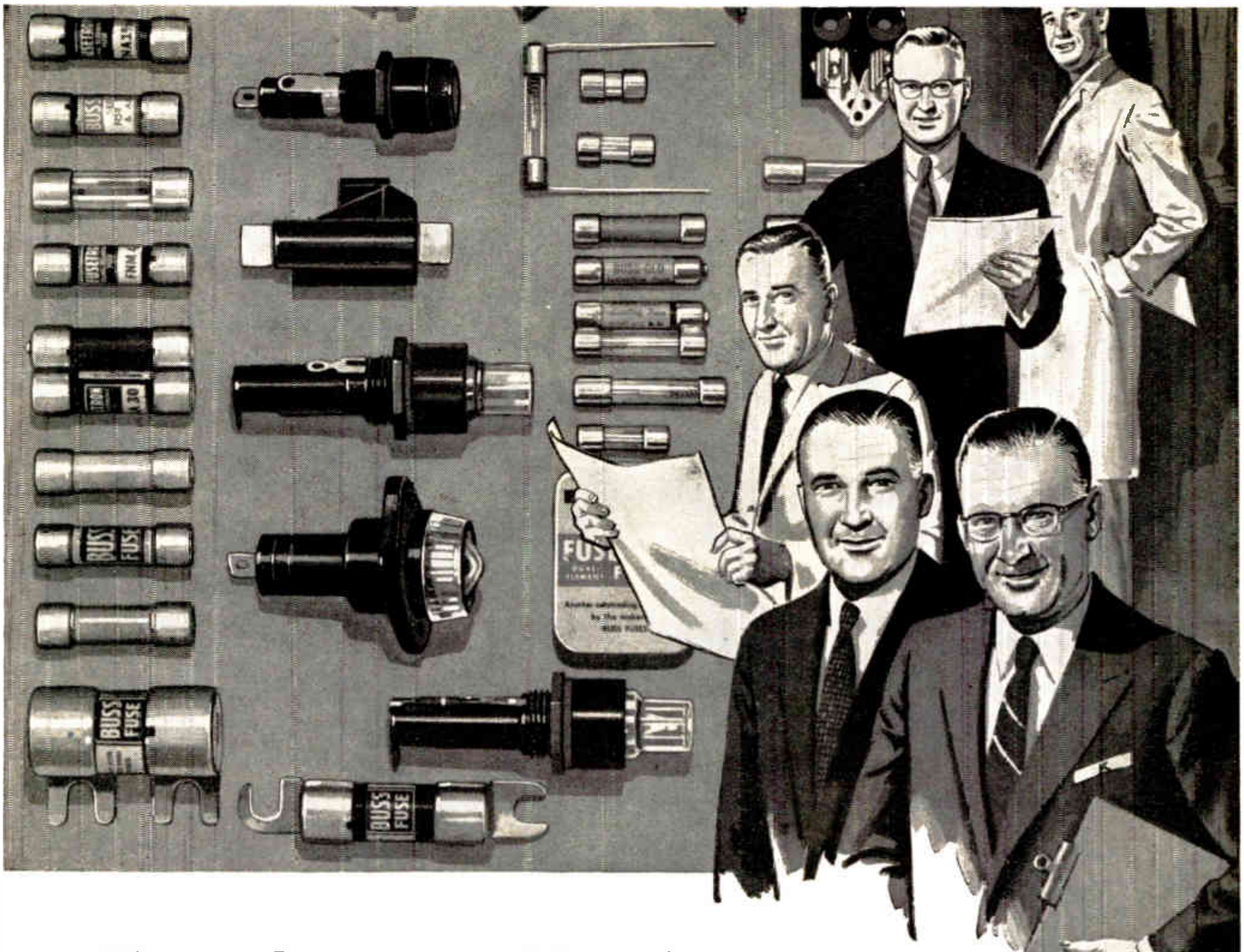
WAYLAND, MASS.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## ..with TI electronic surveillance systems

******Target acquisition and recognition:* You can search a huge area in minute detail for widely separated, lethal forces and installations — many of which are highly mobile.

******Target location:* through navigational aids so accurate that conventional warheads may be used on concentrated targets with a high probability of success.

******Data Handling:* to interpret and relay the target data from TI-equipped drones and snooper aircraft to the field commander in useable form.

******Weapon damage assessment:* verifies weapon accuracy and evaluates the remaining threat.

*Plus:* training aids and maintenance services to assure that both men and equipment are at top efficiency.

This capability now exists at TI, with the latest and most sophisticated airborne reconnaissance systems being flown daily at TI's Avionics Test Center.

For detailed discussion of TI Surveillance hardware, currently in production for the USAF and US Army Signal Corps — cleared personnel "with need to know" are urged to call or write: SERVICE ENGINEERING DEPT.

RESEARCH/DESIGN/DEVELOPMENT/MANUFACTURING of systems for: *Air traffic control • Airborne early warning • Antimissile • Antisubmarine warfare • Attack control • Countermeasures • Missile systems Navigation • Reconnaissance • Space electronics; and on detector cells, engine instruments, infrared, intercom, microwave, optics, sonar, radar, telemetry, time standards, timers, transformers and other precision devices.*

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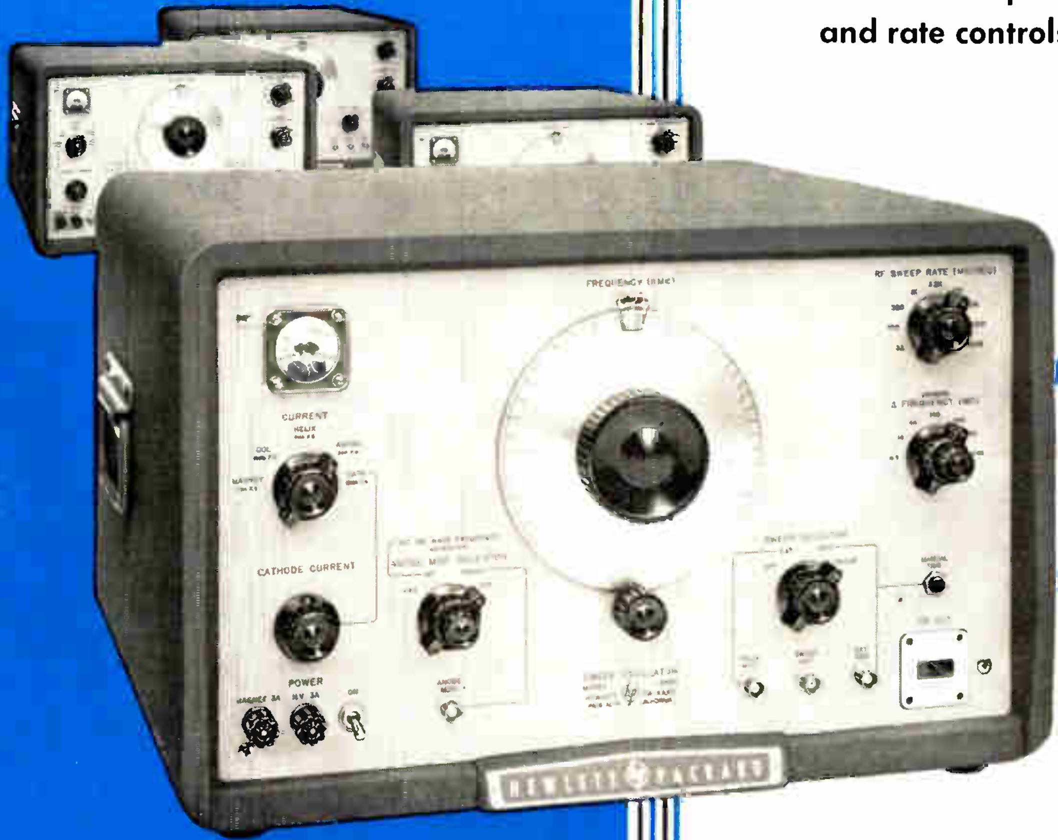
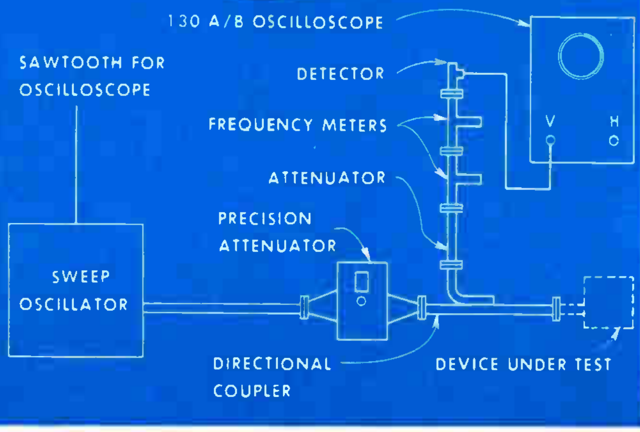
# NOW!

# 4 new microwave sweep oscillators

*speed, simplify measurements 2.0 to 18.0 KMC*

Covers full band, or any part
Use with 'scope or recorder
All electronic; no mechanical sweep
Direct reading, independently adjustable sweep range and rate controls






◀ Figure 1. Arrangement for high speed microwave measurement to provide rapid visual display with (hp) 130A/B oscilloscope.

**hp Dependable, quality**

Hewlett-Packard Electronic Sweep Oscillators are new measuring tools deliberately designed to give you simpler, faster microwave measurements. Four models are provided, covering frequencies 2.0 to 18.0 KMC as follows: Model 683A, 2.0 to 4.0 KMC; Model 684B, 4.0 to 8.1 KMC; Model 686A, 8.2 to 12.4 KMC and Model 687A, 12.4 to 18.0 KMC.

These instruments make possible microwave investigations and evaluations with a convenience previously associated only with lower frequency measurements. These oscillators provide a wide range of sweep speeds so that measurements of reflection, attenuation, gain etc., can be displayed on an oscilloscope or recorded in permanent form on X-Y or strip-chart recorders.

## Electronic Sweeping

Specifically, the new oscillators provide either a CW or swept rf output throughout their individual bands. The instruments employ new backward wave oscillator tubes whose frequency is shifted by varying an applied potential. Thus, troublesome mechanical stops and tuning plungers are eliminated. Sweep range is continuously adjustable and independently variable; sweep rate is selected separately, and either can be changed without interrupting operation. The full band width can be covered in time segments ranging from 140 seconds (very slow for mechanical recorder operation) to 0.014 seconds (high speed for clear, non-flickering oscilloscope presentation).

## Linear Frequency Change

The swept rf output from the ⓗⓟ sweep oscillator is linear with time, and a linear sawtooth voltage is provided concurrent with each rf sweep to supply a linear time base for an oscilloscope or recorder. In addition, for convenience in recording and other operations, rf sweeps can be triggered electrically externally and single sweeps can be triggered by a front panel push button. The rf output can also be internally AM'd from 400 to 1,200 cps and externally AM'd or FM'd over a wide range of frequencies.

## Rapid Visual Presentation

The variety of sweep rates and band widths available from the new oscillators insures convenience and accuracy for reflection and transmission coefficient measurements and many other production line and laboratory tests. For maximum speed, an oscilloscope such as ⓗⓟ 130A/B may be used as indicated in the diagram on opposite page. For maximum information and a permanent record, an X-Y or strip chart recorder may be used.

Complete details of a rapid visual method using an oscilloscope or a maximum-data, permanent record method using a recorder may be obtained from your ⓗⓟ field engineer. Detailed discussions of these methods are also contained in the ⓗⓟ Journal, Vol. 8, No. 6, and Vol. 9, No. 1-2, available on request.

## TYPICAL SPECIFICATIONS

**Below are specifications for -hp- 686A Sweep Oscillator, 8.2 to 12.4 KMC. Specifications for -hp- 683A, 684B, and 687A (P band) are similar except for frequency range and other minor variations.**

**Types of Outputs:** Swept Frequency, CW, FM, AM.

**Single Frequency Operation**

**Frequency:** Continuously adjustable 8.2 to 12.4 KMC.

**Power Output:** At least 10 milliwatts into matched waveguide load. Continuously adjustable to zero.

**Swept Frequency Operation**

**Sweep:** Recurrent; externally triggered; also manually triggered single sweep. Rf sweep linear with time.

**Power Output:** At least 10 MW into matched waveguide load. Output variation less than 3 db over any 250 MC range; less than 6 db over entire 8.2-12.4 KMC range.

**Sweep Range:** Adjustable in 7 steps 4.4 MC to 4.4 KMC.

**Sweep Rate-of-Change:** Decade steps from 32 MC/sec. to 320 KMC/sec.

**Sweep Time:** Determined by sweep range and rate; from 0.014 to 140 seconds over full-band.

**Sweep Output:** +20 to +30-volt-peak sawtooth provided at a front-panel connector concurrent with each rf sweep.

**Modulation**

**Internal Amplitude:** Square wave modulation continuously adjustable from 400 to 1200 cps; peak rf output power equals cw level ± 1 db.

**External Amplitude:** Direct coupled to 300 KC; 20 volt swing reduces rf output level from rated cw output to zero.

**External Pulse:** +10 volts or more, 5 millisecond maximum duration.

**External FM:** Approx. 350 v peak to modulate full frequency range.

**General**

**Input Connectors, Impedances:** BNC; above 100,000 ohms.

**Output Connector:** Waveguide cover flange (686A, 687A); Type N, female (683A, 684B).

**Power Requirements:** 115/230 volts ±10%, 50/60 cps; approximately 540 watts.

**Price:** ⓗⓟ 683A (2.0 to 4.0 KMC) $3,000.00.
ⓗⓟ 684B (4.0 to 8.1 KMC) $2,900.00.
ⓗⓟ 686A (8.20 to 12.40 KMC) $2,900.00.
ⓗⓟ 687A (12.40 to 18.00 KMC) $3,400.00.

(Prices above are f.o.b. factory for cabinet models. Rack mount instruments $15.00 less.)

Data subject to change without notice.

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**instruments that speed and simplify your work**

**EIMAC**
*is an electron tube specialist*

# EIMAC FINDS WAY TO END PREMATURE TUBE FAILURE

No matter how carefully you operate vacuum tubes, power overloads can't always be avoided. In most tubes, the resultant overheating produces vacuum loss or internal arcing. Tubes often fail immediately or fall off in performance.

To overcome this, Eimac developed a group of internal-anode radial-beam tetrodes with exceptional ability to withstand repeated power overloads and peak powers. Operated for millions of hours in every class of service, these rugged tetrodes have proved they last longer, *perform better*, than any comparable internal-anode tubes.

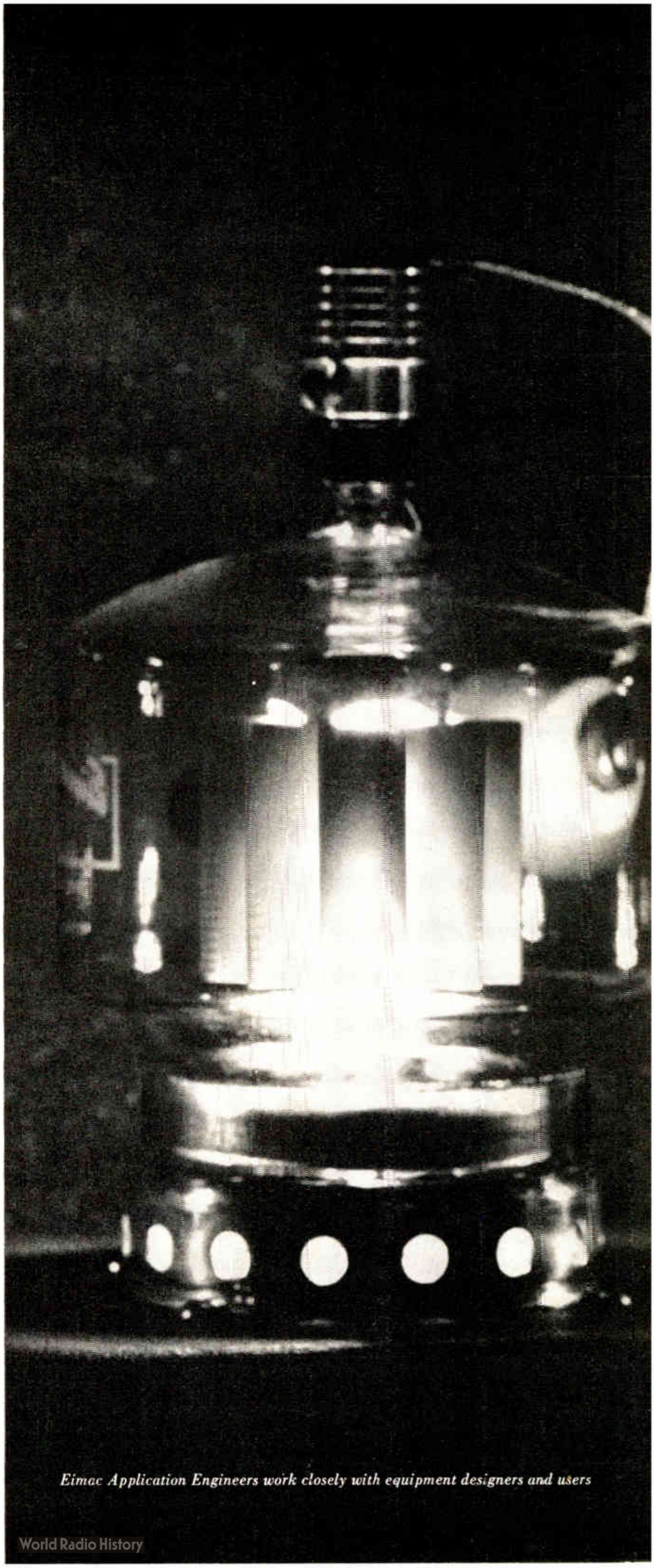
Their amazing reliability is due partly to Eimac's exclusive Pyrovac plate. This outstanding internal-anode material reduces internal arcing, actually absorbs gases which might ruin tube vacuum.

In these tetrodes, low inter-electrode capacitances and low lead inductances assure stable operation at high frequencies. Their high power gain and low driving power requirements simplify driver requirement and associated circuits.

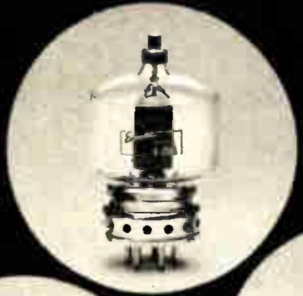
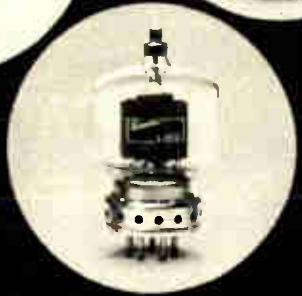
For complete technical and application data on these outstanding tetrodes, see the attached Eimac Report to Design Engineers.

Eimac ®

**EITEL-McCULLOUGH, INC.**
San Carlos, California



*Eimac Application Engineers work closely with equipment designers and users*

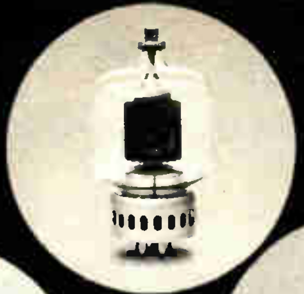
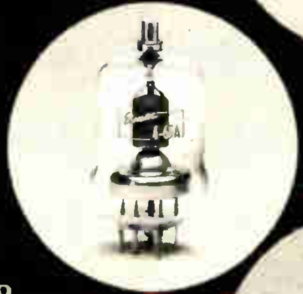
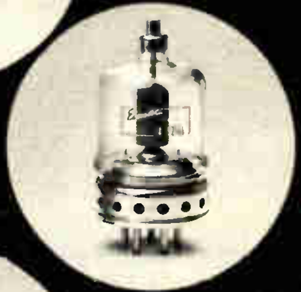
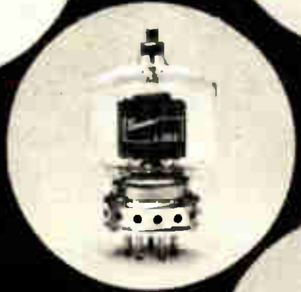
WORLD'S LARGEST MANUFACTURER OF TRANSMITTING TUBES

EITEL-McCULLOUGH, INC. San Carlos, California

REPORT TO DESIGN ENGINEERS ...FILE

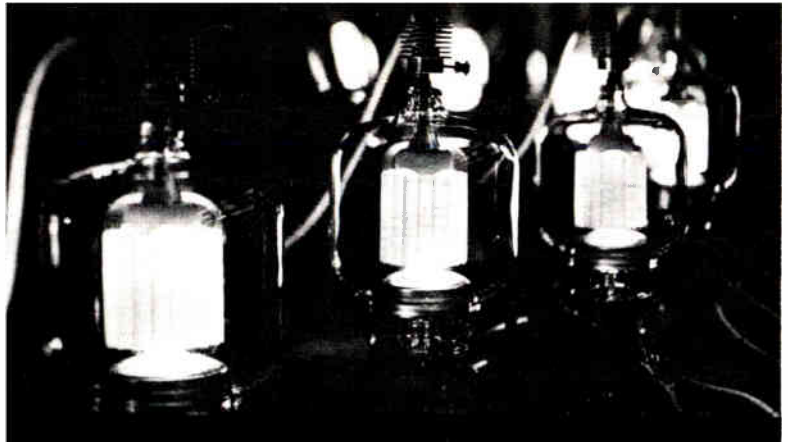
Eimac

REPORT TO DESIGN ENGINEERS ...FILE


# EIMAC RADIAL-BEAM INTERNAL-ANODE TETRODES

*Characteristics and Applications*



## ADVANCED FEATURES OF EIMAC INTERNAL-ANODE TETRODES MEAN LONGER LIFE, BETTER PERFORMANCE

The proved reliability, long life, and outstanding performance of Eimac's five internal-anode tetrodes is a direct result of Eimac's emphasis on Research and Engineering in the areas of tube design, material application, and manufacturing.

All five of these rugged tetrodes feature Eimac's exclusive Pyrovac plate. Found only in Eimac vacuum tubes, this advanced anode material absorbs gases, reduces internal arcing. Non-emitting grids and clean electrode design further add to the long life and dependability of these tubes. All feature thoriated tungsten filaments.

Unusually clean, hard vacuums are achieved on Eimac designed and developed rotary vacuum pumps.

These general purpose negative grid tubes are just part of Eimac's line of over 100 tube types. For rugged applications, Eimac has pioneered the application of ceramics to electron tube construction. Today, more than forty Eimac negative grid tubes, amplifier klystrons, traveling wave tubes, and reflex klystrons feature ceramic-metal construction.

Eimac has risen to its position as the world's largest manufacturer of transmitting tubes by being first with advanced tube design, advanced material application, and leadership in vacuum tube manufacturing techniques.

**These advanced features are also available in Eimac's line of internal-anode triodes, pentodes, and high vacuum rectifiers.**


## SUMMARY

## EIMAC 4-1000A 1000 Watt Radial-Beam Power Tetrode

This Eimac tetrode is capable of efficient operation well into the VHF range. In FM broadcast service on 110 megacycles, two 4-1000A's will deliver a useful output power of over 5000 watts. Operation under Class $AB_2$ modulator conditions with less than 10 watts of peak driving power, two of these tubes will deliver 3,900 watts of output power. In Class $AB_1$ a pair of 4-1000A's will deliver 3,800 watts of output power. Highest frequency for maximum ratings is 110 megacycles.

| TYPE SERVICE | FUNCTION | TYPICAL OPERATION | | | |
|---|---|---|---|---|---|
| | | DC Plate Voltage | DC Plate Current | Driving Power | Plate Power Output |
| Class C Telegraphy or FM below 110 Mc, Per Tube | RF Power Amplifier and Oscillator | 6,000 | 700 ma | 15 watts | 3,400 watts |
| Class C Telegraphy, or FM, 110 Mc, 2 Tubes, Push-Pull | RF Power Amplifier and Oscillator | 6,000 | 1.25 amps | 400 watts | 5,200 watts |
| Class C Telephony, below 110 Mc, Per Tube, Carrier Conditions | Plate-Modulated RF Amplifier | 5,000 | 600 ma | 11 watts | 2,440 watts |
| Class $AB_1$ Sinusoidal Wave, 2 Tubes | Audio-Frequency Power Amplifier and Modulator | 6,000 | 0.95 amps | 0.0 watts | 3,840 watts |
| Class $AB_2$ Sinusoidal Wave, 2 Tubes | Audio-Frequency Power Amplifier and Modulator | 6,000 | 0.95 amps | 4.7 watts | 3,900 watts |
| Class $AB_1$ Per Tube | RF Linear Power Amplifier SSB Single Tone | 6,000 | .44 amps | 0.0 watts | 1,750 watts |

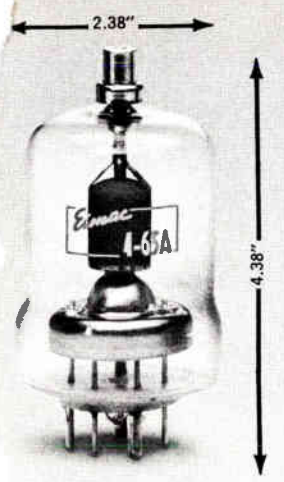
## EIMAC 4-400A 400 Watt Radial-Beam Power Tetrode

This compact power tetrode is cooled by radiation from the plate and by circulation of forced-air through the base, around the envelope, and over the plate seal. Cooling is simplified by using an Eimac SK-400 Air System Socket and its accompanying glass chimney. This tube's thoriated tungsten filament operates at 5.0 volts, with current of 14.5 amperes. Highest frequency for maximum ratings is 110 megacycles.

| TYPE SERVICE | FUNCTION | TYPICAL OPERATION | | | |
|---|---|---|---|---|---|
| | | DC Plate Voltage | DC Plate Current | Driving Power | Plate Power Output |
| Class C Telegraphy or FM below 75 Mc, Per Tube | RF Power Amplifier and Oscillator | 4,000 | 350 ma | 5.8 watts | 1,100 watts |
| Class C Telegraphy or FM, 110 Mc, 2 Tubes | RF Power Amplifier and Oscillator | 4,000 | 540 ma | 20.0 watts | 1,600 watts |
| Class C Telephony, below 75 Mc, Continuous Carrier Conditions | Plate-Modulated RF Amplifier | 3,000 | 275 ma | 3.5 watts | 630 watts |
| Class C Telephony, below 30 Mc, Intermittent Carrier Conditions | Plate-Modulated RF Amplifier | 3,650 | 275 ma | 4.0 watts | 765 watts |
| Class $AB_1$ Sinusoidal Wave, 2 Tubes | Audio-Frequency Power Amplifier and Modulator | 4,000 | 585 ma | 0.0 watts | 1,540 watts |
| Class $AB_2$ Sinusoidal Wave, 2 Tubes | Audio-Frequency Power Amplifier and Modulator | 4,000 | 638 ma | 3.5 watts | 1,750 watts |
| Class $AB_1$, to 110 Mc, Per Tube | RF Linear Power Amplifier SSB Single Tone | 4,000 | 250 ma | 0.0 watts | 650 watts |


## PERFORMANCE

SEND TODAY FOR DATA SHEET GIVING COMPLETE SPECIFICATIONS, APPLICATION INFORMATION AND TECHNICAL DATA.




## PERFORMANCE SUMMARY

SEND TODAY FOR DATA SHEET GIVING COMPLETE SPECIFICATIONS AND TECHNICAL INFORMATION.

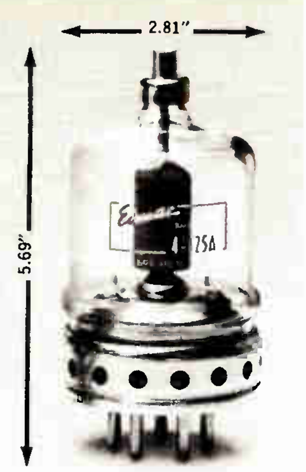
## EIMAC 4-65A 65 Watt Radial-Beam Power Tetrode

This small, radiation-cooled transmitting tetrode features short, heavy leads and low interelectrode capacitances producing stable, efficient operation at high frequencies. Though the 4-65A can withstand high plate voltages, it delivers relatively high power output at a low plate voltage. Quick heating thoriated tungsten filament conserves power during standby periods in mobile applications. Frequency for maximum ratings: 150 Mc.

| TYPE SERVICE | FUNCTION | TYPICAL OPERATION | | | |
|---|---|---|---|---|---|
| | | DC Plate Voltage | DC Plate Current | Driving Power | Plate Power Output |
| Class C Telegraphy or FM, Per Tube | RF Power Amplifier and Oscillator | 3,000 | 115 ma | 1.7 watts | 280 watts |
| Class C Telephony, Per Tube, Carrier Conditions | Plate-Modulated RF Amplifier | 2,500 | 110 ma | 2.6 watts | 230 watts |
| Class $AB_1$ Sinusoidal Wave, 2 Tubes | Audio-Frequency Power-Amplifier and Modulator | 1,750 | 170 ma | 0.0 watts | 175 watts |
| Class $AB_2$ Sinusoidal Wave, 2 Tubes | Audio-Frequency Power-Amplifier and Modulator | 1,800 | 220 ma | 1.3 watts | 270 watts |
| Class $AB_1$, Per Tube | RF Linear Power Amplifier SSB Single Tone | 3,000 | 65 ma | 0.0 watts | 130 watts |

## EIMAC 4-125A

### 125 Watt Radial-Beam Power Tetrode



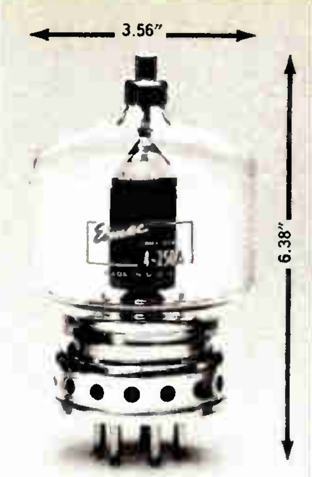

The low grid-plate capacitance of this tetrode together with its low driving-power requirement allows considerable simplification of the associated circuit and driver stage. The 4-125A is cooled by radiation from the plate and by air circulation through the base and around the envelope. It has a quick-heating thoriated tungsten filament. Highest frequency for maximum ratings: 120 Mc.

| TYPE SERVICE | FUNCTION | TYPICAL OPERATION | | | |
|---|---|---|---|---|---|
| | | DC Plate Voltage | DC Plate Current | Driving Power | Plate Power Output |
| Class C Telegraphy or FM Per Tube | RF Power Amplifier and Oscillator | 3,000 | 167 ma | 2.5 watts | 375 watts |
| Class C Telephony, Per Tube, Carrier Conditions | High-Level Modulated RF Amplifier | 2,500 | 152 ma | 3.3 watts | 300 watts |
| Class $AB_1$ Sinusoidal Wave, 2 Tubes | Audio-Frequency Power Amplifier and Modulator | 2,500 | 232 ma | 0.0 watts | 330 watts |
| Class $AB_2$ Sinusoidal Wave, 2 Tubes | Audio-Frequency Power Amplifier and Modulator | 2,500 | 260 ma | 1.0 watts | 400 watts |
| Class $AB_1$, Per Tube | RF Linear Power Amplifier SSB Single Tone | 3,000 | 105 ma | 0.0 watts | 200 watts |

# PERFORMANCE SUMMARY

## EIMAC 4-250A

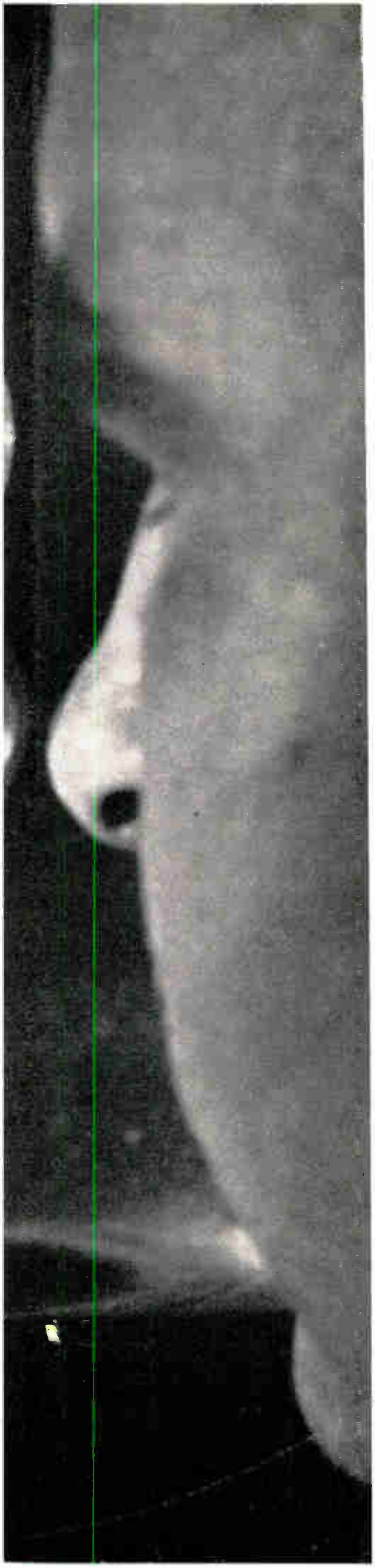
### 250 Watt Radial-Beam Power Tetrode




This compact, ruggedly constructed tetrode is cooled by radiation from the plate and by circulation of forced-air through the base and around the envelope. It features Eimac's exclusive Pyrovac plate, a thoriated tungsten filament, and non-emitting grid. Frequency for maximum ratings: 110 Mc.

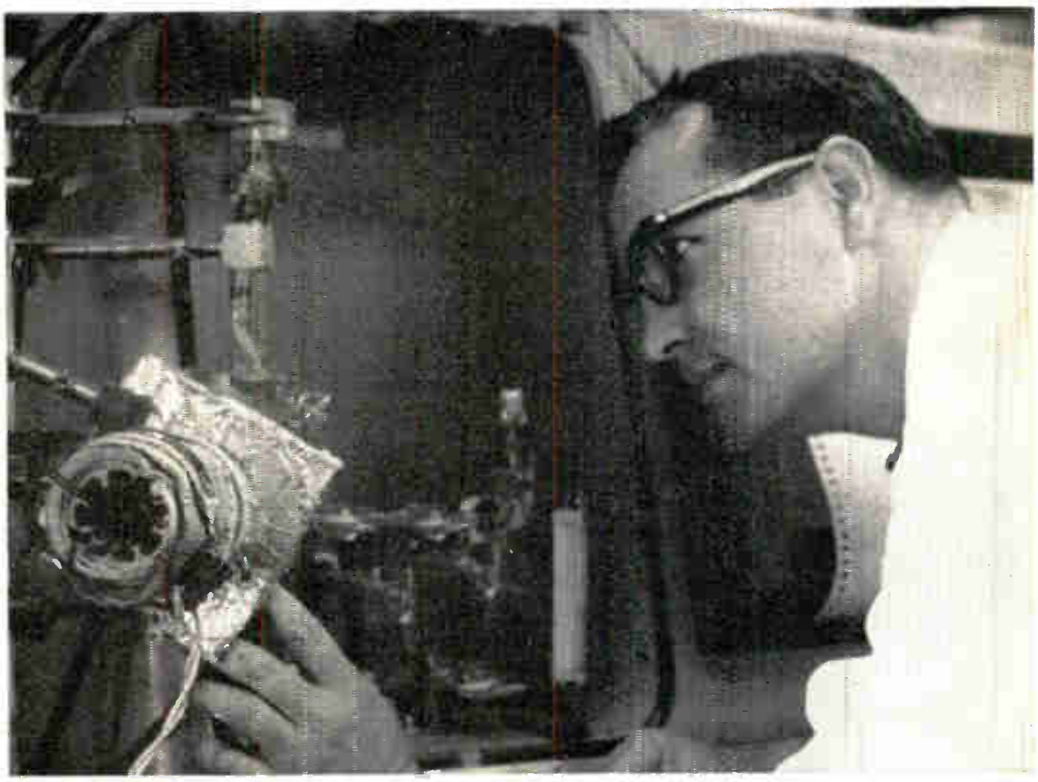
| TYPE SERVICE | FUNCTION | TYPICAL OPERATION | | | |
|---|---|---|---|---|---|
| | | DC Plate Voltage | DC Plate Current | Driving Power | Plate Power Output |
| Class C Telegraphy or FM, Per Tube | RF Power Amplifier and Oscillator | 4,000 | 312 ma | 2.46 watts | 1,000 watts |
| Class C Telephony, Per Tube, Carrier Conditions | Plate-Modulated RF Amplifier | 3,000 | 225 ma | 3.2 watts | 510 watts |
| Class $AB_1$ Sinusoidal Wave, 2 Tubes | AF Power Amplifier and Modulator | 3,000 | 417 ma | 0.0 watts | 750 watts |
| Class $AB_2$ Sinusoidal Wave, 2 Tubes | AF Power Amplifier and Modulator | 3,000 | 473 ma | 1.9 watts | 1,040 watts |
| Class $AB_1$, Per Tube | RF Linear Power Amplifier SSB Single Tone | 4,000 | 165 ma | 0.0 watts | 450 watts |

SEND TODAY FOR DATA SHEET GIVING COMPLETE SPECIFICATIONS, APPLICATION INFORMATION, AND TECHNICAL DATA.



## CLEANER, HARDER VACUUMS INCREASE TUBE LIFE

During production Eimac-designed rotary vacuum pumps evacuate gas at high temperatures. This, plus clean electrode design and non-emitting grids, helps make Eimac internal-anode tetrodes the most reliable available.



## NEWEST TUBE TYPES, TUBE IMPROVEMENTS COME FROM EIMAC RESEARCH AND ENGINEERING

First to develop internal-anode tetrodes, Eimac is also the recognized leader in ceramic-metal vacuum tubes. With emphasis on new tube types, Eimac constantly improves conventional tube types, too.

# Industrial Engineering Notes*

## Government and Legislative

**Japanese production of electronic items in the first quarter of this year was at an annual rate of more than $736 million, or $238 million above the 1958 level, the Business and Defense Services Administration, Commerce Department, reported.** In a compilation of figures based on data from the American Embassy, Tokyo, the Electronics Division, BDSA, said that Japan's electronic output for January–March, 1959 was $184.4 million, and that if this rate of activity is maintained, the 1959 totals will double the 1957 output of $362.2 million. The 1958 total was $498 million, ranking Japan as the fourth largest producer of electronic products, behind the United States, United Kingdom, and West Germany. U. S. electronics production is running at an annual rate of approximately $8.5 billion. The greatest increase in volume in Japanese production between 1957 and 1958 occurred in consumer electronic products—from $170.9 million to $266.2 million. In this category the largest increase was in the production of television receivers, from $86.8 million (0.6 million units) to $154.1 million (1.2 million units) followed by radio receivers, $67.0 million (3.6 million units) to $87.1 million (4.9 million units). These values represent factory prices plus domestic excise taxes and royalties, if any. Excise taxes are 30 per cent on television receivers with picture tubes of over 14 inches and 20 per cent on those with picture tubes of 14 inches and less. Semiconductor output registered the greatest rate of increase—129 per cent—from $10.7 million in 1957 to $24.5 million in 1958; production during the first quarter 1959 amounted to $11.5 million. The principal item in this group is transistors, of which 5.7 million units valued at $8.9 million were produced in 1957; 26.7 million units at $21.4 million in 1958; and 15.0 million units at $9.9 million in the first quarter of 1959. **The value of Japanese electronic products exported to the U. S. during the first half of this year exceeded the total for the entire calendar year 1958, The Electronics Division, Business and Defense Services Administration, Commerce Department has announced.** The BDSA Division also revealed in its compilation that these exports nearly tripled the total for calendar year 1957. Japanese exports of electronic products to this country during the January-June period this year were valued at $22.1 million, more than 50 per cent of the entire foreign market for Japanese electronic products. The value of these exports in calendar year 1958 totaled $21.775 million, or 46 per cent, and $7.582 million in calendar year 1957, or 39 per cent of market for Japanese electronics. The BDSA Electronics Division said that although consumer type radio receivers represent the largest part of this trade, other items such as recorders, electron tubes, transistors, and phonograph parts and accessories are showing "significant gains."

## Engineering

**The Army has released papers presented at an international symposium on image intensifiers held in October last year at Ft. Belvoir, Va., the Commerce Department's Office of Technical Services announced.** The volume contains 24 technical documents read by representatives of industry and government. In the area of image converter tube intensifier research, papers deal with a two-stage electron-image converter, magnetically focused image converter tubes, a light image intensifier, the transmission secondary emission image intensifier, and image converters with protecting foils. Among papers on image orthicon devices are those on a night television system, a light scan camera tube, an image orthicon with a new target, single-layer image intensifying screens with high resolution, and daytime detection of celestial bodies using the intensifier image orthicon. The publication, "Image Intensifier Symposium," is number PB 151813, and can be ordered from OTS, Commerce Department, Washington 25, D. C., at $5 each.

## Industrial Marketing Data

**EIA figures released recently show an increase in radio-TV production during August, 1959, over the July level.** On all counts the figures show a cumulative increase during the first eight months of this year compared with the like 1958 period. TV production in August totaled 547,445 compared with 350,360 sets made in July and 507,526 TVs made in August, 1958. This figure includes 32,847 sets capable of receiving UHF signals as against the 21,022 such sets made in July and 38,166 UHF receivers made in August last year. Cumulative UHF output during the first eight months of this year totaled 234,312 compared with 271,097 last year. Year-to-date TV output totaled 3,680,520 compared with 2,950,455 during the like January–August period last year. The number of radios produced in August totaled 1,009,423, including 279,424 automobile receivers, compared with 829,035 radios made in July including 254,725 auto sets, and 981,394 radios made in August, 1958, which included 242,915 automobile receivers. The number of FM radios made in

* The data on which these NOTES are based were selected by permission from *Weekly Reports*, issues of September 28, October 5 and 12, published by the Electronic Industries Association whose helpfulness is gratefully acknowledged.

*(Continued on page 46A)*

# FREQUENCY STANDARDS

## PRECISION FORK UNIT
TYPE 50

*Size 1" dia. x 3¾" H.* Wght., 4 oz.*

Frequencies: 240 to 1000 cycles
Accuracies:—
Type 50 (±.02% at —65° to 85°C)
Type R50 (±.002% at 15° to 35°C)
Double triode and 5 pigtail parts required
Input, Tube heater voltage and B voltage
Output, approx. 5V into 200,000 ohms

*3⅛" high
400 - 1000 cy.

## FREQUENCY STANDARD
TYPE 50L

*Size 3¾" x 4½" x 5½" High*
*Weight, 2 lbs.*

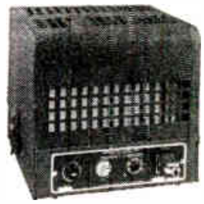
Frequencies: 50, 60, 75 or 100 cycles
Accuracies:—
Type 50L (±.02% at —65° to 85°C)
Type R50L (±.002% at 15° to 35°C)
Output, 3V into 200,000 ohms
Input, 150 to 300V, B (6V at .6 amps.)

## PRECISION FORK UNIT
TYPE 2003

*Size 1½" dia. x 4½" H.* Wght. 8 oz.*

Frequencies: 200 to 4000 cycles
Accuracies:—
Type 2003 (±.02% at —65° to 85°C)
Type R2003 (±.002% at 15° to 35°C)
Type W2003 (±.005% at —65° to 85°C)
Double triode and 5 pigtail parts required
Input and output same as Type 50, above

*3½" high
400 to 500 cy.
optional



## FREQUENCY STANDARD
TYPE 2005

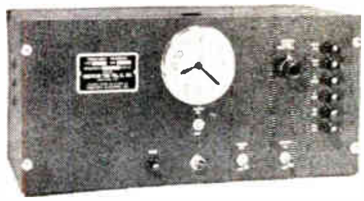
*Size, 8" x 8" x 7¼" High*
*Weight, 14 lbs.*

Frequencies: 50 to 400 cycles (Specify)
Accuracy: ±.001% from 20° to 30°C
Output, 10 Watts at 115 Volts
Input, 115V. (50 to 400 cycles)

## FREQUENCY STANDARD **NEW**
TYPE 2007-6
TRANSISTORIZED, Silicon Type

*Size 1½" dia. x 3½" H. Wght. 7 ozs.*

Frequencies: 400 — 500 or 1000 cycles
Accuracies:
2007–6 (± .02% at —50° to +85°C)
R2007–6 (±.002% at +15° to +35°C)
W2007–6 (±.005% at —65° to +125°C)
Input: 10 to 30 Volts, D. C., at 6 ma.
Output: Multitap, 75 to 100,000 ohms



## FREQUENCY STANDARD
TYPE 2121A

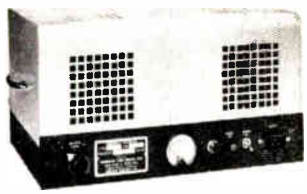
*Size*
*8¾" x 19" panel*
*Weight, 25 lbs.*

Output: 115V
60 cycles, 10 Watt
Accuracy:
±.001% from 20° to 30°C
Input, 115V (50 to 400 cycles)

## FREQUENCY STANDARD
TYPE 2001-2

*Size 3¾" x 4½" x 6" H., Wght. 26 oz.*

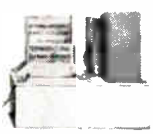
Frequencies: 200 to 3000 cycles
Accuracy: ±.001% at 20° to 30°C
Output: 5V. at 250,000 ohms
Input: Heater voltage, 6.3 - 12 - 28
B voltage, 100 to 300 V., at 5 to 10 ma.



## FREQUENCY STANDARD
TYPE 2111C

*Size, with cover*
*10" x 17" x 9" H.*
*Panel model*
*10" x 19" x 8¾" H.*
*Weight, 25 lbs.*

Frequencies: 50 to 1000 cycles
Accuracy: (±.002% at 15° to 35°C)
Output: 115V, 75W. Input: 115V, 50 to 75 cycles.



## ACCESSORY UNITS
for TYPE 2001-2

L—For low frequencies multi-vibrator type, 40-200 cy.
D—For low frequencies counter type, 40-200 cy.
H—For high freqs, up to 20 KC.
M—Power Amplifier, 2W output.
P—Power supply.

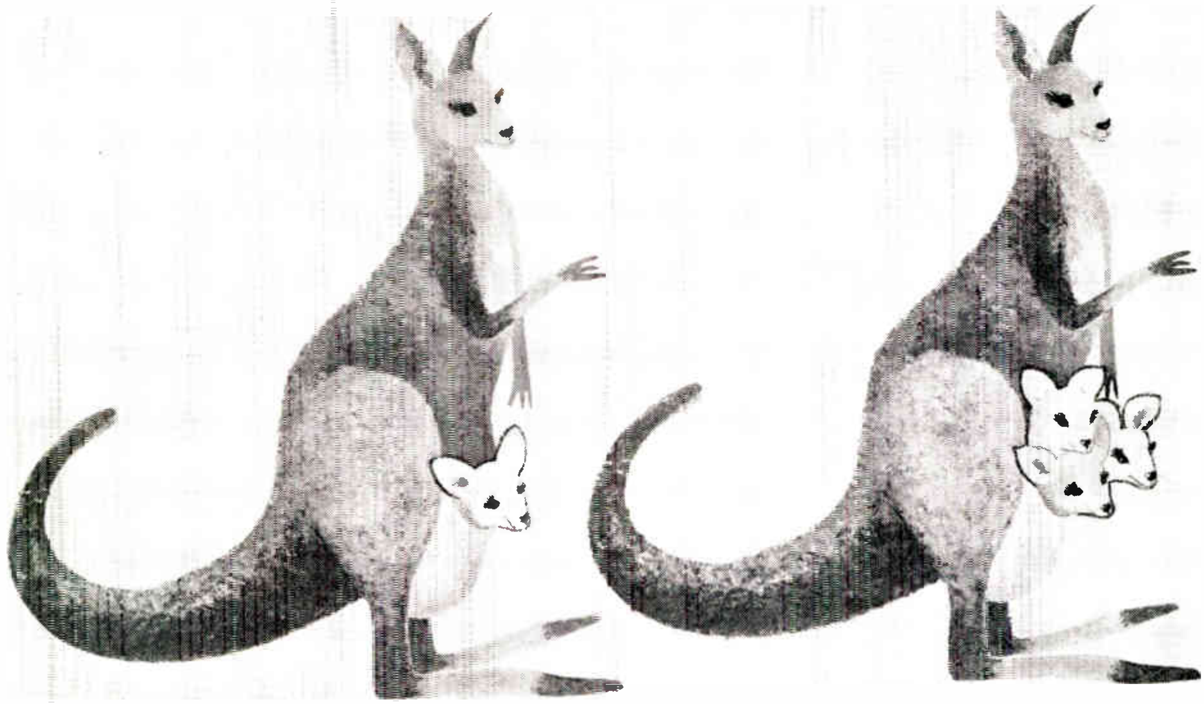
*This organization makes frequency standards within a range of 30 to 30,000 cycles. They are used extensively by aviation, industry, government departments, armed forces—where maximum accuracy and durability are required.*

WHEN REQUESTING INFORMATION PLEASE SPECIFY TYPE NUMBER

# *American Time Products, Inc.*

Watch Master
*Timing Systems*

**Telephone: PLaza 7-1430** **580 Fifth Ave., New York 36, N. Y.**



# TRIPLE THE CAPACITY AT NO INCREASE IN SIZE

## NEW FROM JFD


**MAX-C**

MINIATURE TRIMMER SEALCAP*

From JFD, pioneer in precision electronic components, comes the most important new miniature trimmer development in years!

Now you can have *triple* the range previously attainable in a miniature trimmer capacitor — at *no* sacrifice in volume — with new MAX-C Sealcaps.

Imagine the possibilities in your circuitry!

This new series incorporates revolutionary new advances in trimmer production which combines the advantages of a thin dielectric gap with the structural strength and ruggedness of a heavy wall glass tube. The result is a broad capacitance tuning range at a *300 per cent* saving in volume over other presently available piston trimmer caps.

Also, MAX-C Sealcaps feature a new sealed interior construction that locks out all atmospheric effects, locks in stable performance under critical extremes of altitude, vibration, shock, temperature and other rigorous environmental conditions.

These new trimmers along with the complete JFD line of miniature and subminiature trimmers, and LC tuners offer you new dimensions in design. For complete data, write today for bulletin #221.

MINIATURE PANEL MOUNT MAX-C SEALCAP SERIES

| Model | Min. Max. (pf) | DISTANCE BEYOND PANEL | MAXIMUM DIAMETER |
|---|---|---|---|
| MC601 | 1.0 14.0 | 29/64" | 5/16" |
| MC603 | 1.0 28.0 | 11/16" | 5/16" |
| MC604 | 1.0 42.0 | 29/32" | 5/16" |
| MC606 | 1.0 60.0 | 1 5/32" | 5/16" |
| MC609 | 1.0 90.0 | 1 3/4" | 5/16" |

Also available in printed circuit lug and lead and 4 wire lead type.

JFD

Pioneers in electronics since 1929

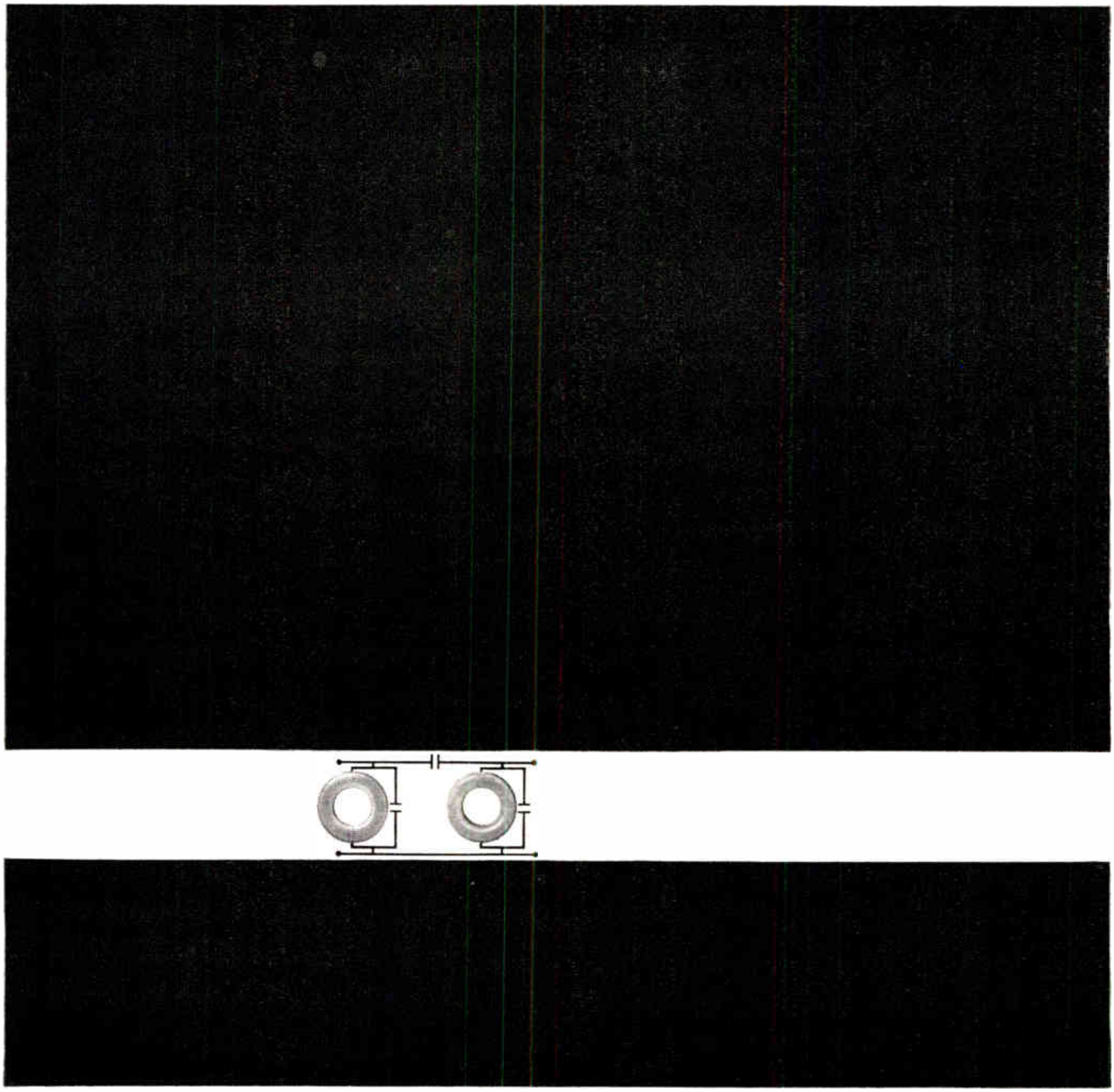
**ELECTRONICS CORPORATION**

1462 62nd Street, Brooklyn, New York

**JFD International,** 15 Moore Street, New York, New York

**JFD Canada Ltd.,** 51 McCormock Street, Toronto, Ont., Conodo

*TRADEMARK



# *Smaller filters ease the squeeze!*

## Filter designers! First 160-mu moly-permalloy powder cores pack high performance into smaller space

Filter and inductor designers specify our 160-mu moly-permalloy powder cores for low frequency applications. Where space is precious, such as in carrier equipment and telemetering filters, the high permeability of these 160-mu cores eases the squeeze.

In many cases, 160-mu cores offer designers the choice of a smaller core. In others, because inductance is 28 percent higher than that of 125-mu cores, at least 10 percent fewer turns are needed to yield a given inductance.

If Q is the major factor, 160-mu cores permit the use of heavier wire with a resultant decrease in d-c resistance.

Like all of our moly-permalloy powder cores, the 160's come with a *guaranteed* inductance. We can ship eight sizes from stock, with a choice of three finishes—standard enamel, guaranteed 1,000-volt breakdown finish, or high temperature finish. Further information awaits your inquiry. *Magnetics Inc., Dept. P-78, Butler, Pa.*

**MAGNETICS inc.**

## Industrial Engineering Notes

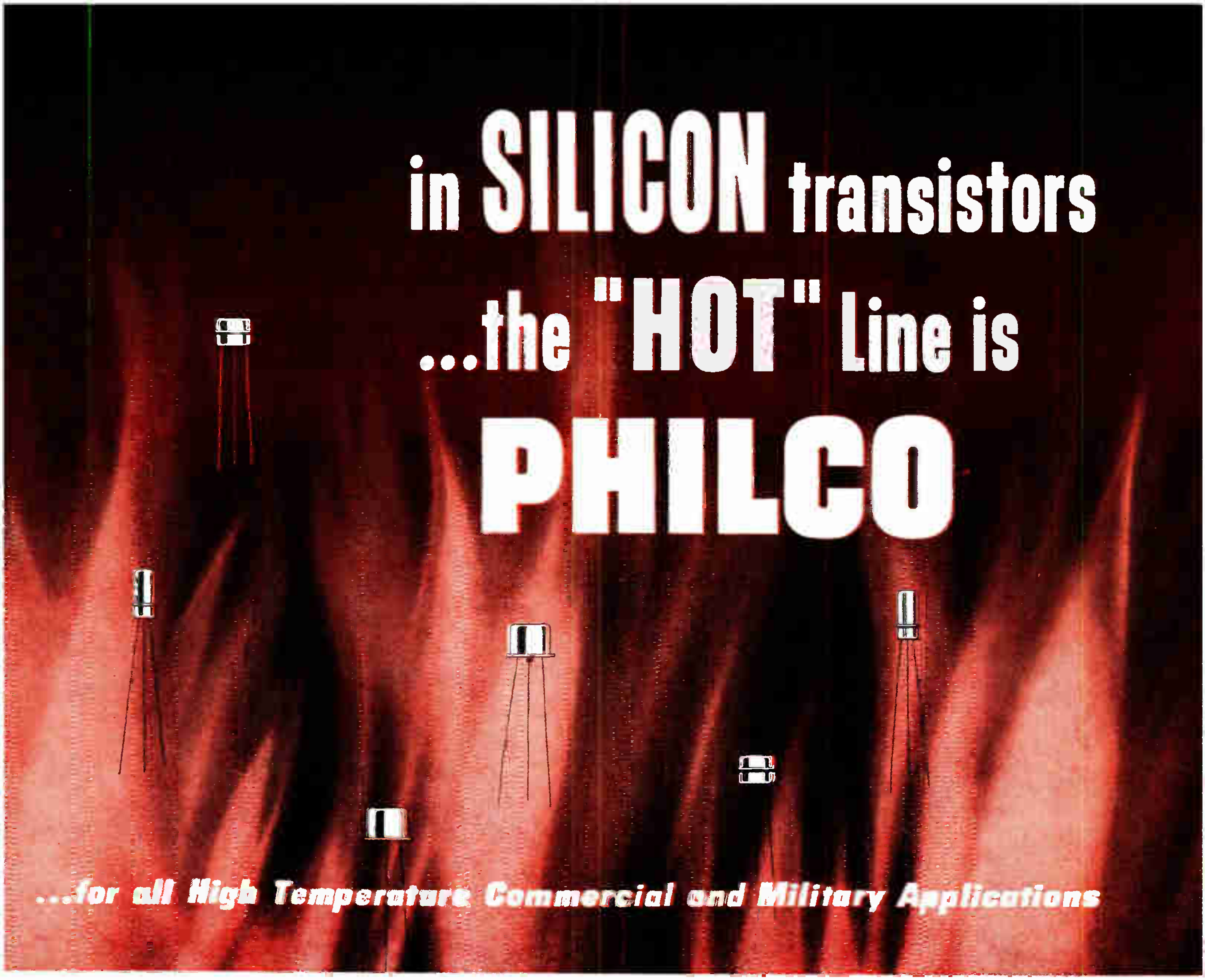
*(Continued from page 42A)*

August totaled 42,886 compared with 24,553 made in July and 21,335 made in August, 1958. Cumulative FM radio output during the first eight months of this year totaled 290,862 compared with 134,653 during the like 1958 period. Cumulative over-all radio output during the first eight months of this year amounted to 8,946,044 including 3,434,345 automobile receivers, compared with 6,193,529 radios made during the like 1958 period, which included 1,893,813 auto receivers.

### Military Electronics

**Both military and commercial communications satellites "are now certainties of the Space Age," the Army's Deputy Chief Signal Officer told the Radio-Television Executives Society in New York in October.** Gen. Earle F. Cook, principal speaker, said the present space communications programs of the military departments ultimately will give us "reliable global communications" so "desperately needed." Gen. Cook outlined the following "ambitions" program which he said would take from 5 to 10 years to complete successfully; (all a part of Project NOTUS which constitutes a family of several kinds of communications satellites): 1) The first phase of the NOTUS Project, he said, is Task COURIER—to provide vitally needed expansion of trunking capacities for global communications by means of delayed-repeater satellites. In this concept, an Army-developed communications satellite will initially be placed in a circular orbit at a relatively low altitude of about 650 miles minimum. 2) Another task of Project NOTUS, Gen. Cook said, is to provide a real-time or instantaneous satellite repeater for two-way communications in the polar regions. This is called Task STEER, and is being developed by the Air Force. 3) A more advanced type of 6-gour polar satellite is also under development by the Army, known as Task TACKLE. It will provide ground-to-air and ship-to-shore two-way communications and will be launched in a polar orbit by an Air Force modified ATLAS missile. 4) Task DECREE is a real-time communications relay station aboard a satellite in a 24-hour equatorial orbit. The satellite operates at about 23,300 statute miles above the earth's surface and at such speed that the rotation of the earth will keep the space vehicle in a fixed position with respect to the earth. When completed, Gen. Cook said, these developments will place us "on the threshold of a vast new era of communications."

**Use your IRE DIRECTORY! It's valuable!**




## ...High Speed Switches

Philco's full range of silicon high speed switching transistors, in both PNP and NPN types, provides the designer with a wide choice to meet the requirements of all high temperature applications. They are engineered and specified to permit simple, straightforward design of practical circuits up to 5 mc pulse rates, using saturated configurations and up to 30 mc pulse rates with non-saturating techniques. Packaged in TO-1, TO-5 and TO-9 cases.

**PNP** 2N496, 2N1119, 2N1429 **NPN** 2N1199

## ...High Frequency Amplifiers

Philco amplifying transistors are available in nine types, covering the complete high frequency range. The designer will find both PNP and NPN types that permit the design of communications systems at frequencies up to 60 mc. They have low collector capacitance and are available with restricted beta ranges to simplify design problems. All offer excellent performance at junction temperatures up to +140°C. Packaged in TO-1, TO-5 and TO-9 cases.

**PNP** 2N495, 2N1118, 2N1428 **NPN** 2N1267, 2N1268, 2N1269, 2N1270, 2N1271, 2N1272

*All types environmentally tested in accordance with MIL-T-19500A . . . and have been thoroughly field-proven in countless critical military and industrial applications.* **For complete data and application information, write Dept. IR-1259**

**All Types Immediately Available in Production Quantities . . . and 1-99 from your local Philco Industrial Semiconductor Distributor**

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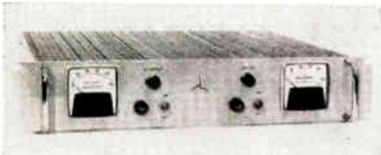
TRANSISTOR CENTER U.S.A.

# NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

## Transistorized Power Supply

**Trygon Electronics, Inc.,** Pleasant Ave., Roosevelt, L.I., N. Y., announces the availability of the "300" Silver Trygon Series of transistorized power supplies. This series furnishes 110 volts dc to 325 volts dc variable output at 200 ma, 400 ma, 800 ma and 1500 ma with 0.1% load and 0.1% line regulation, thus supplying transistorized power heretofore serviced by vacuum tube or hybrid equipment. The solid state design results in smaller and lighter supplies, dissipating less heat and providing high reliability.



The 200 ma, 400 ma and 800 ma, units occupy $3\frac{1}{2}''$ of panel height and require convection cooling. The 1500 ma supply has a $5\frac{1}{4}''$ panel height and employs forced air cooling.

Remote programming is provided on all units, thus making them suited for automatic check out system applications.

Remote error signal sensing capabilities are provided with all units in order to maintain the voltage regulation at the load.

Units are available from stock with prices ranging from $395 to $685.

## Frequency Standard

Model NC-1200, a new transistorized frequency standard, has been announced by **National Company, Inc.,** Malden, Mass.

Model NC-1200 uses a transistorized crystal oscillator identical with the one used in the most advanced models of the Atomichron a precise frequency standard. It provides outputs of 0.1, 1.0 and 5.0 mc, all stable to one part in $10^9$ parts per day. All three outputs may be used simultaneously and each is capable of developing an output voltage of 200 milivolts across a 50 ohm load.

The NC-1200 is designed for standard relay rack installation. All controls and output connections are located on the front panel. The frequency is adjustable by means of a ten turn dial which permits calibration to one part in $10^{10}$.

The oscillator is designed to meet MIL-E 16,400 shock and vibration specifications. The components (oscillator, divider and power supply) can be repackaged to meet military requirements if desired.

Other specifications are as follows: size—6 by 7 by 11" box mounted on a 19 by 7" panel. Operating circuits occupy approximately 570 cubic inches exclusive of front panel. Operating weight, 15 pounds and operates from 115 volt, 60 cps ac line. Special power requirements can be provided for including battery and 400 cps ac operation.

## Center Screwlock Connector

The **Electronic Sales Div., De Jur-Amsco Corp.,** 45-01 Northern Blvd., Long Island City 1, N. Y., has just announced a new Series 1900 miniature rectangular power connectors with center screwlock and closed entry contacts.

These pin and socket connectors are designed for heavy duty applications. They have high dielectric and mechanical strength, and feature stainless steel channels which are riveted to the long sides of plug and receptacle.

A double lead thread action center screwlock assures positive locking action of mating units. Terminals for solderless wire wrap, solderless taper pin or solder cup are available. The closed entry contacts supplied, provide increased reliability and maintain a low millivolt drop under constant and uniform insertion pressure. In addition to the 152-contact type illustrated, this series can also be supplied with 104, 78, or 34 contacts. Body material is molded from glass filled diallyl Phthalate (MIL-M-19833, Type GDI-30).

For a free technical brochure with complete specifications and outline drawings on Continental Connector's new Series 1900, write to the firm.

## Stone Named Chief Of Production At P&B

C. Robert Stone has been named chief production engineer at **Potter and Brumfield** Division of American Machine & Foundry Co., Princeton, Ind., according to an announcement today by H. L. Huntsinger, P&B executive vice-president.

The appointment, part of a program to strengthen and better integrate P&B's engineering service, gives Stone responsibility for all facets of production engineering including tooling, methods, processing, equipment development, and quality assurance. Four new production engineers will be added to his staff. They will function as project engineers and will be assisted on a staff basis by the tooling and processing groups.

Stone was graduated from Indiana Technical College, Fort Wayne, in 1950 with a Bachelor of Science Degree in Electrical Engineering. He started his career with P&B as a production foreman that same year.

## Capacitor Bulletin

Wet-Slug Tantalytic® Capacitors—Bulletin GEA-7008, prepared by **General Electric Co.,** Schenectady 5, N. Y., 4 pages, provides detailed information about wet-type, sintered porous-anode tantalum capacitors used where extremely high capacitance values are required in the smallest possible space.

The publication explains performance characteristics and advantages of the units and includes 4 tables, 5 graphs, outline drawings and complete ratings and dimensions.

## Volt-Ammeter Bulletin

Hook-On Volt Ammeter—Bulletin GEA-6292C, (four pages)—gives description, specifications and construction details of General Electric's pocket-size, hook-on volt ammeters for testing ac voltages. Lists applications, current ranges, accuracy percentage and operating instructions. For a copy contact **General Electric Co.,** Schenectady 5, N. Y.

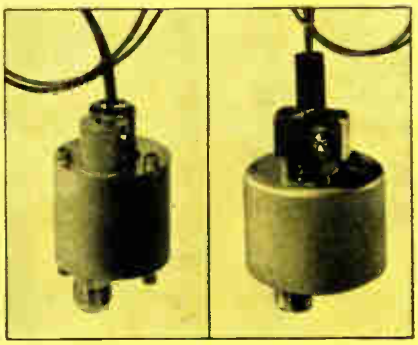
*(Continued on page 96A)*

# Creative Microwave Technology

Published by MICROWAVE AND POWER TUBE DIVISION, RAYTHEON COMPANY, WALTHAM 54, MASS., Vol. 1, No. 5

## NEW RAYTHEON MICROWAVE TUBE DEVELOPMENTS

Miniature pulsed magnetrons for missile beacon applications are ruggedly constructed with integral magnets. The RK-7461 is tunable from 9,300 to 9,500 mc and has minimum peak power output of 60 watts. It is 1¼" in diameter and 2½" long, and weighs only 6 ounces.

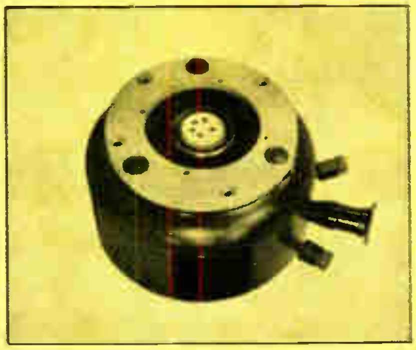


RK-7461 QK-735

The QK-735 is tunable from 5,400 to 5,900 mc with minimum peak power output of 400 watts. 1½" in diameter and 3¼" long, it weighs 8 ounces.

* * *

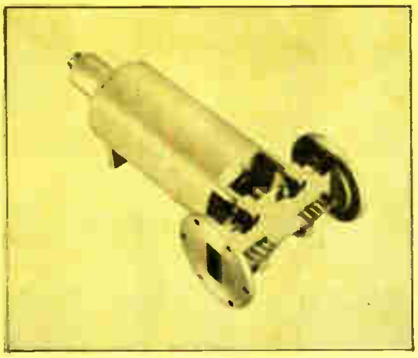
Designed for electronic countermeasures and FM/CW operations, the QK-625 BWO provides a minimum CW power output of 180 watts and a nominal CW power output of 250 to 350 watts over the 2,500 to 3,000 mc band. The tube is voltage tunable over the entire range with tuning sensitivity of approximately 0.4 mc/volt. Liquid-cooled, the QK-625 BWO is equipped with an integral



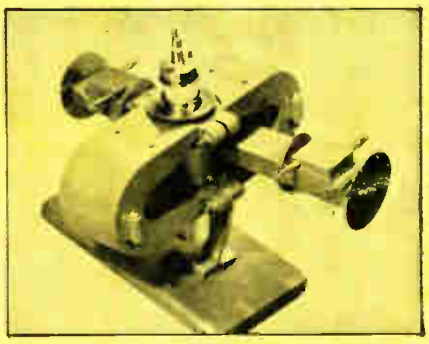
permanent magnet, and can be mounted in any position.

* * *

Small-signal gain of up to 35 db in microwave relay links is achieved by means of a new compact traveling wave tube amplifier -- the QK-542. This permanent-magnet focused CW tube has nominal saturated power output of 5 watts over 5,900 to 7,400 mc. An integral UG 344/U waveguide-type flange is supplied as standard. With an optional coaxial output coupler the QK-542 covers 4,000 to 8,000 mc.



Ideal for linear accelerators and high-power radar systems. The QK-783 and QK-622 Amplitrons operate over the 2,700-2,900 mc and 2,900-3,100 mc bands, respectively, at a peak power of 3 megawatts and a typical efficiency of 75%. Because no heater is required, these tubes are capable of exceptionally long life. RF gain is 8 db under rated conditions, and as high as 12 db at lower peak power outputs. Phase pushing figure is less than 0.5 degrees for a 1% variation of anode current.



* * *

Compiled as a Raytheon service to the field, new Consolidated Data Booklet contains comprehensive information about principal unclassified magnetrons, klystrons, backward wave oscillators and special purpose tubes manufactured by Raytheon. Characteristics presented include maximum ratings, typical operating values, band or frequency ranges and other essential data for microwave engineers and purchasing departments.

A Leader in Creative Microwave Technology RAYTHEON

# IRE People

**John J. Guarrera** (S'42–A'44–M'55–SM'56), engineering management specialist, has been appointed Director of Marketing and Product Development for Burton Instruments, a division of Burton Manufacturing Co. of Santa Monica, Calif., according to an announcement by William Arthur Mendelsohn, President. Mr. Guarrera was formerly associated with Reeves Instrument Corp. and Canoga Corp.


J. J. GUARRERA

He will supervise marketing of Burton's line of aircraft instruments and calibration and associated maintenance equipment, and also guide the development of new Burton instruments, test equipment, and transducers for the electronic and missile industries.

Mr. Guarrera has been a chairman of the San Fernando Valley Subsection and has served on several IRE Committees.

❖

Applied Technology, Inc., Palo Alto, Calif., has announced the election of **Dr. Oswald G. Villard, Jr.** (S'38–A'41–SM'51–F'57), senior professor of Stanford University's Radio Propagation Laboratory, to the board of directors.

He has been on the Stanford electrical engineering faculty since 1939, except for four years, 1942 to 1946, on the engineering staff of Harvard University's Radio Research Laboratory. He obtained the A.B. degree from Yale University, and subsequently the degree of Engineer and Ph.D. from Stanford. He has become well-known for his work in radio studies of the upper atmosphere since 1941–1942, when he directed ionosphere research at Stanford for the National Defense Research Committee.

Dr. Villard is a member of the American Institute of Electrical Engineers and the International Scientific Union.

❖

**Dr. Arthur A. Oliner** (M'47–SM'52), research professor of electrical engineering at the Polytechnic Institute of Brooklyn, left for Japan on October 17, 1959, as an invited guest of three Japanese scientific societies. The visit is sponsored by the U. S. Air Force.

During his month-long visit, which ended November 20, he lectured on the most recent developments in microwave electronics before the Japanese Institute of Electrical Engineers, the Institute of Electrical Communication Engineers of Japan, and the Tokyo Section of the Institute of Radio Engineers.

In addition to lecturing, he visited Japanese electronics laboratories to study the state of electronics developments in that country.

He lectured at universities and scientific installations in Tokyo, Sendai, Sapporo, Osaka and Kyoto. After leaving Japan he spent approximately a week in Taiwan (Formosa) to study the state of the electronics art in that country.

Dr. Oliner received his Ph.D. from Cornell University in 1946. Between 1941 and 1945 he was a graduate teaching assistant and a research assistant at Cornell. Since that time he has been a professor of electrical engineering at the Polytechnic and a research section head in Polytechnic's Microwave Research Institute.

❖

**Frederick R. Lack** (A'20–F'37) former EIA Vice President and Director and Vice President of Western Electric Co. until his retirement in 1958, has been elected Director of the EIA Engineering Department, according to an announcement by President D. R. Hull. Mr. Lack will fill the position occupied for 25 years by Dr. W. R. G. Baker who will continue his advisory role to the Association as Director Emeritus of the EIA Engineering Department.

The election of Mr. Lack by the Board of Directors was effected by mail ballot. By virtue of his office, he becomes an ex-officio member of the Board.

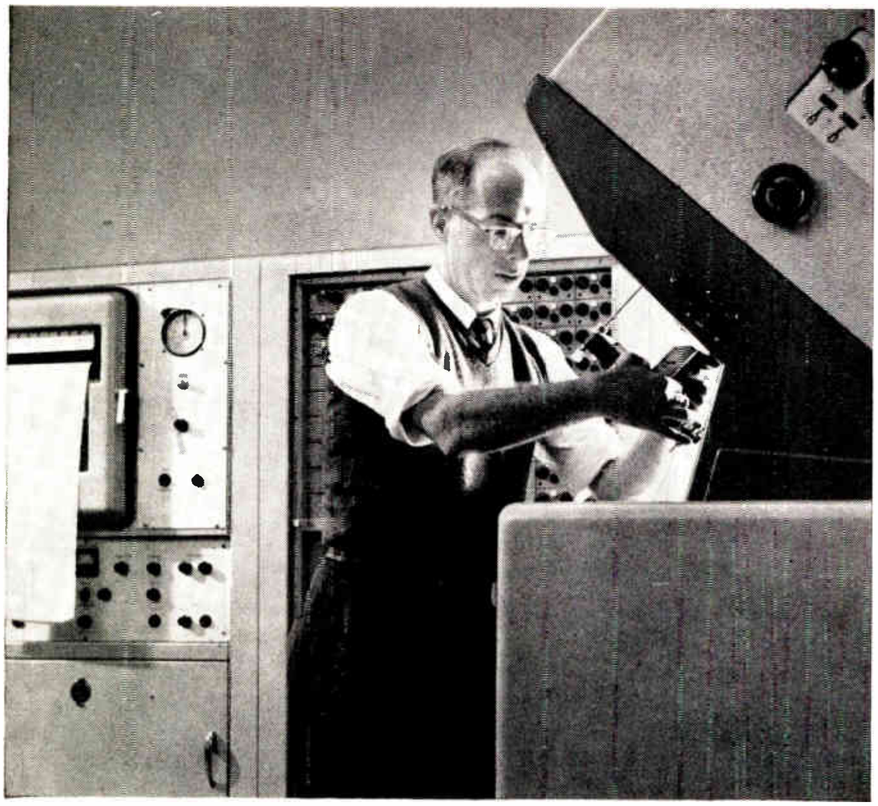
He was one of the leaders in establishing the Military Products Division in EIA and was awarded the 1959 EIA Medal of Honor last May at the Association's annual convention in Chicago for his many contributions to the advancement of the electronic industry.

Following service as a Lieutenant in the U. S. Army Signal Corps in France during World War I, he received the B.S. degree (magna cum laude) from Harvard University in 1925. He was given an honorary degree of Doctor of Science by Albright College in 1908.

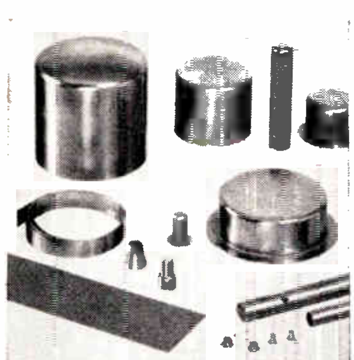
During World War II he served in Washington as Director of the Army-Navy Electronics Production Agency. In 1947 he was awarded the Presidential Certificate of Merit "for outstanding fidelity and meritorious conduct in aid of the war effort against the common enemies of the United States and its Allies in World War II." In 1922 the Order of the Rising Sun was bestowed on him by the Japanese Government.

From 1925 to 1938 he was on the staff of Bell Telephone Laboratories. He later was in charge of vacuum tube development and also directed the design and

*(Continued on page 52A)*









## IRE People

(Continued from page 50A)

building of the first commercial ship-to-shore radio telephone, installed on the liner SS Leviathan. More recently, Mr. Lack undertook the administration of the development and manufacture of the Western Electric Co.'s well-known NIKE family of missiles, many of which have been guarding the nation's cities for over five years. Among his last work on the NIKE before his retirement was with the Army on the development of the NIKE-ZEUS anti-missile missile.

Mr. Lack has been President of the American Standards Association and a director of the Armed Forces Communications and Electronics Association. He is a member of the American Institute of Electrical Engineers, the American Association for the Advancement of Science, the American Physical Society, and the Harvard Engineering Society.

❖

**H. Myrl Stearns** (S'39–A'40–SM'48–F'59), president of Varian Associates, has been elected a Fellow of the American Association for the Advancement of Science.

One of the founders, in 1948, of Varian Associates, he has been a key figure in the development of the electronics industry on the west coast. He has served as director of the San Francisco section and chairman of the Palo Alto subsection of the IRE. He is active in affairs of the Western Electronics Manufacturers Association, having served the group as president in 1955. As 1959 chairman of the board of directors for WESCON, he presided at the association's recent convention in San Francisco. Mr. Stearns also is a past vice-chairman for the west of the American Institute of Electrical Engineers.

❖

**George G. Young** (SM'56) has been appointed Manager of the Production Engineering Subsection of General Electric Co.

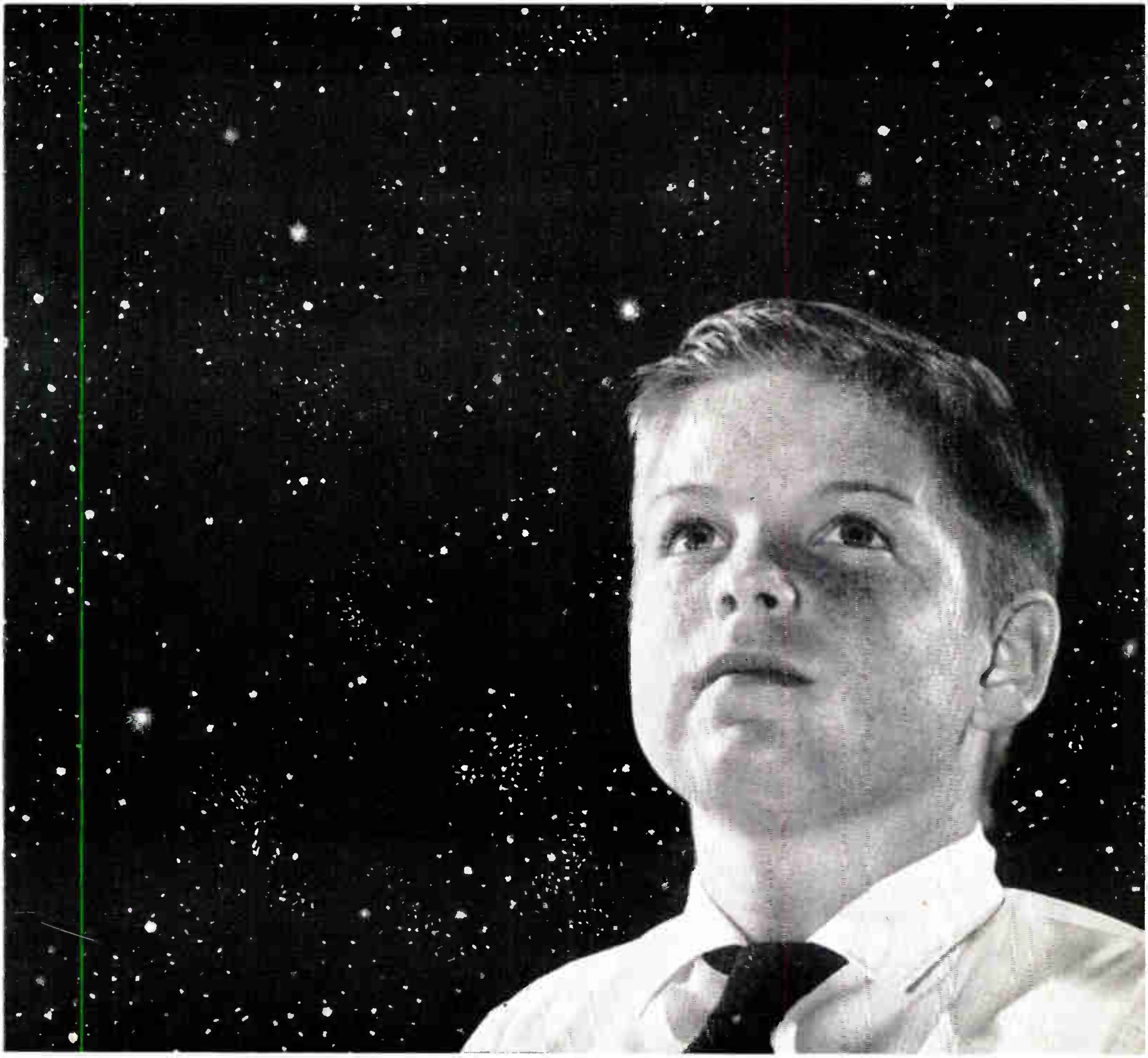
He received the B.S. degree in electrical engineering from North Carolina State College in 1942, and immediately following graduation he joined General Electric's engineering test program at Schenectady, N. Y. In 1942 he transferred to Bridgeport, Conn., where he was associated with the then combined General Electric radio and television department. He came to Syracuse as a production engineer on FM radio receivers when the department was moved to Electronics Park. In 1952 he was named supervisor of production engineering for television receivers.

Mr. Young is a member of Eta Kappa Nu.

❖

**M. E. Femmer** (A'48–SM'53), formerly Associate Director of Research for IBM at the Lamb Estate Research Laboratory,

(Continued on page 56A)



# Signals from Space

A boy can now hear sounds that you were able to hear only in your dreams. Today a boy can actually hear signals from space! A tiny beacon (left) has been developed by Melpar to ride far above the earth, sending back tales of achievement from missiles and satellites. IMAGINEERING at Melpar will turn many of your dreams into realities. Because Melpar is constantly expanding its capacity for original conception, design, and production of advanced defense and space exploration projects.

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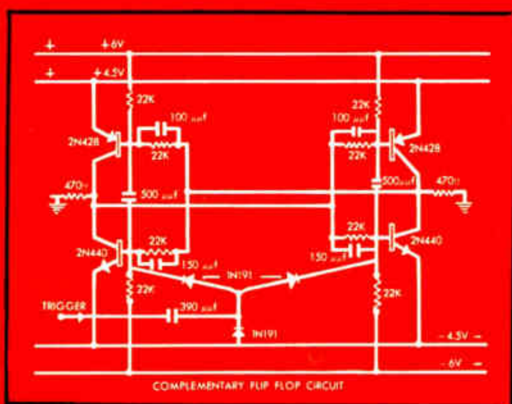
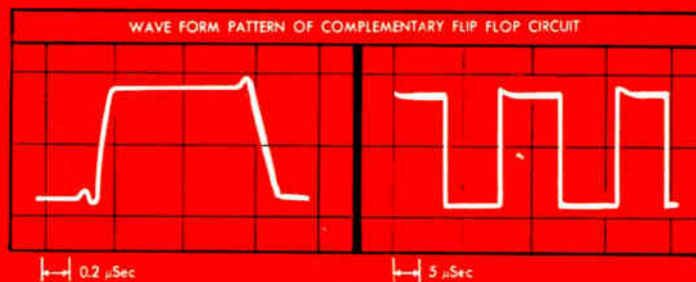
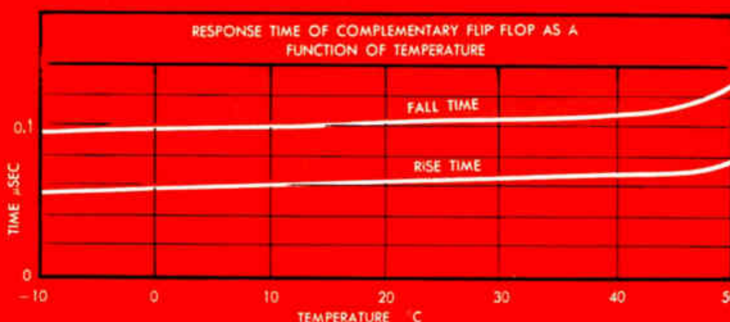
# for switches

## COMPLEMENTARY FLIP FLOP CIRCUIT



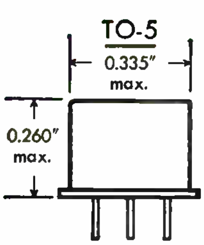



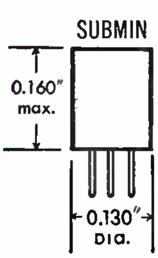




higher efficiency
symmetrical wave shape
lower output impedance
shorter rise and fall times

## DESIGNED FOR COMPUTERS • MADE FOR COMPUTERS

### Medium Current Switches




**GERMANIUM PNP ALLOY — TO-5 CASE**

| Type | $V_{CE}$ Volts | $f_{\alpha b}$ Avg. Mc | $H_{FE1}$ $I_B$ = 1MA $V_{CE}$ = 0.25V | $H_{FE2}$ Min. $I_B$ = 10MA $V_{CE}$ = 0.25V | Rise* Time Max. |
|---|---|---|---|---|---|
| **2N404** | −24 | 12 | — | — | — |
| **2N425** | −20 | 4 | 20–40 | 10 | 1.0 |
| **2N426** | −18 | 6 | 30–60 | 10 | 0.55 |
| **2N427** | −15 | 11 | 40–80 | 15 | 0.44 |
| **2N428** | −12 | 17 | 60 | 20 | 0.33 |
| **2N1017** | −10 | 22 | 80 | 20 | 0.27 |

*$I_C$ = 50MA; $I_{B1}$ = 5MA; $R_L$ = 200Ω $I_{B2}$ = 5MA

**GERMANIUM NPN ALLOY — TO-5 CASE**

| Type | $V_{CE}$ Volts | $f_{\alpha b}$ Avg. Mc | $H_{FE}$ Min. $I_C$ = 50MA $V_{CE}$ = 1.0V | Rise** Time Avg. μsec |
|---|---|---|---|---|
| **2N438** | 25 | 6 | 20 | 0.7 |
| **2N439** | 20 | 11 | 30 | 0.5 |
| **2N440** | 15 | 17 | 40 | 0.3 |

**$I_{B1}$ = $I_{B2}$ = 1MA; $I_C$ = 10MA; $R_L$ = 1KΩ

*Contact the nearest Raytheon office for data on*

**SILICON as well as GERMANIUM Switching Transistors**

## IRE People

*(Continued from page 52A)*

located in Cortlandt, N. Y., has been appointed Manager, Engineering Plans, on the staff of the Vice President—Research and Engineering in the Corporation offices at 590 Madison Avenue, New York, N. Y.

M. E. Femmer

In his new position, he will exercise staff supervision over engineering and product development activities throughout the corporation.

He joined IBM in August, 1946, as a laboratory engineer working on the design of a matrix multiplier and on RF gas tube research for a matrix multiplier. He was later appointed a technical engineer and in July, 1949, became a project engineer working on magnetic tape systems development. In this assignment he helped develop electronic circuits for reading, writing and control of the first IBM prototype tape drive and associated systems. Later he worked on the outline and design of high speed I/O circuits and systems for the NORC computer including coordination of the design of very high speed magnetic tape drives. In April, 1951, he was placed in charge of the overall I/O design for the IBM 701 computer. From that time until September, 1952, he was assigned projects of increasing responsibility including training a group of graduate engineers for temporary field service with the first 701 computer systems, and final engineering changes on the 701 model. In May, 1953, he was assigned to report to R. L. Palmer as staff assistant on all Poughkeepsie engineering programs. In September, 1954, he was appointed development engineer and served as assistant manager and subsequently manager of all EDPM engineering. In this capacity he was responsible for all EDPM engineering development programs. He was appointed Associate Director of Research in March, 1956, and in Septenber, 1956, was assigned to report to Dr. E. R. Piore, Director of Research.

Mr. Femmer holds the B.S. degree in electrical engineering from the University of Missouri. He entered the Army in 1943 and upon discharge to inactive duty in July 1946 was a first lieutenant. He is a member of the Association for Computing Machinery and Eta Kappa Nu, and a life member of Tau Beta Pi.

❖

**Carl D. Bethel, Jr.** (M'46–SM'52) has been elected vice president of Mackay Radio and Telegraph Company, it was announced by B. B. Tower, president of American Cable & Radio Corp. AC&R, an ITT associate, is Mackay Radio's parent company.

A graduate of Pennsylvania State

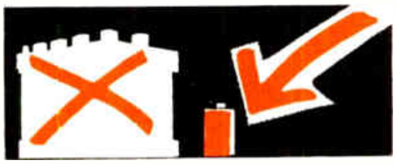
*(Continued on page 62A)*

# Electron Tube News

## —from SYLVANIA

## New designs to meet new demands—everywhere in electronics

### LOW HEATER POWER CATHODE-RAY TUBES...



Low Heater Power CRT's use 1.5 v supply compared to 6.3 v for ordinary tubes

**New 1.5 volt, 140 ma heater for CRT's under development at Sylvania will add new portability to oscilloscopes, radar and TV**

Another revolutionary advance in cathode-ray tube design is now in final stages of experimental development at Sylvania's Industrial & Military Cathode-Ray Tube Department—Low heater power CRT's. The new 1.5 volt, 140 ma heater design requires less than 1/16 the power of ordinary CRT's—or less than ¼ watt compared to 4 watts. This not only means highly significant reductions in power supply requirements with the 210 mw heater but significant reductions in cooling requirements. As a result, new design approaches will be opened for portable oscilloscopes, portable radar, portable transistorized TV, missiles and any other application where minimum power supply weight and size are important considerations.

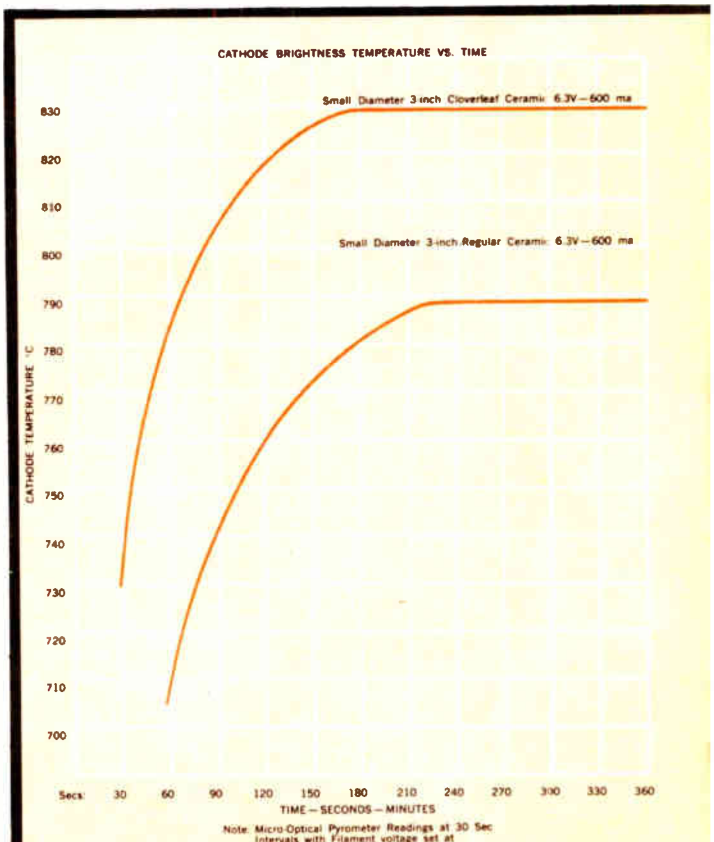
Your Sylvania equipment sales representative will be glad to discuss specific applications and sample availability with you.

### CLOVERLEAF CATHODE ASSEMBLY DESIGN...

**"Cloverleaf" ceramic cathode assembly design, now available in all new Sylvania picture tubes, assures faster warm-up time throughout tube life**

Already proved in hundreds of thousands of picture tubes is the Sylvania Cloverleaf cathode assembly. Its unique ceramic Cloverleaf configuration greatly reduces heat conduction losses and nearly doubles TV warm-up speed by reducing cathode-ceramic disc contact area. This not only increases assembly ruggedness but contributes to the overall efficiency of the tube.

Sylvania Cloverleaf is now available in all new TV picture tubes ranging from 110° 300 ma types to 72° 600 ma types as well as some industrial and military cathode-ray tubes. Contact your Sylvania representative for the full story on Sylvania Cloverleaf.




Faster picture tube warm-up time of the Sylvania Cloverleaf Cathode assembly shows up in this comparison of it with a conventional cathode assembly

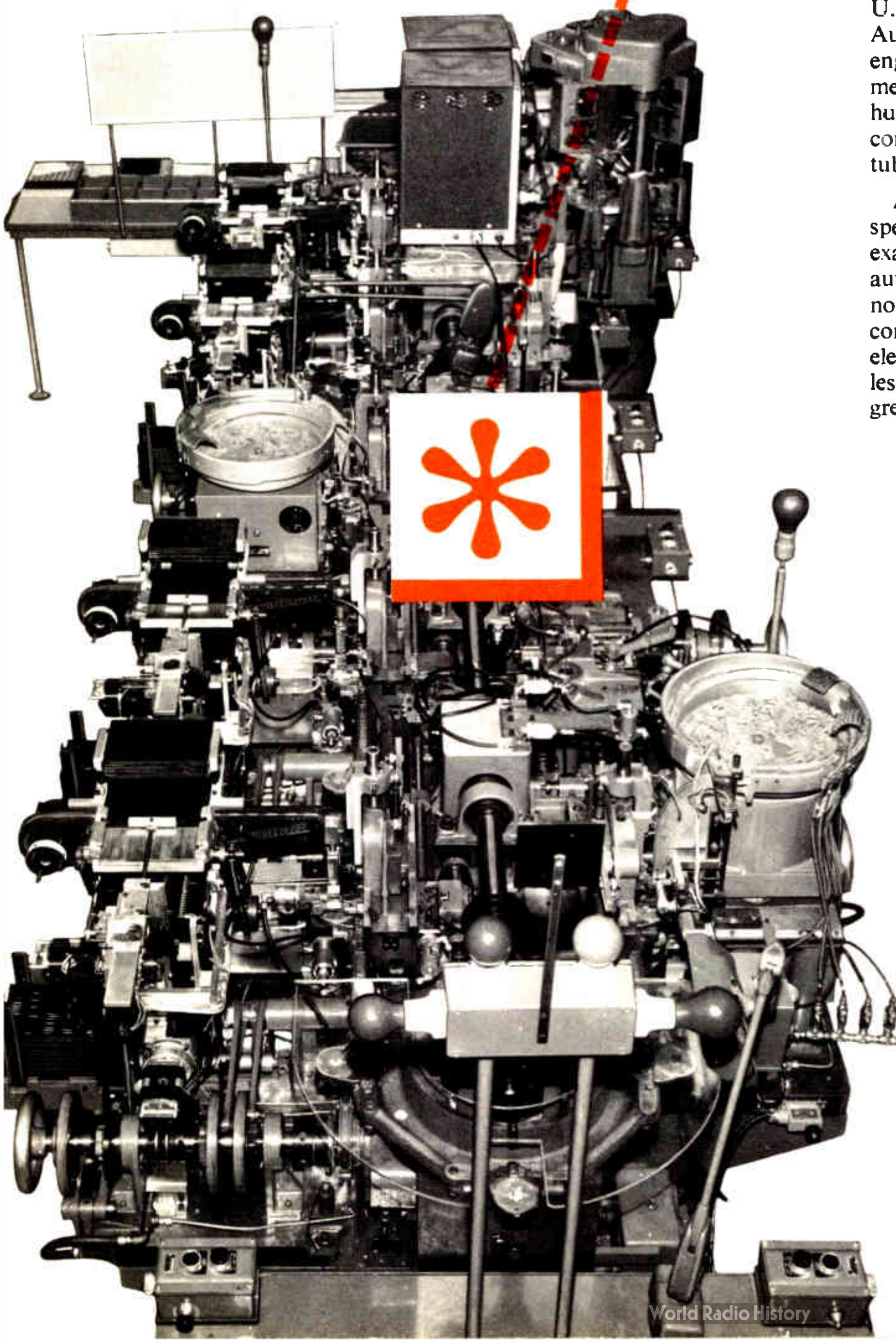
### INDUSTRIAL & MILITARY CATHODE-RAY TUBES...

Today, Sylvania's Industrial and Military Cathode-Ray Tube department is producing over 150 tube types to meet the specialized needs of the growing industrial and military market. Here are the latest additions to this expanding line:

Type 4MP_series—This four-inch square face CRT is designed for use in oscilloscopes and other display devices where space considerations are important. It features electrostatic focus and deflection as well as post deflection acceleration. Its deflection plate leads are sealed through the neck . . . a design which assures low capacity and inductance.

Type 5BCP_series—This five-inch round oscilloscope tube is designed with a ⅞-inch neck diameter that can more effectively utilize low deflection power. It features magnetic focus and deflection.

# THIS IS AUTO-MOUNT... HEART OF SYLVANIA AUTOMATION



Now in operation in Sylvania tube plants throughout the U.S. is this intricate maze of engineering ingenuity called Auto-Mount. Designed and developed by Sylvania engineers, it automatically assembles delicate tube elements with a precision and efficiency unattainable by human hands. It represents one of the greatest single contributions to uniformity in mass-produced electron tubes ever developed.

Auto-Mount first prepunches each mica spacer with specially designed dies that achieve greater precision and exactness than heretofore possible. At the same time, it automatically checks mica thickness and rejects those not meeting its tight tolerances. This new degree of mica control not only means greater spacing precision of tube elements but tighter fit in the mica spacer. The result is less micro, reduced noise, better heat dissipation and greater overall tube efficiency.

Next, Auto-Mount delicately feeds famous Sylvania cathodes to each moving jig assembly and precisely inserts them into proper position. Then, as the assembly moves through each station, grids, plates, and finally the top mica are automatically inserted and assembled. It performs tab bending operations with exact uniformity, resulting in a tighter mount and reduced micro. Each mount undergoes multiple visual and microscopic inspections to assure quality. Any mount that does not meet Auto-Mount's stringent standards is automatically rejected.

Not only does Auto-Mount contribute to better tube performance by eliminating human errors, damage and inaccuracies, but because it requires elements of closer dimension tolerances than hand mounting, the mount it produces is inherently more uniform and rugged. This means less micro, better cutoff, less heater-cathode leakage and more uniform characteristics from tube to tube.

The end result is a new degree of performance perfection from Sylvania receiving tubes unmatched by any other mass-produced electron tube. Contact your Sylvania representative today for complete information on Sylvania Auto-Mount receiving tubes.

**SYLVANIA**

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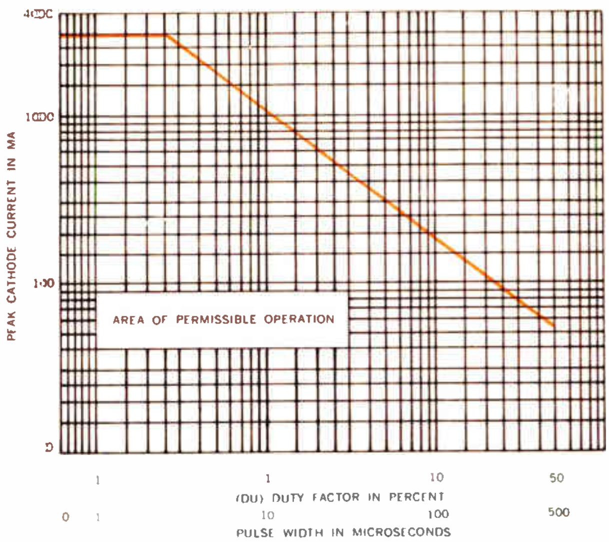


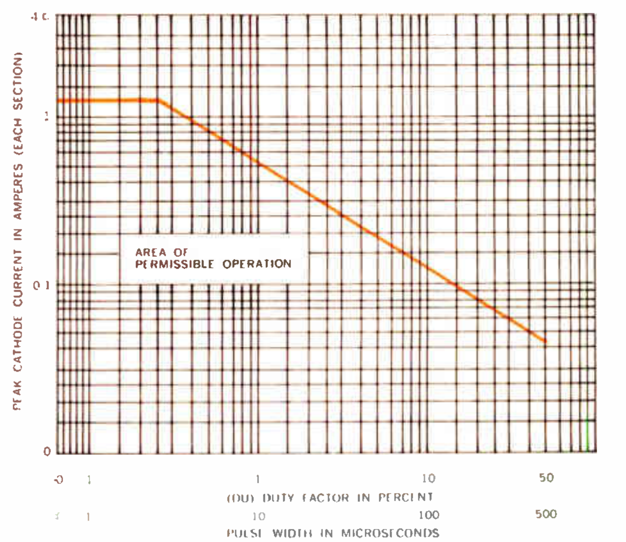


Pulse Rating Charts, exclusive with new Sylvania Pulse Types, show the high current capabilities of the new tubes

# PULSE TUBES . . .

**Sylvania develops industry's first subminiature Pulse Tubes specifically designed for pulse amplifier and BTO circuits**

Now the design engineer can select subminiature tube types specifically designed for pulse applications. Sylvania is developing a line of pulse types rated to deliver high pulse current with reliability, compactness and accuracy. No longer is it necessary to use tubes designed for other purposes that are not rated to consistently meet pulse requirements. With the new Sylvania types, higher pulse current is assured and each is supplied with a pulse rating chart. This not only makes the design problem much simpler but means better end equipment performance.

Two new pulse types GB-7327 and GB-7550 are already in full production at Sylvania with more on the way:

**TYPE GB-7327**—This new subminiature (T-3 bulb) medium mu double triode is specifically designed and processed for pulse applications. It features low vibrational noise and excellent performance under rugged environmental conditions. It is a direct replacement for types 6111 and 6021 and with some modification can replace any double triode. The tube, as its GB prefix indicates, is specifically designed to meet commercial and industrial application requirements. In addition, it is the first tube made by Sylvania that employs both the AQL and new Sylvania ADL quality systems. This means extra assurance that every Sylvania pulse tube will meet customer specifications effectively.

**TYPE GB-7550**—This is Sylvania's newest pulse type, a subminiature (T-3 bulb) double triode with a higher cathode pulse current. It can easily replace types 6111 and 6021. With varying degrees of modification, it can be used in place of any double triode. It features a larger cathode for additional current capabilities and new grid radiators for more effective dissipation. It too is a Sylvania GB type made to meet the specific requirements of industrial and commercial applications. It also incorporates both the AQL and new Sylvania ADL quality standards.

Both new Sylvania pulse types, GB-7327 and GB-7550, may be used in pulse amplifier or BTO circuits. This opens applications in areas such as:

Aerial Navigation Equipment
(Pulse radar and missiles)

Sylvania is continuing to develop additional pulse tube types to meet increasing industry demand for accurate, dependable high-current pulses. Check with your Sylvania representative or contact the factory directly for latest information on Sylvania GB Pulse Tubes.

## New Sylvania Pulse Types GB-7327 and GB-7550

| Characteristics | GB-7327 | GB-7550 |
|---|---|---|
| DIRECT INTERELECTRODE CAPACITANCES (Unshielded) | | |
| Grid to Plate | 1.5 uuf | 4.0 uuf |
| Input: g to (h+k) | 1.9 uuf | 4.0 uuf |
| Output: p to (h+k) | | |
| Section No. 1 | 0.28 uuf | 0.24 uuf |
| Section No. 2 | 0.32 uuf | 0.28 uuf |
| Grid to Grid | 0.011 uuf Max. | 0.16 uuf Max. |
| Plate to Plate | 0.50 uuf Max. | 1.2 uuf Max. |
| RATINGS (Absolute Maximum Values) | | |
| Heater Voltage 3 | 6.3 ± 5% V | 6.3 ± 5% V |
| DC Plate Voltage | 300 Vdc | 300 Vdc |
| Instantaneous Forward Plate Voltage | 400 V | 400 V |
| Plate Dissipation (Each Plate) | 0.95 W | 2.0 W |
| Grid Dissipation (Each Plate) | 0.2 W | 3.6 W (Both Plates) 0.4 W (Each Grid) |
| CHARACTERISTICS RANGES (Each Section) | | |
| Pulse Cathode Current: Ef=6.3 V; Eb=300 Vdc; Ec=−25 Vdc; egk=+50 v at tp=10 usec; prr=1000 pps; tr=0.8 usec Max.; tf=1.0 usec Max. | 700 mA Min. | 1400 ma Min. Ef=6.3 V; Eb=300 Vdc; Ec=−30 Vdc; Instantaneous Voltage Between Grid and Cathode (Smoothed Peak)= +40 v at tp=10 usec; prr=0.8 usec Max.; tf=1.0 usec Max. |

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**SYLVANIA ELECTRIC PRODUCTS INC.**
**1100 Main St.**
**Buffalo 9, N. Y.**

# STRAP-FRAME CONSTRUCTION...

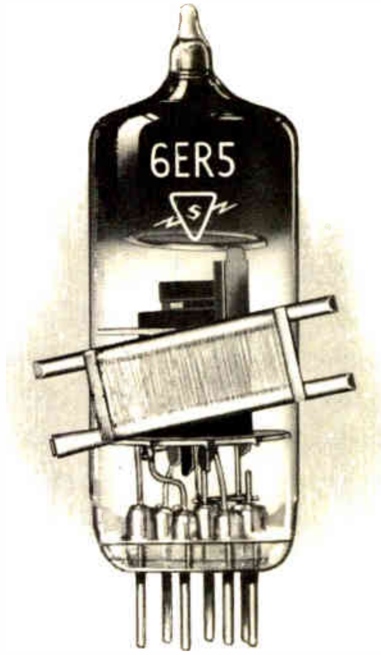
**Sylvania introduces the strap-frame grid design in a new tetrode type 6ER5, designed as a VHF amplifier for TV tuners**

Complementing the Framelok Grid design for power applications is the Sylvania strap-frame grid development for high frequency tuner type applications. First Sylvania tube incorporating strap-frame grid construction in a T-3 envelope is type 6ER5. It is a semi-remote cutoff tetrode designed as a VHF amplifier for TV tuners. It features high transconductance, high input impedance, low intermodulation distortion and dual cathode pins. Grid No. 2 functions as a shield to reduce grid to plate capacitance.

The strap frame, as its name implies, gives new extra support to grid side rods. Not only does this make a more rugged, accurately aligned grid possible, but since the grid laterals themselves do not support the rods, finer grid wire with greater TPI (turns per inch) can be used. The end result is higher gm, better dissipation and overall more efficient performance.

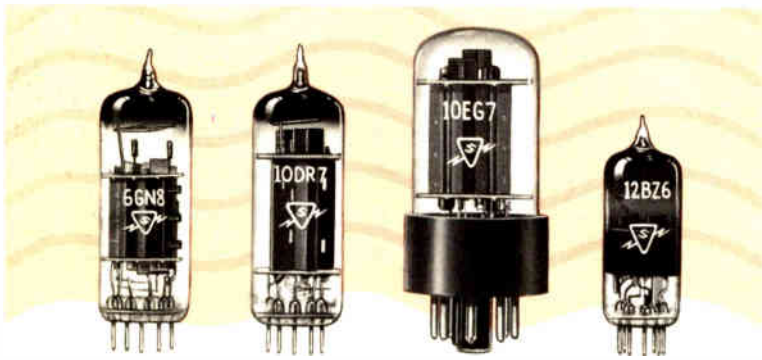
**RATINGS (Design Center Values)**

| | |
|---|---|
| Supply Voltage | 550 Volts |
| Plate Voltage | 250 Volts Max. |
| Grid No. 2 Voltage | 100 Volts |
| Plate Dissipation | 2.2 Watts Max. |
| Grid No. 2 Dissipation | 0.5 Watts |
| Cathode Current | 20 Ma Max. |
| Negative Grid Voltage | 50 Volts Max. |
| Grid Circuit Resistance Cathode Bias | 1.0 Megohm Max. |




Sylvania's new Strap-Frame high frequency tuner type, 6ER5. Strap-Frame grid construction permits use of finer grid wire for more TPI

# VIDEO...




**Five new types from Sylvania for TV service**

**TYPES 6GN8 AND 8GN8**—Both of these new types incorporate a high mu triode and a sharp cutoff pentode in one T 6½ envelope. The triode section is designed for voltage amplifier or sync separator service. The pentode section, designed for video amplifier service, features a controlled knee characteristic.

**TYPE 10DR7**—Double triode in a T 6½ envelope with a high mu section for vertical deflection oscillator use, and a low mu section for use as a vertical deflection amplifier.

**TYPE 10EG7**—T9 double triode for series string TV with a medium mu section designed for vertical deflection oscillator use and a low mu section for vertical deflection amplifier use.

**TYPE 12BZ6**—T 5½ semi-remote cutoff pentode for use as an automatic gain controlled amplifier.

**SYLVANIA** GENERAL TELEPHONE SYSTEM

Subsidiary of
**GENERAL TELEPHONE & ELECTRONICS**

SYLVANIA ELECTRIC PRODUCTS INC.
1740 Broadway, New York 19, N. Y.
*In Canada: Sylvania Electric (Canada) Ltd.*
*P. O. Box 1190, Station "O," Montreal 9*

**Please send additional information on the items checked below:**

Industrial & Military Cathode Ray Tubes
- ☐ Type 4MP—series
- ☐ Type 5BCP—series

New Sylvania Pulse Tubes:
- ☐ Type 7327
- ☐ Type 7550

New Strap-frame Grid Tube
- ☐ Type 6ER5

New entertainment receiving tubes
- ☐ Type 6GN8 ☐ Type 10EG7 ☐ Type 8GN8 ☐ Type 12BZ6
- ☐ Type 10DR7 ☐ Special tube designs for particular applications

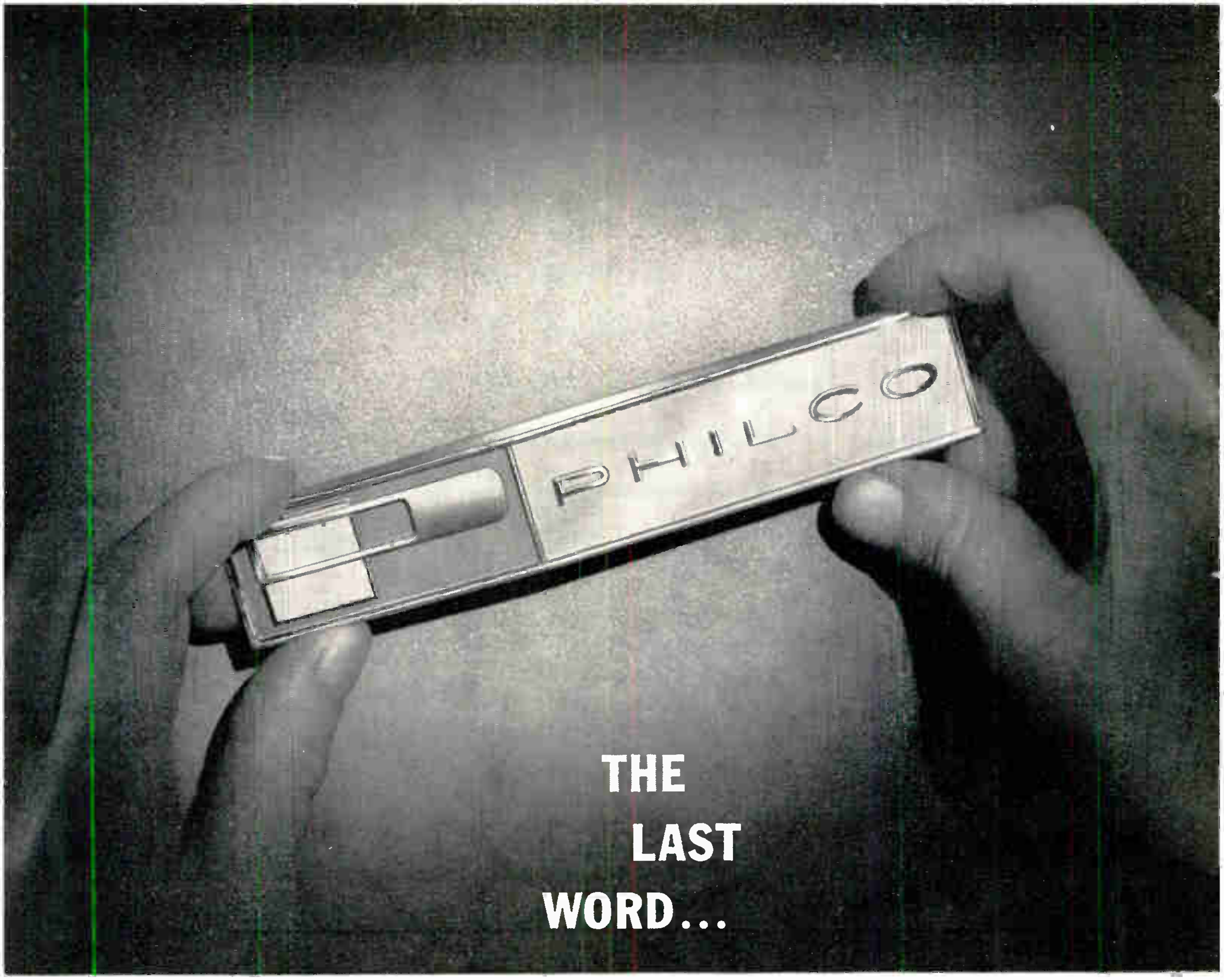
Name____________________

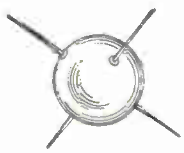
Address____________________

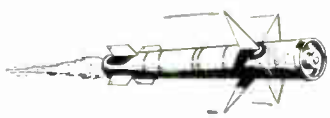
Company____________________

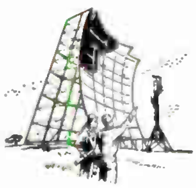
Code 4Q59

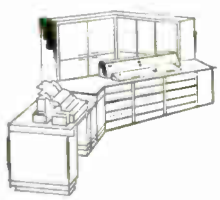
**Use this handy business reply card to request additional information on these important new Sylvania developments**









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*Famous for Quality the World Over*

## IRE People

(Continued from page 56A)

University, Mr. Bethel joined Mackay Radio in 1945 after serving as a U. S. army officer in Europe and North Africa during World War II. He was transferred to Manila in May, 1958, upon his appointment as district manager, and will continue to reside in the Philippines.

❖

**Neal J. Dean** (S'46–A'47–M'50–SM'53) has been admitted to the partnership of Booz, Allen & Hamilton, nationwide management consultants.

N. J. DEAN

He was previously technical director of the firm's Electronic Data Processing Department. He has specialized and will continue to work in consulting on data processing systems for banks, utilities and industrial firms throughout the country. He has presented more than 30 papers before various management groups and professional societies, and has authored several articles on electronic data processing.

Before joining Booz, Allen & Hamilton in 1958, he was head of the Data Processing Consulting Services for Ramo-Wooldridge Corp. Prior to that he was head of the business machines applications department of the Laboratory for Electronics, Inc., and was director of circuit research and development of the Sonotone Corp. He was director of the Electrical Measurements Laboratory of Columbia University and has lectured on engineering and electronics subjects at six universities.

Mr. Dean received the B.E.E. degree from Manhattan College in 1944 and the M.S. degree in electrical engineering from Columbia University in 1946.

❖

Aladdin Electronics, division of Aladdin Industries, Inc., has announced the appointment of **Paul E. Dicker** (S'47–A'50–M'56–SM'59) to the position of Chief Engineer.

He has been associated with Aladdin for approximately four years serving as a consultant on special technical assignments. During this period he has also held the position of associate professor of electrical engineering at Vanderbilt University.

Mr. Dicker received the B.S.E.E. from Swarthmore College in 1945. He was awarded the Master's Degree in Electrical Engineering by Ohio State University. In addition to holding other teaching positions at Ohio State and Princeton, he has done research work and design engineering in many fields of special interest to Aladdin.

❖

(Continued on page 64A)

# 300° C stabilization of FAIRCHILD SILICON TRANSISTORS is a regular step

# WHY?

**TO ACHIEVE MAXIMUM RELIABILITY!** Every completed Fairchild Transistor is stored at 300° C for at least 60 hours before final inspection. Most types would not survive. For Fairchild's Diffused Silicon Mesa Transistors, this step stabilizes parameters an equivalent of thousands of hours at 175° C. Many of our customers are verifying the resulting reliability in test programs of their own.

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DEPT. E-12

545 WHISMAN ROAD • MOUNTAIN VIEW, CALIFORNIA • YORKSHIRE 8-8161

New York Area: WElls 1-4500, ext. 287—Chicago Area: BRowning 9-5680—Philadelphia Area: TUrner 6-6623—Los Angeles Area: OLeander 5-6058

# IRE People

(Continued from page 62A)

**Milton Magid** (S'48–A'49–M'55–SM'57) has joined the FXR engineering staff as Head of Microwave Product Engineering. Prior to joining FXR, he had been associated with the Hughes Aircraft Co., Culver City, Calif. since 1949. Since November, 1953, he had been Supervisor of the "Microwave Section of the Primary Standards Laboratory."

Milton Magid

Mr. Magid received the B.S. degree (with honors) from the University of California at Berkeley and the M.S. degree from the University of California at Los Angeles. He has been elected to Eta Kappa Nu, Tau Beta Pi and Sigma Xi honor societies and is an Associate Member of the Scientific Research Society of America (R.E.S.A.).

❖

**Arthur A. Hauser, Jr.** (M'48) has been appointed to the new position of director of technical planning at Sperry Gyroscope Co., Great Neck, N. Y.

A. A. Hauser, Jr.

He has had 17 years' experience in the management of advanced research efforts. Since joining Sperry in 1942, he has directed numerous research groups in development of advanced computer techniques, air, surface, and under-sea weapon systems, industrial controls, and automated business systems. In 1957 he became responsible for coordination of the research and development activities of Sperry's many widely diversified divisions.

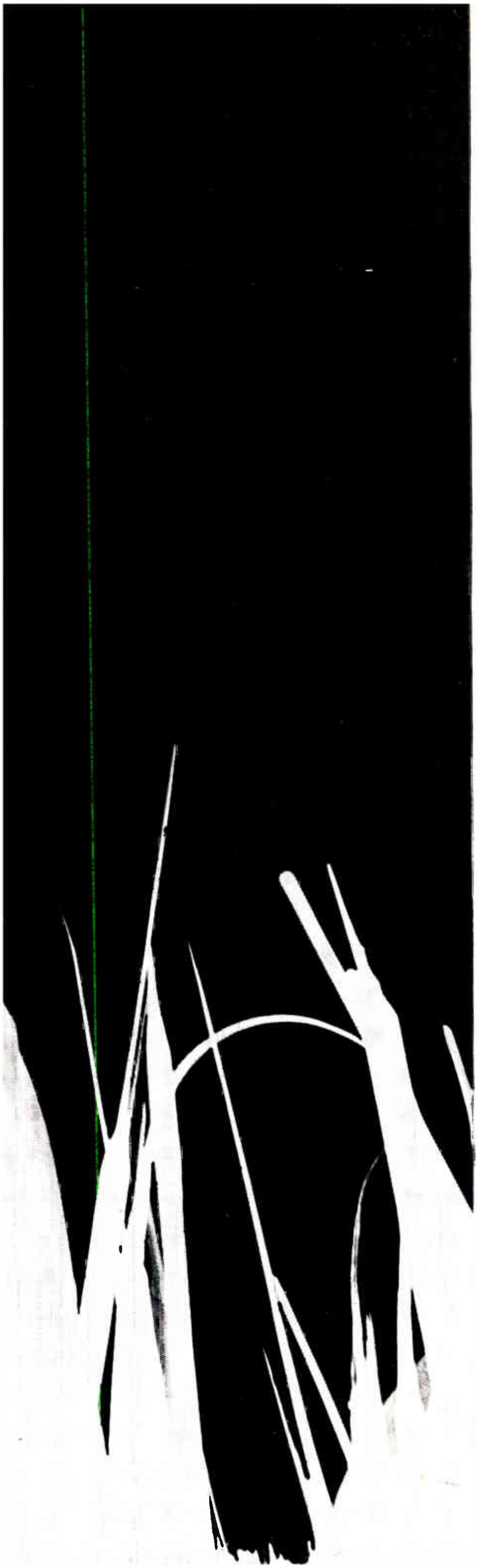
He holds five patents on fire control, guidance, and computer devices and is the author of numerous scientific papers on these subjects.

Mr. Hauser earned the B.S. degree in mathematics at Massachusetts Institute of Technology and the M.S. degree in mathematics at New York University. His professional memberships include the American Physical Society, Sigma Xi, Atomic Industrial Forum, and the Industrial Research Institute.

❖

(Continued on page 66A)

Make Your Plans Now!
1960 IRE SHOW
March 21-24, 1960
New York Coliseum



One of a series

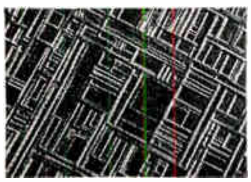
# The revealing face of an iron crystal

A single crystal is an ideal system for studying the solid state. Physicists at the General Motors Research Laboratories have turned to whisker-like growths of nearly perfect single iron crystals to investigate three intriguing phenomena: magnetic domains, dislocation defects, and—more recently—high temperature oxidation.

In this latest study, the two crystallographically different surfaces found on iron whiskers are being used to examine the anisotropy or axial-dependent nature of the oxidation process. In early stages of oxidation, the oxide patterns that form on clean surfaces have been found to be strongly dependent upon the orientation of the underlying crystal. In later stages of oxidation, tiny oxide "cilia" actually grow on the surface of the iron whisker. But these new whiskery forms of oxidation are no longer related to the crystal's surface arrangement. The next step in this program involves correlating the oxidation behavior with lattice structure defects such as vacancies and dislocations.

This type of solid state research is revealing the atomic processes underlying strength, magnetic characteristics, and corrosion resistance of metals. At GM Research, we believe the solution to practical problems is increasingly dependent on fundamental information such as this. And each solution enables us to continue to provide "More and better things for more people."

GENERAL MOTORS RESEARCH LABORATORIES



Early Oxidation (750x)

Oxide Whiskers (12,000x)

Reduction of Oxide Products (2500x)

## IRE People

(Continued from page 64A)

**John L. Heins** (A'32–VA'39) former Chief Electronics Engineer for the Republic Aviation Corp., Missile Systems Div., was named as head of engineering for the GB Electronics Div. of the General Bronze Corp.

J. L. HEINS

He is an electronic systems specialist who has held engineering positions with I.T.T.L., Sperry, Burroughs and other organizations in the industry.

At GB Electronics Corp., he will take over the antenna systems organization and be responsible for an expansion program involving the application of proprietary corporation developments, such as the recently announced S.V.E. array now being applied for major contracts of the National Aeronautics and Space Administration, General Electric Co. and others involved in advanced type tracking and telemetry systems.

❖

**Dr. Albert S. Hoagland** (S'50–A'54–SM'57) has been appointed manager of Engineering Sciences Research at the San Jose, Calif., research laboratory of the International Business Machines Corp.

A. S. HOAGLAND

He joined IBM in June, 1956 as a project engineer working on the magnetic program for the RAMAC at the San Jose laboratory. A short time later his work was expanded to include magnetics work on the Stretch computer.

In January, 1958 he was appointed development engineer and continued responsibility as project leader for the magnetics program. In January of this year he was appointed senior research engineer and given responsibility for large-scale memory research.

Dr. Hoagland received the B.S., M.S., and Ph.D. degrees in electrical engineering at the University of California in Berkeley. He is a member of the AIEE, Phi Beta Kappa, Sigma Xi, Eta Kappa Nu, and Tau Beta Pi.

❖

**John J. McDonald** (A'50), director of engineering for Consolidated Systems Corp., wholly owned subsidiary of Consolidated Electrodynamics Corp., has been elected a vice president of the Instrument Society of America.

(Continued on page 68A)

## IRE People

(*Continued from page 66A*)

He will direct ISA activities in California, Hawaii, Arizona, Nevada, and part of Utah during his two-year term of office.

He has served the Society as a national director, director of the Transportation Industry Division, chairman of the Instrumentation for Transportation Committee, and chairman of the Research and Development Committee.

He is also a member of the American Institute of Electrical Engineers, Society for Experimental Stress Analysis, American Standards Association, and American Rocket Society. He was president of SESA's Chicago section in 1952, and at present is a member of the ASA's Committee to Establish Vibration Standards.

Mr. McDonald received the B.S. degree in physics from the University of Chicago and the B.S. degree in electrical engineering from the Armour Institute of Technology

❖

**Edwin R. Gamson** (A'51–M'56), general manager of the Components Division of Telemeter Magnetics, Inc., Los Angeles, Calif., has been elected a vice president of the company. He was appointed to his present post as general manager in June of this year, when the components Division was organized. He joined TMI in 1956 as director of manufacturing, a position he held until his recent advancement.

E. R. Gamson

Mr. Gamson was graduated from Stanford University in engineering sciences. He has been actively engaged in the development and manufacture of electronic components since 1948, with North American Aviation, Stanford Research Institute, and Telemeter Magnetics.

❖

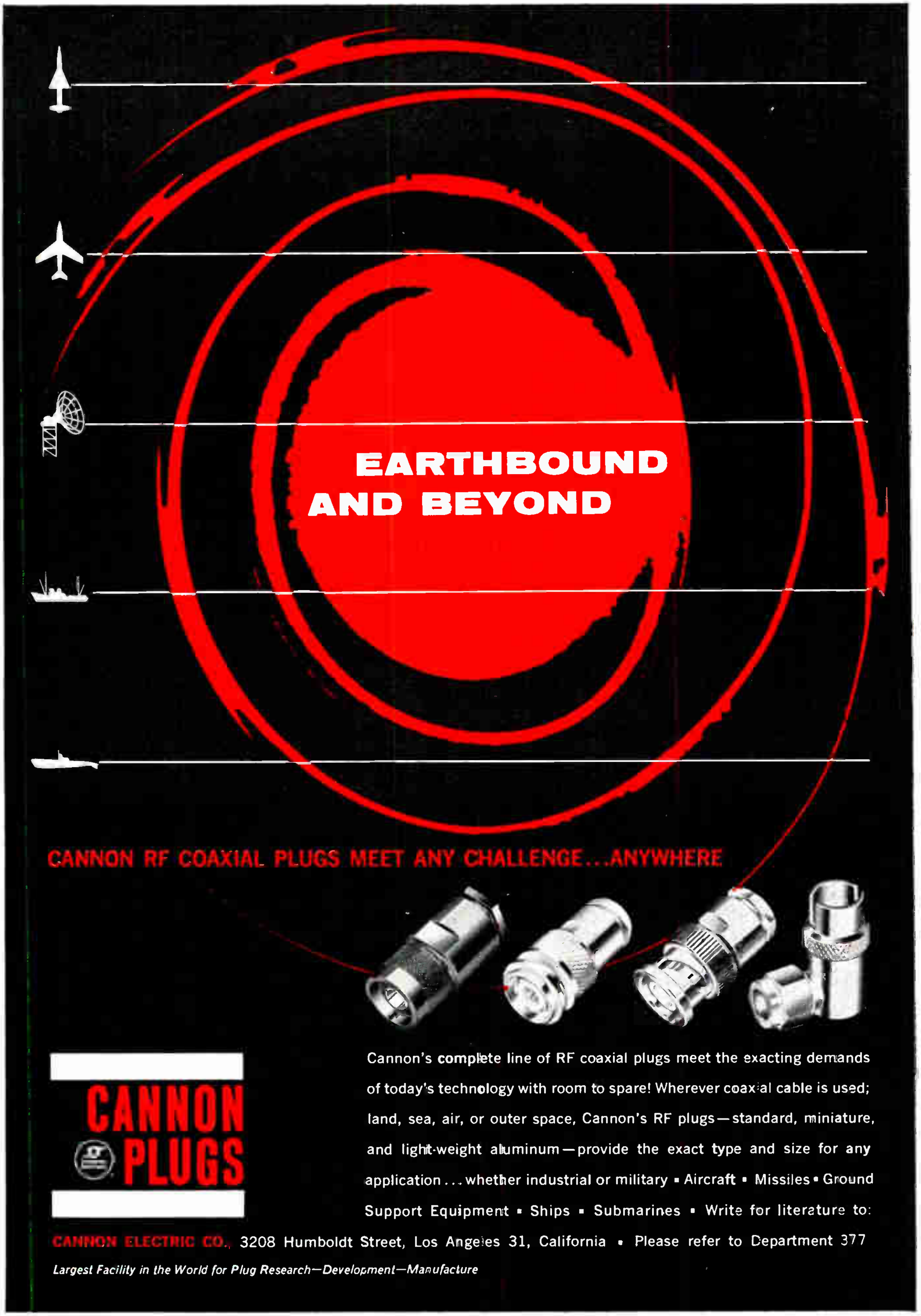
**Fred R. Wellner** (A'51–M'52–SM'56) has been named manager of the Electrical Design Engineering Subsection of General Electric Co. He has been employed at General Electric for the past 9 years.

Born in Munich, Germany, he graduated from the German Naval College in 1940 with a degree in naval engineering. He was awarded the degree of Diplom-Engineer in electrical engineering by the Technical University of Munich in 1949 and he received the M.S. degree in electrical engineering from Syracuse University.

From 1949 to 1951 he was Chief Engineer for the Audivox Co., Boston, Mass. He joined General Electric's television receiver department at Syracuse in 1951 in the capacity of advanced development engineer. Five years later he was appointed supervisor of electrical design, the position he held at the time of his promotion to manager.

❖

(*Continued on page 70A*)


EARTHBOUND
AND BEYOND
CANNON RF COAXIAL PLUGS MEET ANY CHALLENGE...ANYWHERE
CANNON
PLUGS
Cannon's complete line of RF coaxial plugs meet the exacting demands of today's technology with room to spare! Wherever coaxial cable is used; land, sea, air, or outer space, Cannon's RF plugs—standard, miniature, and light-weight aluminum—provide the exact type and size for any application... whether industrial or military ▪ Aircraft ▪ Missiles ▪ Ground Support Equipment ▪ Ships ▪ Submarines ▪ Write for literature to:
CANNON ELECTRIC CO., 3208 Humboldt Street, Los Angeles 31, California ▪ Please refer to Department 377
Largest Facility in the World for Plug Research—Development—Manufacture

## IRE People

(Continued from page 68A)

**Robert E. Talmo** (S'49–A'50–M'55) has joined the senior technical staff of Electro-Optical Systems, Inc., as head of the newly formed Transducer Laboratory of the company's Solid State Division.

In this position he will be responsible for development of solid state transducer devices and application of these to a wide range of instrumentation necessary for space exploration and advanced military weaponry.

Prior to joining EOS, he was Assistant Chief Engineer for Wiancko Engineering Company of Pasadena, Calif., where he had been since 1950. Before joining Wiancko, he was employed by Van Dusen Aircraft Company of Minneapolis, Minn., and prior to that was with Victoreen Instrument Company, Cleveland, Ohio.

Mr. Talmo is a member of the Instrument Society of America.

❖

**Paul Pittman** (S'51–M'57) has been appointed manager of the solid state electronics application section of the materials engineering department, Westinghouse Electric Corporation, East Pittsburgh, Pa. In his new position he will be in charge of the evaluation and application of semiconductor materials and devices.

P. F. Pittman

A graduate of Carnegie Institute of Technology, he has received the Bachelor of Science and Master of Science degrees in electrical engineering.

Mr. Pittman is a member of the American Institute of Electrical Engineers.

❖

**George W. Sioles** (M'52) has been named Section Head for audio research in the Acoustics and Magnetics Department of CBS Laboratories, Stamford, Conn. Before joining CBS Laboratories this year, he had been Engineering Manager for University Loudspeakers, Inc., with whom he had been associated since 1953. He conducted his own consulting and development service for specialized audio systems, and during the period 1950–1953, was Project Engineer for navigation and other training devices with the United States Naval Training Device Center.

G. W. Sioles

Mr. Sioles received the B.S. degree from Columbia University following his service

(Continued on page 72A)

Distributed constant delay lines • Lumped-constant delay lines • Variable delay networks • Continuously variable delay lines • Pushbutton decade delay lines • Shift registers •

# ESC EXTRA

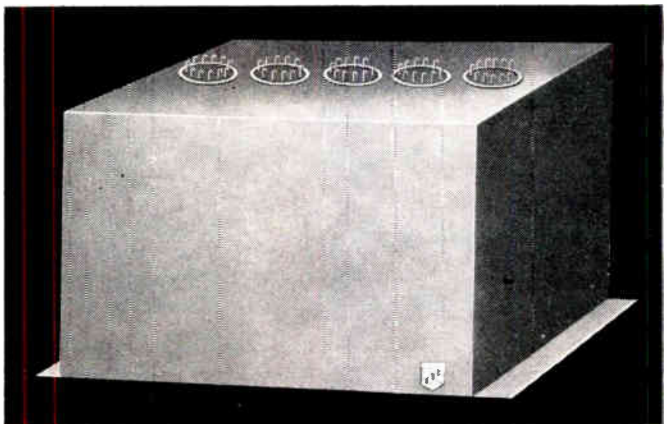
Pulse transformers • Medium and low-power transformers • Filters of all types • Pulse-forming networks • Miniature plug-in encapsulated circuit assemblies

# ESC DEVELOPS DELAY LINE WITH 170 to 1 DELAY TIME/RISE TIME RATIO

**Model 61-34 Perfected**
**For Specialized**
**Communications Application**

PALISADES PARK, N. J.—An entirely new Lumped-Constant Delay Line, with a proven 170 to 1 delay time/rise time ratio, has been announced by the ESC Corporation, Palisades Park, N. J. The new delay line, known as Model 61-34, was specifically designed for a specialized communications application calling for the exceptionally high delay time/rise time ratio.

ESC, the world's leading manufacturer of custom built and stock delay lines, is already widely recognized in the electronics industry for its exceptional engineering advances. In October, 1958, ESC broke through an existing design barrier and produced a delay line with a 145 to 1 delay time/rise time ratio. It had been thought, prior to the announcement of the Model 61-34, that ESC had reached the ultimate in this type of delay line.



SPECIFICATIONS OF NEW DELAY LINE
MODEL 61-34

Delay time/rise time ratio: 170/1
Delay: 200 usec.
Rise time: 1.16 usec.
Attenuation: less than 2 db
Frequency response: 3 db = 325 KC
50 taps with an accuracy of ±0.2 usec. at each tap.

Complete technical data on the new unit can be obtained by writing to

**ESC Corporation, 534 Bergen Boulevard, Palisades Park, New Jersey.**

## IRE People

(*Continued from page 70A*)

during World War II as B-29 bombardier-navigator. He is a member of the Acoustical Society of America and the Audio Engineering Society. He has published and presented papers on various aspects of loudspeaker design including the use of analog circuits. Patents are currently pending on collaborative work with colleagues on stereophonic projection loudspeakers.

❖

**Alfred L. DiMattia** (A'45) recently joined CBS Laboratories as Group Leader for research and development in electro-acoustic and electro-mechanical transducers. He has specialized in this field since 1942, when he entered the U. S. Government's wartime laboratory at Harvard University devoted to research in acoustics, psycho-acoustics, and communications. He subsequently held the position of Chief Engineer with the William J. Murdock Company, and he has served as acoustical consultant in the industrial and medical field. During the period 1947–1959, he was Design and Development Engineer in acoustics and electronics with the Dictaphone Corporation.

A. L. DiMattia

Mr. DiMattia is a member of the Acoustical Society of America, and the American Institute of Physics. His published papers in government publications and technical journals have dealt with primary calibration of microphones and acoustical measurements of other devices.

❖

**Dr. Hans K. Ziegler** (SM'56), an authority of satellite instrumentation and communications, has been named chief scientist at the U.S. Army Signal Research and Development Laboratory.

H. K. Ziegler

He had served as director of the Astro-Electronics Division since it was set up in January, 1959, to consolidate work on all national space projects assigned to the U. S. Army Signal Corps. Prior to this he had served as scientific consultant to the chief of the Power Sources Division and as assistant research director of the laboratory.

❖

Lynch Carrier Systems, Inc., San Francisco, Calif., have announced the appointment of **Henry G. Kuhn** (SM'54) to

(*Continued on page 76A*)

# NOW IN PRODUCTION:

## Widest Range of Backward-Wave Oscillators With Frequencies to 75 kmc


Actual length 10½"

| | PM-1779 | PM-1757 | PM-6902 | BW-623 | 6496 | 7096 | 6699 |
|---|---|---|---|---|---|---|---|
| Frequency range, kmc | 63-75 | 27-41 | 18-27 | 4-8 | 2-4 | 2-4 | 1-2 |
| Power output, mw | 3 | 5 | 10 | 15-135 | 20-700 | 100 | 20-700 |

Sylvania now offers the widest range of production backward-wave oscillators, featuring 3 rugged types at K-band and above.

Greatly simplified power supply design is made possible through use of the PM-1757 and PM-6902 since their design permits grounding of either cathode or helix. These two BWO's have the following advantages:

- **Grounded cathode**
- **Rugged metal-ceramic construction**
- **Permanent magnet focusing**
- **Suitable for airborne applications**
- **Rated for CW or pulse applications**

For other requirements, Sylvania has classified tubes available at frequencies other than those shown.

SYLVANIA
Subsidiary of
GENERAL TELEPHONE & ELECTRONICS

Sylvania Electric Products Inc.,
Special Tube Operations
500 Evelyn Ave., Mountain View, Calif.

## IRE People

(*Continued from page 72A*)

the position of Chief Engineer.

He has had more than 20 years experience in communications with particular emphasis upon carrier telephone and telegraph circuitry and equipment. His most recent employment was with Lenkurt Electric Co., San Carlos, Calif., as Executive Staff Engineer specializing in carrier telephone, remote control and communication switching systems.

H. G. Kuhn

He was formerly a Laboratory Head for the Philips Company in Germany and completed five years with this same company at their Canadian branch. Other employment includes seven years with Siemens & Halske in Germany as a design and development engineer.

Mr. Kuhn graduated from Technical College, Mittweida, Germany, with the Electrical Engineering degree and subsequently did graduate work at Technical University, Dresden, Germany. He holds seven U. S. Patents and European patents in communications and electronics.

❖

At its eighth annual meeting in Boston on September 22, 1959, the Standards Engineers Society conferred its Fellow grade of membership on **Harold P. Westman** (J'24–A'25–M'30–SM'43), manager of technical publications, International Telephone and Telegraph Corporation, for his work on standardization over the past thirty years.

After a dozen years of close association with the standards program of the IRE as its national secretary he served on the staff of the American Standards Association during the war to develop a series of American War Standards on radio and electronic components for the armed services. He has since served on numerous ASA committees concerned with such editorial subjects as abbreviations, illustrations for publication, graphical and letter symbols, and definitions of engineering terms.

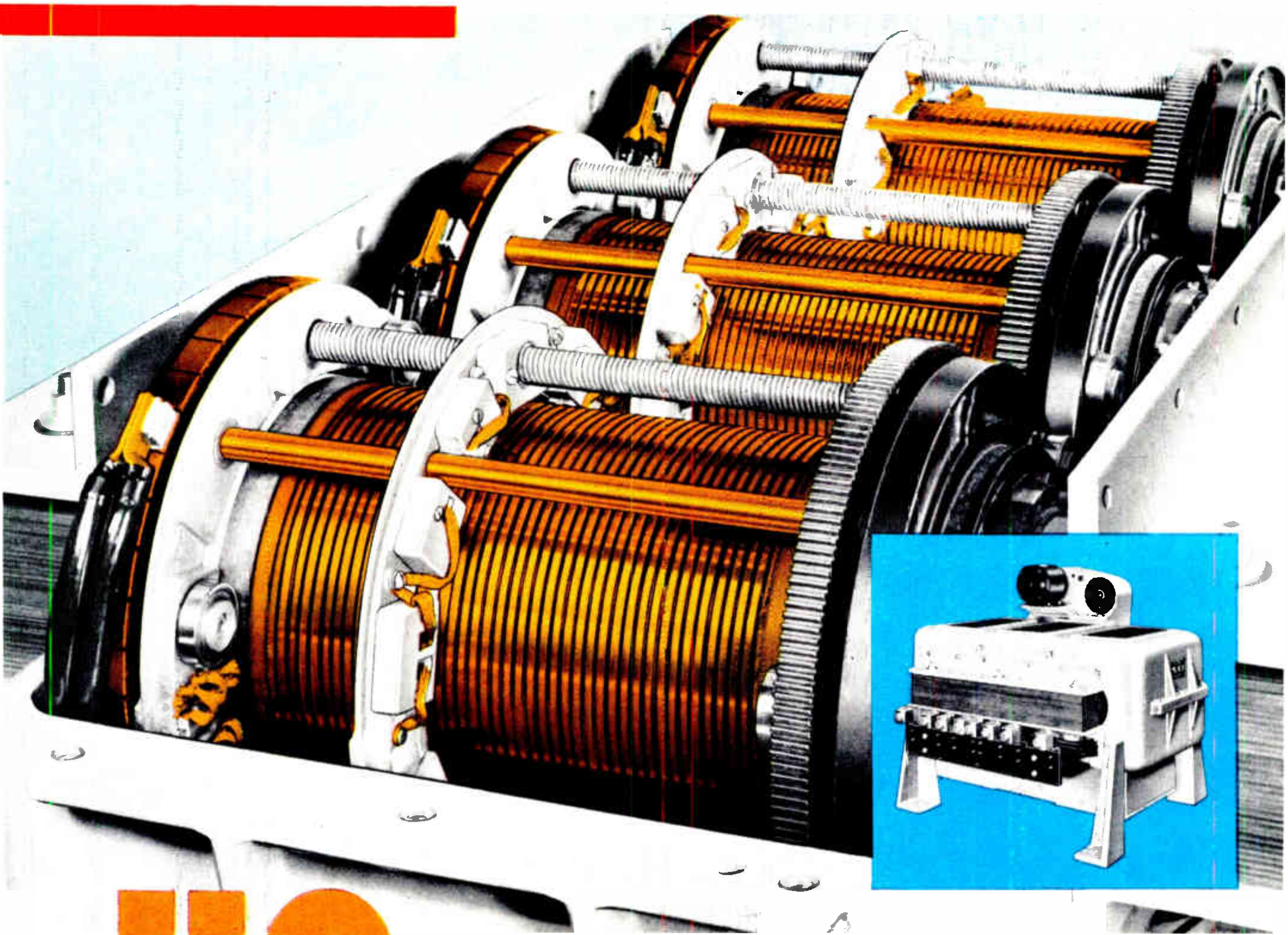
Mr. Westman is editor of the engineering quarterly, Electrical Communication, and of the present edition of Reference Data for Radio Engineers, both of which are published by ITT

❖

**Joseph W. Stehn** (M'55) has been appointed Director of Military Sales of the W. L. Maxson Corporation. In his new post, he will be responsible for directing all sales activities of Maxson's Defense Products Group, which specializes in the

(*Continued from page 80A*)

# A COMPLETELY NEW CONCEPT *in variable transformer design!**



*the* HC *series* **POWERSTAT®** *variable transformers*

**HIGH CURRENT CAPACITY**
— The use of a helical wound coil design instead of the conventional toroidal wound coils permits current capacities much higher than previously available in variable transformers.

**EXTREMELY FINE ADJUSTMENT**
— Patented re-entry rings permit continuously-adjustable control of 1600 increments over the range of zero to maximum output voltage. Resolution is better than 1/10 of 1% of the input voltage.

**HIGHEST EFFICIENCY**
— Low resistance brushes are always in contact with only one turn of the helical wound coil resulting in very low voltage drop.

**PLUS:**

ZERO WAVEFORM DISTORTION, EXCELLENT REGULATION, SMOOTH CONTROL, CONSERVATIVE RATINGS, LINEAR OUTPUT VOLTAGE, LOW COST PER KVA.

THE SUPERIOR ELECTRIC COMPANY
Bristol, Connecticut, U.S.A.

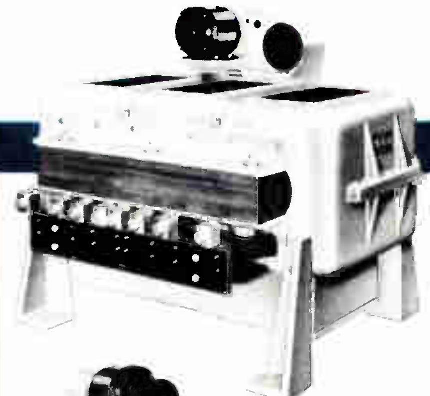
* The Superior Electric Company's U.S. Patent No. 2,864,992.

# NEVER BEFORE

*• such high efficiency • such fine adjustment • such high current capacity*

## *the* HC *series* POWERSTAT® *variable transformers*

*for heavy duty applications requiring cool, efficient operation*



**TYPE 2HCB200-3Y (FORCED AIR COOLED)**

| | | | |
|---|---|---|---|
| INPUT: | 240 VOLTS | 60 CYCLES | 3 PHASE |
| OUTPUT: | 0-270 VOLTS | 360 AMPERES | 168 KVA |

**TYPE 2HC200-3Y (CONVECTION COOLED)**

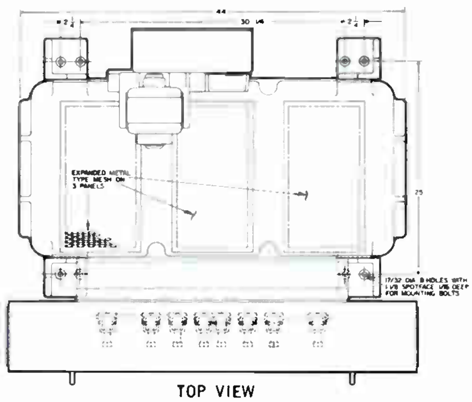
| | | | |
|---|---|---|---|
| INPUT: | 240 VOLTS | 60 CYCLES | 3 PHASE |
| OUTPUT: | 0-270 VOLTS | 200 AMPERES | 93.5 KVA |

### TYPES

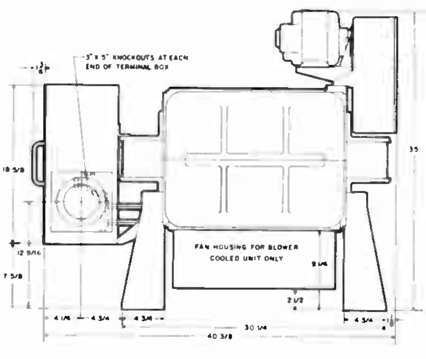
*Two 240 volt, 3-phase types are offered. Type 2HC200-3Y is cooled by normal convection. Type 2HCB200-3Y is similar in construction but incorporates fans for forced air cooling of the coils. Output rating of the forced air cooled type is nearly double that of the convection cooled type. Types for 480 volt, 3-phase duty are available also.*

**POWERSTATS** *of the H-C Series can be remotely operated from a control unit mounted either on the POWERSTAT frame or at any other convenient location. Raise-lower signals from the control unit operate the adjustable speed motor driving the contact brush assembly. Full range travel speed is fully adjustable between 15 seconds and 10 minutes. Travel is smooth with fast starting and stopping at any voltage setting. Integrally mounted travel limit switches provide stops and unit protection.*

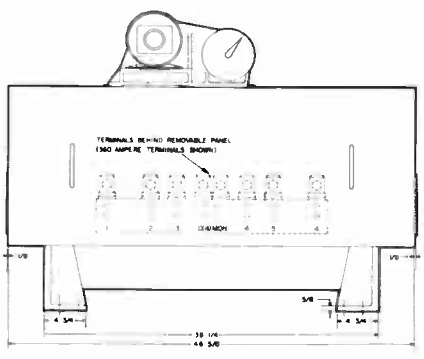
### OUTLINE DIMENSIONS



TOP VIEW



SIDE VIEW



FRONT VIEW

**THE SUPERIOR ELECTRIC COMPANY, Bristol, Connecticut**

☐ Please send H-C Series POWERSTAT Bulletin.

☐ Please have your representative call.

name

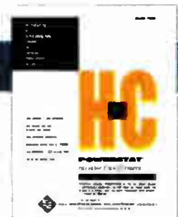
company

address

city zone state

**. . . FOR YOUR FILES**

Request H-C Series Bulletin giving full technical information, ratings and specifications.

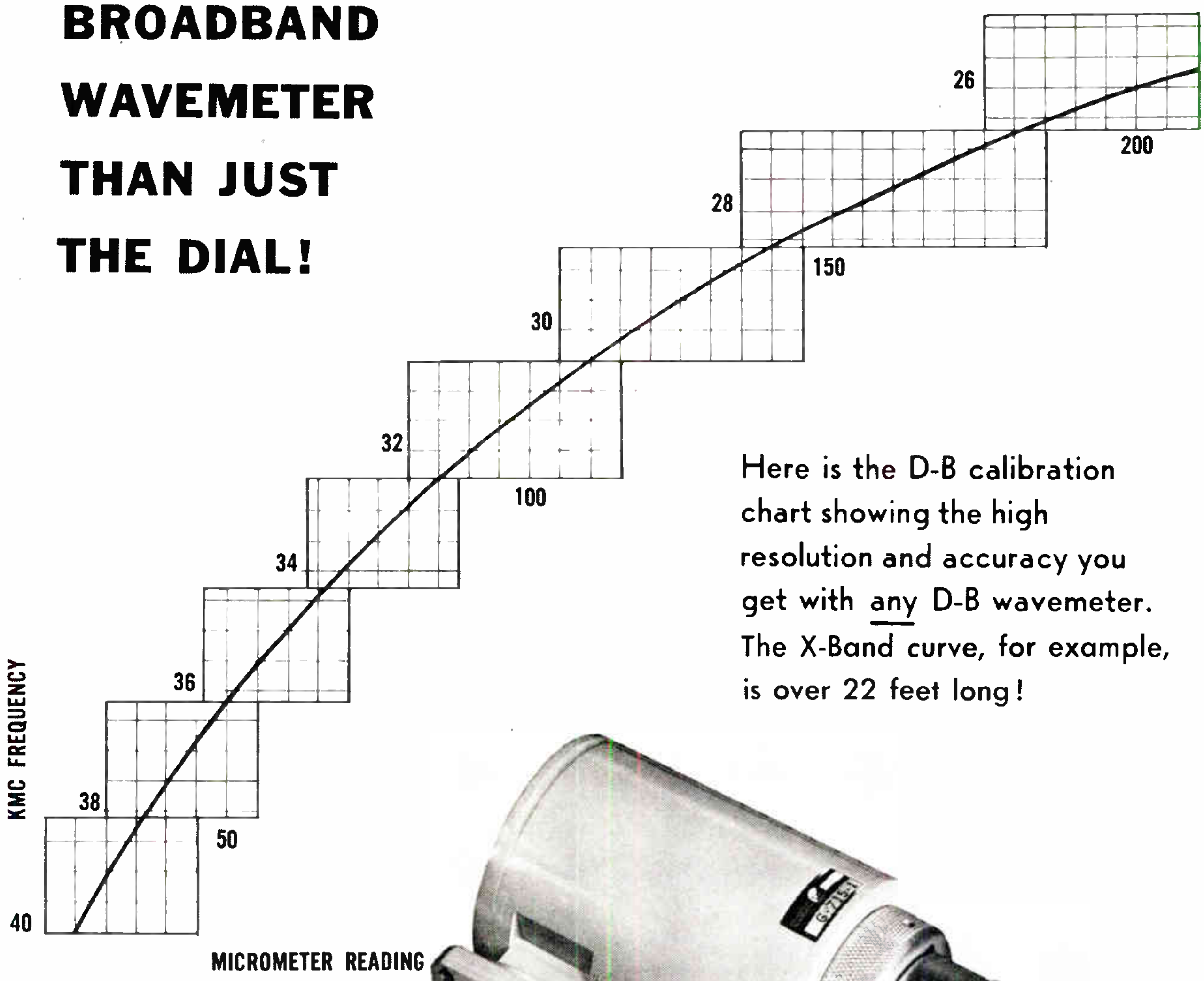


**THE SUPERIOR ELECTRIC COMPANY**

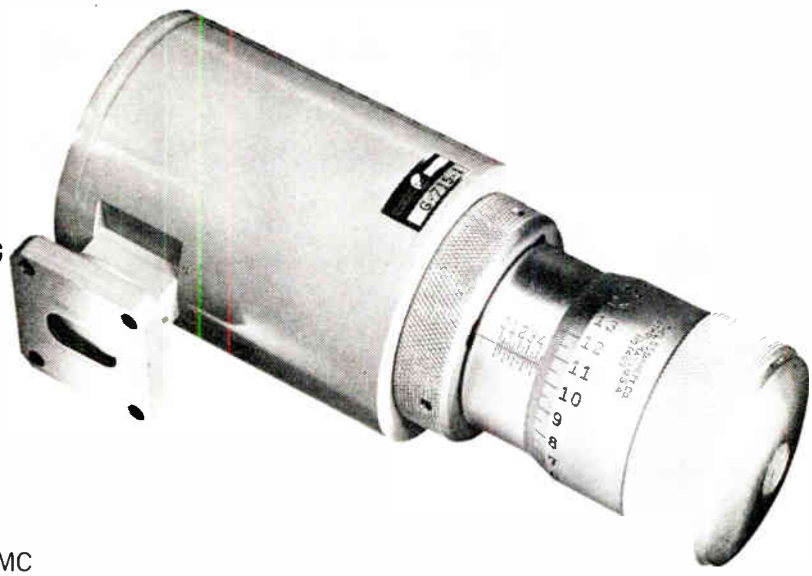
**Bristol, Connecticut, U.S.A.**

SE-L85911

# THERE'S MORE TO A D-B BROADBAND WAVEMETER THAN JUST THE DIAL!




Here is the D-B calibration chart showing the high resolution and accuracy you get with any D-B wavemeter. The X-Band curve, for example, is over 22 feet long!



**Fail-Safe Design**—
loss of gas pressure makes unit immediately inoperative.
**Twelve models** cover from 2.6 KMC to 140 KMC. Write for complete data in Bulletin D-B 715.

DE MORNAY BONARDI

DE MORNAY-BONARDI
780 SOUTH ARROYO PARKWAY • PASADENA, CALIF.

## IRE People

(*Continued from page 76A*)

research, development and production of advanced airborne, missile and ordnance components and systems.

Since joining Maxson in 1953, he has served successively as Contracts Administrator, Applications Engineer, Manager of Ordnance Products, Manager of Electronic Products, and most recently as Assistant Sales Manager.

Following World War II, in which he served as a Captain in the U. S. Army, he attended Manhattan College from which he was graduated in 1949 with the B.S. degree in electrical engineering.

Mr. Stehn is a member of the American Ordnance Association.

❖

**Dr. Arthur G. Anderson** (A'54) has been appointed manager of the Physical Science research at the San Jose, Calif., research laboratory of the International Business Machines Corporation.

A. G. Anderson

He joined IBM in May 1951 as a technical engineer working on analytical mechanics, acoustics and instrumentation on mechanics problems at the Poughkeepsie, N. Y., research laboratory.

He was subsequently appointed to the positions of associate engineer, staff engineer, and research engineer, and has worked in high speed computer research, spin echo storage, research in solid state physics, nuclear magnetic resonance in solids, and has served as acting manager of the physics and chemistry research group at the San Jose laboratory.

Dr. Anderson received the B.S. degree in physics at the University of San Francisco, the M.S. in mathematics at Northwestern University, and the Ph.D. in physics at New York University. He is a member of the American Physical Society and the Scientific Research Society of America.

A native of Glenview, Illinois, Dr. Anderson is married and has two sons and a daughter. The family make their home in Morgan Hill, California.

❖

**William Perzley** (A'54) is the new director of engineering at Consolidated Avionics Corp., Westbury, N. Y. The firm, a manufacturer of electronic data reduction systems, instrumentation, automatic test and control systems and transistorized power supplies, is a subsidiary of Consolidated Diesel Electric Corp.

Prior to joining Consolidated Avionics, he was chief electronics engineer for Kaiser Metal Products Corp. and an engineering supervisor for American Bosch Arma. His work has included the development of such items as large scale general purpose digital machines, numerical control systems for machine tool control, lightweight airborne computers and associated test equipment.

A graduate of Newark College of Engineering, Mr. Perzley holds a master's degree in electrical engineering from Stevens Institute of Technology. He has also done graduate work at the University of Pennsylvania and M.I.T. He holds several basic patents in the digital instrumentation field.

❖

An advanced nuclear system company, the Atomium Corporation, has been announced by **Hugh F. Stoddart** (M'55), president of the new Waltham, Mass. plant. The firm designs and manufactures special nuclear systems of high engineering and physics content. The three primary areas of activity are controlled background low-level radiation detection facilities, automatic nuclear systems, and special medical nuclear instrumentation.

Mr. Stoddart was formerly vice president in charge of atomic instruments at Baird-Atomic, Inc. **James B. Williams** (S'53–M'56) is vice president of the corporation; he was formerly chief physicist and later marketing manager for Baird-Atomic.

Leonard W. Cronkhite, chairman and treasurer of Atomium Corporation was recently a director and vice president of Baird-Atomic.

❖

Radiation, Inc., Melbourne, Fla., has announced the appointment of **Louis P. Clark** (SM'56) as Manager of the Florida Division. He is also a Vice President of the company.

L. P. Clark

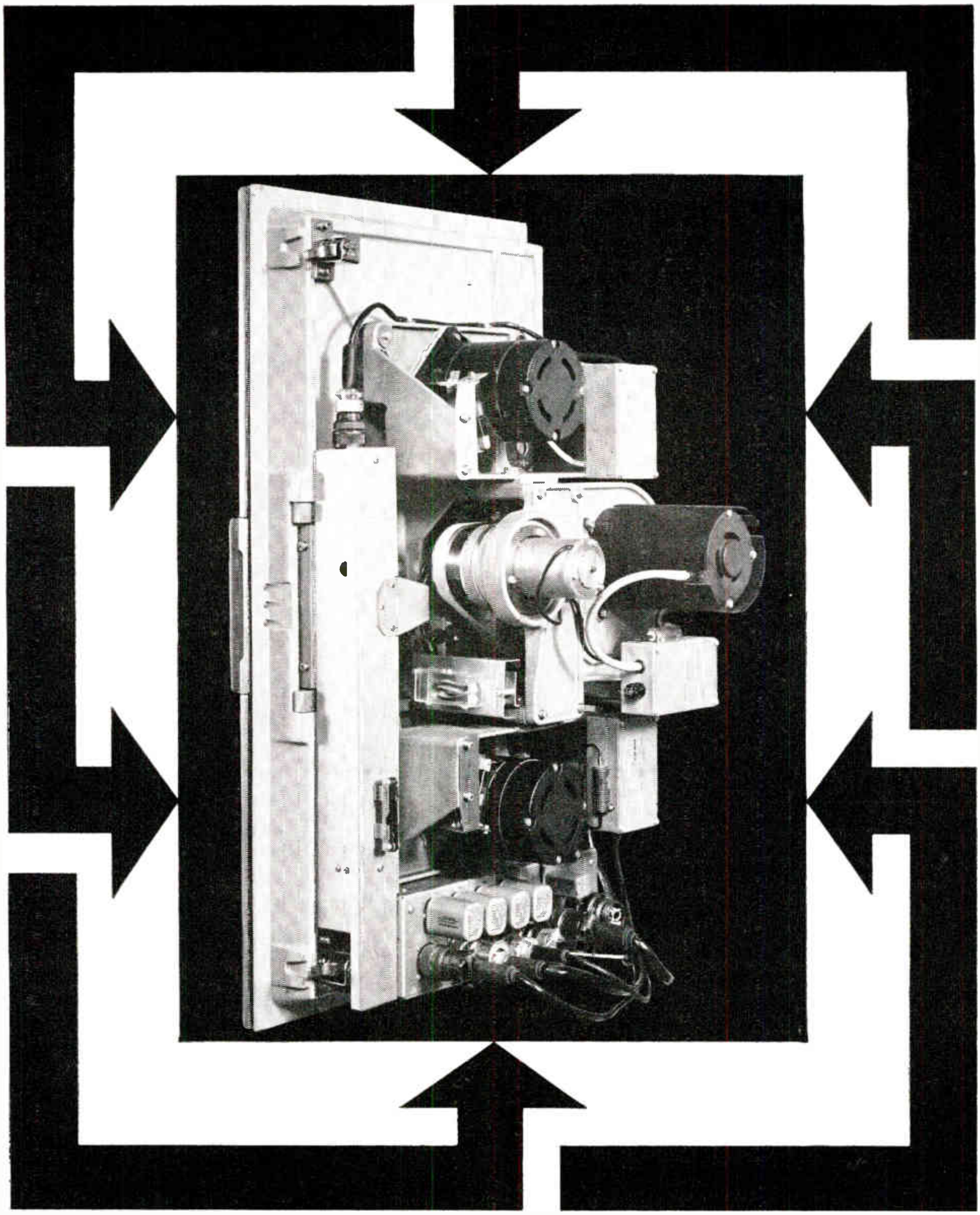
A founder and former executive vice president of Tele-Dynamics Inc., Philadelphia, Pa., he brings to his new post over 25 years of executive experience in the advanced electronics industry. This long and outstanding service has earned Mr. Clark a national reputation for leadership in the fields of telemetry, communications, and instrumentation. He is National Vice Chairman of the PGTRC, a member of the American Rocket Society, the Armed Forces Communications and Electronics Association and the American Ordnance Society.

❖

**J. A. Tucker** (M'56), Assistant to the Department Head, Electrical Engineering Department, M.I.T., has been elected to the National Board of Directors of the Eta Kappa Nu Association, Electrical Engineering Honorary Society. He served as President of the Boston Alumni Chapter of this Association during 1953–54 and has been on its Advisory Board since.

Mr. Tucker is currently Assistant to Dr. Jerome B. Wiesner, Acting Head of the Department of Electrical Engineering at M.I.T.

❖



# AMPEX PRECISION NOW 'LOCKED IN'

Lose the precise alignment of tape guiding and driving components in an instrumentation recorder and you lose the fine edge of designed-in performance. As alignment is lost, flutter and skew set in.

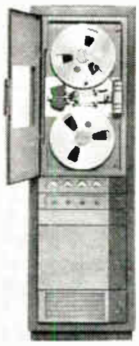
In the new Ampex FR-100B analog recorder, the possibility of misalignment—even under conditions of shock and vibration incidental to shipment or installation — is now eliminated by a framework of three precision castings with machined 'V' mating surfaces that lock all critical parts into a single rigid unit. The result: an instrumentation recorder with built-in performance and reliability that stays built in.

Other advanced features: 1. A unique electrical holdback system keeps tape tension constant within narrow limits, reducing flutter and eliminating mechanical feedback of speed variations. 2. Modular plug-in amplifiers and power supplies give quick versatility for direct, FM carrier, PDM, and NRZ digital recording. 3. Front-panel, four-speed switching over a six-speed range from 1⅞ to 60 ips allows flexibility in selecting upper frequency limit for maximum tape economy.

These and other features of the new Ampex FR-100B add up to unmatched performance and reliability. The full story is available in the new Ampex FR-100 brochure.

AMPEX INSTRUMENTATION, 934 Charter Street, Redwood City, Calif.

AMPEX CORPORATION



# Section Meetings

AKRON

"The Bell System and Continental Defense," Dale Moon, Ohio Bell Telephone Co. 9/16/59.

ALAMOGORDO-HOLLOMAN

"Hi-Fi and Stereo," Dr. M. Jones, Geo. Science: Demonstration of Hi-Fi and Stereo by Maj. Ursel Nolte, USAF. 9/21/59.

ATLANTA

Guided tour of Lockheed Aircraft Corp. 9/25/59.

BALTIMORE

"The Air Defense of North America," Col. C. E. Towne, North American Air Defense Command. 9/14/59.

BENELUX

"General Principles Affecting Shipboard Radio Communications," C. B. Broersma, Radio-Holland N.V.; "The Radio Station Aboard the S. S. Rotterdam," H. T. Hylkema, Radio-Holland N. V.; "Electronic Navigational Aids on the S. S. Rotterdam," A. Wepster, Holland-American Lines. Visit to the S. S. Rotterdam. 10/3/59.

BINGHAMTON

"Flight Simulators," William Wood, Link Aviation, Inc.; "Fringe Count Micrometer," J. Whitmore, Link Aviation, Inc. Plant tour of Link Aviation. 10/14/59.

CENTRAL FLORIDA

"IRE of Yesterday," Arthur Van Dyke, Past President IRE. 4/25/59.

"Radar Reflectivity Measurements," M. Cox, Radiation, Inc. 6/18/59.

"Project Mercury—Man in Outer Space," G. Lowe, NASA. 9/17/59.

CENTRAL PENNSYLVANIA

"Stacked-Mount Vacuum Tubes with a Choice of Glass or Ceramic Envelopes," C. F. Douglass, Sylvania Electric, Inc. 9/15/59.

CINCINNATI

"Manned Versus Unmanned Space Observation," Col. J. P. Stapp, USAF. "The Emotional Dynamics of Sports," P. Harmon, Cincinnati Post and Times Star. "Sports and your Child," R. Schwartz, Boxing and Sports Analyst. 9/15/59.

CLEVELAND

"Design of Control Systems for Space Vehicles," P. E. Lanman, Designers for Industry. 9/10/59.

"Antarctica," Rev. H. F. Birkenhauer, S. J., John Carrol University. 10/8/59.

DALLAS

"Do Tubes Leak?" Dr. H. D. Doolittle, Machlett Laboratories. 9/15/59.

DENVER

"The Space Age and IRE," Dr. Ernst Weber, President IRE. 9/22/59.

DETROIT

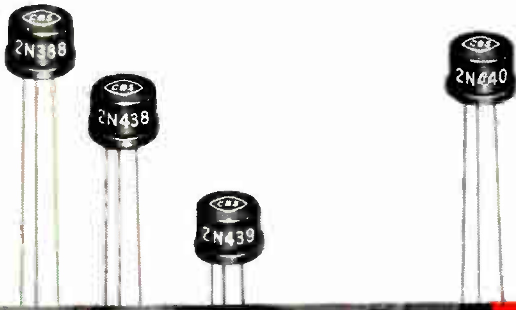
"Global Communications by Means of Satellites," Dr. J. B. Wiesner, MIT. 9/18/59.

ELMIRA-CORNING

"Technological and Sociological Factors Influencing the Military Utility of Space Vehicles," Israel Katz, General Electric Co. 9/28/59.

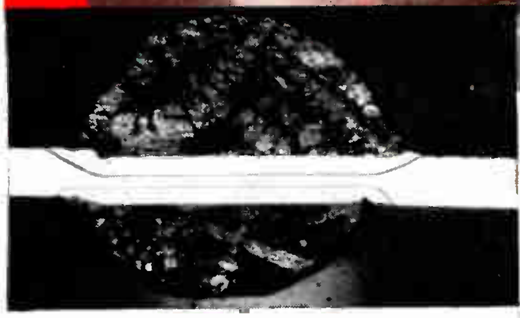
*(Continued on page 84A)*

# CBS NPN SWITCHING TRANSISTORS GIVE YOU MISSILE RELIABILITY


**Here Are Some of the Reasons Why . . .**

**Contamination is eliminated.** Baking, surface treatment, electrical testing and package welding are all conducted in dry-boxes at a dewpoint temperature below −90°F.



**Flat, even junctions avoid "hotspots."** Precise control of time and temperature (±0.03%) of alloying process eliminates localized heating, gives long reliable life. Characteristics are more uniform.

**Ruggedness exceeds MIL specification.** Severe requirements for shock (1000 g, 1 ms), vibration (10 g, 100-3000 cps) and acceleration (20,000 g) are met by: electronic welding of formed lead wires, horizontal base tab, and welded JEDEC TO-9 case.

CBS NPN switching transistors have proved themselves in flight in many of our important "birds." They have been found to have the advantages of fast switching, high voltage, low cutoff current, and low saturation resistance. All 28 of these CBS transistors exceed the MIL-T-19500A specification.

This same proven reliability under the most adverse environmental conditions is yours for military or industrial core drivers, logic circuits or general switching functions. Write for complete data sheet E-353. Order from your local Manufacturers Warehousing Distributor.

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|---|---|---|---|---|---|---|
| 2N306 | 2N357 | 2N388 | 2N439A | 2N445 | 2N558 | 2N1000 |
| 2N312 | 2N358 | 2N438 | 2N440 | 2N446 | 2N634 | 2N1012 |
| 2N356 | 2N377 | 2N438A | 2N440A | 2N447 | 2N635 | 2N1090 |
| 2N356A | 2N385 | 2N439 | 2N444 | 2N556 | 2N636 | 2N1091 |

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## Section Meetings

*(Continued from page 82A)*

El Paso

"Subsonic Amplifiers and Microphones," Prof. T. Barnes, Texas Western College, 9/24/59.

Florida West Coast

"Radio Aids to Positioning and Navigation," Col. E. L. White, Retired, 9/16/59.

Fort Huachuca

"Hi-Fi and Stereo Sound," A. Woolery, Cactus Radio Network, 9/28/59.

Hawaii

"Automatic Switching Center as Developed by Western Union," K. M. Leber, Western Union Telegraph Co. 8/12/59.

"Problems in Reception of Signals from Space Satellite Vehicles," E. Farger, Jr., University of Hawaii, 9/9/59.

Huntsville

"Evolution of Radio Astronomy," J. M. Donnini, Brown Engineering Company; "Equipment and Hardware," E. Wells, ABMA; "The Radio Sky," R. D. Ferdie, Chrysler Missile Division, 7/30/59.

"High Reliability Statistically Demonstrated (Capacitors)," B. L. Wheeler, Vitramon, Inc. 10/8/59.

Kansas City

"Transistor Manufacturing Techniques," R. Berger, Western Electric Co., Inc. 9/8/59.

"Project Mercury," R. J. Pierce, Collins Radio Co. 10/13/59.

Little Rock

"The Electronic Production of Choral Tone," W. C. Wayne, Jr., Baldwin Piano Co. 10/12/59

London

Tour of Dominion Electrohome, Inc., with explanations by Frank Gordon. 9/22/59.

"Education for the Electronic Age," Dr. Ernst Weber, President IRE. 10/9/59.

Long Island

"Stero Transmission by FM Broadcasting," M. G. Crosby, Crosby-Teletronics Corp. Movie: "The Significant Years." 9/8/59.

Los Angeles

"The U. S. Army Electronic Proving Ground, Fort Huachuca, Arizona," Col. E. T. Bullock, USA; "Automatic Data Processing," Capt. J. Crawford, USA. 9/1/59.

"Frontiers at Infinity—World's Largest Radio Telescope," Prof. A. B. C. Lovell, University of Manchester, England. 10/1/59.

Lubbock

Film "Sage," Comments by L. Pease, Southwestern Bell Telephone Co. 9/22/59.

Miami

"University Meterology Radar Station," P. R. Ray and H. W. Kiser, 9/24/59.

Montreal

"Electron Beam Parametric Amplifiers," Dr. F. J. F. Osborne, Canadian Marconi Co. 9/23/59.

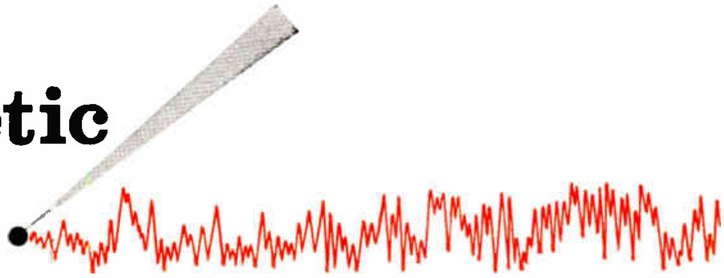
North Carolina

"Semi-conductor Switching Equipment for Broad Band Video," J. W. Wentworth, RCA. 9/18/59.

*(Continued on page 86A)*

interfering

# electromagnetic energy



within the frequency range of

# 30 cps to 10.7 kmc

...can be investigated, analyzed, monitored and measured to the highest practical degree of accuracy with Stoddart Radio Interference & Field Intensity Measuring Systems.

Stoddart RFI Measuring Equipment is approved for use by all departments of the Department of Defense. Military and commercial equipments are identical... were designed and manufactured to Military Equipment Specifications to meet the requirements of Military Measurement Specifications. Equipments are portable, dripproof, dustproof, and ruggedized for all-weather field use... precise and dependable for sensitive-selective laboratory measurements.

Applications include interference measurement and location, frequency conservation and allocation studies, spectrum signatures, antenna propagation studies, field intensity surveys, RF energy surveillance and monitoring, and verification of the electronic compatibility of modern weapons systems, i.e., missile firing and guidance, computer, telemetering and communications; the measurement of all rotating electrical devices, transmitting and receiving equipment, or any system or equipment capable of producing unwanted radiated or conducted electrical disturbances.

Stoddart instruments are available as individual self-contained units covering specific frequency ranges, or in rack-mounted console systems for laboratory, mobile, airborne and marine use.

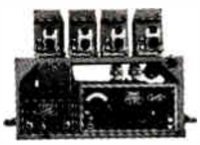
NM-40A (AN/URM-41)
30 cps to 15 kc

NM-10A (AN/URM-6B)
14 kc to 250 kc

NM-20B (AN/PRM-1A)
150 kc to 25 mc

NM-30A (AN/URM-47)
20 mc to 400 mc

NM-50A
(AN/URM-17)
375 mc to 1000 mc



NM-60A
(AN/URM-42)
1 Kmc to 10.7 Kmc

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will give you individual consideration and information in the areas of interference problems or measurement with which you are particularly concerned... provide engineering bulletins, military specification information, descriptions of new measurement techniques and applications... class or individual instruction in the operation, calibration, and maintenance of Stoddart instruments. For prompt service please call "Sales Engineering", HOllywood 4-9292.

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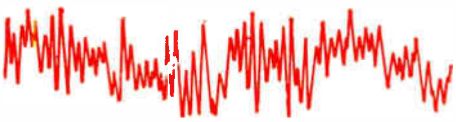


serving 33 countries in radio interference control

## Section Meetings

*(Continued from page 84A)*

NORTHERN NEW JERSEY

Panel discussion on "Educational Television," E. deA. Partridge, Montclair State College; "Chelsea Closed Circuit Television Project," L. Creshkoff and Leon Polk, WPIZ. 9/11/59.

NORTHWEST FLORIDA

"An Instantaneous Multiple Plotter," Capt. F. J. Sites, APGC, Eglin AFB. 8/11/59.

"Electronic Systems for Satellite Navigation, R. Werner, Cubic Corp. 9/15/59.

OKLAHOMA CITY

"IRE and the Space Age," Dr. Ernst Weber, President IRE. 9/24/59.

PHOENIX

"Present State of the Art of the Parametric Amplifier," Dr. H. Seidel, Bell Telephone Laboratories. 9/25/59.

QUEBEC

Guided tour of Davie Shipbuilding, Ltd. 9/19/59.

ROME-UTICA

"Management and the Engineer," Ralph I. Cole, Melpar, Inc. 9/29/59.

ST. LOUIS

"Communications Systems for Project Mercury Space Capsule," W. Benner, McDonnell Aircraft Corp. 9/22/59.

SALT LAKE CITY

"A Highly Selective I-F Amplifier," Garth Hess, Brigham Young University; "An Improved Telemetry Receiver for High Altitude Rockets," Ian Graham, University of Utah; "Velocity Response Displacement of Stable Linear Systems," Harold Vitale, University of Utah. 5/19/59.

"High Accuracy Data Acquisition," T. W. Gardner, Thiokol Chemical Corp. 6/9/59.

"IRE and the Space Age," Dr. Ernst Weber, President IRE. 9/21/59.

SAN DIEGO

"Principles and Applications of Inertial Guidance," D. C. Hiser, North American Aviation. 9/1/59.

SCHENECTADY

Guided tour and explanation of communication facilities of New York Thruway Authority. 9/22/59.

SHREVEPORT

"The Grinding, Polishing, Calibration and Finishing of Quartz Crystals," R. Freeland, International Crystal Corp. 10/6/59.

TOLEDO

"Comparison Between Electronic Industry in the U.S.A. and Germany," Helmut Seike, Kaiser Electronics. 9/10/59.

"Autolite Transistorized Ignition System," James Gage, Autolite Co. 10/8/59.

TORONTO

"Stereo Broadcasting," T. Jamroz, Northern Electric Co., and C. Eastwood, Station CFRB. 9/21/59.

TULSA

"Space Age and the IRE," Dr. Ernst Weber, President IRE. 9/25/59.

TWIN CITIES

"Tunnel Diodes: Principles and Some Applications," Dr. A. G. Tweet, General Electric Research Lab. Discussion led by S. Schulz. 9/16/59.

"Latest Developments in Jet Aircraft Electronics—Doppler Navigation," C. I. Rice, Bendix Aviation. 10/8/59.

VIRGINIA

Business Meeting. 6/11/59.

"Atmospheric Phenomena at High Altitudes," Dr. H. M. Parker. 9/25/59.

WASHINGTON

Panel Discussion: "Are You Properly Educated?" Moderated by Dr. A. H. Waynick, Penn State University with panel consisting of: Prof. G. F. Corcoran, University of Maryland; Prof. J. C. Michalowicz, Catholic University of America; Prof. E. Frank, George Washington University. 9/14/59.

WESTERN MASSACHUSETTS

"Inertial Guidance," Dr. Vachter, American Bosch Arma. 9/30/59.

Field trip to the Direct Distance Dialing Station of New England Telephone Co. at Northampton, Mass., with explanations by William Stewart of the company. 10/10/59.

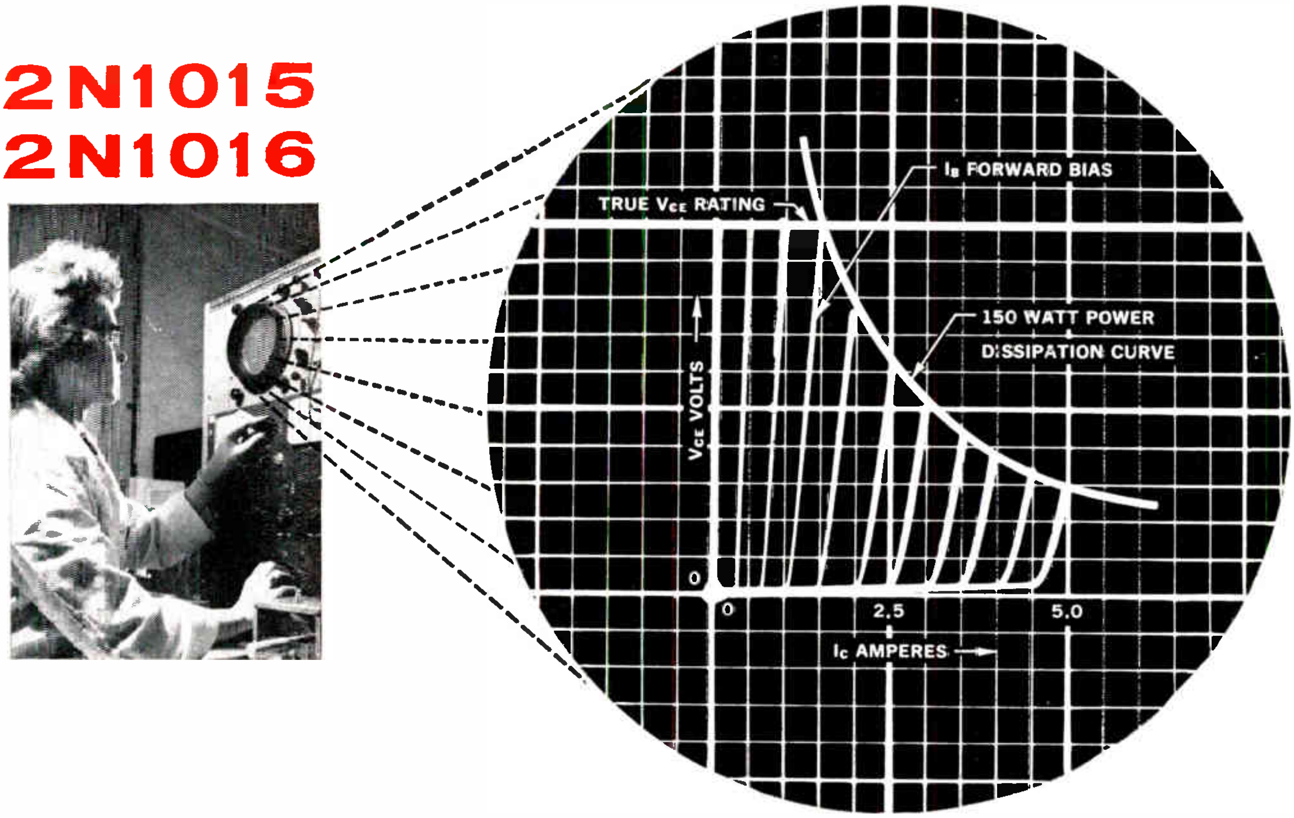
WILLIAMSPORT

Business meeting and plant tour of Sylvania Electric Products Co. with comments by W. Bresee of the company. 9/23/59.

*(Continued on page 88A)*

# WESTINGHOUSE SILICON POWER TRANSISTORS

## 2N1015
## 2N1016




# TRUE VOLTAGE RATINGS

## *Guaranteed by 100% power testing*

This Power-voltage Test consists of testing the transistor in common emitter configuration under all bias conditions in the area defined by the *TRUE* voltage rating of the transistor ($V_{CE}$); the constant power dissipation curve for the transistor (150 watts); and its rated current (2 amps for 2N1015 and 5 amps for 2N1016).

The voltage at which alpha equals one, and other voltage ratings commonly given for transistors such as $V_{CES}$, $V_{CER}$, $V_{CEX}$ and $V_{CBO}$, are *above* the voltage rating given to these transistors.

Each Westinghouse silicon power transistor has been completely tested throughout its rated voltage-power-current region before shipping. Thousands of transistors performing under all types of operating conditions have proved the validity of this method of *TRUE* voltage rating.

*TRUE* voltage ratings from 30 to 200 volts give you complete freedom in designing your equipment—you can operate Westinghouse silicon power transistors at the manufacturer's ratings without risking transistor failure. This *TRUE* voltage rating of Westinghouse silicon power transistors coupled with their still unequaled low saturation resistance and low thermal drop makes them an ideal first choice for military, industrial and commercial applications.

| Type | $V_{CE}$* | B (min) | $R_S$ (max) | $I_C$ A (max) | $T_j$ max. operating | Thermal drop to case (max) |
|---|---|---|---|---|---|---|
| 2N1015<br>2N1015A<br>2N1015B<br>2N1015C<br>2N1015D | 30<br>60<br>100<br>150<br>200 | 10<br>@ $I_C$=2 amp | .75 ohms<br>@ $I_C$=2 amp<br>$I_B$=300 ma | 7.5 | 150°C | .7°C/W |
| 2N1016<br>2N1016A<br>2N1016B<br>2N1016C<br>2N1016D | 30<br>60<br>100<br>150<br>200 | 10<br>@ $I_C$=5 amp | .50 ohms<br>@ $I_C$=5 amp<br>$I_B$=750 ma | 7.5 | 150°C | .7°C/W |

*TRUE voltage rating (The transistors can be operated continuously at the $V_{CE}$ listed for each rating.)

**YOU CAN BE SURE...IF IT'S Westinghouse**

Westinghouse Electric Corporation, Semiconductor Department, Youngwood, Pa.

## Section Meetings

(*Continued from page 86A*)

### Subsections

**Buenaventura**

"Transistorized Crystal Oscillator Circuits," Dr. T. S. Amlie, NOTS, China Lake. 9/9/59.

**Gainesville**

"The Satellite Communications Age," G. S. Shaw, Radiation Inc. 9/23/59.

**Kitchener-Waterloo**

"Video Tape Recording," W. McGregor and P. Turcham, CKCO-TV. 9/21/59.

**Merrimack Valley**

"Use of Educational Aids in Electronics," Dr. H. E. Stockman, Merrimack College. 10/19/59.

**Monmouth**

"International Comparison of Atomic Clocks," Dr. G. M. R. Winkler, USA Research and Development Lab., Fort Monmouth. 9/16/59.

**Panama City**

"Guidance Systems for Ballistic Missiles," D. R. Hagner, Bell Laboratories, Inc. 10/13/59.

**Santa Ana**

"Rockets and Celestial Navigation," Dr. R. M. L. Baker, Jr., Aeronutronic Division of Ford Motor Co. 9/23/59.

**Santa Barbara**

"Modern Circuit Methods in Circuit Applications," Dr. W. K. Linvill, Rand Corp. 9/15/59.

**Northern Vermont**

"Ingredient 'X' and Electronic Ovens," R. B. Stem, General Electric Co., 9/29/59.

**Westchester**

"Automatic Programming and the Design of General Purpose Computers," Dr. J. Mauchly, Mauchly Associates. 9/16/59.

**Western North Carolina**

"Semi Conductor Switching Equipment for Broad-Band Video Signals," J. W. Wentworth, RCA. 9/18/59.

## Professional Group Meetings

### Antennas and Propagation

Orange Belt—September 16

"Electromagnetic Scattering by a Short Right Circular Cylinder at Wavelengths Long Compared with Cylinder Dimensions," T. T. Taylor, U. of California at Riverside.

### Audio

Boston—September 17

"Speech Amplification," D. L. Klepper, Bolt, Beranek & Newman.

(*Continued on page 90A*)

# Professional Group Meetings

*(Continued from page 88A)*

## Automatic Control

Los Angeles—September 8

"Has an Emphasis on Adaptive Control Techniques Accomplished Anything Worthwhile," R. R. Rath, U. S. Air Force.

## Broadcasting

Philadelphia—October 8

"Operation of Ampex Video Tape Recorders," I. L. Ross, WFIL-TV.

## Communications Systems

Oklahoma City—September 8

Main intent of the meeting was to demonstrate operation of the AAE ampex video tape recorder. The group was also conducted through all facilities of the WKY-WKY-TV operation, including their experimental operation with regard to directional operation of television stations.

Philadelphia—September 29

Field Trip Inspection of City Communication Facilities, F. Sherif, City of Philadelphia.

## Electron Devices

Washington, D. C.—September 21

"Tunnel Diodes—How They work and How to Apply Them," Dr. I. A. Lesk, GE Co.

## Electronic Computers

Boston—September 23

Report on the International Conference on Information Processing, J. Raffel, Lincoln Lab., A. G. Oettinger, Harvard Univ., H. Sherman, Lincoln Lab., and D. Brown, MITRE Corp.

San Francisco—September 22

"Trip to Russia and Russian Computers," M. Astrahan, IBM Corp.

Washington, D. C.—October 7

"Data Display," M. Macaulay, Data Display Inc.

## Engineering Management

Rome-Utica—September 29

"Management and the Engineer," R. I. Cole, Melpar, Inc.

Washington, D. C.—September 21

"Command Management," J. C. Lackas, Industrial College of the Armed Forces.

*(Continued on page 92A)*

Component Specification: ARNOLD

**TOROIDAL CORES** — Aluminum and Plastic Cased / **SILECTRON CORES** — Types C, E and O / **BOBBIN CORES** — Stainless Steel and Ceramic

# The ARNOLD LINE-UP includes ANY TAPE CORES you need

## APPLICATIONS

We'll welcome your inquiries on your Tape Wound Core requirements for Pulse and Power Transformers, 3-Phase Transformers, Magnetic Amplifiers, Current Transformers, Wide-Band Transformers, Non-Linear Retard Coils, Reactors, Coincident Current Matrix Systems, Static Magnetic Memory Elements, Harmonic Generators, etc.

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**SC-107A**—*Silectron Cores, Types C, E and O*
**TC-101A**—*Toroidal Cores, of Supermalloy, Deltamax and 4-79 Mo-Permalloy*
**TC-108A**—*Bobbin Cores*
**TC-113A**—*Supermendur Tape Cores*

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Arnold produces Silectron C, E and O cores, aluminum and plastic cased toroidal cores of high-permeability materials, and bobbin-wound cores to meet whatever your designs may require in tape thickness, material, core size or weight.

As a fully integrated producer, Arnold controls every manufacturing step from the raw material to the finished core . . . and modern testing equipment permits 100% inspection of cores before shipment.

Wide selections of cores are carried in stock as standard items for quick delivery; both for engineering prototypes to reduce the need for special designs, and for production-quantity shipments to meet your immediate requirements.

• *Let us help you solve your tape core problems.* Check Arnold, too, for your needs in Mo-Permalloy or iron powder cores, and for cast or sintered permanent magnets made from Alnico or other materials. Just write or call *The Arnold Engineering Company, Main Offices, Marengo, Illinois.*

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SPECIALISTS in MAGNETIC MATERIALS

BRANCH OFFICES and REPRESENTATIVES in PRINCIPAL CITIES
*Find them FAST in the YELLOW PAGES*

## Professional Group Meetings

*(Continued from page 90A)*

### Instrumentation

Los Angeles—June 3

"Biological Instrumentation," H. M. Hanish, Litton Ind.

Los Angeles—September 1

"Transducers for Instrumentation," J. Hernandez, Statham Instr.

### Instrumentation Automatic Control

Long Island—September 15

"Automatic Control in the Human Body," P. Suckling, State Univ. of N. Y. (L. I. College of Medicine).

### Medical Electronics

Los Angeles—September 17

"Electrosurgery; Its History, Clinical Considerations and Engineering Aspects," S. Bollas, Birtcher Corp.

"Electrosurgery; Its History, Clinical Considerations and Engineering Aspects," (covered engineering aspects) H. Finch, Birtcher Corp.

### Microwave Theory and Techniques

Boston—September 16

"Parametric Amplifiers: UHF TW Amplifier Using Diodes," W. W. Mumford and R. S. Engelbrecht, Bell Telephone Labs.

Los Angeles—October 8

"The Amplitron and Its Applications," E. Shelton, Raytheon Microwave and Power Tube Div.

Washington—September 15

"A Compact Frequency Translator for Use with the Ammonia MASER," W. K. Saunders, D.O.F.L., Army Ordnance Corps.

Washington—October 13

"Comparison of Deviations from Square Law for R. F. Crystal Diodes and Barretters, G. U. Sorger, Weinschel Engr. Co.

### Military Electronics

Central Florida—June 16

"1969 Astronautic Systems," M. Alperin, Office of Scientific Res. USAF.

### Nuclear Science

Oak Ridge—September 17

"Status Report of Project Sherwood," E. S. Bettis, Oak Ridge National Lab.

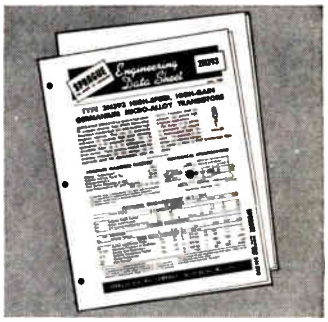
*(Continued on page 94A)*

*micro-alloy transistors from SPRAGUE**


## HIGH-SPEED, HIGH-GAIN MICRO-ALLOY TRANSISTORS for modern digital computer circuitry

TYPE 2N393 Micro-Alloy Transistors combine high gain with excellent high frequency response to meet the demands of high-speed computer switching applications in the megacycle range. Low saturation resistance, low hole storage, and exceptionally good life characteristics make these transistors top performers in computer circuits as well as in general high-frequency applications.

D-C $\beta$ is remarkably linear up to 50 milliamperes collector current. The design of the 2N393 is particularly well adapted to direct-coupled logic circuitry. The polarities of the emitter and collector voltages are similar to those of PNP junction-type transistors.




Made by electrochemical manufacturing techniques, Sprague Micro-Alloy Transistors are uniformly reliable and very reasonably priced.

Write for complete engineering data sheets to Sprague Electric Company, 235 Marshall Street, North Adams, Massachusetts.

ACTUAL SIZE

**2N393**

| | Min. | Typ. |
|---|---|---|
| $h_{FE}$ | 20 | 95 |
| $f_{max}$ | 40 | 60 |

* *Sprague Type 2N393 micro-alloy transistors are fully licensed under Philco patents. All Sprague and Philco transistors having the same type numbers are manufactured to the same specifications and are fully interchangeable. You have two sources of supply when you use micro-alloy transistors!*

**SPRAGUE COMPONENTS:**

TRANSISTORS • RESISTORS • MAGNETIC COMPONENTS
CAPACITORS • INTERFERENCE FILTERS • PULSE NETWORKS
HIGH TEMPERATURE MAGNET WIRE • CERAMIC-BASE PRINTED NETWORKS • PACKAGED COMPONENT ASSEMBLIES

**SPRAGUE**®

*THE MARK OF RELIABILITY*

## Professional Group Meetings

*(Continued from page 92A)*

### Production Techniques

Los Angeles—September 24

"Packaging Ferrite Cores for Military Applications," D. Slotnick, R. Igram and H. Chrystie, Telemeter Magnetics, Inc.

San Francisco—September 22

"Production Planning in Rapidly Growing Electronic Factories," 1) W. McGinnitty, Ampex Corp., 2) G. M. Eustachy, Beckman/Berkeley, 3) O. Landeck, Electro Engrg. Works.

### Radio Frequency Interference

Washington, D. C.—June 10

"Shortcomings of Interference Specifications," C. F. W. Anderson, Martin Co.

### Space Electronics and Telemetry

Central Florida—January 29

"New Telemetry Techniques," L. Rauch, U. of Michigan.

Central Florida—May 21

"IRIG Standards for PCM Telemetry," E. E. Ollikkala, RCA Missile Proj.

"Renaming of Professional Group on Telemetry and Remote Control to Space Electronics and Telemetry," C. H. Hoeppner, Radiation, Inc.

Central Florida—June 23

"2200 Megacycle Telemetry," P. Richardson, WADC.

Detroit—September 18

"Global Communications by Means of Satellites," J. B. Wiesner, M.I.T.

### Vehicular Communications

Baltimore—September 22

"New Transistorized Progress Line (General Electric)," R. T. Myers, GE Co.

Philadelphia—September 29

Field Trip Inspection of City Communication Facilities, F. Sherif, City of Philadelphia.

Washington—September 29

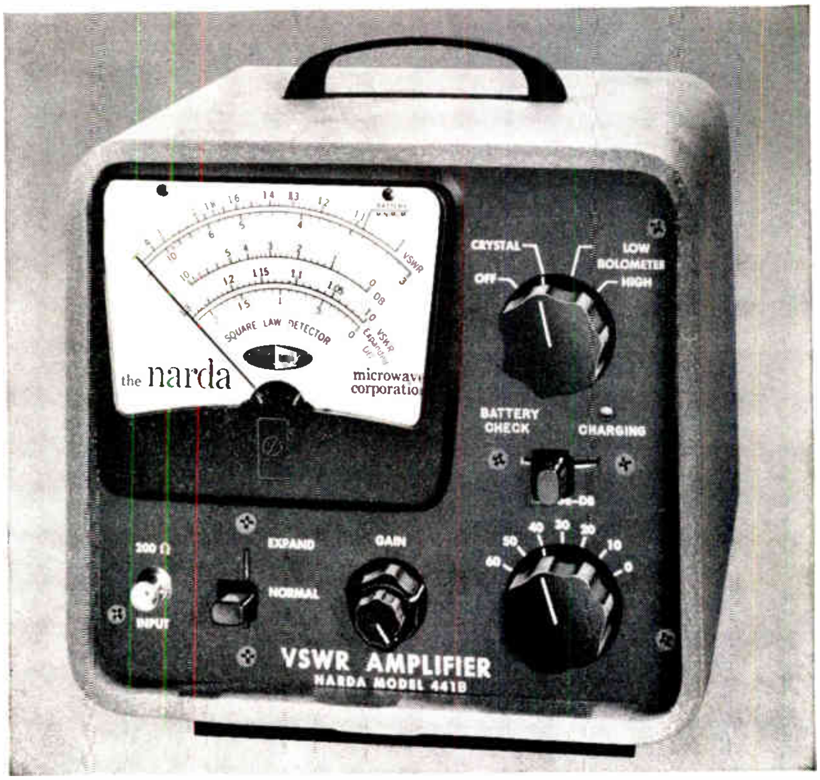
"Tape-Recorded Address on Status of Geneva Radio Conference," W. H. Watkins, FCC.

"Elaboration on Geneva Radio Conference," J. M. Kittner, McKenna and Wilkinson.

# SIX VSWR AMPLIFIER FEATURES

## ...available only from NARDA

1. Battery-operated (rechargeable nickel-cadmium).
2. Completely transistorized for low current drain.
3. Independent of line voltage variations.
4. Complete bolometer protection during switching.
5. Most compact unit available.
6. Completely portable.




Model 441B—$225

Now you can get a completely portable battery-operated VSWR Amplifier offering complete protection against bolometer burnout at the same time!

Narda's Model 441B is supplied with nickel-cadmium batteries, providing complete freedom from line voltage deviations. Batteries recharge automatically when unit is plugged in; provision is built-in to show state of battery charge. A special protective circuit permits switching and connect-disconnect with no danger of bolometer burnout. Provision is made for both crystals and high and low current bolometers.

Full sensitivity is provided over both normal and expanded scales; eliminates switching attenuation range. Other features are shown on this page; for complete information and a free copy of our latest catalog, write to us at: Department PIRE-10.

## FEATURES:

- **SENSITIVITY:** 0.1 microvolts at 200 ohms for full scale.
- **FREQUENCY:** 1,000 cps ± 1% (plug-in frequency networks available for 315-4,000 cps and broad-band applications)
- **BANDWIDTH:** 25-30 cps
- **RANGE:** 72 db (60 db in 10 db steps, 11 db continuous)
- **ACCURACY:** ± 0.1 db per step • ± 0.2 db maximum cumulative • meter linearity: 1% of full scale

**the narda microwave corporation**

118-160 HERRICKS ROAD, MINEOLA, L. I., N. Y. • PIONEER 6-4650

## NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

*(Continued from page 48A)*

### Zener Diodes

U. S. Semiconductor Products, a Division of Topp Industries, Inc., 3540 West Osborn Rd., Phoenix, Ariz., announces the industry's first 35-watt zener diode, according to J. C. Worth, Jr., vice president-sales. The new line comprises single diffused silicon junction zeners with voltages ranging from 8.2 to 100 volts and rectifiers with PIVs from 50 to 600 volts.

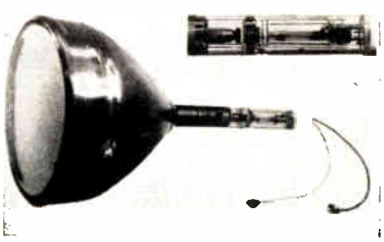
The rectifiers feature high forward conductance, with forward current up to 40 amperes at 1 volt, and 1 ma saturation current at rated PIV.

According to Worth, these diodes are built with matched coefficients of expansion which prohibit separation of internal lead wire and silicon wafer, even under extreme thermal shock. They are not position-sensitive and are resistant to vibration. These hermetically sealed diodes have plated copper heat sink and to provide thermal conduction.

Technical details may be obtained by writing to the firm.

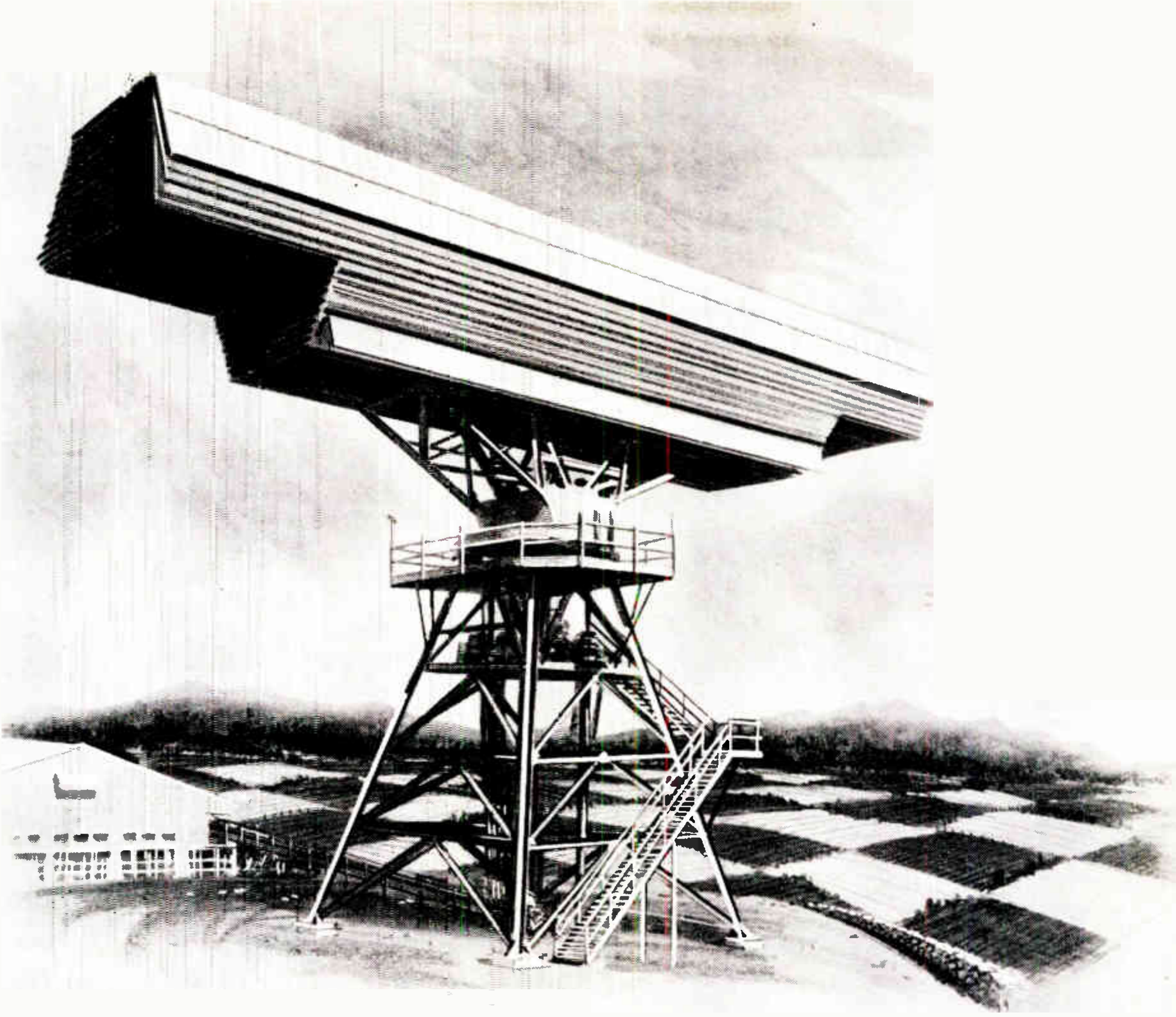
### Microwave Frequency C-R Tube Display

The development of a newly designed, compact "Wamoscope," a cathode ray tube capable of presenting microwave frequency information directly on its screen, was announced today by **Sylvania Electric Products Inc.**, 730 Third Ave., New York 17, N. Y., subsidiary of General Telephone & Electronics Corp.



The insert shows the signal coupler which incorporated within the neck of the tube envelope. The new tube, which was

*(Continued on page 98A)*



# CHESSMAN . . . 1960

New orders of power through Amplitron transmitter application. New frequency areas. Ferrite mechanisms. Sophistication in receiving and data processing techniques. This is advance technology at Raytheon Heavy Electronics.

Developments in such areas are already incorporated in these Heavy Electronic long range radars, ordnance and communications systems:

**AN/FPS-28 800-ton warning system for SAGE network.**
**96-voice channel pulse-code-modulation equipment.**
**Two-gun MEMRAD Bright Display.**
**AN/SPG-51 radar for Tartar Missile fire control system.**

Each development evolved from imagination . . . technical command . . . experience — the qualities we always seek.

Select positions may be investigated by writing: Mr. Donald H. Sweet, Executive & Engineering Placement, Raytheon, 624X Worcester Road, Framingham, Mass. (suburban Boston).

## HEAVY ELECTRONIC
### GOVERNMENT EQUIPMENT DIVISION

RAYTHEON

EXCELLENCE IN ELECTRONICS

HEAVY ELECTRONIC | AIRBORNE ELECTRONIC | SYSTEMS MANAGEMENT | SUBMARINE SIGNAL | SANTA BARBARA

## NEWS New Products

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*(Continued from page 96A)*

developed for use in advanced electronic systems applications, does not require a solenoid, a bulky focusing structure requiring an external source of electric current. The "Wamoscope" is only slightly longer than conventional television tubes.

The improved "Wamoscope" operates over a frequency range of 2 to 10 kmc, and will be particularly important in high-resolution radar applications. The new tube has a signal coupler incorporated within the tube en elope and "spot size" has been improved to 160 lines per inch at the center of its 10-inch screen. Sylvania developed the original "Wamoscope" in 1956 in conjunction with the U. S. Naval Research Laboratory.

### Mercury-Wetted Contact Relays

A full-line of Clare mercury-wetted contact relays is pictured and described in a new catalog just issued by **C. P. Clare & Co.**, 3101 Pratt Blvd., Chicago 45, Ill., manufacturer of relays and allied electronic devices.

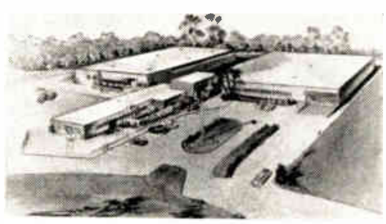
Relay types are for both single-and multi-element operation, biased with permanent magnets, or adjustable to provide single-side-stable, bi-stable, or chopper characteristics.

These relays provide long operating life . . . over 8 billion operations and are still going on a 4-year test. Basic element is a magnetic switch, sealed in a glass capsule which is filled with pressurized hydrogen. With every make and break, the mercury-film contact surface is renewed by capillary action, like a lamp wick. As a result, contacts never wear out, never chatter or bounce, and require no maintenance whatsoever.

For a copy of Catalog 201 contact the firm.

### New Ling-Altec Plant

A $600,000 expansion of the **Ling-Altec Electronics** plant in Anaheim, California has been announced by Company President Cameron G. Pierce.



Pierce said that the enlarged facility, which will include one new manufacturing building, will provide approximately

*(Continued on page 100A)*

**DON'T INVEST IN TEST EQUIPMENT 'TIL YOU COMPARE FEATURES WITH THE**

# NEW Simpson LABORATORY LINE

### PULSE GENERATOR . . . model 2620

***No Other Unit Offers Such Accuracy, Versatility, and Set-Up Speed Within This Price Range***

Twin meters read pulse repetition frequency and pulse duration simultaneously. Rise time is 0.02 microseconds; decay time, 0.03 microseconds. Pulse duration, continuously variable from 0.1 to 1000 microseconds. Jitter, less than 0.005 microseconds. Pulse repetition rate, continuously variable from 10 to 100,000 pps in four ranges. Price . . . . . . . . . . . . . . . **$625**

**WRITE FOR COMPLETE SPECIFICATIONS**

### WIDE-BAND OSCILLOSCOPE . . . model 2610

***For the 1001 Jobs Where You Don't Need an Expensive Specialized Scope***

Here's a high-gain scope that makes your test equipment appropriation go farther. Vertical sensitivity, 6 mv RMS. Vertical calibration accuracy, ± 3%. Response (linear position): DC to 5.0 mc/sec, ± 0.5 db; DC to 8.0 mc/sec, ± 1.5 db. Response (transient position): DC to 3.5 mc/sec, −3 db, and −6 db at 5.0 mc/sec. Triggered and recurrent sweeps. Precalibrated sweep positions of 5, 50, 500, 5000 microseconds. Price . . . . . . . . . . . . . . . . . . . . . . . **$575**

**WRITE FOR COMPLETE SPECIFICATIONS**

### LABORATORY STANDARD VOLT-OHM-MILLIAMMETER . . . model 2600

***A Self-Powered Calibrator for Electrical Instrument Maintenance and High Accuracy Testing***

Two terminal connections cover all 49 ranges for unusually fast operation. DC accuracy is ± 0.5% F.S.; AC, ± 0.75% F.S. (at 77°F, 25°C). Separate meters (*self shielded* movements) for DC and AC readings. Price . . . . . . **$1620**

**WRITE FOR COMPLETE SPECIFICATIONS**

**AVAILABLE FROM MANY INDUSTRIAL ELECTRONIC DISTRIBUTORS, COAST-TO-COAST**
**Write to Factory for Details**

MANUFACTURERS OF ELECTRONIC TEST EQUIPMENT FOR OVER 50 YEARS

**Simpson ELECTRIC COMPANY**

5204 West Kinzie St., Chicago 44, Illinois • Telephone: EStebrook 9-1121
In Canada: Bach-Simpson Ltd., London, Ontario

## NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

*(Continued from page 98A)*

65,000 additional square feet of plant area on the company's 13-acre site near Harbor Boulevard and the Santa Ana Freeway at 1515 South Manchester.

The company will move its Culver City plant, which manufactures high power vibration test equipment and sonar components, to the Orange County site, which is the main plant of the Altec companies subsidiary of Ling-Altec Electronics Corp.

Approximately 450 persons will be employed in the facility.

### Transformer Brochure

A new 4-page brochure, "Encapsulated Transformer," describes performance characteristics and applications of patented HR/Epseal and Electroseal transformer constructions. Three basic design improvements, which achieve higher reliability, reduced size and weight, and improved cooling, are illustrated along with photographs of typical transformer configurations. Units are designed to custom requirements from microwatt ratings to 250 kva. for both commercial and Mil-T-27A (Grade 2 or 5) applications.

For free copy write to Rex Brooks, Sales Manager, Electro Engineering Works, 401 Preda St., San Leandro, Calif.

**Use your IRE DIRECTORY! It's valuable!**

### Aune Named SM of Burndy Omation Div.

Alan E. Aune has been named sales manager of the Omaton division of Burndy Corp., Norwalk, Conn., it was announced by S. D. Bergman, director of sales.

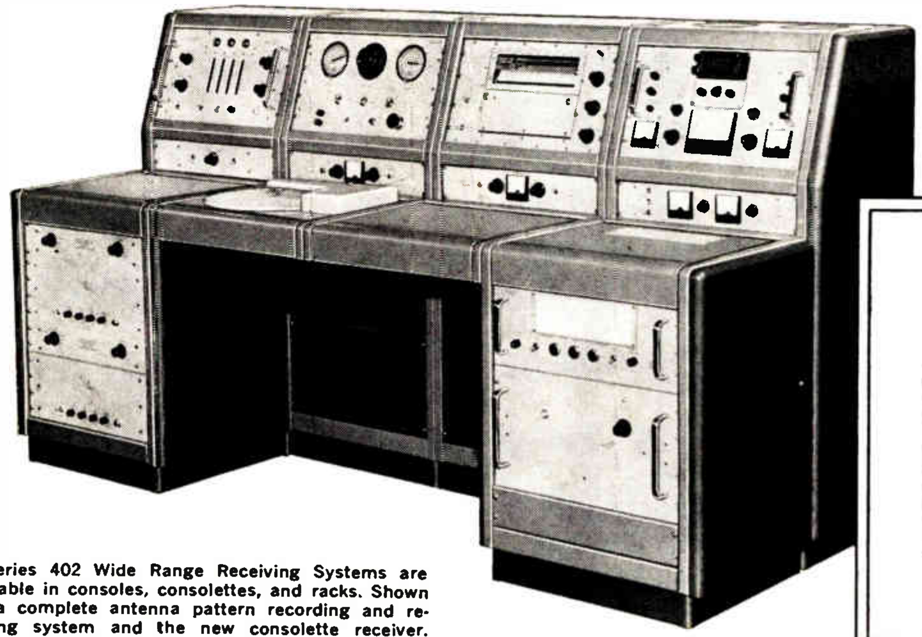
Aune's background in sales, service and production includes 11 years with the Cities Service Oil Co. and the United Motors division of General Motors as an automotive engineer specializing in electrical systems. He then served the United States Rubber Company as production supervisor in the munitions and the wire and cable divisions and as manager of automotive and aircraft sales.

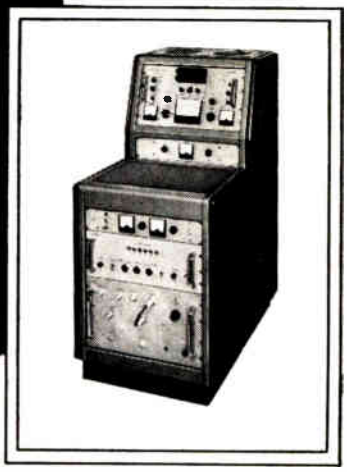
Since joining Burndy in 1949, he has been manager of automotive sales and of ordnance sales, and OEM sales manager.

*(Continued on page 101A)*

# MAJORS and MINORS

*...A Message to the Antenna Designer*





● Series 402 Wide Range Receiving Systems are available in consoles, consolettes, and racks. Shown are a complete antenna pattern recording and receiving system and the new consolette receiver.

A crowded spectrum plus high power radar and communication systems critically compound the problems of the antenna design engineer.

More than ever, the complete pattern including **all** the major and minor lobes of every radiating element must be graphed for sound engineering evaluation.

## S-A Receiver Gets the Whole Signal

Scientific-Atlanta Series 402 Wide Range Receiving Systems are specifically designed for antenna pattern measurements. Unique in design, these receivers combine maximum sensitivity and linearity from 30 mc to above 100 kmc. They are also useful as multipurpose laboratory instruments for microwave testing, monitoring, and measuring applications.

## Only from S-A, 1 db Linearity over Full 60 db Dynamic Range

A recent development, S-A's P-4 modification adds 20 db to the normal 40 db dynamic range. The modification takes advantage of the gain vs AGC voltage characteristics of the Series 402. Existing receivers can be modified at the factory.

## New Modification Z Broadens Use

Modification Z adds a precision IF attenuator and VTVM to the Series 402. Now RF and microwave signal level, gain, and isolation measurements can be made with fewer components and instruments. *For instance,* an X band 80 db attenuator can be calibrated to within ±0.5 db with a 1 mw signal source, a flap attenuator, a mixer, and an S-A Series 402Z Receiver. Antenna gain can be measured by direct comparison with a standard gain antenna. Signal levels can be compared against a reference standard.

## Other Features

One coaxial cable from antenna to receiver eliminates costly lossy waveguides and rotary joints. Antenna can be located up to 75 feet away with negligible loss in sensitivity ☆ One receiving system covers 30 mc to above 100 kmc without plug-ins ☆ Reception of cw signals from simple sources eliminates need for precise modulation ☆ High sensitivity means low source power and long ranges ☆ High selectivity reduces interference and cross talk between adjacent test ranges ☆ Positive AFC action over full dynamic range provides pattern recording in deep nulls.

## PRICES

| | |
|---|---|
| Series 402, 2 to above 100 kmc . . . . . . . . | $7500 |
| Series 402A, 2 to above 100 kmc with AGC . . . . | 8000 |
| Series 402B, 30 mc to above 100 kmc . . . . . . | 8500 |
| Series 402C, 30 mc to above 100 kmc with AGC . . | 9000 |
| Modification P-4 . . . . . . . . . . . . . . | 500 |
| Modification Z . . . . . . . . . . . . . . | 1000 |

## NEW DATA FOLDER READY

For complete information ask for our new data folder from your nearby S-A engineering representative or write directly to Box 4312.

**SCIENTIFIC-ATLANTA, INC.**
2162 PIEDMONT ROAD, N. E.
ATLANTA 9, GEORGIA
PHONE: TRinity 5-7291

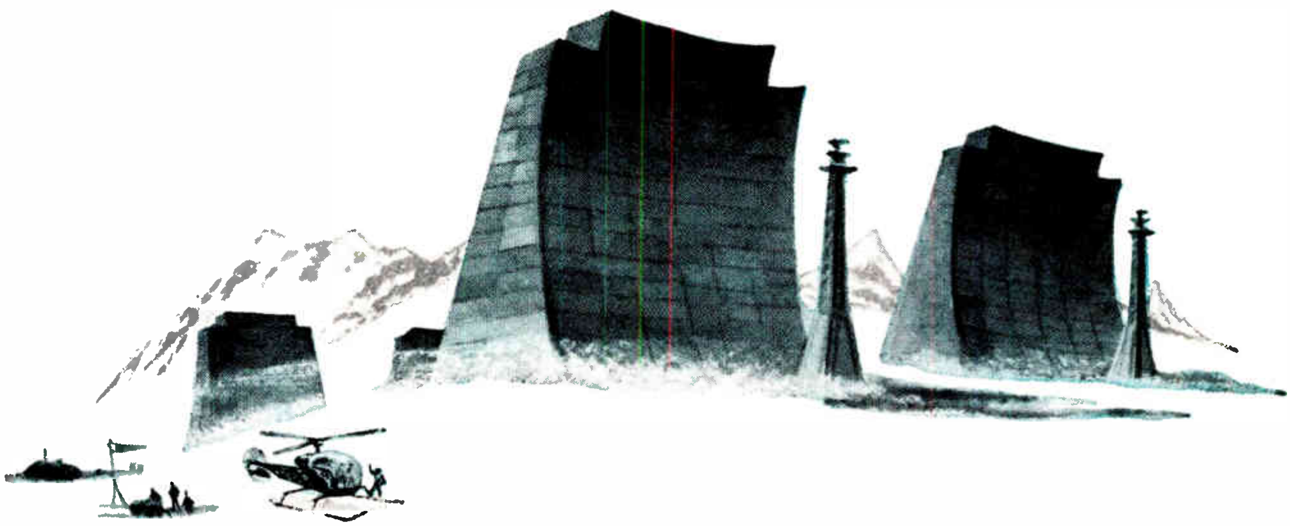
3

# THE 'DO' LINE THAT TELLS AGGRESSORS, 'DON'T!'

Because the tropo scatter radio equipment of Radio Engineering Laboratories, Inc., has proved its worth in installations around the world, it is also specified for the U.S. Air Force's DEW-East—the vital DEW Line extension from the present terminal on Baffin Island 1,200 miles east to Iceland. Once again, Western Electric Co., Inc., has chosen REL apparatus for this "can do" communications system to bridge the gap of ice and open water, and overcome the plagues of atmospheric and electromagnetic disturbances.

It's the unequalled reliability of REL equipment which has made it the choice for eight of the nine major networks in operation or on order. In fact, more kilowatt miles of REL tropo apparatus are in use or on order than those of all other companies combined.

The hazards of snow, ice and weather that make construction of DEW-East stations so formidable for the men who build them, call for equipment with the same sturdiness, the background of experience, the same quality of "can do". That's REL. And that's why you'll want REL's help in solving your specialized radio problems.



**Radio Engineering Laboratories · Inc**

*A subsidiary of Dynamics Corporation of America*

**Dept. I · 29-01 Borden Ave · Long Island City 1, NY**

REL

*Creative careers at REL await a few exceptional engineers. Address résumés to James W. Kelly, Personnel Director*

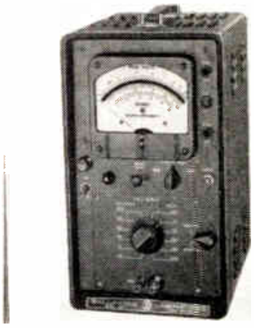
## NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

*(Continued from page 100A)*

### Peak Responding Voltmeter

A new peak responding Voltmeter, Model 305A, is announced by **Ballantine Laboratories,** Boonton, N. J. The new instrument measures peak or peak-to-peak values of any repetitive waveforms—distorted or undistorted sine-waves, or pulses. Its operating mode can be selected to respond to a peak-to-peak and positive or negative peak of the waveform.



The dc component of the waveform is not measured by the instrument.

The frequency range when measuring sinewaves extends from 5 cps to 500 kc., but distorted waveforms with harmonics extending up to 2 mc, however, can also be measured. Pulses with duration from 0.5 μsec to 5 μsec and with a repetition rate from 5 to 500,000 pps can also be measured.

The accuracy is 2 to 5% depending on the waveform measured. The precision of the reading is better than 0.5% at any part of the scale.

The Model 305A can be used as a wide-band amplifier with a gain of 86 db and a source impedance of approximately 3 ohms in series with 0.22 μf. The maximum output voltage from amplifier is 150 volts pp. The amplifier output is intended to be used for waveform monitoring only into loads above 30,000 ohms and below 10 μμf.

The instrument has a magnetically regulated power transformer in addition to an electronically regulated power supply.

### Microwave Waveguide Ferrite Isolators

Latest issue of "new From PRD," describes PRD 1203–1209 Ferrite Isolators which are specially designed to offer maximum isolation and minimum insertion loss over a frequency range of 3.95 to 26.5 kmc.

The two page bulletin gives typical performance curves which show VSWR, isolation and insertion loss plotted over the isolators' entire frequency range.

These ferrite isolators are conservatively rated at 5 watts, but can dissipate

*(Continued on page 108A)*

# NOW...every volume tester of semiconductor devices can profit with SMART

**(TI's Sequential Mechanism for Automatic Recording and Testing)**

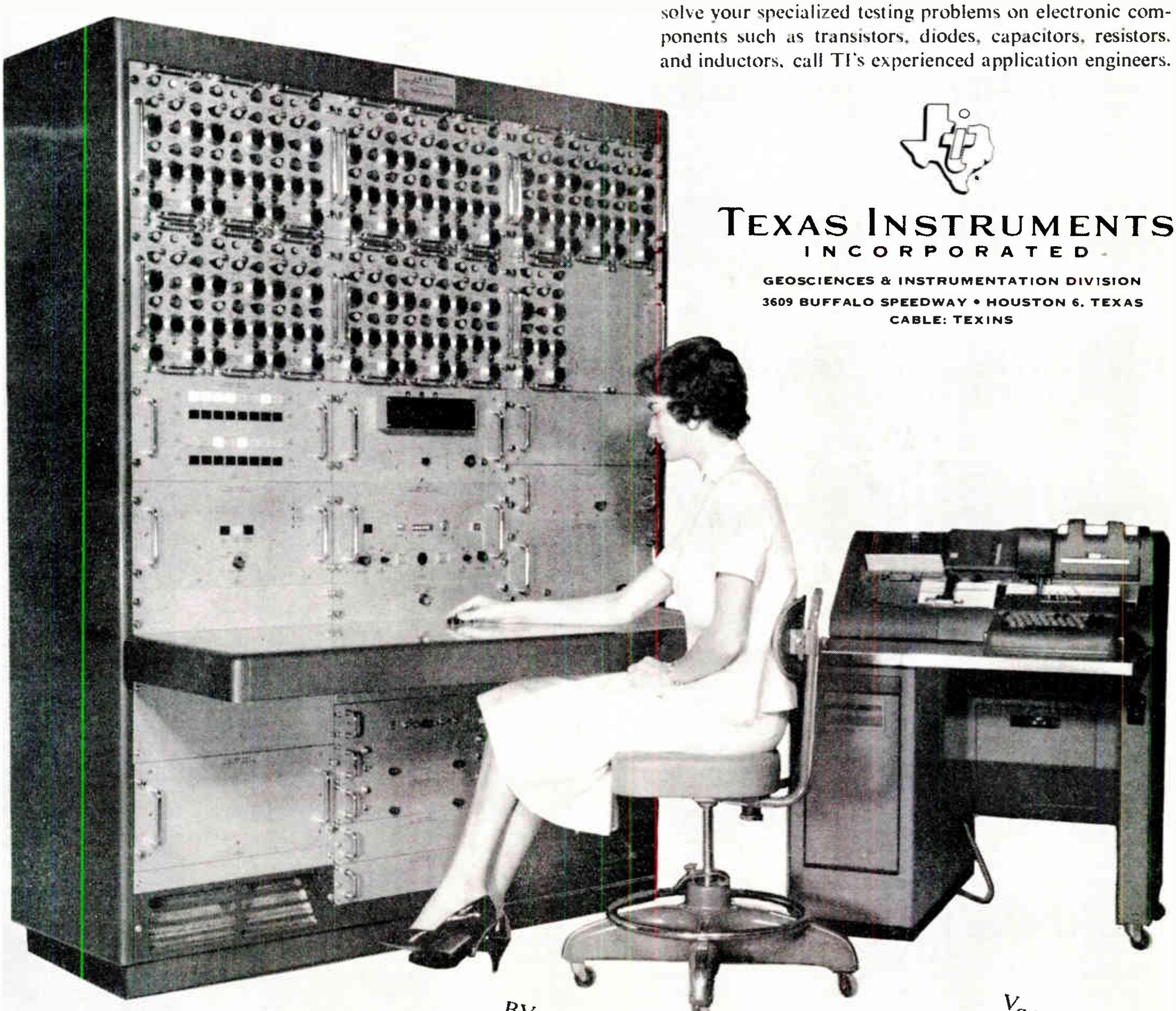
This new automatic testing-recording system offers you greater speed, more consistent accuracy, and lower unit testing costs than are obtainable by any hand testing means. Whether your requirements are Engineering Studies, Quality Assurance, Quality Control or Reliability Testing of semiconductor devices, SMART will add greatly to the efficiency of your operation.

The standard SMART machine enables you to measure up to 16 different d-c parameters of a transistor or other semiconductor device and record these data within 12 seconds. A minimum time of .5-second is required to test each parameter and an additional .2-second records the intelligence on an IBM 526 Summary Punch or other digital recording device. Using all 16 parameters, of course, 300 transistors may be tested per hour: however, fewer parameters would be desired on most testing runs and upwards of 500 semiconductors/hour could be handled easily.

Sixteen programming modules permit you to skip, hold, or delay individual tests as well as control the level of biasing supplies. You may record actual parameter values or set the machine for rejection limits only. Overall system accuracy is 1% of full scale readout.

The highly versatile SMART, with auxiliary consoles, may also be used for small signal h parameters; pulse, high frequency and power testing; and with environmental equipment in many types of factorial analyses. Also, the system may utilize scanning units for production runs, thus adding another high speed automatic feature.

Request Bulletin A-701 for additional information. To solve your specialized testing problems on electronic components such as transistors, diodes, capacitors, resistors, and inductors, call TI's experienced application engineers.



**TEXAS INSTRUMENTS**
INCORPORATED

GEOSCIENCES & INSTRUMENTATION DIVISION
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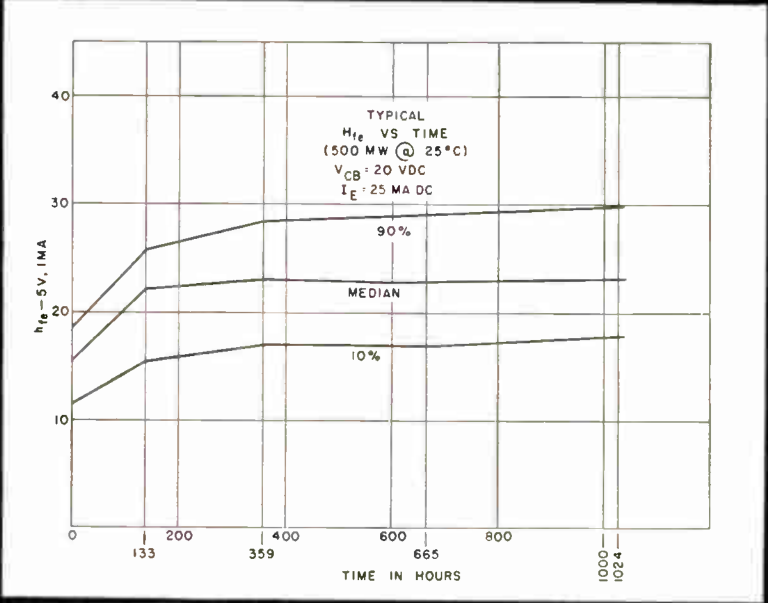
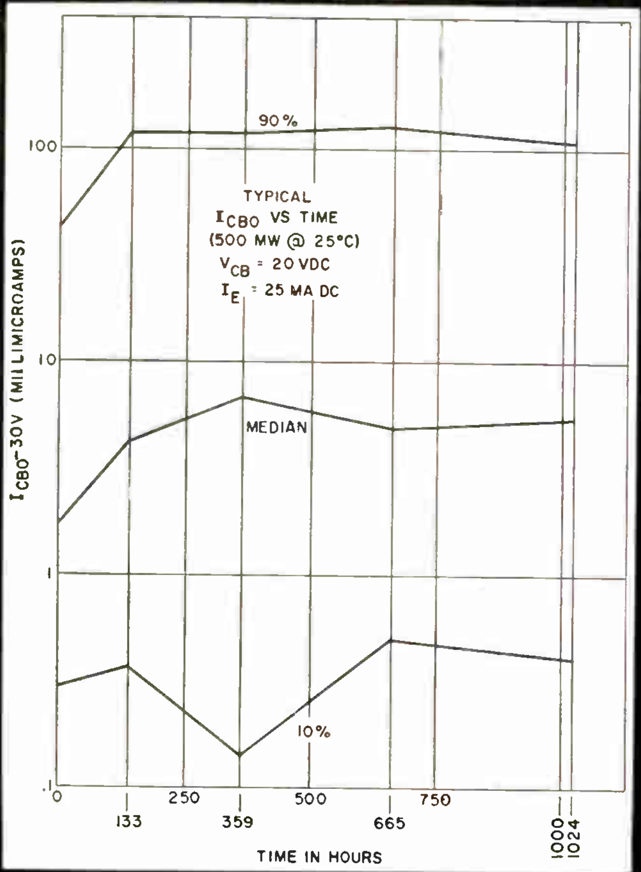
$I_{EBO}$ $BV_{CBO}$ $V_{SAT}$ $I_{CBO}$ $I_{CEO}$ $I_{CER}$ $BV_{CEO}$ $V_{PT}$ $BV_{CEX}$ $h_{FE}$ $V_{BE}$

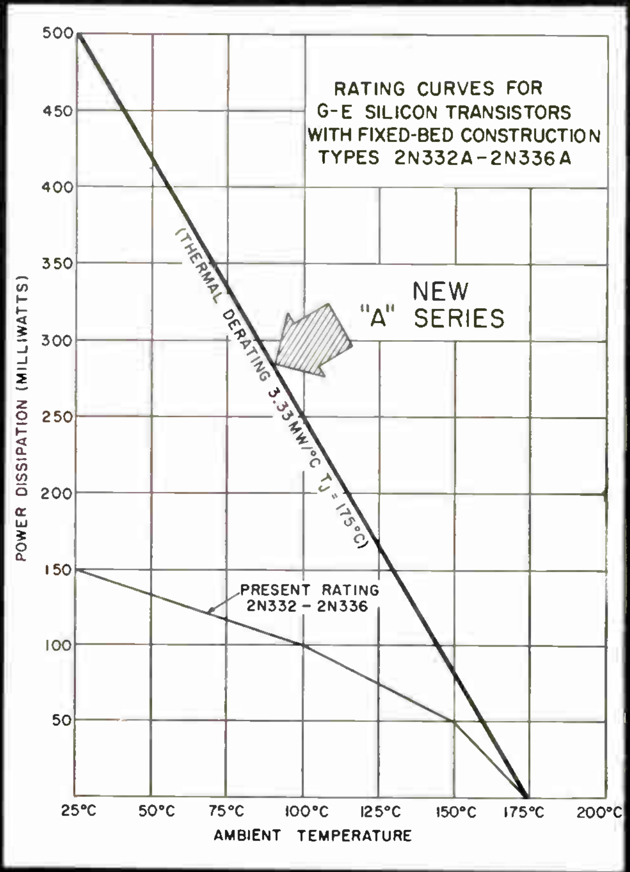
# New silicon triodes dissipate

Greatly magnified photo of silicon transistor showing Fixed Bed Construction. All parts are firmly fastened, with no suspended parts except wire lead. Transistor reacts as a solid block in resisting shock and vibration. Power dissipation is inherently higher.




Power dissipation of the 2N332A-through-2N336A silicon transistors (see chart below) ranges from 500 mw at 25°C to 83 mw at 150°C without heat sink. Note also (see chart below, left) the extremely low $I_{CBO}$ throughout 1000 hours of testing. Nearly 90% of units fall within 100 mμa. Beta spread (chart above) is stable out to 1000 hours.



# 500 mw without heat sink at 25°C

## *FIXED BED MOUNTED TRANSISTORS 2N332A-through-2N336A ALSO FEATURE: 4 VOLT $V_{EB}$ . . . GUARANTEED 45 VOLT $V_{CE}$ . . . .005 μa MAX. $I_{CBO}$ AT 25°C AND 30 VOLTS . . . PHYSICAL AND ELECTRICAL STABILITY*

The 2N332A-through-2N336A line of silicon NPN triodes is a new series of amplifier and switching transistors capable of much higher performance than ever before achieved.

Collector dissipation without heat sink is 500 mw at 25°C . . . 83 mw at 150°C. Since reliability is related to junction temperature, even those designs which do not require maximum-rated power may be enhanced greatly by this device series because of the wide safety-factor potential provided.

**FOUR OTHER ADVANTAGES**—Collector-to-emitter voltage is guaranteed at 45 volts. Collector leakage current is a maximum of 500 mμa at 30 volts and 25°C. Collector-to-emitter leakage current is 60 μa at 150°C. Minimum cutoff frequency is 2.5 mc, typical $f_{ab}$ is 10 to 15 mc.

**FIXED BED MOUNTING**—Fixed Bed Mounting is an exclusive G-E construction technique which contributes to the extreme stability obtained by this series of transistors. Storage and operating tests have resulted in a performance rate of better than 99.2% after 1000 hours.

Besides the demonstrated electrical characteristics, General Electric's silicon transistors can absorb physical punishment far beyond normal specifications. All parts are solidly fixed together and react as a solid block in resisting shock and vibration. Test units have been fired from a shotgun, struck with a golf club and rattled freely in an auto hubcap for 700 miles—and worked afterward.

**IMMEDIATELY AVAILABLE**—All types are available now from warehouse stock. Call your General Electric Semiconductor Sales Representative for complete details on the "hot" transistor line that operates the coolest. General Electric Company, Semiconductor Products Dept., Electronics Park, Syracuse, N. Y.

**TYPE 2N333-THROUGH-2N335 SILICON TRANSISTORS MEET MIL-T-19500/37A SPEC.**

Designing to the new MIL-T-19500/37A Spec? General Electric types 2N333, 2N334 and 2N335 can be supplied from warehouse stock to meet this specification.

### SPECIFICATIONS

**Absolute Maximum Ratings (25°C)**

| | | |
|---|---|---|
| **Voltages** | | |
| Collector to Base | $V_{CB}$ | 45 volts |
| Collector to Emitter | $V_{CE}$ | 45 volts |
| Emitter to Base | $V_{EB}$ | 4 volts |
| **Current** | | |
| Collector | $I_C$ | 25 ma |
| **Power** | | |
| Collector Dissipation RMS | $P_c$ | 500 mw @ 25°C (Free Air) |
| | $P_c$ | 83 mw @ 150°C (Free Air) |
| **Temperature** | | |
| Storage | $T_{STG}$ | −65 to 200°C |
| Operating Junction | $T_J$ | −65 to 175°C |

**Electrical Characteristics (Typical at 25°C)**

| | | 2N332A | 2N333A | 2N334A | 2N335A | 2N336A | |
|---|---|---|---|---|---|---|---|
| **D C Characteristics** | | | | | | | |
| Forward Current Transfer Ratio (low current) ($I_C$=1 ma, $V_{CE}$=5 V) | $h_{FE}$ | 16 | 27 | 36 | 45 | 75 | |
| Saturation Voltage ($I_B$=1 ma, $I_C$=5 ma) | $V_{CE}$ (Sat) | .5 | .45 | .42 | .4 | .4 | volts |
| **Cutoff Characteristics** | | | | | | | |
| Collector Current ($V_{CB}$=30 V; $I_E$=0; $T_A$=25°C) | $I_{CBO}$ | 1 | 1 | 1 | 1 | 1 | mμa |
| Collector Emitter Current ($V_{CE}$=30 V; $I_B$=0; $T_A$=150°C) | $I_{CEO}$ | 60 | 60 | 60 | 60 | 60 | μa |
| **Low Frequency Characteristics** ($V_{CB}$=5 V; $I_E$=−1 ma; f=1000 cps) | | | | | | | |
| Forward Current Transfer Ratio | $h_{fe}$ | 16 | 30 | 38 | 52 | 95 | |
| Input Impedance | $h_{ie}$ | 750 | 1300 | 1700 | 2000 | 3700 | ohms |
| Output Admittance | $h_{oe}$ | 3.5 | 5.0 | 6.0 | 7.0 | 8.0 | μmhos |
| Output Admittance | $h_{ob}$ | .25 | .2 | .18 | .15 | .13 | μmhos |
| **High Frequency Characteristics** (Common Base) ($V_{CB}$=5 V; $I_E$=−1 ma) | | | | | | | |
| Output Capacity (f=1 mc) | $C_{ob}$ | 7 | 7 | 7 | 7 | 7 | μμf |
| Cutoff Frequency | $f_{ab}$ | 10 | 11 | 12 | 13 | 15 | mc |
| Power Gain (common emitter) ($V_{CE}$=20 V; $I_E$=−2 ma; f=5 mc) | $G_e$ | 11 | 11 | 12 | 12 | 12 | db |

**GENERAL ELECTRIC**

## NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

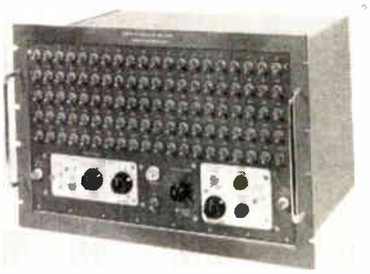
(*Continued from page 104A*)

five times as much power with only temporary electrical characteristic degradation.

Copies are available from **Polytechnic Research & Development Co., Inc.**, 202 Tillary St., Brooklyn 1, N. Y.

### Pulse Pattern Generator

Designed for versatility in electronic equipment testing both for military and industrial applications, by **Data Products Co., Inc.**, 7320 Westmore Rd., Rockville, Md., the transistorized Pulse Pattern Generator provides a simulated and flexible time division pulse pattern.



The test set provides a single dependable unit for testing both slow and high-speed electronic systems such as: guidance systems, computers, communications systems, data transmission systems, and telementary systems.

This generator performs well on electronic equipment employing a time division multiplex principle, because of the following operational characteristics:

Generates a pulse pattern any length from 1 to 100 pulses.

Pulse rate continuously variable from 10 to 100,000 pps using internal oscillator.

Can be driven by external oscillator at a pulse rate as low as desired and up to 100,000 pulse per second.

State of each pulse in a pulse sequence can be controlled independently from the front panel. Each pulse assumes a mark or space condition depending on the position of the switch representing that pulse. Test set has 100 switches which represent 100 possible pulse positions.

Output level for the mark (one) condition is continuously variable from zero to +10 volts. Output for the space (zero) condition is continuously variable from zero to 10 volts.

Eight microsecond cycle pulse output (occurring at beginning of each pulse sequence) is provided.

Two microsecond clock pulse output (occurring every pulse time) is provided.

Provides up to ±30% pulse width bias.

Operates from a nominal 117 volts, 50–400-cps, power system.

One microsecond rise and fall time.

Tone keyer optionally available.

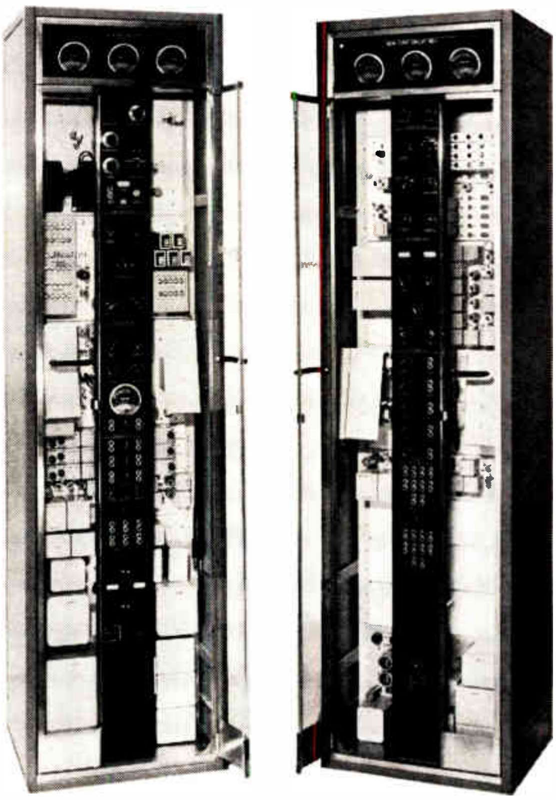
Complete technical information can be obtained by writing to the firm.

(*Continued on page 114A*)

# WHY is WESTREX PLEXITEL the most advanced single sideband radio communications system?

Single sideband radio transmission systems have been in use since the early 1930's. At Westrex we were among the pioneers with these systems and, in fact, Westrex has engineered and installed in foreign countries the majority of the commercial overseas point-to-point single sideband radio telephone circuits in use today.

The advantages of SSB are obvious. With one sideband suppressed, power thus saved is available for the remaining sideband, and tube load is much reduced. SSB transmission conserves space in the frequency spectrum, requires only a fraction of the power of double sideband, and provides a gain of approximately 9 db in signal-to-noise ratio.



Systems design through the years has evolved into very compact units. Today the Westrex Plexitel transmitter and receiver are each contained in a cabinet 84 inches high, 22¼ inches wide, and 17 inches deep. A lot of capability is packed into that space.

The transmitter provides a peak power output of 500 watts on any of ten predetermined crystal-controlled frequencies in the range of 3-30 megacycles. It is available in a number of combinations which permit the transmission of 1, 2, 3, or 4 separate telephone channels or each of these 3 kc voice channels may be selected to transmit up to 16 channels of radio printer intelligence, giving a total of 64 teleprinter channels. Facilities for channel grouping are an optional feature and may be added as future requirements dictate. Various linear amplifier combinations up to 10 kw may be used with the 8A transmitter.

The channel arrangement of the Westrex receiver in the Plexitel System is identical with that of the transmitter. Each 6 kc sideband may be used as a whole or subdivided into multi-message channels by appropriate optional equipment. As many as ten crystal-controlled frequencies may be pre-set for rapid selection by one manually operated knob. Remote control equipment is available which will activate or deactivate the receiver and select any one of the ten channels.

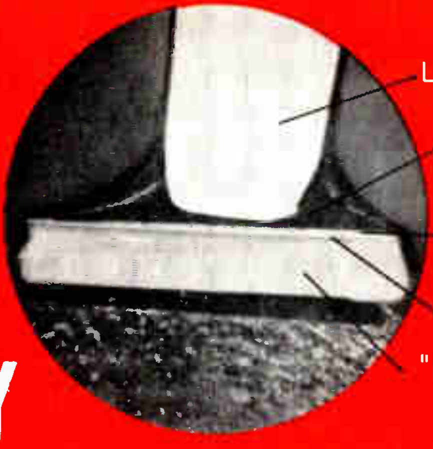
Both transmitter and receiver are designed to operate at altitudes up to 10,000 feet and under severe climatic conditions. Frequency stability of the Plexitel System is in the order of ±3 parts in ten million per day. No other SSB system is so conveniently adaptable to simple point-to-point, aviation ground, or marine applications; or to the more complex point-to-point radio system applications.

The 8A transmitter or 52A receiver may be used with any SSB system having similar characteristics and may also be operated on AM or DSB.

The many high quality refinements of construction are listed in our Plexitel brochure. We will send you your copy by return mail. Westrex Corporation, 111 Eighth Avenue, New York 11, N.Y.

**Westrex Corporation**
A DIVISION OF LITTON INDUSTRIES

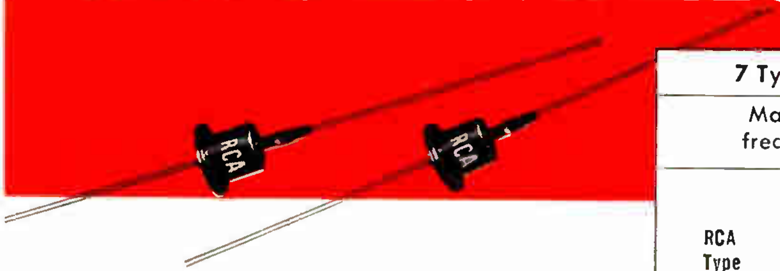
# DIFFUSED-JUNCTION UNIFORMITY




This photomicrograph shows the exceptional junction flatness across the entire pellet that is typical of silicon rectifiers produced by the RCA diffusion process. This junction flatness is achieved by slow rate diffusion, which permits precise control of diffusion depth and junction gradient. Results—uniform current density throughout the silicon, with consequent freedom from "hot spots", improved electrical characteristics in both forward and reverse directions, and exceptional uniformity from unit to unit.

## assures reliability, long life of

# RCA SILICON RECTIFIERS




Advanced manufacturing techniques and extensive quality-control procedures are your assurance of reliability and long life when you specify RCA Silicon Rectifiers. *Every RCA Silicon Rectifier* you receive has been subjected to a 24-hour seal test under pressures in excess of 5 atmospheres, and has been stabilized by repeated thermal cycling over the full operating-temperature range before final electrical testing. *Every RCA Silicon Rectifier* you receive has also been subjected to the following extra tests to insure dependable performance under extreme conditions: reverse (leakage) current at 25°C; forward characteristics at 25°C; high-temperature dynamic reverse (leakage) current test at full load current and maximum rated voltage. In addition, samples from every production lot of RCA Silicon Rectifiers are subjected to life tests under maximum rated conditions of temperature, current, and voltage to provide further assurance of RCA's high standards of quality.

**7 Types for INDUSTRIAL and MILITARY Power Supplies**

Maximum Ratings, Absolute-Maximum Values: For supply frequency of 60 cycles and with resistive or inductive load

| RCA Type | Peak Inverse Volts | DC Forward Ma at Ambient Temperature of 50°C | CHARACTERISTICS at Ambient Temperature of 25°C: Maximum Reverse Current (DC) at maximum peak inverse voltage (μa) | CHARACTERISTICS at Ambient Temperature of 150°C: Maximum Reverse Current (averaged over one complete cycle) at maximum peak inverse voltage (μa) |
|---|---|---|---|---|
| 1N536 | 50 | 750 | 5 | 400 |
| 1N537 | 100 | 750 | 5 | 400 |
| 1N538 | 200 | 750 | 5 | 300 |
| 1N539 | 300 | 750 | 5 | 300 |
| 1N540 | 400 | 750 | 5 | 300 |
| 1N1095 | 500 | 750 | 5 | 300 |
| 1N547 | 600 | 750 | 5 | 350 |
| **6 Types for MAGNETIC-AMPLIFIER Applications requiring exceptionally low leakage current** | | | | |
| 1N440-B | 100 | 750 | 0.3 | 100 |
| 1N441-B | 200 | 750 | 0.75 | 100 |
| 1N442-B | 300 | 750 | 1.0 | 200 |
| 1N443-B | 400 | 750 | 1.5 | 200 |
| 1N444-B | 500 | 650 | 1.75 | 200 |
| 1N445-B | 600 | 650 | 2.0 | 200 |

Contact the RCA Field Office nearest you for information on types for your specific applications. For technical data see the new RCA HB-10 SEMICONDUCTOR PRODUCTS HANDBOOK, or write RCA Commercial Engineering, Section L-35-NN, Somerville, N.J.

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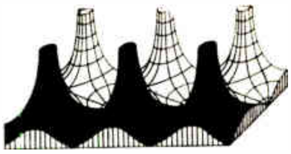
**RADIO CORPORATION OF AMERICA**

*SEMICONDUCTOR AND MATERIALS DIVISION • SOMERVILLE, N. J.*

*December, 1959*
*Vol. 47 No. 12*

**Proceedings of the IRE**

# Poles and Zeros



**The International Scene.** In connection with the IRE Canadian Region Convention and Exposition in Toronto in October, the Board of Directors met for the first time outside the bounds of the United States, again demonstrating that the IRE is international in scope. To further carry out this theme, the Board occupied an extra day in discussion of the IRE position on international science and electronic questions.

The duties of the Senior Past President, in connection with Sections outside North America, were reiterated, and a resolution offering the services of the IRE in radio and electronic professional matters wherever located, was passed. At the same time it was emphasized by the Board that the IRE had no intent to displace any activities undertaken on a national basis.

The Board also established the policy of inviting to its meetings the Vice-President who resides outside North America. It is hoped, thereby, to increase the knowledge of IRE abroad, as well as to aid the Board in its handling of international questions. Such visits have occurred in the past, our most recent visitors being Dr. Yasujiro Niwa of Japan, M. J. H. Ponte of France, Dr. Franz Tank of Switzerland, and Herre Rinia of the Netherlands.

In the past, IRE has cooperated with or appointed representatives on many international scientific bodies. Director Berkner, who has served as director of the U.S. program for the I.G.Y., and in other international activities, gave the Board a briefing on the operating objectives and relationships between the numerous international scientific bodies such as ICSU (International Council of Scientific Unions), URSI (International Scientific Radio Union), CCIR (International Radio Consultative Committee), ITU (International Telecommunications Union), IEC (International Electrotechnical Commission), and IAU (International Astronautical Union). Because of similar or complementary interests, the IRE has particularly close contact with URSI and IEC. Director Berkner's discussion will ultimately appear in the PROCEEDINGS, since it was felt that a knowledge of the international scientific scene would be of interest to all members.

It was also pointed out that India and Japan had in recent years taken steps to change to the metric system of weights and measures, and that the U.S.A., Canada, and Great Britain might soon remain the only domains still measured by King Canute's pedal extremity. In view of studies by the National Bureau of Standards, an *ad hoc* committee will be established to study the technical implications and practical problems which would arise in electronics through the possible adoption of the metric system of weights and measures in the United States.

The Canadian Region Convention Committee set a high mark for friendliness and hospitality. The Region is certainly favored in having available one of the finest hotels in the British empire as headquarters, and ample and pleasant exposition space. It was a great pleasure to visit an exposition which had aisles between the exhibits, instead of the usual cowpaths in the Casbah.

**Teaching Teachers.** Last month we mentioned that teaching staffs in engineering colleges were short. We are now advised that the shortage is in the neighborhood of 13 per cent, although much greater if less than desired competence is allowed for. Certainly many are being found to stand in front of classes who do not yet measure up to what the engineering profession would like, or has a right to expect.

The teaching fraternity is taking positive steps to attract and develop new teachers. The American Society for Engineering Education of Urbana, Ill., has for several years had an active Committee for the Development of Engineering Faculties, logically referred to as C.D.E.F.

An engineering teacher becomes such only after exposure to the academic atmosphere of learning in residence on a campus, and acquisition of several degrees beyong the bachelor's level. Because of this C.D.E.F. is beginning by showing qualified seniors the advantages of graduate work *in residence*, as preparation for teaching, or if that fails to appeal, for a fuller professional life. The in residence emphasis is important, because only in this way does the student gain unhampered time for graduate study, plus the opportunity to experiment with teaching as a life work.

The C.D.E.F. group has prepared a helpful booklet "Teaching Tomorrow's Engineers." The possibilities opened to a young teacher by this booklet make one wish he were starting over again, complete with all modern advantages.

The National Science Foundation has also aided the teaching cause through grants allowing young teachers to complete their degree programs free of financial worry, or as a "capitalist," as one young faculty man put it.

**More and More.** Most Professional Groups have been publishing their Transactions on a quarterly basis over the past eight years. As an historical note, we here record that, because of increasing quantities of material, the Transactions of the Professional Group on Antennas and Propagation, and of the Professional Group on Microwave Theory and Techniques will in 1960 shift to a bimonthly basis.

This is an important milestone in the growth of the Professional Groups. Conceived eleven years ago, and only in their eighth year of publication, they are now publishing at an annual rate of more than 6000 pages. Additional indication of the value of the Groups in disseminating technical information is their enthusiasm in sponsoring symposia to serve their members across the country.

Will we have monthlies by 1965?—J.D.R.

# Gordon K. Teal

*Director, 1959*

Gordon K. Teal (SM'53–F'56), assistant vice-president and director of research of Texas Instruments Inc., was born in Dallas, Texas, on January 10, 1907. After receiving the B.A. degree from Baylor University in 1927, he went to Brown University as a Marston Scholar and during the two succeeding years was a University Fellow and a Metcalf Fellow. Brown awarded him the M.S. degree in 1928 and a Doctorate in 1931. From 1933 to 1935 he was research associate at Columbia University where he carried on a research program concerned with heavy hydrogen.

He joined Bell Telephone Laboratories in 1930 and over a period of 22 years with BTL conducted research and development in numerous areas. These included studies in electricity, secondary emission, photoconductance, electron multipliers, silicon carbide varistors, germanium and silicon rectifiers, microwave attenuators, borocarbon resistors, germanium and silicon single-crystals, and transistors. He has over 46 patents granted or pending as a result of his research in these fields.

He joined Texas Instruments in 1953 as head of the Materials and Components Research Department, with primary responsibility for semiconductor research. Since 1955 he has been in charge of TI's Central Research Laboratories, where research is carried on in the broad areas of chemistry, physics, electronic devices, as well as systems and earth sciences.

His IRE activities have included service on the Editorial Review Committee from 1955–1959, and on the Editorial Board from 1958–1959. He has served as Chairman of the Sections Publications Committee since 1957, his present term extending to 1960. He was secretary of the Dallas-Fort Worth Section in 1953–1954 and vice-chairman in 1955–1956, becoming chairman of the Dallas Section in 1956–1957. He is Chairman of the Technical Program Committee for the 1960 IRE Convention.

Dr. Teal holds membership in the American Chemical Society, the American Physical Society, the Electrochemical Society, and Sigma Xi. He is an honorary member of Sigma Pi Sigma and is a fellow of the American Association for the Advancement of Science. He is the 1959–1960 Executive Vice-President for the Texas Academy of Sciences. He is a member of the American Management Association, serves on the Working Group on Electronic Materials of the Advisory Group on Electronic Parts, and is the representative for Texas Instruments on the Industrial Research Institute.

# Scanning the Issue

**Poisson, Shannon, and the Radio Amateur** (Costas, p. 2058)—It should be mentioned at the outset that this paper is by no means addressed solely to radio amateurs nor confined to amateur radio. It deals rather with a topic of much broader import, namely, the efficient usage of congested communication channels. Frequency spectrum conservation has become one of the major post-war crusades of the radio engineering fraternity. Much attention has been devoted to techniques for reducing the bandwidth of communication systems, to the point where bandwidth conservation is now generally accepted as being synonymous with spectrum conservation. It may therefore come as somewhat of a shock to some to find someone proposing that in some situations a more efficient system can be achieved by *increasing* the bandwidth. The author is specifically concerned with the relative merits of single sideband versus double sideband systems in situations where a large number of transmitters operate intermittently in an uncontrolled fashion within the same portion of the radio band. These conditions are common not only in amateur radio but, perhaps more importantly, in military communications. The author reminds us that the broader bandwidth signals of DSB increase the ability of the receiving system to discriminate between the desired signal and interference. This results in significant improvements in operational reliability and in channel capacity. In military communications, it also makes the system decidedly less susceptible to jamming. Some of the author's contentions will probably arouse controversy from some readers, principally because they seem to contradict commonly held notions of systems design and frequency assignment practice. In calling attention to the advantages of broad-band systems over narrow-band systems, the author has presented some novel and stimulating ideas regarding the congested band problem which will be of considerable interest to communication system designers and users and to information theorists.

**Electronic Scanning System for Infrared Imaging** (Lasser, Cholet and Emmons, p. 2069)—Close on the heels of the Infrared Issue of the PROCEEDINGS comes a totally new technique for converting infrared images into visible ones. Readers of the September issue will remember that mechanical scanning systems have undergone many years of development and are used in a majority of applications at present. Electronic systems, on the other hand, although presently limited in system detectivity, offer great promise for the future because they are inherently faster and less cumbersome. In the latter category, two principal types have been developed to date: 1) photoemissive image tubes, in which the infrared image radiation is converted into electron emission which is picked up either by a phosphor screen or by an image orthicon television camera tube, and 2) photoconductive tubes, in which the infrared image is converted into variations in surface charge which are sensed by a scanning electron beam. The electronics and optics of scanning and display systems have already been developed to a high degree by television engineers. The application of these techniques to infrared imaging depends primarily on the development of photosensitive transducer materials of good sensitivity and spectral response. In the present paper, the authors have developed a new type of tube in which the crucial element is a semiconducting window made of silicon. The window will normally pass infrared radiation. However, if the window is subjected to electron bombardment, the bombarded area will become opaque. Thus by focussing an infrared image on the window and scanning it with an electron beam, a moving opaque spot is produced which subtracts a small variable amount of energy as the image passes through the window and on to an infrared detector. The energy variations are converted by the detector into a video signal, which is then fed to a television-type monitor for display. This novel development will interest many workers in the television and semiconductor fields, as well as those concerned with infrared and military systems.

**Frequency Multiplication with Nonlinear Capacitors—A Circuit Analysis** (Leeson and Weinreb, p. 2076)—There is widespread interest today in circuits with varying parameters, especially in connection with parametric amplifiers and harmonic generators. With respect to the latter, earlier PROCEEDINGS papers have shown that theoretically a relatively lossless nonlinear reactance is far more efficient than an ideal diode (nonlinear resistance) in converting power at the fundamental frequency into power at a harmonic. Meanwhile, the recent development of high-Q semiconductor nonlinear capacitors has offered a very promising practical way of obtaining a nonlinear reactance that is relatively lossless. The present paper derives basic circuit equations and impedance relationships which enable a designer to specify the conditions which will give him optimum power capabilities and efficiency for any given circuit and harmonic. The analysis, incidentally, is also applicable to frequency dividers, and to multipliers employing nonlinear inductance.

**Operating Characteristics of an Ammonia Beam Maser** (Barnes, p. 2085)—The first operating maser was constructed by Townes and his associates at Columbia University in 1954. Shortly thereafter, workers at Stanford constructed the two masers on which the measurements described in this paper were made. Masers of this type have found important use as ultra-stable frequency standards. To date, long term stabilities of better than one part in $10^{11}$ and short term stabilities of 2 parts in $10^{12}$ have been achieved. This paper investigates the kinds of side effects which must be overcome or minimized to obtain even greater accuracies, not only in frequency stability, but also in reproducibility of a selected frequency. It presents what is probably the most complete description of operating characteristics and comparison of theory and experiment that has yet been published.

**Coaxial Resonators with Helical Inner Conductor** (Macalpine and Schildknecht, p. 2099)—The resonators described in this paper are especially noteworthy because they provide high $Q$'s over a wide frequency range—from a few megacycles to over 1000 mc—and are of a very practical size. For example, one of these helical resonators designed for use at 10 mc need be only 8 inches long, whereas a conventional coaxial resonator would require 25 feet. This paper gives exact details for constructing helical resonators. The designs and performance characteristics are given in the clear and concise form of handbook information. This paper will be of wide interest to workers in many electronic fields. It represents very fine reduction of known relations to a highly practical and usable form.

**Digital Rate Synthesis for Frequency Measurement and Control** (Rey, p. 3006)—This paper describes a method of frequency measurement and control in which conventional techniques are replaced by pulse techniques. In essence, the method consists of representing the signal whose frequency is to be measured or controlled in the form of a pulse train and comparing its pulse rate with that of a controllable variable-rate pulse reference source. A detector measures the difference rate and produces an output which indicates the magnitude and sign of the difference. In an automatic frequency control circuit, the rate difference signal would be used to drive a tuning motor to reduce the tuning error toward zero. At present the technique is of special interest in the fields of computing systems and motor speed control. However, frequency measurement and control is of such basic importance to so many fields that new ideas are certain to find a broad and receptive audience.

**Scanning the Transactions** appears on p. 2123.

# Poisson, Shannon, and the Radio Amateur*

J. P. COSTAS†, SENIOR MEMBER, IRE

*Summary*—Congested band operation as found in the amateur service presents an interesting problem in analysis which can only be solved by statistical methods. Consideration is given to the relative merits of two currently popular modulation techniques, SSB and DSB. It is found that in spite of the bandwidth economy of SSB this system can claim no over-all advantage with respect to DSB for this service. It is further shown that there are definite advantages to the use of very broadband techniques in the amateur service.

The results obtained from the analysis of the radio amateur service are significant, for they challenge the intuitively obvious and universally accepted thesis that congestion in the radio frequency spectrum can only be relieved by the use of progressively smaller transmission bandwidths obtained by appropriate coding and modulation techniques. In order to study the general problem of spectrum utilization, some basic results of information theory are required Some of the significant work of Shannon is reviewed with special emphasis on his channel capacity formula. It is shown that this famous formula, in spite of its deep philosophical significance, cannot be used meaningfully in the analysis and design of practical, present day communications systems. A more suitable channel capacity formula is derived for the practical case.

The analytical results thus obtained are used to show that broadband techniques have definite merit for both civil and military applications. Furthermore, such techniques will result in far more efficient spectrum utilization in many applications than any practical narrow-band, frequency-channelized approach. Thus broad-band techniques can, in many cases, increase the number of available "channels." With regard to military communications it is shown that the ability of a communication system to resist jamming varies in direct proportion to the transmission bandwidth for a given data rate. Thus narrow-band techniques lead progressively to more expensive communications systems and less expensive jammers. It is concluded that in the military field broad-band techniques are not only desirable but also often mandatory.

## I. Introduction

MOST common usage of the radio frequency spectrum involves operation at specified frequencies as assigned by the appropriate regulatory agencies in the various countries. In contrast, the radio amateur service is assigned various bands of frequencies and properly licensed stations are permitted to operate at any frequency within these bands. This freedom of choice of frequency is necessitated by the obviously impossible administrative problem of assigning specific frequencies to specific stations and, furthermore, the available bandwidths fall short by several orders of magnitude of providing exclusive channels to each authorized station. Thus, as one might suspect, the situation in the amateur bands is a chaotic one in terms of mutual interference. There is very little tendency to "channelize" for several reasons. The crowded conditions normally leave no empty spaces in frequency so that a station starting operation has no choice but to transmit "in between" two strong stations or on top of a weaker station. Furthermore, at the higher HF frequencies, the ionospheric "skip" makes it impossible to choose a good operating frequency by listening, since the signal situation will be radically different between two points spaced many miles apart. Thus, the very nature of the amateur service would lead one to expect that any meaningful analysis of this problem must be based on a statistical approach.

A mathematical study of amateur radio communications can be of use in other important areas. Consider, for example, military communications where allocation of frequencies cannot possibly prevent interference due to the use of the same frequencies by the opposing forces. It is not hard to imagine that under such conditions each operator will shift frequency and take other appropriate action in order to get his message through. Thus, in a combat area we might well expect to find the very same chaos in the communications services that we observe in the amateur bands today. Certainly in such situations interference cannot be eliminated by allocation; interference will exist and we must simply learn to live with it. We are not speaking here of intentional jamming but rather of the casual interference which is inevitable when two opposing military forces (which today depend heavily on radio) attempt to operate independently and use the same electromagnetic spectrum. The problem of intentional jamming will be treated in detail in Section VI.

In the analysis of the radio amateur problem which follows, three modes of operation are compared. It is first assumed that all stations employ suppressed-carrier single-sideband (SSB). Then exclusive use of suppressed-carrier AM (DSB) is assumed. Finally, a frequency diversity system is examined in which each station transmits a large number of identical signals at randomly selected frequencies in the band. Intuitively we might suspect that SSB would be superior to DSB because of the two-to-one difference in signal bandwidths. The frequency diversity system is intuitively ridiculous because it apparently "wastes" bandwidth rather indiscriminantly. As we shall see, intuition is a poor guide in these matters. The feeling that we should always try to "conserve bandwidth" is no doubt caused by an environment in which it has been standard practice to share the RF spectrum on a frequency basis. Our emotions do not alter the fact that bandwidth is but one dimension of a multidimensional situation.

* Original manuscript received by the IRE, April 21, 1959; revised manuscript received, June 13, 1959.
† General Electric Co., Syracuse, N. Y.

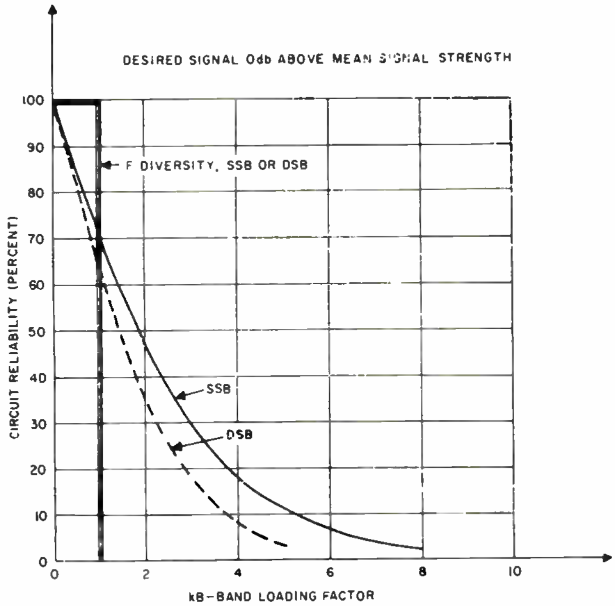



Fig. 2—Per cent circuit reliability vs band loading.

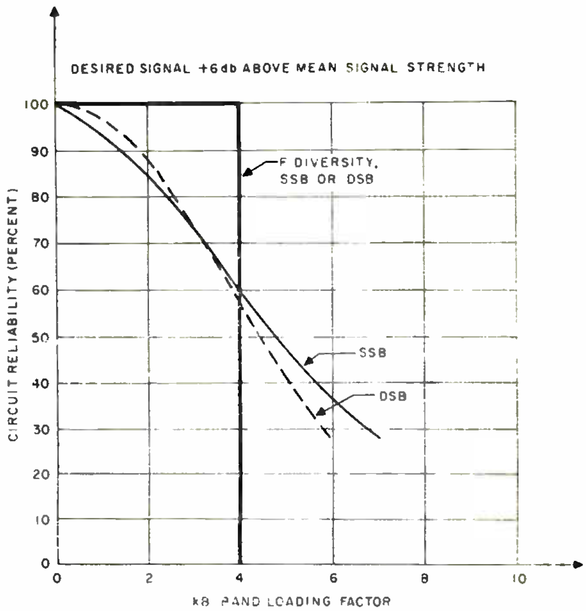



Fig. 4—Per cent circuit reliability vs band loading.

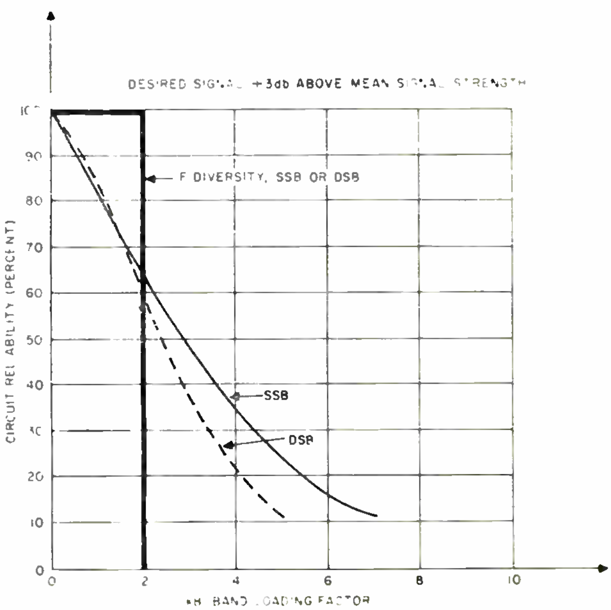



Fig. 3—Per cent circuit reliability vs band loading.

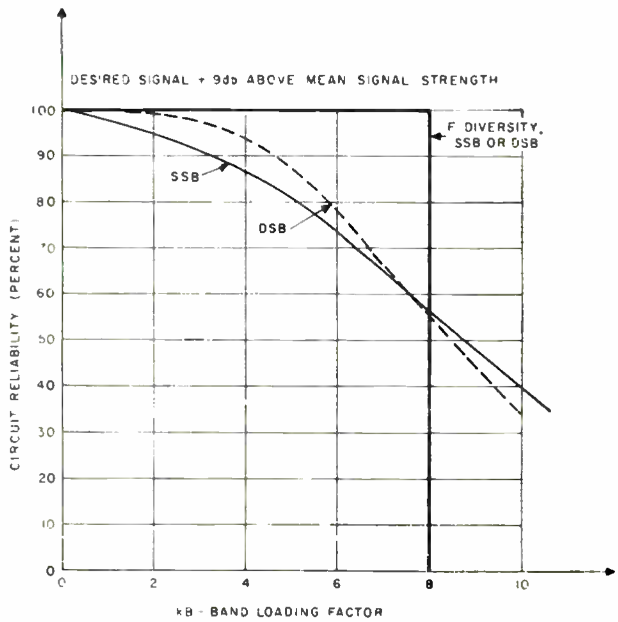



Fig. 5—Per cent circuit reliability vs band loading.

ordinate value and noting the *kB* values at which this line interesects the SSB and DSB curves. The two-to-one increase in loading which we might at first expect from SSB certainly does not materialize, except at values of circuit reliability which are so low as to be meaningless. Thus, the randomness of band occupancy has a significant effect on performance, and any intuitive conclusions based on orderly channel assignments are subject to considerable error. Note in particular that the circuit reliability for SSB at $kB=1$ is 70 per cent. At this loading there are enough channels to satisfy all needs, and 100 per cent reliability could be had if some organization could be obtained. About the only conclusions to be drawn from Fig. 2 are that SSB and DSB give nearly the same performance and that it is usually hopeless to try to communicate with a station whose signal strength is only average at times when the band is crowded. This last conclusion will come as no surprise to the experienced operator.

As the strength of the desired signal increases above the mean value the situation improves rather rapidly, as shown by Figs. 3–5. The SSB and DSB curves now "cross over" and both curves tend to stay at higher reliability values as *kB* is increased, which is to be expected. Note in Fig. 5 that DSB shows a slight advantage over SSB for the lower loading values and the cross-over occurs when the reliability factor is 63 per cent. In total these results show the futility of claiming any advantage for either SSB or DSB in this service. If one is insistent upon claiming an advantage, the specific conditions under which the comparisons are made must be given.

In our attempt to determine the sensitivity of the calculated results with respect to the choice of the amplitude distribution function, an exponential distribution was tried in place of the chi-squared. The exponential distribution gave more weight to signals above the mean than did the chi-squared. However, the final results were very nearly the same. A further calculation involving a delta-function distribution (all interfering signals of the same strength) showed no significant differences. Thus, one is led to believe that the results obtained are not particularly sensitive to the choice of any reasonable distribution function for the signal strengths.

The performance of the frequency diversity system shows up in a rather unusual manner in the graphs. This is due in part to the way in which we chose to interpret the results, and in part to the fact that in this case the interference is not random but constant. In the narrow-band cases the interference level changes considerably in short periods of time because of the random appearances and disappearances of signals close to the operating frequency. In the broad-band case, the interference observed is the net result of *nearly all* the stations on the band so that the actions of *any one* station have a negligible effect on the interference level at the output of an appropriate broad-band receiving system. Thus, for a given loading, the interference level stays fixed and only the signal strengths of the various stations to which the receiver is "tuned" will be found to vary. Some signals will be sufficiently above the noise to be understood all of the time, while others will be below the noise and will not be heard at all. We have made a rather interesting trade in going from narrow- to broad-band operation. In narrow-band operation, we can copy a strong signal most of the time and a weak signal just part of the time. In broad-band operation, we can copy a strong signal all of the time but a weak signal cannot be copied at all. The reason for the shape of the frequency diversity curves should now be clear, and the nature of the "trade-off" may be evaluated by an examination of Figs. 2–5.

Amateur band operation with broad-band systems will prove to be somewhat different in certain respects. There will be fewer stations with which contact may be established (since the weaker signals which were formerly heard intermittently will now not be heard at all), but once contact is established the conversation can be expected to continue without interruption for a considerable period of time. Since the amateur is not normally concerned with communicating with a specific person, the exchange of some freedom of choice of possible contacts for reliability of communications will probably be welcomed.

In the case of military communications, the problem is more difficult, since specific messages must be transmitted to specific stations. If the signal strengths are weak, the narrow-band approach certainly offers no solution since, as we have seen, the circuit reliability will be poor. The message will have to be repeated over and over again before it is received with any reasonable degree of completeness and accuracy. Thus, under such adverse conditions *we have been forced to lower the data rate* because the necessity for repetition has increased the time required for the transmission of a given message. Broad-band operation under the same adverse conditions will suffer the same fate, but to a lesser degree. The data rate will have to be lowered (this can be done without decreasing the bandwidth) but since the interference level will be fixed at some average value we can lower the rate by just the amount necessary to keep the error rate below the acceptable maximum. With narrow-band operation, practical considerations will no doubt force us to reduce the data rate to a value determined by the *maximum* interference level. Thus, for congested-band operation, broad-band systems appear to offer a more orderly approach to the problem and a potentially higher average traffic volume than narrow-band systems.

Nothing that has been said so far should be construed as meaning that broad-band systems will always give us the traffic volume we would like to have, or feel we must have to support operations. As the congestion becomes worse it will be impossible to avoid reducing the data rate per circuit. The important point here is that the broad-band philosophy *accepts interference as a fact of life* and an attempt is made to do the best that is possible under the circumstances. The narrow-band philosophy essentially denies the existence of interference since there is an implied assumption that the narrow-band signals can be placed in non-overlapping frequency bands and thereby prevent interference. It is perhaps redundant to state that the realities of most practical military situations almost completely destroy the validity of such reasoning.

At this point we shall leave the problem of the radio amateur and turn our attention to other communications areas. We have seen that the operating environment of the amateur is not unique to his service but that in other services, especially the military, conditions in actual practice will quite often degenerate to the congested situation of the amateur service. Under such conditions we have shown the necessity for a statistical approach to the problem. It has been further demonstrated that the efficient use of additional transmission bandwidth does not constitute a "waste" in the basic sense of the word. The policy of "conserving bandwidth" is not based on sound physical principles but is based rather on a very common but still myopic view of communications. Such a policy will, in many situations, conserve only the opportunity to communicate as efficiently as might otherwise be possible. Even worse, this point of view quite often leads to the design of systems which have little or no true military capability because of extreme sensitivity to intentional interference. These and other matters will be discussed in Sections VI and VII in more detail. First, it is necessary to derive some rather simple results from information theory.

## IV. Information Theory

Consider the problem of data transmission by electrical means. We transmit pulses over a noisy circuit and the pulses, together with the noise, are received and interpreted. Errors in interpretation of the message occur because of this noise. If the error rate is too high and the transmitter power is fixed, we have traditionally lowered the data rate in order to reduce the errors. This has always worked and the reason given was very simple. A lower data rate means that the pulse lengths can be increased, which in turn allows narrower bandwidths to be used, thereby reducing the amount of noise accepted by the receiver. Thus, it became axiomatic that lower error rates could be obtained only by corresponding decreases in bandwidth and data rate. To almost everyone in the communications art the validity of this axiom was unquestioned since there was a great deal of experience in support and none in contradiction. It remained for Shannon to show that systems could be constructed, in theory at least, which would behave quite differently from what our previous experience would lead us to expect. First of all, he showed that the data rate could be held at a constant value (provided this value were below a certain maximum) and at the same time the error rate could be reduced to arbitrarily small values. As for the general belief that one should always use the minimum possible bandwidth in order to reduce the noise accepted by the receiver, Shannon showed that in the ideal case, with a white-noise background, the system bandwidth should be increased to the point where the accepted noise power is at least equal to the signal power.[3] This new theory presented a radically different picture of the limiting behavior of communications systems.

A very superficial study of Shannon-type systems will now be made in the belief that many readers, who are not specialists in information theory, might find a practical discussion of this topic interesting and perhaps useful. Fig. 6 shows a form of communications system suggested by Shannon's work. The channel has a bandwidth $W$ and average (white) noise power $N$. The transmitter is limited to an average power $P$. Consider a white-noise generator having a bandwidth $W$. We record $M$ different samples of the generator output, each sample having a duration of $T$ seconds. These waveforms are now designated $f_1(t)$, $f_2(t)$, $f_3(t)$, $\cdots$, $f_k(t)$, $\cdots$, $f_M(t)$ and are made available as transmitted symbols, as indicated in the figure. Copies of each of the $M$ wave-

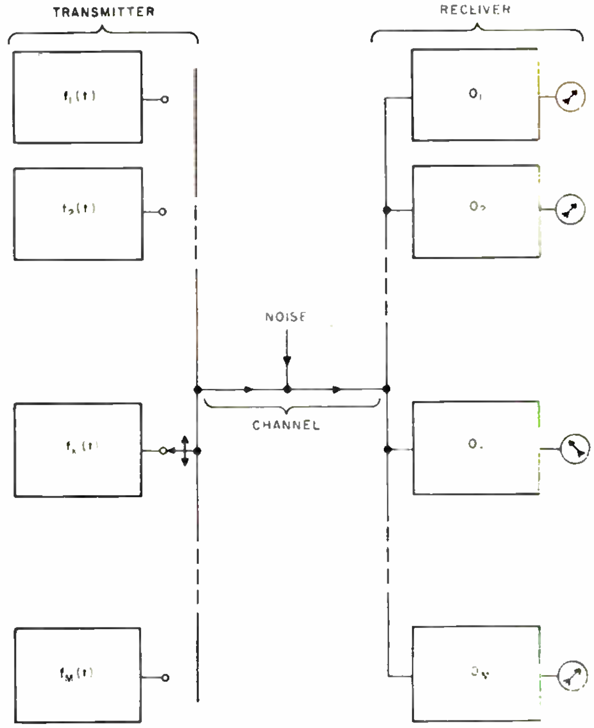



Fig. 6—An ideal communications system.

forms are made and placed at the receiver in the corresponding operator units $O_1$, $O_2$, $\cdots$, $O_k$, $\cdots$, $O_M$. In operation, one of the $M$ waveforms (say the $k$th one) is selected for transmission. Waveform $f_k(t)$ plus channel noise is received by each of the operator units. The operator units subtract the waveform stored within each unit from the received signal, square this difference, integrate the square for $T$ seconds (which is the duration of the symbols), and indicate this mean-square value as shown. If $T$ is sufficiently large, each meter (except for the $k$th one) will with almost unit probability read very nearly a value corresponding to $2P+N$, which is the average power of the difference voltage in each case. The $k$th meter will give a reading corresponding to very nearly $N$ (again with almost unit probability), since the $f_k(t)$ portion of the received signal is completely removed in the subtraction process and only the channel noise remains. Thus, by noting which meter has the lowest reading we can identify which of the $M$ symbols was transmitted. Of course, because of the channel noise we will make an occasional error and identify the wrong symbol.

Before investigating the problem of errors we should examine the relationships between data rate $R$, symbol duration $T$, and number of symbols $M$. Assume that in each $T$ seconds of time the system receives $S$ binary digits (0, 1) to transmit. $R$ will then be $S/T$ bits per second. Since our symbol length is $T$, we must be prepared to indicate a choice of one out of $2^S$ possibilities with each symbol transmitted, since this is the number of different sequences of $S$ binary digits. Then clearly

[3] C. E. Shannon, "Communication in the presence of noise," Proc. IRE, vol. 37, pp. 10–21; January, 1949.

$M = 2^S$ and

$$R = \frac{S}{T} = \frac{\log_2 M}{T} \text{ bits per second.} \tag{7}$$

Note that if the symbol length $T$ is increased, the number of symbols $M$ used must increase *exponentially* with $T$ in order to keep a constant data rate. Thus, if $T$ is *doubled*, $M$ will have to be *squared* for the same data rate. In general terms

$$M = A^T \tag{8}$$

and

$$R = \log_2 A. \tag{9}$$

Returning again to Fig. 6, assume the $k$th symbol has been transmitted. Thus, we look to see if the $k$th meter gives the lowest reading. If this is so, there is no error. If any one of the other meters gives a lower reading, an error in selection will occur. The probability that any meter will read less than the $k$th one can be made progressively smaller by increasing $T$, which increases the integration time in the operator units. However, this is only part of the story. As $T$ is increased to lower the probability of any one meter indicating lower than the $k$th, the number of such comparisons needed rises according to (8) in order that the data rate remain fixed. Thus, we have two conflicting trends as $T$ is increased. The probability of error per comparison drops, but the number of comparisons necessary to arrive at a selection rises with increasing $T$. Shannon shows that we can always reduce the over-all probability of error in selection to as small a value as we may choose by letting $T$ become large, *provided* that $M$ does not increase with $T$ faster than

$$M = \left(1 + \frac{P}{N}\right)^{TW}. \tag{10}$$

This maximum permissible rate of increase of $M$ with $T$ determines the maximum data rate which can be supported with an arbitrarily small error rate. This maximum rate is known as the channel capacity $C$ and is obtained by substituting (10) into (7) to obtain

$$C = W \log_2 (1 + P/N). \tag{11}$$

Of course, we do not have to send data at the rate given by (11). We may send slower, and enjoy arbitrarily low, error rates. We may even send faster than $C$, but then we must accept a certain irreducible error rate.

As remarkable as (11) may be, the engineer concerned with practical system design needs more information than has been given thus far. We now know that multi-symbol systems of the type shown in Fig. 6 are capable, practical considerations aside, of making the most efficient possible use of the communications channel. There are two engineering constraints which must be considered carefully. First, there is an inherent delay of $2T$ seconds involved in data transmission because a $T$-second length sample of input binary data must be available before choice of transmitted symbol may be made, and another $T$ seconds is required for processing at the receiver before identification may be made. What will be the order of magnitude of this transmission delay? Secondly, how many different symbols $M$ will be required in a given situation? This last consideration is of special importance because it determines, rather directly, system complexity. We might suspect that any attempt to operate at or very near the rate $C$ would require intolerably large $T$ and $M$ since this rate represents a limiting condition. Similarly, large $T$ and $M$ would be expected to result at operating rates lower than $C$ if the error rate is specified at a very small value. What we really need to know is the behavior of $T$ and $M$ for a practical error rate, say $10^{-5}$, as the data rate is varied from zero to 100 per cent of capacity. Rice, in an excellent paper,[4] gives us a good indication of the orders of magnitude involved. Rice assumed an SNR of 10 and an error rate of $10^{-5}$. He then determined the number of bits per symbol $S$ which would be necessary for various values of the ratio of actual data rate to channel capacity. The results are shown plotted in Fig. 7. Notice

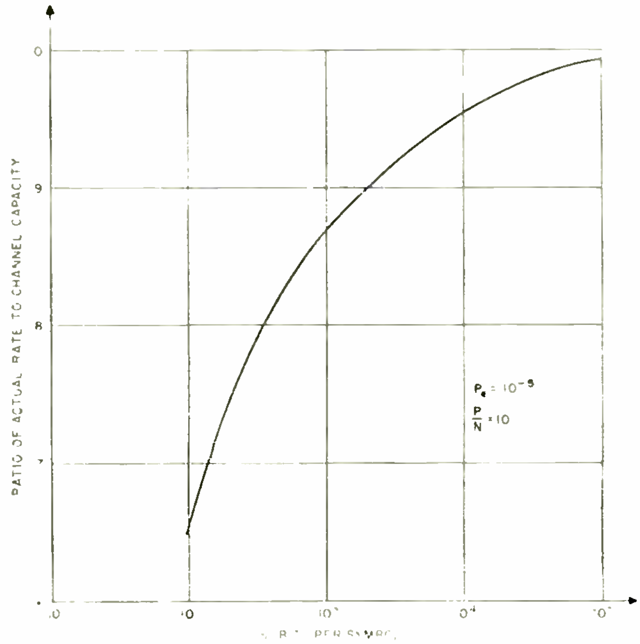



Fig. 7—Curve from Rice showing approach to capacity.

that the numbers $S$ of bits per symbol are quite large, and keep in mind that the number of symbols $M$ is $2^S$. We need no numerical examples to conclude that the number of symbols needed will be fantastically large and that it is completely impractical to attempt to build systems which operate at rates close to the Shannon capacity under the conditions assumed above. (An

[4] S. O. Rice, "Communication in the presence of noise," *Bell Sys. Tech. J.*, vol. 29, pp. 60–93; January, 1950.

interesting piece of work by Stutt[5] shows that the situation is not quite so unreasonable if the SNR is low and the symbol waveforms are chosen systematically rather than at random.)

In brief retrospect, we (as communications engineers) have been shown by Shannon that there is an upper limit to what we can do no matter how hard we may try or how ingenious we may be. That it may be extremely difficult to achieve or even approach this upper limit in practice can hardly be blamed on Shannon. He has located the top of our mountain: the problem of reaching the peak is ours, not his.

## V. A Practical System of High Efficiency

It is quite clear that any analysis of a communications problem which uses the capacity formula without careful qualification may give results of doubtful practical value. If a system of high efficiency and of reasonable complexity could be found, perhaps problem analysis could be carried out with results which would be significant in practice. Consider once more the system of Fig. 6, but now let there be only two symbols used, $f_1(t)$ and $f_2(t)$. Shannon's idea of using noise-like symbols is quite intriguing. This will be retained except that $f_2(t)$ will be the negative of $f_1(t)$ instead of being chosen at random as before. Thus, $f_1(t)$ is now transmitted for mark (or binary 1) and $-f_1(t)$ for space (or binary 0). For obvious reasons we shall refer to this two-symbol system as the binary system.

In the analysis of this binary system it is convenient to recall one form of the sampling theorem which states that a time function of $T$-seconds duration and of $W$-cycles bandwidth is completely specified by $2TW$ equally-spaced sample values of the funtion. Thus, we will represent the function $f_1(t)$ by the sequence of numbers $\{x_1, x_2, \cdots, x_{2TW}\}$, which are the values of the function at the sampling times. The function $f_1(t)$ will be noise-like except that we shall adjust the function so that we obtain the exact relationship

$$\frac{1}{2TW}\sum_{1}^{2TW} x_j^2 = P, \tag{12}$$

where $P$ is the average transmitter power. In a like manner the channel noise, which has an average power $N$, will be represented by the sequence of numbers $\{n_1, n_2, \cdots, n_{2TW}\}$, where the $n_j$ are independent normal variables with zero mean and variance $N$. If one performs the operations described for Fig. 6 one obtains the following for the probability of error $P_e$:

$$P_e = \text{Prob.}\left[\frac{1}{2TW}\sum_{1}^{2TW} x_j n_j < -P\right]. \tag{13}$$

The summation term may be shown to be Gaussian with zero mean and variance $PN/2TW$. If operating conditions yield a low error probability, then

$$P_e = \frac{e^{-\gamma}}{2\sqrt{\pi}(\gamma)^{1/2}}, \tag{14}$$

where

$$\gamma = \frac{P}{N}\,TW. \tag{15}$$

A plot of $\log_{10} P_e$ as a function of $\gamma$ is shown in Fig. 8.

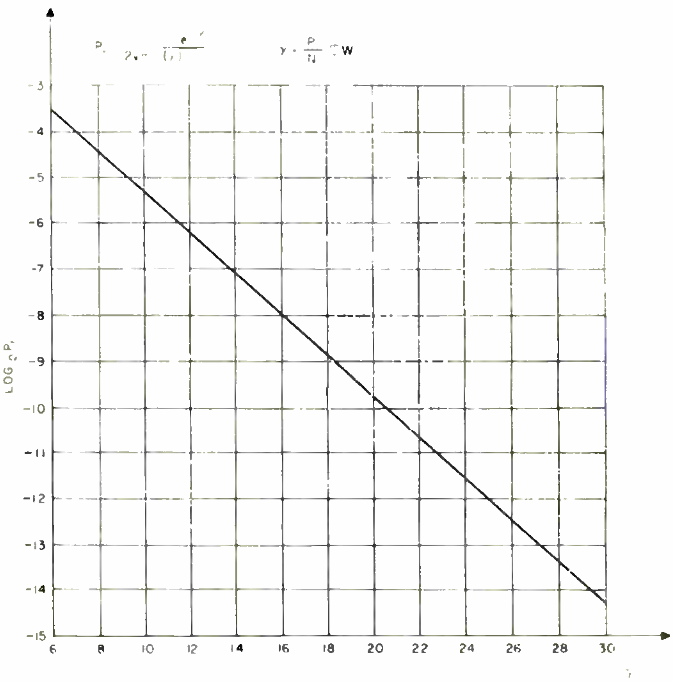



Fig. 8—Plot of $\log_{10} P_e$ vs $\gamma$ for the binary system.

Note that once the system error probability is fixed, the relationship between SNR, bandwidth, and data rate ($1/T$ bits per second) is immediately determined.

We might inquire now as to how good our binary system is. It is certainly as good as any two-symbol system can be. Better results can be obtained only by increasing the number of symbols. The gain in doing this, however, does not generally appear to be worth the effort. For example, Stutt[5] shows that for a $P/N$ of $1/10$ and error probabilities in the neighborhood of $10^{-4}$ to $10^{-6}$, the most efficient symbol choice requires the use of about 100 symbols in order to increase the data rate over binary by a factor of five. Note, however, that at a fixed error rate the data rate of the binary system may be made 5 times as large by inceasing transmitter power by 7 db. Thus, we must evaluate the relative costs of a 7-db transmitter power increase vs the increase in symbols from two (actually one in terms of equipment complexity) to 100. We must conclude, therefore, that our binary system performance represents about the best that can be done in practice. Better results may be obtained by using more symbols but the rate of improve-

[5] C. A. Stutt, "Regular Polyhedron Codes," Research Laboratory, General Electric Co., Schenectady, N. Y., Tech. Rept. No. 59-RL-2202; February, 1959.

ment will generally prove to be low.[6]

This places us in a good position to derive expressions for the channel capacity in the practical case from (14) and (15). Before doing so we should understand that for high SNR's these equations may yield rates in bits per second far in excess of the bandwidth in cycles per second. There is a mathematical limitation which prevents this. This limitation will not be discussed except to mention the fact that in theory the binary system is limited to a maximum rate $2W$ regardless of SNR.[7] In practice it is usually quite difficult to achieve even $W$ as a rate; we shall choose this as our limiting value.

Since the rate $R$ is $1/T$, the channel capacity $C_p$ in the practical case may be obtained from (15) as

$$C_p = \frac{W}{\gamma}\,\frac{P}{N}, \tag{16}$$

$$C_p \leq W, \tag{16a}$$

where $\gamma$ is fixed by the desired error probability according to (14). For an error probability of $10^{-5}$, $\gamma$ is approximately 9.2.

Admittedly, the result (16) is not as elegant as (11). Keep in mind, however, that the concise nature of the capacity formula (11) is made possible by a limiting process in mathematics which cannot be duplicated in practice. A valid objection could also be raised to the application of the term "capacity" to the rate indicated by (15) and expressed in (16). From purely theoretical considerations, such an objection is certainly justified. From a practical point of view, (16) does, in a sense, qualify as a capacity since the performance indicated may only be approached by the most efficient use of modulation and processing techniques. It is quite doubtful that there exist at present any operating systems which perform as well as (16) indicates is obtainable. The main point to remember is that for many years to come (16) will represent a sensible, realizable (but not easily realizable) design goal for the communications engineer; the capacity formula (11) can never serve this purpose. As processing and storage techniques improve, it is to be expected that at some future time multisymbol systems may be built whose performance will exceed that indicated by (16). This does not in any way lessen the utility of (16) as a frame of reference.

## VI. Jamming

From the work of the previous section, we now derive some rather simple results which are well-known to information theory specialists the world over, but whose significance is apparently not appreciated by many engineers, at least in this country.

Consider first the performance of the binary system in a white-noise background having a density of $n_0$ watts per cycle. The effective noise power $N$ will then be

$$N = n_0 W, \tag{17}$$

and (15) will read in this case

$$\gamma = \frac{PT}{n_0} = \frac{E}{n_0}, \tag{18}$$

where $E$ is the energy per transmitted symbol. We now have derived the well-known result that for binary systems of this type operating against flat channel noise, the error probability is independent of bandwidth and is a function only of energy per symbol and noise power density. Thus, for fixed average signal power and fixed data rate, the error probability does not change as the system bandwidth is increased. It is clear that as the bandwidth increases, the noise power accepted by the receiver increases, and for large bandwidths the received noise power becomes quite large compared to received signal power. Thus, systems of this type can operate with SNR's far below unity, or put another way, these systems can be made to operate satisfactorily in the presence of very large amounts of noise power. One might begin to suspect that a broad-band system would be fairly immune to intentional jamming, since in normal operation it is contending (satisfactorily) with such large amounts of natural noise that the additional noise contributed by the jammer would be insignificant by comparison. That this is precisely the case will be made more definite in what follows.

Consider a binary communications system designed to operate in a white-noise background of power density $n_0$ watts per cycle. Let practical considerations demand that the error probability be kept at or below a critical value $P_{e0}$ corresponding to a $\gamma$ value of $\gamma_0$. Then the channel capacity will be from (16):

$$C_p = \frac{W}{\gamma_0}\,\frac{P}{n_0 W} \tag{19}$$

as far as natural noise is concerned. For the sake of argument, we shall choose to operate at a data rate $R$ corresponding to one-half capacity. Then,

$$R = \frac{1}{T} = \frac{C_p}{2} = \frac{P}{2\gamma_0 n_0}. \tag{20}$$

Consider now the appearance of a jamming signal of average power $J$ in the channel and let us investigate the effect of $J$ on $\gamma$, since this factor must be kept above the assumed critical value of $\gamma_0$. The noise term $N$ in (15) will now be

$$N = n_0 W + J, \tag{21}$$

and when (20) and (21) are substituted into (15) we obtain

$$\gamma = \gamma_0 \frac{2n_0}{n_0 + J/W}. \tag{22}$$

[6] This, like all generalizations, will have exceptions. One can conceive of situations in which the multisymbol system would have sensible application. In such cases the work of Stutt, *ibid.*, should prove quite useful.

[7] See discussion of sampling theorem which precedes (12).

This last equation tells a very interesting story. First of all, note the appearance of the $J/W$ term in the denominator. This indicates that the effectiveness of a given average jamming power varies *inversely* as system bandwidth. The broader the bandwidth the less effective will be the resultant jamming. In particular, in order to disrupt the circuit ($\gamma=\gamma_0$) one needs an amount of average jamming power $J_0$ equal to

$$J_0 = n_0 W \tag{23}$$

under the conditions specified. Thus, the relationships between bandwidth and jamming power become quite clear and may be summarized as follows: *If the most efficient system design is assumed for a fixed data rate in each case, the necessary power required to jam the ciruit varies in direct proportion to system bandwidth. The broader the bandwidth the more difficult it will be to jam the circuit. Conversely, the narrower the bandwidth the easier it becomes to jam the circuit.*

It should be quite clear that if intentional jamming is a consideration, one must of necessity choose a broad-band technique. The narrow-band approach can only lead to eventual disaster.

## VII. The Question of Channels

The well-known, but not necessarily sufficiently appreciated, relationship between jamming immunity and system bandwidth discussed above leads to a natural concern over loss of channels if broad-band techniques are employed, as obviously they must be in many applications. It is the purpose of this section to discuss the general problem of "channels" somewhat more thoroughly than before, through use of the practical channel capacity formula (16).

Consider the following problem. Communications service must be provided which requires that a total of $K$ stations be permited to transmit messages at *any* time. Let $\alpha$ be the average fraction of time each station is active. The average signal strength (power) at a particular receiver will be denoted by $\overline{P}$ and it is assumed that $\Omega$ cycles of total bandwidth are allocated to this service. Background or natural noise will be ignored. Thus:

$\Omega$ = Total bandwidth allocated to service.
$K$ = Number of stations, each of which must be permitted to transmit at any time.
$\alpha$ = Average fraction of time each station is actually transmitting.
$\overline{P}$ = Mean signal power at a receiving site (one station).
$C_{pN}$, $C_{pB}$ = Practical channel capacity per circuit in narrow- and broad-band operation, respectively.

We now wish to inquire as to the relative merits of narrow- and broad-band techniques for this service.

First let us assume an environment in which *all* stations are under the complete control of a central authority. Under this special condition, frequency division will result in circuit bandwidths of $\Omega/K$ and, since there will be no interference and background noise is ignored, the capacity per circuit will be, using (16a),

$$C_{pN} = \frac{\Omega}{K} \cdot \tag{24}$$

By comparison, the broad-band approach would yield a circuit bandwidth of $\Omega$ and a noise power $N$ of $\alpha K\overline{P}$, which, if an average strength signal were being received, would result in a capacity per circuit of

$$C_{pB} = \frac{\Omega}{\gamma\alpha K}, \tag{25}$$

using (16). Comparing (25) and (24) we see that if such a well-disciplined environment can be found, the narrow-band system would be superior *provided* that the duty cycle factor $\alpha$ is kept high. For example, if $\alpha=1$ (each station transmitting continuously) the narrow-band system appears to offer about a ten-to-one data rate advantage (for $\gamma=10$). If, due to operational considerations, the average duty cycle is low (say, 10 per cent or even 1 per cent or less as may quite often be the case), then the broad-band system, even under such ideal conditions, becomes superior.

The reasons for this are quite clear. If the duty cycle is low, the narrow-band system wastes spectrum since most of the allocated channels in $\Omega$ will be idle at any time. This cannot be avoided since each of the $K$ stations must have access to communications at any time. The broad-band system takes immediate advantage of a low-duty cycle since this keeps the "noise" level at low values and increases the per-circuit capacity. The narrow-band approach guarantees complete elimination of interference between stations (orthogonality, as the specialist would say), while in the broad-band case each station appears as noise to the others. Thus, at high duty cycles the narrow-band system is superior because it avoids this "noise" problem completely. We must conclude then that the narrow-band system has sensible application under very special conditions (such as in radio broadcasting), but that even where complete control of all transmitters is possible, the broad-band system can easily prove to be the more efficient user of spectrum.

We shall now consider the same communications service problem as before, except that we shall abandon any hope of a disciplined use of the bandwidth $\Omega$. In most military applications, a congested band assumption is much more realistic for several reasons. Certainly two opposing military forces will have planned their spectrum usage independently. Under such conditions interference will be the expected rather than the unusual event. If narrow-band systems have been chosen, it is quite likely that each operator will shift frequency when severe interference is encountered in an attempt to maintain service. This is only the natural and sensible thing to do. Furthermore, under conditions where signals propagate over distances of many thousands of miles, interference will no doubt be quite common even between stations that are a part of the same military force. It seems unrealistic to expect that interference can be prevented by administrative means when the total number of users is large and when the geographic distances between groups of users is great. It must be presumed then that, in spite of careful allocation attempts, the narrow-band approach will not prevent interference and that congested operating conditions will certainly prevail.

Consider the problem that an operator faces when trying to clear messages in a congested band using narrow-band systems. As we have shown, the SNR in such a case is a statistical quantity varying from very good at one time to hopelessly poor minutes or even seconds later. If the data rate is set too high (based on those times when the SNR is good), much of the traffic will be lost and repetition will be necessary. In order to know what messages or parts of messages were lost, a return link is required, but this will also suffer from interference. Such operation is quite inefficient and it would soon be discovered that the data rate would have to be determined by the *least favorable* SNR anticipated during the operating period. Thus, the per-circuit channel capacity in this case may be approximated roughly by

$$C_{pN} = \left(\frac{P}{N}\right)_{\min} \frac{\Omega}{\gamma K}, \tag{26}$$

using (16).

The assumption of congestion does not alter the performance of the broad-band system so that (25) still holds. A rough estimate of the relative performance of these two approaches to the problem of congested band operation may now be obtained by taking the ratio of (25) to (26):

$$\frac{C_{pB}}{C_{pN}} = \frac{1}{\alpha(P/N)_{\min}}. \tag{27}$$

As rough as this approximation may be it still seems rather certain that in a congested band the broad-band system will normally far outperform the narrow-band system.

Eq. (25) may then be taken as the average capacity per circuit of a congested band. In slightly modified form we have:

$$C_{pB} = \frac{1}{\gamma k} \text{ bits per second}, \tag{28}$$

where $k$ is the average number of actual users per cycle of bandwidth and $\gamma$ is determined by the required error probability according to (14).

It might be mentioned at this point that with broadband operation the DSB and SSB methods of modulation give identical results for the same transmission bandwidth. As a practical matter, the DSB system offers a two-to-one increase in transmission bandwidth in the modulation process over and above the bandwidth increase obtained by coding processes at baseband. This may sound strange to engineers accustomed to design work aimed at conserving bandwidth. It is still true that there are practical difficulties involved in designing equipment which uses more bandwidth *efficiently* and that the bandwidth doubling which may be obtained in the modulation process with DSB will prove quite helpful in general.

## VIII. Conclusions

Since the invention, many years ago, of the frequency-selective filter, it has been common practice to share the inherent capacity of the RF spectrum among users on the basis of frequency allocations. As the number of users increased, methods were found for reducing transmission bandwidths so that new services could be accommodated in the existing spectrum. Extrapolating the past into the future has led to the natural attempt to continue this evolutionary process of seeking methods for the further narrowing of transmission bandwidths, thus providing service for the increasing user population.

This philosophy of spectrum usage is based on a particular course of development which the radio art happened to take, rather than on any fundamental physical principles. The inherent communication capacity of the spectrum can be shared in ways other than by frequency allocation and for many applications the frequency division approach represents a very poor choice indeed. In the field of military communications in particular, the tendency to follow the trends of the past quite often leads to systems having negligible military capability although good intentions may be to the contrary.

This is not to say that broad-band systems have been completely ignored in the past. It could safely be said, however, that the magnitude of the effort thus far expended on the broad-band approach is far out of proportion to the importance of this technique.

## Acknowledgment

The author wishes to express appreciation to his many colleagues at the General Electric Company who assisted in the work upon which this paper is based. Special thanks are due to J. C. Kovarik who contributed much original material for the congested-band analysis and to S. Applebaum and Dr. H. D. Friedman for their constructive discussions of information theory problems.

# Electronic Scanning System for Infrared Imaging*

M. E. LASSER†, P. H. CHOLET†, AND R. B. EMMONS†

*Summary*—**A new all electronic infrared imaging system has been designed and constructed. The infrared image of a given field of view is focussed onto a scanning tube which dissects the image; after passing through the scanning tube, the radiation is then refocussed onto a separate infrared detector. The tube face is a semiconducting window. An electron beam, striking the window, generates free carriers and reduces the transmission of the window locally. As the electron beam is swept across the scanning tube face, the moving opaque spot produces a video signal at the detector. Both the conditions for the operation of the device and the over-all sensitivity have been analyzed. It is found that the sensitivity and information rate of the system are limited only by the sensitivity and time constant of the detector employed.**

## Introduction

The problem of conversion of an image formed by infrared radiation to a visible image has been approached in a number of ways.

Mechanical scanning systems have undergone years of study, and have extremely varied forms[1] but suffer from scanning speed limitations. Photoemissive image tubes developed to date suffer from serious limitations in wavelength response, and vidicon or photoconductive tubes which show promise of long wavelength sensitivity appear to be limited by the fact that the very high resistivity required by the screen material can only be achieved by cooling the entire sensitive area.

Following the suggestion of one of the authors (M. E. Lasser), a high-speed electronic scanner has been constructed and tested in the laboratory. This tube does not have the storage capabilities of a vidicon, but it is extremely easy to construct, and has proven to be a practical operating device when used with any one of several highly sensitive, small-area infrared detectors.

The infrared scanner consists of a tapered tube with a semiconducting window at one end and any suitable infrared transparent window at the other. Another tube, containing an electron gun, is joined to the first at an angle which allows the electron beam to strike the semiconductor, but which keeps the gun out of the optical path between the two windows.

An infrared image of the object to be viewed is formed on the semiconducting window. When the electron gun is not operating, the infrared radiation continues through the second window of the tube. It is then reimaged on the surface of an infrared sensitive detector.

When the beam is turned on and focused on the first window, the moderately high-energy electrons create free carriers locally in the semiconductor, changing its conductivity and, hence, its absorption coefficient at that point. Deflection yokes allow the beam and the absorbing spot which it generates to be swept over the semiconductor to form a raster. Since the amount of light absorbed at any instant depends on the intensity of the infrared image under the absorbing spot, the output of the detector will be a time function whose amplitude is dependent on the spatial intensity variations in the infrared image. This time function may be used to modulate the beam of a television-type monitor, thus rendering the infrared image visible.

## Theory

### *Free Carrier Absorption*

We will first determine the increase in free-carrier density which is required to make the semiconductor locally opaque, and whether it is possible to produce this required density through the action of an electron beam.

A qualitative explanation of the optical properties of semiconductors at wavelengths too long to produce absorption by means of valence to conduction band transitions may be obtained from the classical Drude-Zener theory. Later work,[2,3] has produced no essential modification of the classical theory, and none of the theories is as yet in very good quantitative agreement with experimental absorption data. The classical theory, adjusted to fit the experimental data, will be used here.

According to the Drude-Zener theory, the absorption coefficient $\alpha$ of a semiconductor for light of angular frequency $\omega$ is given by

$$\alpha = \frac{1}{c\epsilon_0 n}\sigma \tag{1}$$

where

$$\sigma = \sigma_0\left(\frac{1}{1+\omega^2 t^2}\right), \tag{2}$$

$\sigma$ is the frequency dependent conductivity,
$\sigma_0$ is the dc conductivity,
$\epsilon_0$ is the permittivity of free space,
$n$ is the index of refraction,
$c$ is the velocity of light, and
$t$ is the mean time between collisions for the charge carriers and is related to the drift mobility $\mu$ of the free carriers present by the expression $t = m^*\mu/q$ where $m^*$ is the effective mass of the free carriers and $q$ is their charge.

* Original manuscript received by the IRE, July 14, 1959; revised manuscript received, September 28, 1959.

† Philco Corp., Philadelphia, Pa.

[1] J. C. Wilson, "Television Engineering," Pitman and Sons, Ltd., London, Eng., ch. 1; 1937.

[2] R. de L. Kronig, "The quantum theory of dispersion in metallic conductors, part II, *Proc. Roy. Soc. (London)*, vol. 133, pp. 255–265; September, 1931.

[3] H. Y. Fan, W. A. Spitzer, and R. J. Collins, "Infrared absorption in $n$-type germanium, *Phys. Rev.*, vol. 101, pp. 566–572; January, 1956.

For most semiconductors, $t$ is in the range $10^{-13}$ seconds to $10^{-12}$ seconds. Thus, for wavelengths from the absorption edge to wavelengths well beyond 20 $\mu$, $\omega^2 t^2 \gg 1$, and we may use the approximation

$$\alpha = \frac{1}{4\pi^2 \epsilon_0 n c^3 t^2} \sigma_0 \lambda^2 = C\sigma_0 \lambda^2. \qquad (3)$$

The value of the constant $C$ as defined by (3) will not be used in the following. Instead, we will choose a value for $C$ which brings the equation into better agreement with experimental absorption data.

In the wavelength range of interest, then, we can expect that the absorption coefficient will depend linearly on the conductivity and on the square of the wavelength of the incident light. Structure, such as that observed in the absorption curves of $p$-type germanium[4] superimposes additional absorption[5] which disturbs this functional dependence but this dependence is supported by the experimental data for silicon[6] (see Fig. 1), $n$-type germanium, and a number of other materials.[7]

The relative intensity of light transmitted through a semiconductor will then be (neglecting Fresnel losses)

$$\frac{I_1}{I_0} = e^{-C\sigma_0\lambda^2 x} \qquad (4)$$

where $x$ is the thickness of the semiconductor window. Fresnel losses are independent of wavelength and conductivity for semiconductors in the wavelength region and with the conductivities $\sigma_0$, of interest here. When electrons strike the material, producing, to the depth of their penetration $d$, a higher conductivity $\sigma_1$, the relative transmission of the window becomes

$$\frac{I_2}{I_0} = e^{-C\sigma_0\lambda^2 x} e^{C(\sigma_0 - \sigma_1)\lambda^2 d} \qquad (5)$$

at the point where the beam strikes the material. If the material is to be made essentially opaque (<1 per cent transmission) the exponent of the right member of the expression must be at least 4.6. If we assume that $\sigma_1 \gg \sigma_0$ then the terms of the exponent involving $\sigma_0$ can be neglected.

Consequently the requirement for 99 per cent absorption is simply

$$C\sigma_1\lambda^2 d \geq 4.6. \qquad (6)$$

The conductivity $\sigma_1$ of the semiconductor at the point where the beam strikes it may be written

$$\sigma_1 = qn(\mu_e + \mu_h) + \sigma_0 \qquad (7)$$

[4] W. Kaiser, H. Y. Fan, and R. J. Collins, "Infrared absorption in $p$-type germanium," *Phys. Rev.*, vol. 91, pp. 1380–1381; September, 1953.

[5] This additional absorption, which is due to intraband transitions, is useful in that it reduces the number of free carriers required to make the semiconductor locally opaque.

[6] W. G. Spitzer, "Infrared Properties of Semiconductors," Ph.D. dissertation, Purdue University, Lafayette, Ind., p. 50; 1957.

[7] H. P. R. Frederikse and R. F. Blunt, "Photoeffects in intermetallic compounds," Proc. IRE, vol. 43, pp. 1828–1835; December, 1955.

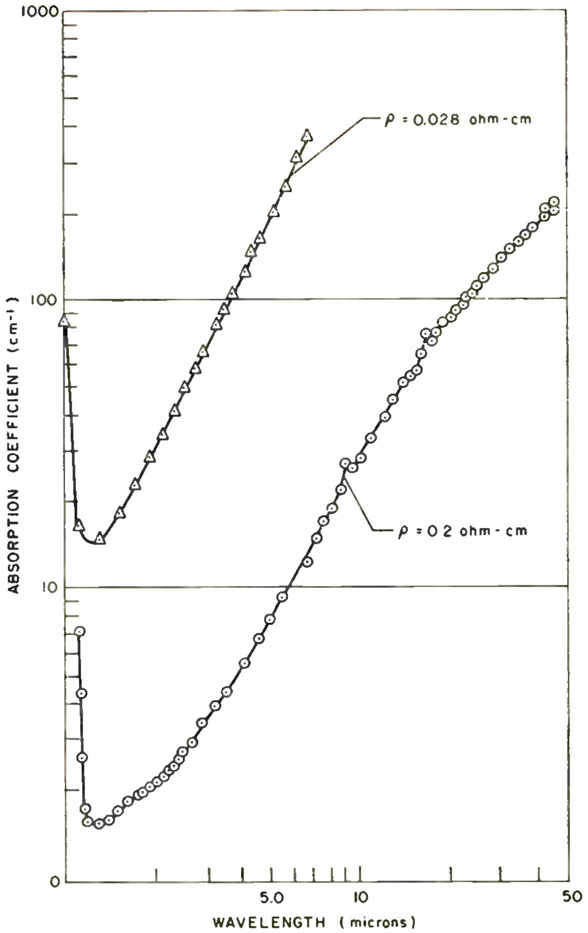



Fig. 1—Free carrier absorption in $p$-type silicon (after Spitzer).

where $n$ is the steady-state density of the pairs of carriers created by the beam and $\mu_e$ and $\mu_h$ are the mobility of the electrons and holes, respectively. $\sigma_0$ will be again neglected in comparison with the first term. The steady-state density of pairs $n$ may be written

$$n = g\tau \qquad (8)$$

where $g$ is the pair generation rate per unit volume and $\tau$ is the lifetime of the material. It is assumed that the beam dwells on any one spot at least long enough so that equilibrium is established between the generation and recombination rates. In terms of the beam current $i$ and spot area $s$ of the electron gun, and in terms of $Z$, the efficiency of production of pairs by the electrons, the generation rate is

$$g = \frac{Zi}{qsd} \qquad (9)$$

where it has been assumed that the current density is constant over the area $s$ of the beam. An empirical curve for $Z$, the number of pairs created by each electron as a function of its energy, has been reported for silicon[8] and

[8] V. M. Patskevich, U. S. Vavilov, and L. S. Smirnov, "Energy of ionization by electrons in silicon crystals," *Soviet Phys. JETP*, vol. 6(33), pp. 619–620; March, 1958.

is reproduced in Fig. 2. The curve is linear with a slope of about 1 pair/7 ev above 10 kev, and less than this below 10 kev, indicating that some energy is lost in penetrating the surface without commensurate production of hole electron pairs. The curve may be reasonably extrapolated to higher energies; the mechanism for the loss of energy of the electrons continues to be pair production by ionization up to the electron energies of 140–150 kev, at which point Frenkel defects begin to occur.[9] Thus if the electron beam energy is maintained below the 140-kev value, the bulk characteristics of the silicon will not be adversely affected by the incident electron beam.

We are now in a position to determine whether a local conductivity sufficient to produce complete absorption can be obtained. Substituting (7), (8), and (9) into (6), we have as the condition for 99 per cent absorption that

$$C\sigma_1\lambda^2 d = \frac{CZi\tau(\mu_e + \mu_h)\lambda^2}{s} \geq 4.6. \qquad (10)$$

Assuming the semiconductor is silicon, we take $C = 8 \times 10^6$ ohms²/cm², $\mu_e = 1500$ cm²/volt second, and $\mu_h = 500$ cm/volt second. The wavelength at which the inequality (10) is most difficult to satisfy is the shortest in the range of interest. Consequently, we take $\lambda = 1.2\ \mu$. Silicon may be obtained with lifetime $\tau$ ranging from $10^{-8}$ seconds to $10^{-3}$ seconds. We will choose, for the present, the easily obtained value $10^{-6}$ seconds. The depth of penetration of the electrons has canceled out of the above expression, but an estimate of its value will be required to insure the choice of silicon with the proper lifetime.

The penetration depth for 25 to 30 kev electrons is of the order of $10^{-3}$ cm, as estimated from the experimental data for aluminum,[10] whose density and atomic number are quite close to those of silicon. This depth of penetration is small enough so that the surface recombination lifetime may be expected to predominate over the bulk lifetime. Consequently when a silicon window is chosen for the tube, the lifetime should be measured with the surface finished as it is to be used, and nonpenetrating light should be used to take the measurement.

A triode gun of the type used in a flying spot scanner tube will yield a beam current $i$ of 1.0 milliampere at an accelerating potential of 30 kv, with a spot diameter of 0.01 cm. Each of the electrons, accelerated to an energy of 30 kev, will yield 2800 pairs when it strikes the silicon. Substituting these numbers into (10), we obtain

$$C\sigma_1\lambda^2 d = 8.0.$$

Thus, we see that it is possible to produce a spot which is opaque even at the shortest wavelength of the

[9] P. Rappaport and J. J. Loferski, "Radiation damage in Ge and Si detected by carrier lifetime changes: damage thresholds," *Phys. Rev.*, vol. 111, pp. 432–439; July, 1958.

[10] L. Katz and A. S. Penfold, "Range-energy relations for electrons and the determination of beta-ray end-point energies by absorption," *Rev. Mod. Phys.*, vol. 24, pp. 28–44; January, 1952.

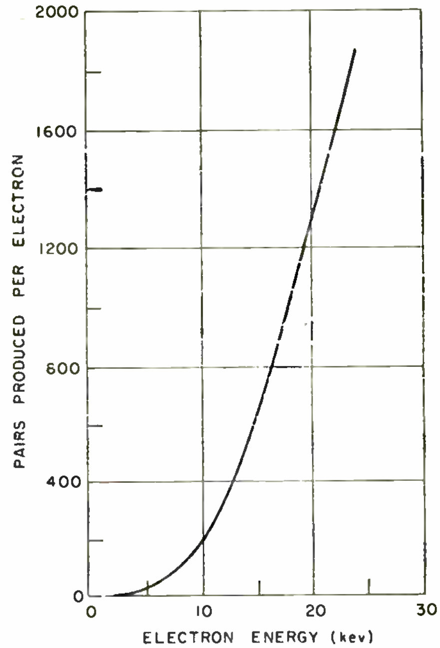



Fig. 2—Pair production in silicon by high-energy electrons (after Patskevich, Vavilov, and Smirnov).

useable range in silicon with a beam current which is easy to obtain. At the longer wavelengths, effectively complete absorption is obtained with currents well below 1 milliampere.

In the design of the tube, it is important to insure sufficient absorption, both to produce maximum signal and to avoid the possibility of noise modulation of a less than fully opaque spot. Within this limitation it is necessary to consider the effect of the lifetime of the semiconductor on the bandwidth, the resolution, and the sensitivity of the system in which it is to be used.

The lifetime of the material should be chosen to match approximately the dwell time of the electron beam on any one spot. If the scanning rates are such that the beam dwells on one spot much longer than a lifetime, it becomes a relatively inefficient producer of free carriers. A longer lifetime would in such a case allow the beam current to be reduced while maintaining complete absorption. On the other hand, if the beam dwells on any one spot a time shorter than the lifetime of the material an after-image may result.

The diffusion length in the material determines how much the electron hole pairs created by the beam will spread before recombination. This spreading will put a lower limit on the spot size for material with a given lifetime. The average diffusion path length is given by

$$L_D = \sqrt{D\tau}$$

where $D$ is the diffusion constant for the material, and $\tau$ is as before the lifetime. For silicon, $D \approx 20$ cm²/second; hence, if $\tau = 10^{-6}$ seconds,

$$L_D = \sqrt{20 \times 10^{-6}} \approx 4.5 \times 10^{-3} \text{ cm}$$

which will effectively double the size of the opaque spot for an electron beam spot size of $10^{-2}$ cm. The resolution of the system will of course depend on the optical system used to place an image on the silicon as well as on the spot size given above, but the limitation arising from the diffusion of the pairs must be kept in mind.

### *Possibility of Reflecting or Refracting Mode*

The possibility of using the scanning tube in the reflecting or refracting mode rather than the absorptive mode has also been considered theoretically. Noise arguments given below show that, in most practical cases, the decrease in sensitivity arising from the fact that the entire field of view is always on the detector is negligible. However, if the carriers created by the electron beam could change the index of refraction sufficiently, it would in principle be possible to have only a particular scanned element reflected or refracted onto the detector.

The reflection coefficient for normal incidence is given by

$$R = \frac{(n-1)^2 + k^2}{(n+1)^2 + k^2}$$

where $n$ and $k$ are the index of refraction and extinction coefficient respectively.

When there are no free carriers present $k=0$ at wavelengths longer than the band edge. To determine the effect of a change in the free-carrier concentration on the reflection coefficient we have to evaluate how large an effect the free carriers have on the values of $n$ and $k$.

The optical constants are related to the conductivity and the dielectric constant by the following relationship.

$$K_e - \frac{j\sigma}{\omega\epsilon_0} = (n - jk)^2$$

where $K_e$ is the dielectric constant and $\sigma$ is the conductivity as measured at the angular frequency $\omega$.

Solving for $n$ and $k$ we find

$$n^2 = \left[\sqrt{1/2 \quad K_e^2 + \left(\frac{\sigma}{\omega\epsilon_0}\right)^2} + K_e,\right]$$

$$k^2 = \left[\sqrt{1/2 \quad K_e^2 + \left(\frac{\sigma}{\omega\epsilon_0}\right)^2} - K_e.\right]$$

Since $K_e \approx 12$ for silicon, changes in $n$ (or $k$ if we are interested in a reflection change) due to changes in the free carrier concentration will not be significant unless

$$\sigma \geq \omega\epsilon_0.$$

This reduces to the condition that $\sigma$ at $3\mu$ must be greater than or equal 55 $\Omega^{-1}$ cm$^{-1}$.

Therefore, in order to obtain a change in the index of refraction at 3 $\mu$, the dc conductivity as given by (2) must be at roughly $3.5 \times 10^6$ $\Omega^{-1}$ cm$^{-1}$, which will be difficult to achieve with injection by the electron beam. In contrast, note that from (6), the dc conductivity required to produce complete absorption at 3 $\mu$ is $1 \times 10^4$ $\Omega^{-1}$ cm$^{-1}$, somewhat more than two orders of magnitude less. At longer wavelengths, the magnitude of the dc conductivity required to produce a change in the refractive index will decrease, and the changes will be easier to achieve. Thus, if the tube is to be used at wavelengths of 10 $\mu$ or longer it will work in a reflecting or refracting mode. For wavelengths below 10 $\mu$, however, the absorption coefficient remains considerably easier to change through the action of the electron beam.

### *Energy Considerations*

Fig. 3 shows the principal elements which will be required to make use of the variation in absorption in a semiconductor, as described above, to construct a practical image-scanning system.

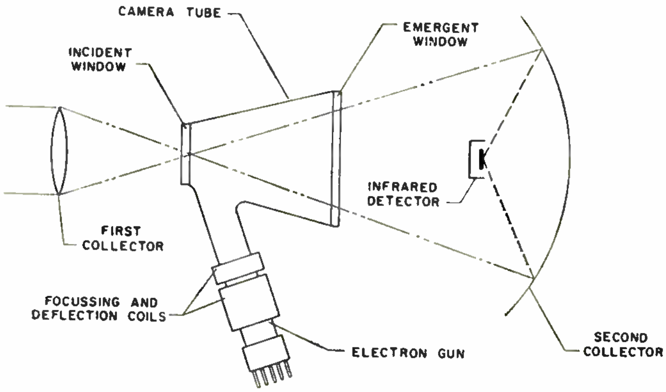



Fig. 3—Scanner tube in the associated optical system.

Assuming the objects in a distant target field of view to be self luminous in the infrared portion of the spectrum, the power $P$ at the filter is given by

$$P = A_T A_c \frac{\eta\gamma T^4}{\pi D^2} (K)$$

Here

- $\gamma$ is the Stefan-Boltzmann constant,
- $\eta$ is the emissivity,
- $T$ is the target temperature °K,
- $K$ is the appropriate optical transmission factor for the system,
- $A_T$ is the area of the target,
- $A_c$ is the area of the collector, and
- $D$ is the distance to the target.

The electron gun provides a beam of electrons sufficient to form an absorbing or blanking spot of area $s$ on the filter. The area $s$ corresponds to a target area $A_T = sD^2/fl^2$, where $fl$ is the focal length of the first collector. The optical power focussed on the blanking spot is thus

$$P_s = A_c \frac{\eta\gamma T_t^4 s}{\pi fl^2} (K). \qquad (11)$$

Correspondingly, the power on the whole surface of the filter may be written

$$P_F = A_c \frac{\eta\gamma T_\Sigma^4 F}{\pi f l^2}(K) \tag{12}$$

where $F$ is the area of the filter and

$$T_\Sigma = \frac{\sum_{i=1}^{i=n}(T_i)}{n}.$$

$T_i$ and $T_\Sigma$ have been introduced to indicate that the temperature $T_i$ of an area in the field of view corresponding to the scanning spot may be different from the temperature $T_\Sigma$ averaged over the total field of view.

In terms of $f$, the "$f$ number" of the first collector, the expressions (11) and (12) may be written as

$$P_s = \frac{\eta\gamma T_i^4 s}{4f^2}(K) \tag{13}$$

$$P_F = \frac{\eta\gamma T_\Sigma^4 F}{4f^2}(K) \tag{14}$$

These expressions are valid for $f$ greater than or equal to 1.

Given a suitable second collector, positioned as shown in Fig. 3, the power on the detector will be the total power on the filter minus the small amount absorbed in the area under the blanking spot. Thus $P_D = P_F - P_s$.

$P_D$ represents the power on the infrared detector which comes through the optical system. In addition to this power, consideration must be given to the background power radiated from elements of the optical system and apparatus surrounding the detector. All the radiant energy to which the detector is exposed will be background radiation except for the signal information coming through the silicon filter. In the case in which the detector may receive radiation from a solid angle of $2\pi$ steradians, the total power when the beam is off will be

$$P_B = A_D\gamma\left[\eta_B T_B^4 + \frac{\eta_\Sigma T_\Sigma^4 - \eta_B T_B^4}{4f^2}(K)\right]. \tag{15}$$

$A_D$ is the detector area and $\eta_B$ and $\eta_\Sigma$ are the average emissivities of the background and the target area, respectively. In the limiting case where $\eta_\Sigma$ equals $\eta_B$, and $T_\Sigma$ equals the background temperature $T_B$, $P_B = A_D(\eta_B\gamma T_B^4)$ as is required thermodynamically.

Were the blanking spot to remain stationary, the detector output signal from the system as so far described would be simply the dc signal corresponding to the detector responsivity times the total power $(P_B - P_s)$. Now, if suitable voltages are applied to the deflection coils, the blanking spot may be made to describe a television-type raster. Under these circumstances, changes in detector output will be proportional to differences in power falling on the detector which correspond to differences in the temperature (or emissivity), of the various portions of the total field of view.

The instantaneous peak-to-peak ac signal power will be

$$\Delta P_s = \frac{\gamma(\eta_i T_i^4 - \eta_j T_j^4)s}{4f^2}(K). \tag{16}$$

Thus, we have an elementary system for scanning a field of view. The detector gives an output signal proportional to differences in power radiation from the successively scanned elements $i$ and $j$ of the field of view. If, as outlined in Fig. 4, the detector is connected to a video channel, we may intensity modulate an oscilloscope driven in synchronism with the blanking spot, and reconstruct a visual picture of an infrared source, or sources. This system then is an electronic analog of a mechanical scanning system.

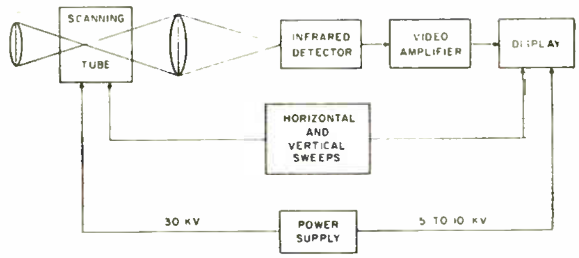



Fig. 4—System block diagram.

The analogy is quite close, but it is worthwhile to point out the significant differences. In (16) the parameter $s$ refers to the electron beam spot area, whereas in a mechanical scanner the term would refer to the area of the detector employed. Since it is easier to obtain a very small electron beam spot than to obtain a very small detector, the present system can provide high resolution more easily than can a mechanical scanner. But as (16) indicates, the signal power is directly proportional to $s$, so that, as with a mechanical scanner, high resolution is obtained only at the expense of sensitivity.

The need for a second collector in the present system places a restriction on $f$ in (16) which is not present in a mechanical scanner where a second collector is not required. Application of the Abbé sine condition to the second collector shows that to the first order, the minimum value of $f$ is given by $f_{min} \approx y/2d$, where $y$ is the diameter of the field of the first collector and $d$ is the diameter of the detector employed. In some applications, satisfaction of this relation may limit the useable $f$ number.

A third difference is that, in the present system, the detector is always exposed to radiation from the entire field of view. The signal is obtained by subtracting a small variable amount of energy from this large steady background. The detector of a mechanical scanner is of course exposed to radiation from only one element of the field of view at any given instant. Possible adverse effects of the large steady background are cell saturation or an increase in system noise due to statistical fluctuations in the background radiation. To determine whether the exposure to the entire field of view is likely to saturate the detector we may compute from (15) at what point the effective background radiation from the target field of view becomes equal to that from the optical apparatus surrounding the detector. Because this system is a double imaging system, and is intended to yield good visual images with flat field and low distortion, it is reasonable to assume that the first collector will not be faster than $f=1$. Under these conditions $4\,T_B^4=(T_\Sigma^4-T_B^4)$, ignoring optical losses and assuming emissivities of one for convenience. When $T_B=300°$K, $T_\Sigma=450°$K. Therefore, if the detector does not saturate upon exposure to room temperature background, it is reasonable to infer that even if the entire field of view were at as high a temperature as 450°K, no saturation would occur. When the field of view is at this temperature, the detector is receiving only twice the usual background power, according to the above calculation.

We may also use the above situation to determine whether the sensitivity of the system will be limited by statistical fluctuations in the background radiation reaching the detector. If we assume a detctor to be sensitive in the wavelength range 0–6 $\mu$, for example, $n$-type gold doped Ge or InSb,[11] a hemispheric background at 300°K will produce an effective flux density at the detector of $1.8\times10^{-3}$ watts/cm$^2$. The situation above provides twice this amount, the energy being carried by $30\times10^{16}$ photons/cm$^2$ seconds. The root-mean-square fluctuation in this number is simply $\sqrt{30\times10^{16}}=5.5\times10^8$, the Bose-Einstein correction being negligible. The root-mean-square fluctuation in energy density is then $2\times10^{-11}$ watts/cm$^2$.

Thus, the system is not radiation noise limited, unless detectors can be obtained which are sensitive to a flux density of this or a lesser magnitude. At the present time, detectors which are within a factor of 3 of being limited by the radiation noise from a full hemisphere at room temperature, are laboratory curiosities. The above situation, with the entire field of view at 450°K and no care taken to shield the detector from the equipment surrounding it, provides radiation noise only 2.5 times as intense as that from a full hemisphere of room-temperature radiation.

### *System Performance*

The sensitivity of an infrared detector is commonly described in terms of its Noise Equivalent Power, or NEP. The NEP is simply that incident blackbody power just sufficient to make signal equal to noise under the test conditions chosen. The resultant sensitivity is normally reduced to a one-cycle bandwidth and unit signal-to-noise ratio. Hence, if the test blackbody temperature is $T_0$ we have $\text{NEP}_{T_0}=P/[\sqrt{\Delta B}(V)]$, where $\Delta B$ is the bandwidth, $V$ is the signal-to-noise ratio, and $P$ is the blackbody power incident on the detector. Solving this equation for $P$ and converting to peak-to-peak notation, we have

$$P = \text{NEP}_{T_0}\, 2.8\, \sqrt{\Delta B}(V). \tag{17}$$

Using (16) and (17), we may obtain an expression which will allow the prediction of the minimum observable temperature differential in the field of view.

$$(\eta_i T_i^4 - \eta_j T_j^4) = \frac{V\, \text{NEP}_{T_0}\, 2.8\sqrt{\Delta B} 4 f^2}{K\gamma s}. \tag{18}$$

It is necessary to inquire closely into the value of NEP to be used in this equation. As $T_i$ and $T_j$ become appreciably larger than the background temperature, the value of $\text{NEP}_{T_0}$ changes accordingly, due to the shift in the spectral distribution of energy at this $T_i$ or $T_j$. Thus $\text{NEP}_{T_0}$ in (18) should be replaced by $\text{NEP}_{T_1}$ to indicate improved sensitivity to higher temperature targets. Since $\text{NEP}_{T_1}$ is a function of the temperature difference being calculated, graphical or successive approximation methods must be used for accurate solutions of (18) where $T_i$ or $T_j \gg T_B$.

While using $\Delta B$ for computation is convenient when NEP values are concerned, from a system point of view the bandwidth must be related to other parameters. It may be shown that the bandwidth required is approximately $\frac{1}{2}$ the number of picture elements transmitted per second to the accuracy required here.[12] If $1/z$ is equal to the number of elements scanned per second, $\Delta B$ is equal to $\frac{1}{2}z$ or $b/2\,\mathfrak{F}$ where $b$ is the number of elements per frame and $\mathfrak{F}$ is the frame time in seconds. It is possible therefore to substitute $b^{1/2}/\mathfrak{F}^{1/2}\sqrt{2}$ for $\sqrt{\Delta B}$ in (18). Implied in the wide bandwidth required for transmission of many picture elements per second is the assumption that the detector has a sufficiently short time constant to respond to the highest frequencies.

Derivation of the equations for temperature sensitivity presumed that the scanning spot was completely opaque and that the spot moved "cleanly" from one scanned picture element to the next. As indicated previously, too short a lifetime in the scanned window causes poor blanking, while too long a lifetime may cause smearing. An associated effect, which is not treated explicitly here, arises due to the aperture admittance[13] of the scanned spot. This effect results in a loss of high frequency components of $\Delta P_s$, and in order to maintain maximum S/N ratios the high frequency response of the video amplifier must be correspondingly limited.

[11] M. E. Lasser, P. H. Cholet, and E. C. Wurst, Jr., "High-sensitivity infrared detectors," *J. Opt. Soc. Amer.*, vol. 48, pp. 468–473; July, 1958.

[12] D. G. Fink, "Principles of Television Engineering," McGraw-Hill Book Co., Inc., New York, N. Y., p. 29; 1940.

[13] V. K. Zworykin and G. A. Morton, "Television," John Wiley and Sons, Inc., New York, N. Y., p. 182; 1940.

### Experimental Results

In order to check the validity of the foregoing, an experimental version of this scanning system was built. The scanning tube (Filterscan tube No. FTS-100) is shown in Fig. 5 and the laboratory system assembly is shown in Fig. 6. In operation, this system had the following parameters:

Blanking spot area $s$, $3.1\times10^{-4}$ cm$^2$;
Raster area $A_F$, 2.24 cm$^2$;
Detector area $A_D$, 0.1 cm$^2$;
Horizontal sweep, 1 kilocycle;
Vertical sweep, 30 cycles;
Front $f$ number, 3;
Rear $f$ number, 0.75;
System bandwidth, 30 kilocycles.

A beam current of 0.5 milliampere and an anode potential of 25 kv proved sufficient to give complete blanking. The window becomes warm to the touch at this power level. Optical transmission curves for silicon[14] at elevated temperatures indicate however that the window may be operated as hot as 300°C without degrading the performance of the tube, due to thermally-induced free-carrier absorption.

Computation from the sweep rate and raster size gives a frame time $\mathcal{F}$ of $9\times10^{-2}$ seconds. The calculation of the emissivities $\eta_i$ was not attempted for the target area. The target was an aluminum hot plate surface, viewed through the aperture plate shown in Fig. 6.

Because some of the available optical elements were not optimized for this application, the resulting system was not capable of maximum performance. The optical path transmission factor K was only 0.3.

An InSb detector (Type 1SC-301) with a 300°K NEP of $1.3\times10^{-9}$ and 500°K NEP of $1.5\times10^{-10}$ was used. When this detector was used with an available transistor preamplifier, the NEP was degraded by a factor of 2. In the experimental test, the hot plate temperature was reduced until a video signal-to-noise ratio of 2 was achieved. This proved sufficient to give a readable picture of the target. The observed temperature difference corresponding to this video signal-to-noise ratio was 125°C.

When the parameters given are put into (20), the predicted observable temperature difference is 133°C. The fact that the observed difference was slightly smaller indicates that small variations from actual values were rounded off. It was of course necessary to use an appropriate NEP; in this case $NEP_{450°K}$ was used as a good approximation to the observed temperature. If $NEP_{300°K}$ had been used, the same computation gives a predicted $\Delta t = 245$°C, illustrating the fact that exact predictions of temperature sensitivity require careful choice of the NEP value to be used in the computation.

Fig. 7 shows the visible image of the target at 125°C above ambient. It appears that the assumptions made in the development of the theory are reasonable and that high-speed electronic scanning of infrared targets may be accomplished in actual practice.

[14] C. M. Phillippi and N. F. Beardsley, Wright Air Dev. Center, Dayton, Ohio, WADC Tech. Note 55-194; December, 1956.

Fig. 5—The scanner tube.

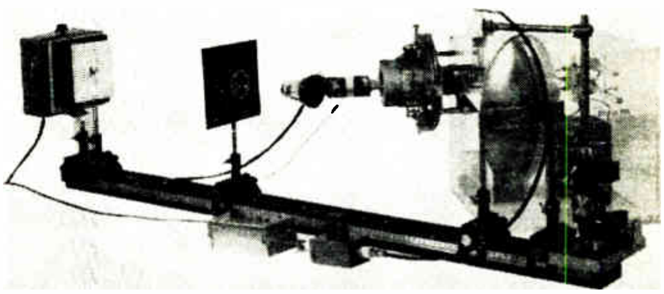


Fig. 6—Laboratory optical assembly.

Fig. 7—Oscilloscope presentation of hot plate as seen through aperture plate. Hot plate temperature = 125°C.

# Frequency Multiplication with Nonlinear Capacitors—A Circuit Analysis*

D. B. LEESON† AND S. WEINREB‡

*Summary*—**This paper presents a circuit analysis of frequency multipliers employing nonlinear capacitors. The analysis applies to the case of a multiplier of any order using semiconductor nonlinear capacitors, and specifies impedance levels, power capabilities, and efficiency in terms of the characteristics of the nonlinear element and the associated linear network. From the formulas derived it is possible to specify the optimum nonlinear characteristic for a given circuit and harmonic number, and to calculate the conditions for maximum efficiency. The procedure is also applicable to frequency dividers, and to frequency multipliers employing nonlinear inductance.**

## Introduction

The possibility of efficient frequency multiplication by means of a nonlinear reactance has received considerable attention in recent literature.[1–4] Frequency multiplication with a relatively lossless nonlinear reactance promises efficiencies far in excess of those obtainable with conventional techniques.

Page[5] has shown that the efficiency (power out/power available) for a frequency multiplier employing ideal diodes (nonlinear resistance) is limited to $1/N^2$, where $N$ is the harmonic number of interest. On the other hand, simple energy considerations, supported by the relations of Manley and Rowe,[6] show that all of the power introduced at a single fundamental frequency into a lossless nonlinear reactance must be converted into power at harmonics of the driving frequency.

Thus there exists the theoretical possibility of a lossless frequency multiplier employing nonlinear reactance, and the recently developed high-$Q$ semiconductor nonlinear capacitors provide a promising means of obtaining a relatively lossless nonlinear reactance.

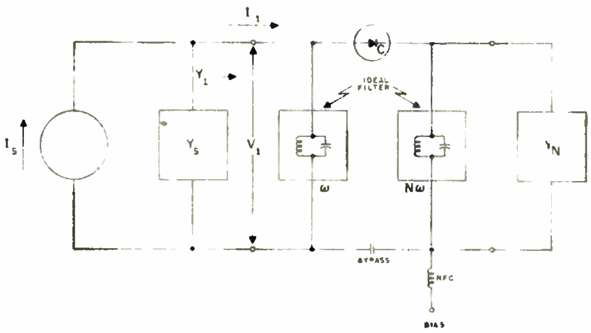



Fig. 1—The "ideal filters" are short circuits at all frequencies except the one specified. The contents of the boxes are merely examples of filters of this type.

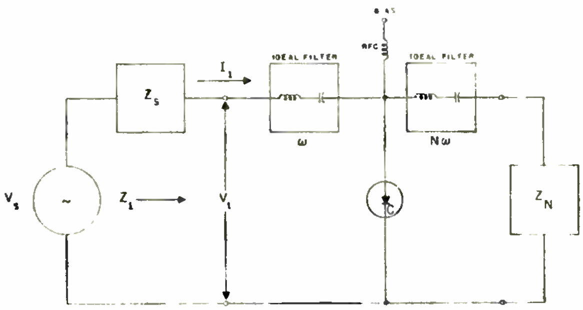



Fig. 2—The "ideal filters" are open circuits at all frequencies except the one specified. The contents of the boxes are merely examples of filters of this type.

Papers on the subject have avoided a circuit analysis, dealing instead with either general energy relations or empirical results. The one exception is a paper by Chang[3] which deals analytically with the problem of losses in some special cases.

It is the purpose of the present paper to provide a basis for design and optimization of frequency multipliers employing nonlinear capacitors. A circuit analysis of such frequency multipliers is presented (the analysis may be adapted to a large class of nonlinear elements). The impedances, efficiency, and other characteristics of the two frequency multiplier circuits of Figs. 1 and 2 are derived as a function of the capacitor characteristics and the circuit operating conditions.

### *Power Considerations*

Power conservation considerations tell us that the efficiency of a frequency multiplier can approach unity if the following conditions can be satisfied:

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[1] A. Uhlir, "The potential of semiconductor diodes in high frequency communications," Proc. IRE, vol. 46, pp. 1099–1115; June, 1958.

[2] M. M. Fortini and J. Vilms, "Solid-state microwave power source," Digest of Technical Papers, 1959 Solid-State Circuits Conference, pp. 82–85; February 12 and 13, 1959.

[3] K. K. N. Chang, "Harmonic generation with nonlinear reactances," *RCA Rev.*, vol. 19, pp. 455–464; September, 1958.

[4] C. H. Page, "Frequency conversion with nonlinear reactance," *J. Res. NBS*, vol. 58, pp. 227–236; May, 1957.

[5] C. H. Page, "Harmonic generation with ideal rectifiers," Proc. IRE, vol. 46, pp. 1738–1740; October, 1958.

[6] J. M. Manley and H. E. Rowe, "Some general properties of nonlinear elements—pt. I, general energy relations," Proc. IRE, vol. 44, pp. 904–913; July, 1956.

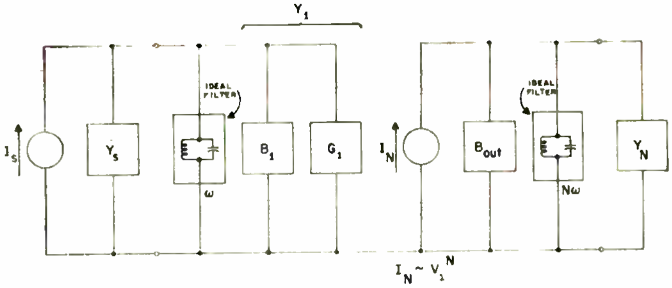


Fig. 3—Model of circuit 1.

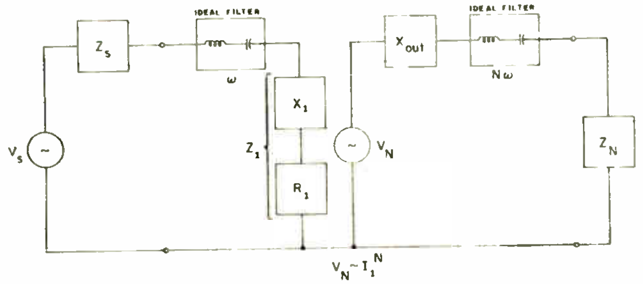


Fig. 4—Model of circuit 2.

1) The nonlinear element and associated linear circuitry are lossless.
2) Power is dissipated in the load only at the desired harmonic frequency; no power is dissipated in the source at any harmonic frequency.
3) The source is conjugate matched at the fundamental frequency.

The analysis will begin assuming that conditions 1 and 2 are met; the consequences of lossy elements and unwanted harmonic dissipation will be considered at a later time. Condition 1 can be met reasonably well with presently available nonlinear capacitors at frequencies below tens of kilomegacycles. Condition 2 can conceivably be met through the use of filters in circuits such as shown in Figs. 1 and 2 (although more sophisticated filters than the simple prototypes shown may be required). The initial concern of this paper will be to state how condition 3 can be met, given ideal filters and reactances, the $Q$-$V$ (charge vs voltage) characteristics of the nonlinear capacitor, the circuit configuration, the signal level, and the load impedance at the desired harmonic.

## Analysis

The analysis derives from Figs. 1 and 2 the circuit models of Figs. 3 and 4, assuming lossless, small-signal operation. The more general case of lossy, large-signal operation will be considered later.

The $Q$-$V$ relationship of the nonlinear element can be expressed in either of the following two functional forms:

$$Q = Q(V) \tag{1}$$

or

$$V = V(Q). \tag{2}$$

The charge $Q$ can be expressed as

$$Q = Q_0(1 + q) \tag{3}$$

where $Q_0$ is the dc operating point and $q$ is the normalized ac component of the charge. Similarly, we can let

$$V = V_0(1 + v) \tag{4}$$

where $V_0$ is the dc operating point, and $v$ is the normalized ac component of voltage. For this analysis, $q$ and $v$ are small with respect to unity.

$Q(V)$ and $V(Q)$ may be approximated in this small-signal case by Taylor series expansions about the zero-signal operating point. Thus,

$$Q(V) = Q_0[1 + \alpha_1 v + \alpha_2 v^2 + \alpha_3 v^3 + \cdots] \tag{5}$$

and

$$V(Q) = V_0[1 + \beta_1 q + \beta_2 q^2 + \beta_3 q^3 + \cdots] \tag{6}$$

where

$$\alpha_k = \frac{V_0^k}{Q_0 k!} \frac{d^k Q}{dV^k}\bigg|_{V=V_0} \tag{7}$$

and

$$\beta_k = \frac{Q_0^k}{V_0 k!} \frac{d^k V}{dQ^k}\bigg|_{Q=Q_0}. \tag{8}$$

Eqs. (3)–(6) can be combined to yield the relations

$$q = \sum_{k=1}^{\infty} \alpha_k v^k \tag{9}$$

and

$$v = \sum_{k=1}^{\infty} \beta_k q^k. \tag{10}$$

These are the general relations of normalized ac charge and voltage in the nonlinear element. Current is determined by taking the time derivative of charge.

Let us make use of (9) to obtain the charge on the nonlinear element in terms of the voltage; a dual analysis employs (10) to solve for the voltage in terms of the charge.

The normalized ac variables will be represented throughout by their complex Fourier series

$$q = \sum_{\substack{n=-\infty \\ n\neq 0}}^{\infty} q_n \epsilon^{jn\omega t}; \quad i = \sum_{\substack{n=-\infty \\ n\neq 0}} i_n \epsilon^{jn\omega t} = \sum_{\substack{n=-\infty \\ n\neq 0}} jn\omega q_n \epsilon^{jn\omega t};$$

$$v = \sum_{\substack{n=-\infty \\ n\neq 0}}^{\infty} v_n \epsilon^{jn\omega t} \tag{11}$$

where $\omega$ is the fundamental driving radian frequency.

In these series $v_{-n}=v_n^*$ and $q_{-n}=q_n^*$ because the actual voltages and charges are real physical quantities. Further, it should be remembered that if one of the variables were to be put in the trigonometric form $v=v_{\text{trig}}\cos(n\omega t+\lambda)$, then $|v_{\text{trig}}|=|v_n|+|v_{-n}|=2|v_n|$.

The quantities $v^k$ appearing in (9) can be represented by their respective complex Fourier series in the following manner:

$$v^2 = \sum_{n=-\infty}^{\infty} (v^2)_n \epsilon^{jn\omega t} \quad \text{where} \quad (v^2)_n = \sum_{\substack{j,l=-\infty \\ j+l=n}}^{\infty} v_j v_l$$

$$v^3 = \sum_{n=-\infty}^{\infty} (v^3)_n \epsilon^{jn\omega t} \quad \text{where} \quad (v^3)_n = \sum_{\substack{j,l,m=-\infty \\ j+l+m=n}}^{\infty} v_j v_l v_m. \tag{12}$$

and so on. Note that all possible permutations must be considered in the calculation of one of the Fourier coefficients. $(v^k)_n$ is the sum of all combinations of products of $k$ voltages whose indices add up to $n$.

We insert these series for $v^k$ into (9), and by equating terms of equal frequency we can find $q_n$, given all of the $v_n$. In the general case the process is prohibitively complicated, but there are some simplifications which can be made in the case of a frequency multiplier of order $N$.

Eq. (9) is solved by allowing only fundamental and $N$th harmonic voltage to be present ($v_{\pm1}$, $v_{\pm N}\neq0$, all others zero as is the case in Fig. 1) in a frequency multiplier of order $N$. This allows us to calculate the value of $(v^k)_n$ in terms of $v_{\pm1}$ and $v_{\pm N}$ only; with the introduction of the load constraint, $i_N=jN\omega q_N=-v_N y_N$ (where $y_N$ is the normalized load admittance at the $N$th harmonic) we can then calculate $q_1$ and $q_N$ in terms of $v_1$, which is the immediate object of the analysis. Note that we are not interested in any other frequency components of $q$; further, we are not interested in $q_{-1}$ and $q_{-N}$ since these are simply the complex conjugates of the quantities of interest.

If we choose to specify charge rather than voltage as the independent variable, we then employ a similar procedure to solve (10). Eq. (10) is solved in the same manner as (9), except that now we limit the possible frequencies for $q$ rather than $v$, use the load constraint $v_N=-i_N z_N=-jN\omega q_N z_N$ (where $z_N$ is the normalized load impedance at the $N$th harmonic), and substitute the series expansions for $q^k$ (which are the dual of those for $v^k$) into (10) to solve for $v_1$ and $v_N$ in terms of $q_1$. This analysis pertains to Fig. 2.

Any nonlinear element whose characteristics can be put in the form of (9) or (10) can be treated in the manner of this analysis.

### *Small-Signal Approximations*

One last important simplification is necessary before the solution may be readily obtained. If we follow the procedure outlined in the previous section we get an expression for $q_N$, which is of the form

$$q_N = \alpha_1 v_N + \alpha_2 \sum_{\substack{j+l=N \\ |j|,|l|=1 \text{ or } N}} v_j v_l + \alpha_3 \sum_{\substack{j+l+m=N \\ |j|,|l|,|m|=1 \text{ or } N}} v_j v_l v_m + \cdots. \tag{13}$$

We can now show that, for the small-signal case, only the first and $N$th terms of (13) need be considered.

Consider the summations in each term of (13). Since the only voltages present are $v_{\pm1}$ and $v_{\pm N}$, these summations contain only terms of the following two types:

$$1)\quad v_N\{(v_1v_{-1})^a(v_Nv_{-N})^b(v_Nv_{-1}{}^N)^c(v_{-N}v_1{}^N)^d\}$$

where $a$, $b$, $c$, $d$ are positive integers or zero and $2a+2b+(N+1)c+(N+1)d+1=k$. Note that $c$ and $d$ are zero here for $k<N+2$.

$$2)\quad v_1{}^N\{(v_1v_{-1})^a(v_Nv_{-N})^b(v_Nv_{-1}{}^N)^c(v_{-N}v_1{}^N)^d\}$$

where $a$, $b$, $c$, $d$ are positive integers or zero (not necessarily the same as above) and $2a+2b+(N+1)c+(N+1)d+N=k$. Note that here $c$ and $d$ are zero for $k<2N+2$.

The quantities $(v_1v_{-1})$, $(v_Nv_{-N})$, and $\alpha_k$ are positive real. Inspection will reveal that all coefficients of $v_N$ for $k<N+2$ are positive real, and all coefficients of $v_1{}^N$ for $k<2N+2$ are positive real. We can write (13) in the form

$$q_N = Av_N + Bv_1{}^N \tag{14a}$$

where we have neglected higher order ($k>N+2$ for $A$, $k>2N+2$ for $B$) contributions to $A$ and $B$; thus, they are positive real quantities.

The current ($i_N=jN\omega q_N$) due to the first term of (14a) is in quadrature with $v_N$. This means that this term does not contribute to the exchange of power at the $N$th harmonic frequency; rather, it represents a reactance. The second term, on the other hand, represents an independent current source; it is this term which accounts for the power transferred to the $N$th harmonic.

In a small-signal analysis we need consider only the lowest order contribution to the factors $A$ and $B$. Thus the "reactive" term becomes $\alpha_1 v_N$, which is the first term of the Taylor series (9). The largest term of the "generator" type results from the $N$th term of the Taylor series (9), and is the quantity $\alpha_N v_1{}^N$. The remaining portions of the factors $A$ and $B$ are composed of quantities which are of higher order in the small-signal variables; in a small-signal analysis these may be neglected.

In the dual case where we specify the charges and solve for the voltages, a similar argument applies. Thus we conclude that only the first and $N$th terms of the appropriate Taylor series (9) or (10) need be considered in the case of a frequency multiplier of order $N$.

Using this simplification we can reduce the first and $N$th frequency components of (9) and (10) to a small number of terms, and can complete the analysis.

*Circuit Equations*

Let us solve first the case for which (9) is appropriate. This case, which corresponds to Figs. 1 and 3, involves the solution for the various charges in terms of the driving voltage $v_1$.

For this case, (9) is simplified to

$$q = \alpha_1 v + \alpha_N v^N. \tag{14b}$$

The term $v^N$ is replaced by its complex Fourier series (12).

The two frequency components of (14) which are of interest are

$$q_1 = \alpha_1 v_1 + \alpha_N (v^N)_1 \tag{15}$$

and

$$q_N = \alpha_1 v_N + \alpha_N (v^N)_N. \tag{16}$$

Separating (15) and (16) into real and imaginary parts and making small-signal approximations, we obtain the four equations which arise from (14). We let $v_1 = v_{-1}$ for convenience; this amounts to specifying the heretofore arbitrary time origin. There is no loss of generality by specifying $v_1$ real.

$$q_{1_r} = \alpha_1 v_1 \tag{17}$$

$$q_{1_i} = N\alpha_N v_1^{N-1} v_{N_i} \tag{18}$$

$$q_{N_r} = \alpha_1 v_{N_r} + \alpha_N v_1^N \tag{19}$$

$$q_{N_i} = \alpha_1 v_{N_i}. \tag{20}$$

The subscripts $r$ and $i$ signify real and imaginary components, respectively

Expanding the load constraint $q_N = -v_N y_N / jN\omega$ into real and imaginary parts yields

$$q_{N_r} = -\frac{1}{N\omega}\left[b_N v_{N_r} + g_N v_{N_i}\right] \tag{21}$$

$$q_{N_i} = \frac{1}{N\omega}\left[g_N v_{N_r} - b_N v_{N_i}\right] \tag{22}$$

where $g_N$ and $b_N$ are the components of $y_N$, the load admittance.

We can solve (19)–(22) for $v_{N_i}$ which appears in (18)

$$v_{N_i} = -\alpha_N v_1^N \left\{ \frac{\dfrac{g_N}{N\omega}}{\left(\dfrac{g_N}{N\omega}\right)^2 + \left(\alpha_1 + \dfrac{b_N}{N\omega}\right)^2} \right\}. \tag{23}$$

At this point it is possible to calculate the input admittance of the model of Fig. 3. The normalized admittance is

$$y_1 = \frac{i_1}{v_1} = \frac{j\omega q_1}{v_1} = \frac{-\omega q_{1_i}}{v_1} + \frac{j\omega q_{1_r}}{v_1}$$

$$= N\omega\alpha_N^2 v_1^{(2N-2)} \left\{ \frac{\dfrac{g_N}{N\omega}}{\left(\dfrac{g_N}{N\omega}\right)^2 + \left(\alpha_1 + \dfrac{b_N}{N\omega}\right)^2} \right\} + j\omega\alpha_1. \tag{24}$$

If the output is resonated (*i.e.*, if $\alpha_1 + b_N/N\omega = 0$), then the input conductance is the simpler form

$$g_1 = \frac{N^2\omega^2}{g_N}\alpha_N^2 v_1^{(2N-2)}. \tag{25}$$

Eqs. (24) and (25) are normalized expressions for the input parameters of the equivalent circuit of Fig. 3.

In the case corresponding to Figs. 2 and 4, (10) is appropriate. Here we solve for the various voltages in terms of the driving charge $q_1$.

For this case (10) becomes

$$v = \beta_1 q + \beta_N q^N \tag{26}$$

where the term

$$q^N = \sum_{n=-\infty}^{\infty} (q^N)_n \epsilon^{jn\omega t}; \quad (q^N)_n$$

is evaluated as in (12).

The two frequency components of (26) which are of interest are

$$v_1 = \beta_1 q_1 + \beta_N (q^N)_1 \tag{27}$$

$$v_N = \beta_1 q_N + \beta_N (q^N)_N. \tag{28}$$

We can let $q_1 = q_{-1}$ ($q_1$ = real) without any loss of generality. Separating (27) and (28) into real and imaginary parts and making small-signal approximations we obtain

$$v_{1_r} = \beta_1 q_1 \tag{29}$$

$$v_{1_i} = N\beta_N q_1^{N-1} q_{N_i} \tag{30}$$

$$v_{N_r} = \beta_1 q_{N_r} + \beta_N q_1^N \tag{31}$$

$$v_{N_i} = \beta_1 q_{N_i}. \tag{32}$$

The load constraint, $v_N = -i_N z_N = -jN\omega q_N z_N$, is expanded into real and imaginary parts to yield

$$v_{N_r} = N\omega(x_N q_{N_r} + r_N q_{N_i}) \tag{33}$$

$$v_{N_i} = -N\omega(r_N q_{N_r} - x_N q_{N_i}) \tag{34}$$

where $r_N$ and $x_N$ are the components of $z_N$.

We can solve (31)–(34) for $q_{N_i}$ which appears in (30):

$$q_{N_i} = \beta_N q_1^N \left\{ \frac{N\omega r_N}{(N\omega r_N)^2 + (\beta_1 - N\omega x_N)^2} \right\}. \tag{35}$$

Here it is possible to calculate the input impedance of the model of Fig. 4. The normalized impedance is

$$z_1 = \frac{v_1}{i_1} = \frac{-jv_1}{\omega q_1} = \frac{v_{1_i}}{\omega q_1} - j\frac{v_{1_r}}{\omega q_1}$$

$$= \frac{N\beta_N^2 q_1^{2N-2}}{\omega}\left\{ \frac{N\omega r_N}{(N\omega r_N)^2 + (\beta_1 - N\omega x_N)^2} \right\} - j\frac{\beta_1}{\omega}. \tag{36}$$

If the output is resonated (*i.e.*, if $\beta_1 = N\omega x_N$), then the input resistance becomes

$$r_1 = \frac{\beta_N^2}{\omega^2 r_N} q_1^{2N-2} = \frac{\beta_N^2}{\omega^{2N} r_N} i_1^{2N-2}. \tag{37}$$

If the reactive term of (36) is canceled by series tuning, and the output circuit is resonated as in (37), then the conditions of Fig. 5 apply, and we can write the input resistance as a function of $v_1$ rather than $i_1$. Using the fact that $v_1 = i_1 r_1$, and substituting, we have

$$r_1 = \frac{1}{\omega}\left(\frac{\beta_N^2}{r_N\omega}\right)^{1/(2N-1)}(v_1)^{(2N-2)/(2N-1)}. \tag{38}$$

These last three expressions are normalized expressions for the input parameters of the equivalent circuit of Fig. 4.

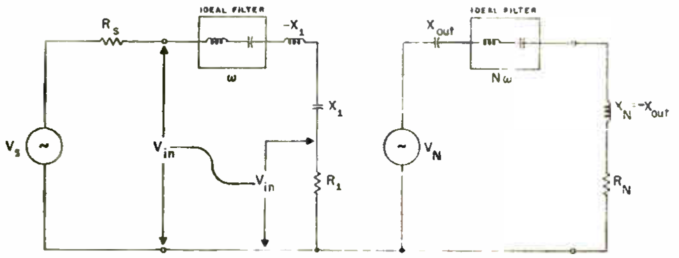


Fig. 5—Equivalent circuit at resonance. The additional elements $-x_1$ and $-x_{out}$ result in resonance.

*Semiconductor Nonlinear Capacitor*

Let us now see how this generalized, normalized analysis applies to the case of a frequency multiplier employing a semiconductor nonlinear capacitor (varactor). The small-signal capcitance of the element is taken to be

$$C(V) = \frac{dQ}{dV} = \frac{C_1}{(V+\phi)^\gamma} \tag{39}$$

where $V$ is the terminal voltage, $\phi$ is the "contact potential" of the junction, $C_1$ is the value of the capacitance for $(V+\phi)=1$ volt ($C_1$ has units of farad-volt$^\gamma$), and $0<\gamma<1$.

Integrating this gives the $Q$-$V$ characteristics of the element

$$Q = \frac{C_1}{1-\gamma}(V+\phi)^{1-\gamma} \tag{40}$$

where the constant of integration has been absorbed in $Q$.

Separating the variables into static and ac components, $Q = Q_0 + Q_{ac}$ and $V+\phi = V_0 + V_{ac}$, and setting the ac components equal to zero, we have the following relation between the dc operating points:

$$Q_0 = \frac{C_1 V_0^{1-\gamma}}{1-\gamma} \equiv \frac{C_0 V_0}{1-\gamma}. \tag{41}$$

$V_0$ is the total bias voltage (terminal voltage plus contact potential), and $C_0 = C_1/V^\gamma$, which is the capacitance of the element at bias voltage $V_0$.

Note that if $V_{ac}$ should exceed $V_0$, the diode forming the capacitor would conduct over part of the period. Should this occur, the circuit would presumably be subject to the limitations set forth by Page[5]; at any rate the mode of operation changes, and the device is no longer used purely as a high-$Q$ capacitor. Thus, for operation in the capacitive mode analyzed here, $V_{ac}$ cannot exceed $V_0$.

The Taylor series coefficients (7) and (8) are

$$\alpha_k = \frac{1}{k!}\{[(1-\gamma)][(1-\gamma)-1][(1-\gamma)-2] \cdots [(1-\gamma)-k+1]\} \tag{42}$$

and

$$\beta_k = \frac{1}{k!}\left\{\left[\left(\frac{1}{1-\gamma}\right)\right]\left[\left(\frac{1}{1-\gamma}\right)-1\right]\left[\left(\frac{1}{1-\gamma}\right)-2\right] \cdots \left[\left(\frac{1}{1-\gamma}\right)-k+1\right]\right\} \tag{43}$$

for this case. These can be put in gamma function form if convenient.

We can now "un-normalize" the expressions obtained earlier for the input parameters of the equivalent circuits. We use the following relationships:

$$v_n = \frac{V_n}{V_0}$$

$$q_n = \frac{Q_n}{Q_0} = \frac{Q_n(1-\gamma)}{C_0V_0} = \frac{I_n(1-\gamma)}{\omega C_0 V_0}$$

$$|V_{in}| = 2|V_1|; \qquad |I_{in}| = 2|I_1|$$

$$z_n = \frac{v_n}{i_n} = \frac{C_0}{1-\gamma}Z_n; \qquad y_n = \frac{1-\gamma}{C_0}Y_N$$

where upper case letters indicate actual quantities and lower case letters are normalized quantities. $V_{in}$ and $I_{in}$ are the peak values of the input voltage and current.

The input admittance of Fig. 1, (24), becomes

$$Y_1 = \omega C_0 \frac{N^2\alpha_N^2}{(1-\gamma)^2 2^{2N-2}}\left(\frac{V_{in}}{V_0}\right)^{2N-2} \cdot \left\{\frac{\dfrac{G_N}{N\omega C_0}}{\left(\dfrac{G_N}{N\omega C_0}\right)^2 + \left(1+\dfrac{B_N}{N\omega C_0}\right)^2}\right\} + j\omega C_0. \tag{44}$$

If the output circuit is resonated, we have, from (25)

$$G_1 = \omega C_0 \frac{\alpha_N^2 N^2}{(1-\gamma)^2 2^{2N-2}}\left(\frac{V_{in}}{V_0}\right)^{2N-2}\left(\frac{\omega C_0}{G_N}\right). \tag{45}$$

The input impedance of Fig. 2, (36), becomes

$$Z_1 = \frac{1}{\omega C_0}\frac{N\beta_N^2(1-\gamma)^{2N}}{2^{2N-2}}\left(\frac{I_{in}}{\omega C_0 V_0}\right)^{2N-2} \cdot \left\{\frac{N\omega C_0 R_N}{(N\omega C_0 R_N)^2 + (1 - N\omega C_0 x_N)^2}\right\} - j\frac{1}{\omega C_0}. \tag{46}$$

For the case of resonant output, we have

$$R_1 = \frac{1}{\omega C_0} \frac{\beta_N^2(1-\gamma)^{2N}}{2^{2N-2}} \left(\frac{I_{in}}{\omega C_0 V_0}\right)^{2N-2} \frac{1}{\omega C_0 R_N} \cdot \quad (47)$$

In the special case of series resonant input and output, the input resistance of Fig. 2 is

$$R_1 = \frac{1}{\omega C_0} \frac{(1-\gamma)\left[(1-\gamma)\beta_N^2\right]^{1/(2N-1)}}{2^{(2N-2)/(2N-1)}} \left(\frac{V_{in}}{V_0}\right)^{(2N-2)/(2N-1)} \left(\frac{1}{\omega C_0 R_N}\right)^{1/(2N-1)} \cdot \quad (48)$$

Note that these contain information about the nonlinear element ($\gamma$, $\alpha$, $\beta$, $C_0$), the signal and bias level ($V_{in}/V_0$, $I_{in}/V_0$), and the external circuit and load ($R_N$, $X_N$, $G_N$, $B_N$). Note that $1/\omega C_0$ is the no-signal reactance at the fundamental frequency of the nonlinear capacitor.

A case of particular interest is that of the frequency doubler. In this case (45) becomes

$$G_1 = \omega C_0 \frac{\gamma^2}{4} \left(\frac{V_{in}}{V_0}\right)^2 \left(\frac{\omega C_0}{G_2}\right) \quad (49)$$

and (48) becomes

$$R_1 = \frac{1}{\omega C_0} \left(\frac{\gamma}{4}\right)^{2/3} \left(\frac{V_{in}}{V_0}\right)^{2/3} \left(\frac{1}{\omega C_0 R_2}\right)^{1/3}. \quad (50)$$

These equations may be employed to design a frequency doubler of the type of Fig. 1 or Fig. 2.

### *Large-Signal Validity*

It is reasonable to inquire whether the analysis is valid in the large-signal case. In order to aid the thinking of the reader on the point of signal magnitude, it should be mentioned again that the signal voltage cannot exceed the total bias voltage, $V_0$, if operation in a purely capacitive mode is to be maintained, *i.e.*, if conduction is to be prevented. Since the magnitudes of the complex Fourier coefficients are equal to one-half the magnitudes of the actual voltages, the normalized voltage coefficients cannot exceed one-half.

Inspection of the various assumptions and approximations made in the analysis will show that for $v_1$ and $v_N$ of magnitude one-quarter, for example, all of the approximations are extremely good. It is reasonable to expect that there should be no appreciable error involved in applying the small-signal results at any signal level likely to be encountered in frequency multipliers employing semiconductor nonlinear capacitors in a purely capacitive mode.

Experimental data will be seen to support this conclusion. Even with the junction on the verge of conduction, it is felt that the relationships derived in the earlier sections will certainly serve to indicate the order of magnitude of impedance or admittance one could expect in a given application.

## Losses

We come now to the question of losses. As mentioned previously, losses can arise from one of two sources. There are 1) resistive losses in the nonlinear element and its associated filters, and 2) losses in the source and load at unwanted frequencies.

Let us first treat losses due to non-ideal elements. The equivalent circuit of Fig. 6 will apply. The losses will be calculated for one circuit configuration, and the losses for the other are simply derived from the dual analysis.

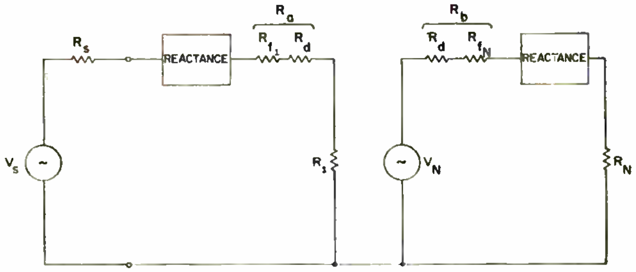


Fig. 6—Equivalent circuit for losses.

$R_a$, the resistance appearing in the input circuit (in addition to $R_1$), is the sum of the filter series equivalent resistance, $R_{f_1}$, and the diode equivalent series resistance, $R_d$. Any shunt losses in the diode must be transformed to their series equivalent.

The power dissipated in the actual equivalent input resistance $R_1$ is $P_1$, and the input power to the whole circuit is $P_{in}$.

From simple circuit relations

$$\frac{P_{in}}{P_1} = 1 + \frac{R_a}{R_1} \cdot \quad (51)$$

Similarly, on the output side,

$$\frac{P_1}{P_N} = 1 + \frac{R_b}{R_N} \quad (52)$$

where $R_b$ represents the losses on the output side of the circuit. $P_N$ is the power at the $N$th harmonic reaching the load.

Combining the two relations, we obtain

$$\frac{P_{in}}{P_N} = \left(1 + \frac{R_a}{R_1}\right)\left(1 + \frac{R_b}{R_N}\right). \quad (53)$$

In calculating the value of $R_1$ in the lossy case, we must include $R_b$ in the load resistance at the $N$th harmonic. If the filters used are good enough so that all other frequency components may be neglected, then (53) may be used to calculate the efficiency to be expected in the frequency multiplier.

In the dual case, the same calculation can be made using $G_1$, $G_N$, $G_a$, and $G_b$.

The other source of loss—dissipation at unwanted frequencies—may be made negligible in some cases by the use of appropriate realizable filters. If loss of this second type must be considered, it may be calculated by the following procedure.

The load impedance at the unwanted harmonic(s) may be calculated or measured. This impedance is then used to calculate the equivalent input resistance or conductance of the multiplier, assuming it to be operating only to the unwanted harmonic under consideration. This additional loss may then be included in $R_a$ or $G_a$ (since even in a nonlinear circuit we may add real power and can indicate the total loss by a resistance or conductance). The additional losses due to dissipation at harmonics other than the desired one may thus be taken into account approximately.

## Experimental Verification

Experimental verification of the relationships derived has been carried out with the circuits shown in Figs. 7 and 8. The data obtained with frequency doublers are presented in Figs. 9 and 10.

In the case of Fig. 9, which corresponds to the circuit of Fig. 7, no input filter was employed, as the bridge had a very low impedance at all frequencies. The input admittance of the frequency multiplier was measured as a function of the output resistance and the signal level. The efficiency in this case was calculated from the voltage and admittance measurements obtained, and the power gain $G_p$ was of the order of $-0.7$ db. The curve "corrected for loss" includes fundamental loss, $G_{loss_1}$, in parallel with $R_1$.

Fig. 10 is a plot of input resistance vs signal level for the circuit of Fig. 8. The calculated resistance is derived from (50), including $R_b$ in the output resistance and adding $R_a$ to the input resistance calculated. $R_a$ and $R_b$ were measured and found to be approximately 22 ohms for the particular circuit. The efficiency was calculated to be $-1.1$ db and the measurements corroborated this

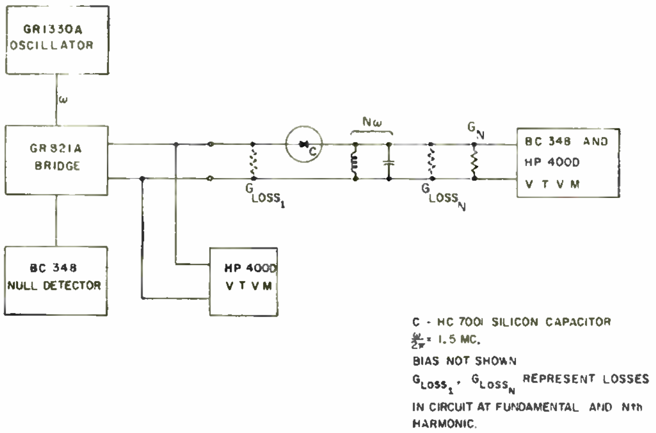


Fig. 7.

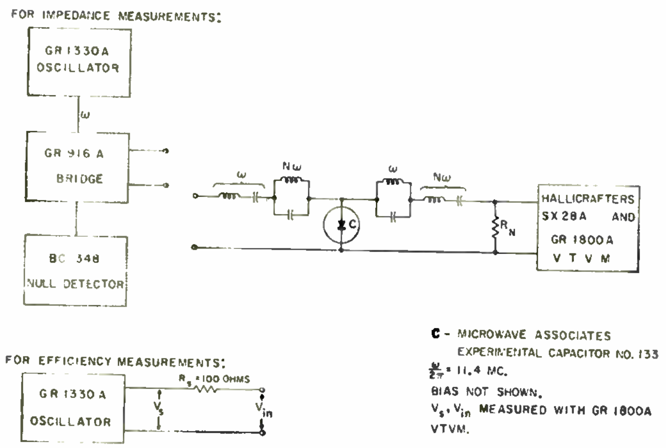


Fig. 8.

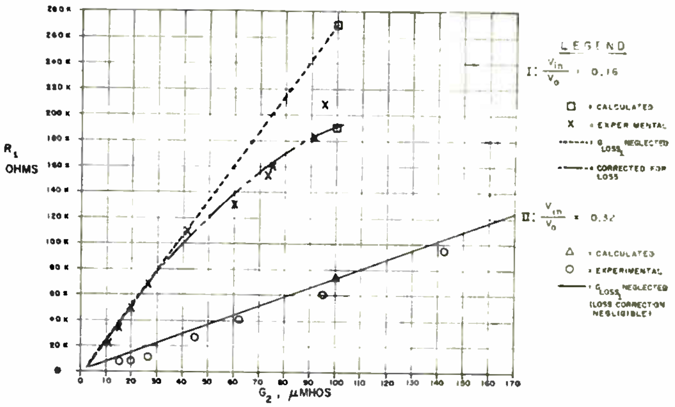


Fig. 9—Input resistance of Fig. 7 vs output conductance.

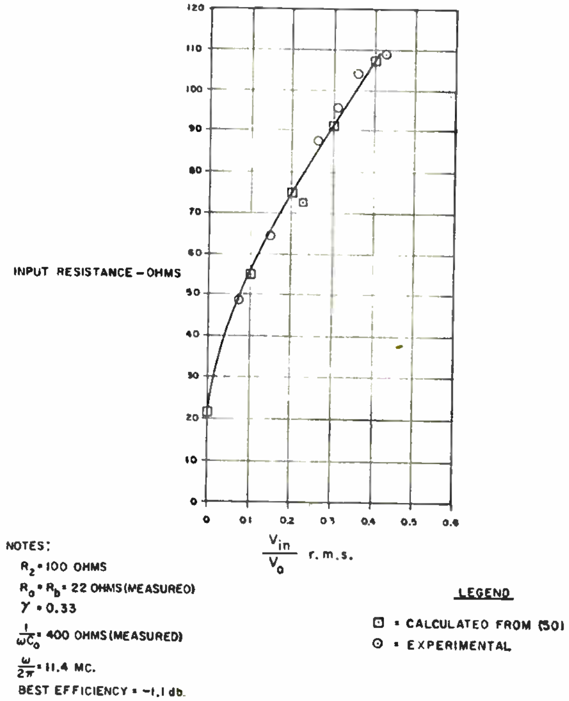


Fig. 10—Input resistance of Fig. 8 vs signal level.

figure (this efficiency is transducer gain or power out divided by power available from the source).

This experimental work was performed at low frequencies to facilitate both construction and measurement.

## Conclusions

The circuit equations and impedance relationships derived should help to clear the picture of frequency multiplication with nonlinear reactance. They can be used in the design of frequency multipliers at any frequency and, presumably, of any order.

A few thoughts about maximizing efficiency of a given circuit are now in order. Let us consider the circuit of Fig. 2; our remarks will apply in dual form to that of Fig. 1. The maximum efficiency occurs when $R_1$ and $R_N$ are large with respect to the equivalent loss resistances $R_a$ and $R_b$ (see Fig. 6). Generally, one would not choose $R_N$ such that losses in the output circuit are intentionally high. Given a reasonable $R_N$, the problem is attaining a suitably large $R_1$. Inspection of the formulas for $R_1$ will reveal that this is not always possible; in particular, it is difficult for very small signal levels, and it is difficult if the appropriate Taylor series co-coefficient, $\alpha$ or $\beta$, is small. Further, it becomes increasingly difficult with increasing $N$; that is, with increasing multiplication order.

From the expressions for $R_1$ we conclude that it is generally desirable to operate with a signal fairly large with respect to the bias voltage (although not exceeding it, of course).

Considering the fact that a large $N$th Taylor series coefficient is desirable, one may determine what type of nonlinearity is best for a given application. A $Q$-$V$ relationship which provides the largest possible $N$th Taylor coefficient is optimum from the standpoint of efficiency in a practical circuit.

It may also be determined that certain harmonics may not be obtained with particular characteristics and circuit configurations. For example, a capacitance of the form $C=C_1/(V+\phi)^{1/2}$ will generate no harmonics higher than the second in the circuit of Fig. 2 since all of the higher order Taylor coefficients are zero.

From the impedance equations it is also clear that $R_1$ is maximized for the condition of the output circuit resonant. This condition is particularly convenient to implement since it is desirable to resonate the load with the capacitance of the nonlinear element in order to form the required output filter.

The case of very high order frequency multiplication is interesting to consider. Considerable difficulty has been experienced in constructing efficient multipliers of order 100, for example. The efficiencies reported,[7] although they represent a material improvement in the state of the art, are not significantly different from the Page limitation of $1/N^2$ (40 db for $N=100$). This endeavor is hampered, of course, by filter limitations.

Considering again the circuit of Fig. 2, we see that for high order multiplication the product of $R_1$ and $R_N$ becomes quite small. This means that for a reasonable $R_N$ one must suffer an $R_1 \ll R_a$, with the resulting severe losses (or if $R_1$ is reasonable, then $R_N \ll R_b$). Note that the minimum value of load seen by the circuit is $R_b$; that is, in the lossy case we must include $R_b$ in the load resistance for the purposes of calculating $R_1$.

Some calculations based on an input and output filter $Q$ of 50 (unloaded, but including varactor $Q$), optimum source and load $\gamma=\frac{1}{2}$, and input and output resonant yield the data presented in Fig. 11. Note that for higher order multipliers the nonlinear resistive mode may be more efficient than the capacitive mode; the efficiency of the capacitive mode in this circuit environment drops approximately 6 db per *harmonic* rather than 6 db per *octave*. It is the feeling of the authors that the explanation for the lower-than-expected efficiencies reported in higher-order multipliers (it had been hoped by some that the efficiency of a higher-order reactive multiplier might approach unity) may be that in these practical, lossy situations the capacitive effect does not predominate over the "diode" effect. The presence of nonlinear reactance may enhance the efficiency, but it seems that higher-order multipliers presently constructed operate predominantly in the nonlinear resistive, or switching, mode. It would appear unwarranted

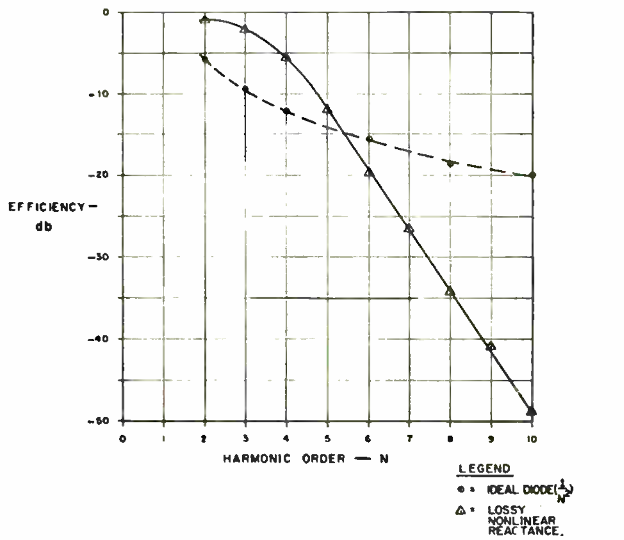


Fig. 11—Calculated loss vs harmonic number. $1/N^2$ plotted for comparison. The optimum efficiency for a typical lossy semiconductor nonlinear capacitor frequency multiplier is compared with the efficiency of a *lossless* ideal rectifier. The optimum efficiency has been calculated for the case of an abrupt junction nonlinear capacitor, $V_1/V_0=\frac{1}{2}$, input and output unloaded $Q=50$, and the circuit of Fig. 1.

[7] C. L. Searle, M.I.T., Cambridge, Mass., D. R. Holcomb, Hughes Aircraft Co., Culver City, Calif., and others, private communication; April 15, 1959.

to expect higher-order multiplier efficiencies greatly in excess of the Page ideal-diode limitation.

Note, however, that the equations and relations in this paper allow one to design quite good doublers, triplers, and other lower order multipliers (the filter requirements are much less stringent in these cases). It is not unreasonable to assume that six of the doublers of Fig. 8 could be cascaded to give a multiplication of 64 with a loss of some 6 or 7 db. This method may well prove superior to a single multiplier of high order, despite a rather higher complexity and component count.

The maximum power which can be handled may be limited by one of two factors. These are: the voltage across the nonlinear capacitor cannot exceed the total bias voltage or breakdown voltage, and the $I^2R$ losses in the varactor must remain below a certain minimum. In general, the power which can be handled by the frequency multiplier is greater for lower impedance circuits. The configuration of Fig. 2 has the advantage in this respect. The doubler of Fig. 8 has been capable of handling several hundred milliwatts without reduced efficiency.

As pointed out earlier, the circuit equations apply equally well to frequency dividers. With an interchange of source and load constraints, the divider circuit may be described.

ACKNOWLEDGMENT

The authors wish to acknowledge the support of Prof. C. L. Searle who supervised the research. The valuable comments of Prof. S. J. Mason, Prof. W. M. Siebert and R. P. Rafuse were also greatly appreciated.

# CORRECTION

The following correction should be noted in "IRE Standards on Navigation Aids: Direction Finder Measurements, 1959," which appeared on pages 1349–1371 of the August, 1959, issue of PROCEEDINGS.

Section 1.1.4.6, page 1358. The equation in this Section should be as follows:

$$\underset{\text{(Meters)}}{\text{Pick Up Factor}} = \frac{\begin{bmatrix}\text{Field Strength of}\\ \text{Section 1.1.4.5}\end{bmatrix}\begin{bmatrix}\dfrac{\text{Effective Height of Dipole of Section 1.1.4.6}}{2}\end{bmatrix}\begin{bmatrix}1-\dfrac{R_{\text{series}}\text{ of Section 1.1.4.4}}{\text{Dipole Cable Impedance}}\end{bmatrix}}{\text{Field Strength of Section 1.1.4.1}}$$

# Operating Characteristics of an Ammonia Beam Maser*

FRANK S. BARNES†

*Summary*—**This paper describes the operating characteristics of an ammonia beam maser. The simple theory for the operation is expanded to predict the angular distribution of the molecules coming from the beam collimator and the effect of the focuser on the velocity distribution of the molecules entering the cavity.**

**Experimental results for the operation of the cavity in the $TM_{011}$ and $TM_{012}$ mode show the effects of the variation in beam current and cavity tuning on the frequency and amplitude of oscillation. Relating these results to the theory with the help of measurements of the beam flux density demonstrates the importance of molecular collisions and the beam divergence. Three methods of locating line center are examined, and it is shown that the line centers obtained in each case may be varied over a range of at least 5 parts in $10^8$ by changing the operating parameters.**

## Introduction

The ammonia beam oscillator is the first of a new group of devices which makes use of the internal energy of a molecule as a source of microwave power. In this device, a beam of ammonia molecules travels through a large inhomogeneous focusing field to a cavity which is resonant at the transition frequency of a molecule. The focusing field separates the molecules so that more molecules in high energy levels than in low energy levels enter the cavity. Therefore, more molecules radiate than absorb energy, and the beam becomes a source of microwave power.

The sharpness and reproducibility of the molecular energy levels make the coherent radiation in the maser cavity a useful source of microwave power for a very stable oscillator. Recently, short term stabilities of about 2 parts in $10^{12}$ have been measured at the Watson Laboratories [16] and long term stabilities of better than 2 parts in $10^{11}$ have been measured at the National Bureau of Standards [33] for periods of six hours.

The first operating maser was constructed by Townes and his associates at Columbia University in 1954 [23], [24]. Shortly after this, Helmer, at Stanford [25a], constructed the two masers on which the measurements described in this paper were made. The objectives of the present study were to examine the characteristic of the beam and to compare several methods of establishing a line center.

## Description of the Maser Oscillator

The two Stanford masers with auxiliary equipment are shown in Fig. 1. There are essentially four parts to an ammonia beam oscillator:

1) an ammonia beam-forming device called the *effuser* or *beam collimator*,

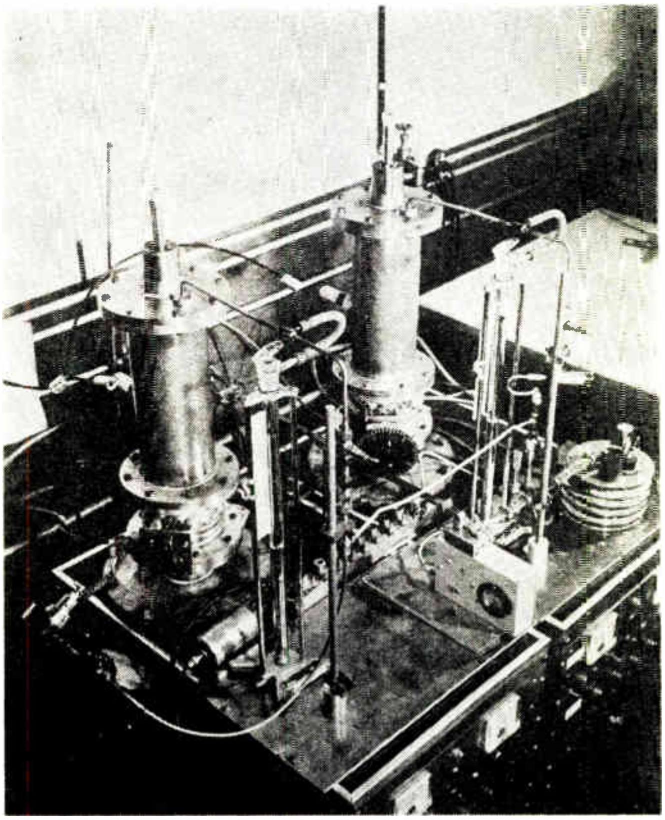

Fig. 1—Over-all picture of Stanford masers.

2) an energy-state separator or *focuser*,
3) a resonant cavity,
4) a vacuum pump to remove the excess ammonia from the vicinity of the resonant cavity and the focuser.

Fig. 2 shows the arrangements of these parts without the vacuum system. The ammonia is supplied from a large tank through a needle valve to the beam collimator which consists of a large number of long tubes through which the gas is allowed to diffuse. The beam entering the focuser from the collimator has reasonable directivity and is relatively dense.

The focuser consists of a number of parallel rods placed symmetrically about the beam axis and alternately biased to a high potential. This configuration produces a large inhomogeneous electric field in the region of the beam. The electric field may be thought of, in the classical sense, as inducing an average dipole moment in the ammonia molecule. The field, in turn, applies a force to the dipole moment which tends to focus the high-energy molecules toward the beam axis and defocus the low-energy molecules out through the rods.

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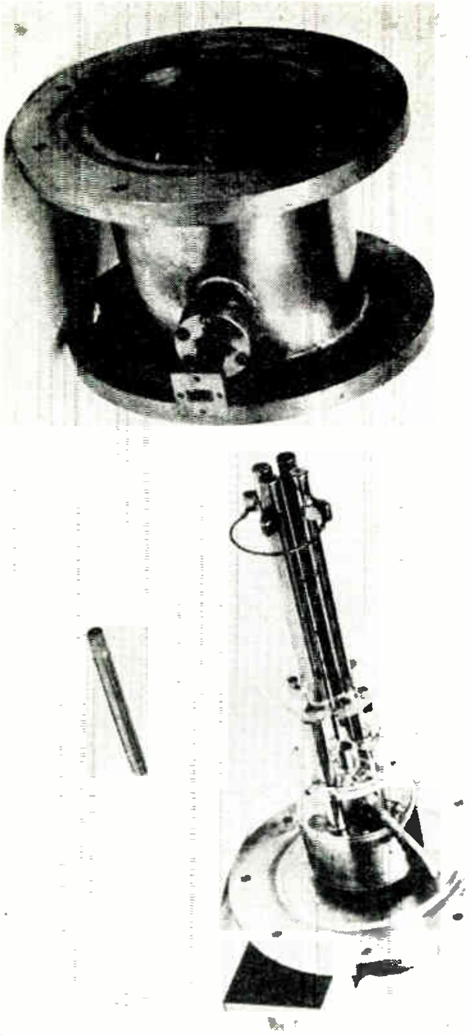

Fig. 2—Beam collimator, cavity and focuser.

The focuser is sufficiently effective to permit, in the first approximation, only high-energy molecules to enter the cavity. Each high-energy molecule is capable of radiating a quantum of energy, $E = hf_{kn}$. The beam entering the cavity is thus a potential source of microwave energy. If the cavity is tuned to the transition frequency $f_{kn}$, and if the density of high-energy molecules is sufficiently great, the noise energy at $f_{kn}$ is amplified until the induced emission of radiation from the molecules causes the system to break into oscillation. Molecules leaving the cavity and passing through the focusing rods are pumped away with a small diffusion pump and a liquid nitrogen cold trap.

To utilize the maser as a frequency standard, it is necessary to know how the frequency of oscillation varies as a function of the system parameters; *i.e.*,

1) the *source pressure*, *P*, or pressure of the ammonia gas on the back of the effuser tubes,
2) the *focusing voltage*, *FV*, or the potential between alternate rods of the focuser, and
3) the *cavity tuning*, *ct*, or the resonant frequency of the cavity.

With the equipment indicated by the block diagram in Fig. 3, it is convenient to measure the relative frequency and amplitude of a maser oscillator as a function of these operating parameters. Unfortunately, the source pressure and focusing voltage do not bear a simple relation to the theoretically important *beam current*, which is defined as the difference between the number of high and low-energy molecules in the energy state of interest entering a cavity per second. The molecule-to-molecule collisions, and the hyperfine structure of the emission line, make the relation between these operating parameters and the beam current difficult to compute.

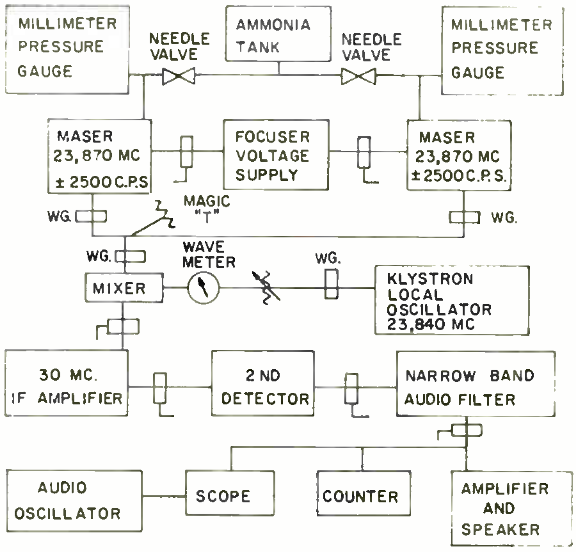


Fig. 3—Block diagram for measuring variations in frequency and amplitude.

## Explanation of Maser Operation

Professor Townes and his associates [23], [43] worked out the theory of operation for ammonia beam maser under the simplified assumption of a uniform beam velocity. For this condition, they have predicted the magnitude of various sources of frequency pulling. Helmer and Lamb [25a] extended the theory to the case of a beam with a Maxwellian velocity distribution. Recent papers by Helmer [26] and Shimoda [44] have extended the theory to cover the divergence of the beam and the effects of the unresolved hyperfine structure.

## Distribution of Energy in Ammonia Gas

In thermal equilibrium, the density of molecules in a given state is proportional to $e^{-E/kT}$, where $E$ is the total energy of the state, $k$ is Boltzmann's constant, and $T$ is the absolute temperature. This internal energy is distributed among various modes of rotation and vibration. The Stanford masers were designed to operate on the frequency of the inversion transition of the $J=3$, $K=3$ rotational state, where $J$ and $K$ are quantum numbers which specify the total angular momentum and its projection on the axis of symmetry.

The $J=3$, $K=3$ state has the largest population of ammonia molecules at room temperature, containing approximately 6 per cent of the molecules [25a]. The ratio between the densities of the molecules in the high and low-energy inversion levels for a specific rotational state is approximately $e^{-hf/kT}$. For the inversion transition at 23.87 kmc, $hf/kT=1/250$, so that the inversion levels are nearly equally populated. Thus, approximately 3 per cent of the molecules entering the beam collimator are in the high inversion state and are potentially useful for maser operation.

### Operation of the Beam Collimator

The beam collimator and focusing system must supply at least $10^{13}$ high-state molecules per second to the cavity. The effectiveness of the focuser in separating the high and low-energy molecules decreases rapidly with the increasing radial velocity of the entering molecules. When the mean-free-path of the molecules is large compared to the dimensions of the individual tubes of the effuser, it is possible to calculate the distribution of molecules leaving a single tube. At a large distance from the effuser, the angular distribution of the molecules leaving the effuser is approximately the same as the angular distribution from a single tube.

The angular distribution of the molecules coming from a long tube for angles $\theta > \tan^{-1} a/l$ is given by $dN=(4/3\pi)(a/l)\cot\theta dN_0$ where $a$ and $l$ are respectively the radius and length of the long tube, and $dN_0$ is the cosine distribution of molecules entering the tube from a gas at equilibrium [2]. Most of the molecular flow is contained in an angle defined by $\theta=\tan^{-1} 2a/l$ [34].

In practice, the maser effuser operates in the transition region between viscous and free molecular flow. Thus the mean-free-path is less than the diameter of the tubes at the entrance and greater at the exit. The angular distribution of the molecules, therefore, is expected to be largely determined by the exit portion of the long tube which is operating in free molecular flow. The effective length of this exit portion of the tubes decreases with increasing source pressure and the resulting divergence of beam increases.

### Operation of the Focuser

The forces separating the high and low-energy inversion states of the ammonia molecule may be derived from the expression for the total energy of the molecule in an electric field. For ammonia this energy is given by [48], [22]

$$W_{12} = W_0 \pm \left[\left(\frac{hf_{kn}}{2}\right)^2 + \left(\frac{|\mu| EMK}{J(J+1)}\right)^2\right]^{1/2} \quad (1)$$

where $h$ is Planck's constant, $f_{kn}$ is the frequency of oscillation characterizing the inversion transition of interest, $W_0$ is the rotational energy of the molecules, $E$ is the electric field, $|\mu|$ is the effective dipole moment, and $M$, $K$, and $J$ are quantum numbers. The radial force exerted by the focuser on the induced dipole moment of the ammonia molecules is given by the gradient of the energy, or

$$f_r = \mp \frac{2}{hf_{kn}}\left[\frac{|\mu| MK}{J(J+1)}\right]^2 E\frac{\partial E}{\partial r} = \frac{CM^2}{4} E\frac{\partial E}{\partial r}, \quad (2)$$

where for the $J=3$, $K=3$ inversion transition of the ammonia molecule, $C$ is equal to $3\times10^{-36}$ farad-m², and $M$ is the quantum number which describes the projection of the angular momentum in the direction of the electric field.

In the particular case of the Stanford masers, the quadrupole electric field is described by $|E| = |(2V_0/a^2)r|$, where $V_0$ is the potential between the surface of adjacent rods, $a$ is the separation of the edge of the rods from the axis, and $r$ is the distance from the axis. The resulting trajectories for particles passing through this focuser are portions of a sine wave which may be written in the form

$$r = R_0 \sin(\gamma t + \phi_1), \quad (3)$$

where $R_0$, $\gamma$, and $\phi$ are constants which are defined by the initial conditions of a molecule entering the focuser, the geometry, and the focusing voltage.

It is possible to make a useful estimate of the velocity distribution of the molecules leaving the focuser and the focuser efficiency, with the following simplifying assumptions:

1) The effuser may be treated as a point source with the angular distribution for the molecules leaving it as measured by Helmer in Fig. 4.
2) The molecules coming from the effuser in each element of a solid angle contain a Maxwell distribution of speeds. This means that the probability of a molecule having a given speed is independent of direction.
3) The effect of fringing fields may be neglected.
4) A focused molecule is one for which $r$ never exceeds the radius to the edge of the focusing rods.

Under these assumptions, the velocity distribution for molecules leaving the focuser is shown in Fig. 5 [2].

The results shown in Fig. 5 have several important consequences with respect to the frequency pulling characteristics of a maser oscillator:

1) The most probable velocity of the molecules entering the cavity is considerably less than the most probable thermal velocity.
2) This velocity is a function of focusing voltage, the quantum number $M$, and the angular distribution of the molecules coming from the effuser.
3) By substituting in the constant for the Stanford quadrupole focuser, it can be shown that the total focusing efficiency can be expected to be approximately 0.2 per cent of the total number of entering molecules.
4) Integration of the area under the curves in Fig. 5 shows that the number of focused high-state molecules increases approximately as the square of the voltage.

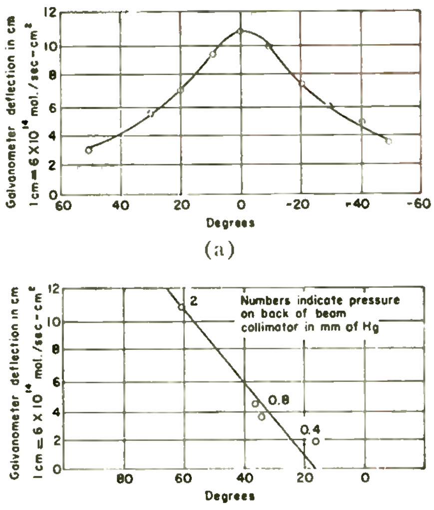


Fig. 4. (a) The measured angular distribution of molecules flowing out of the beam collimator. (b) The density at half peak intensity as function of the angular separation between half intensity points. (Varian Assoc. Rept. 25c)

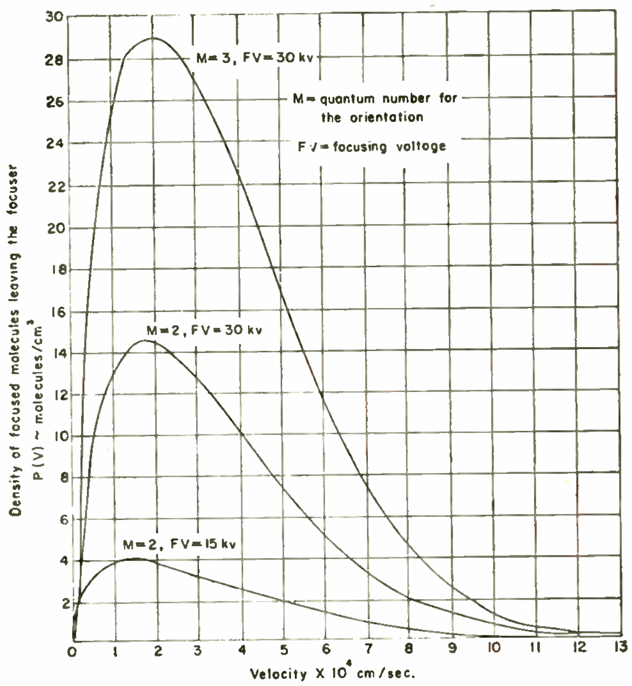


Fig. 5—The beam density of high state $J=3$, $K=3$ molecules leaving the focuser as a function of velocity.

A calculation of the number of low-state molecules which are defocused shows that the number of low-state molecules in the quantum states of interest entering the cavity equals about 15 per cent of the number of high-state molecules [2].

### Molecular Collisions

In addition to the radiation induced by the electric field in the cavity, the high-state molecules may be caused to radiate by means of a dipole interaction between two passing molecules, and these collisions tend to return the system to thermal equilibrium. The molecules in the beam may collide with either the residual background gas or with other molecules in the beam traveling at a different velocity.

Since the operation of the maser is critically dependent upon the ability of the focuser to supply an excess of high-state molecules to the entrance of the cavity, the density in the region of the focuser must be low enough so that the mean-free-path of the molecules is large compared to the distance from the beam collimator to the entrance of the cavity. For the Stanford masers, this distance is about 30 cm. Therefore, the density of ammonia molecules must be less than about $1.6\times10^{11}$ molecules/cm$^3$, corresponding to a pressure of about $2\times10^{-5}$ mm of Hg. For greater pressures the effective length of the focuser appears to be shortened.

In both the cavity and the focuser, the effective density of the molecules is greater than in the general vacuum system. A portion of both the low and high-state molecules with large radial velocities is reflected from the walls of the focuser and the cavity. In the particular case of the Stanford masers, the molecules which are not focused make, on the average, about one additional trip across the beam before they escape. Thus, the density of the gas in the focusing region should be about 3/2 the density of the molecules in the beam.

### Emission of Radiation in a Resonant Cavity

To a first approximation, all the molecules coming from the focuser are in high-energy inversion states. If these molecules are induced to make a transition between two adjacent quantum states, the power available is given by:

$$W = Nhf_{kn}P_n, \tag{4}$$

where $N$ is the number of molecules in the high-energy inversion state of interest entering the cavity per second, $h$ is Planck's constant, $f_{kn}$ is the transition frequency, and $P_n$ is the average transition probability.

The transition probability $P_n$ contains terms due to both spontaneous and stimulated emission probabilities. The probability of spontaneous emission is very closely related to the noise properties of the maser amplifier which have been extensively treated in the literature [1], [21], [27], [29], [39], [41], [46], [49]. However, for the case which we are considering, this probability of spontaneous emission is negligible compared to the stimulated emission due to the electromagnetic field in the resonant cavity.

The induced transition probability depends upon the details of the electromagnetic fields and can be found from the solution of the time-dependent Schrödinger equation. For our purposes, however, it is more convenient to work with the related effective beam current which is defined by

$$J = n\frac{\partial P}{\partial t}, \tag{5}$$

where $n$ is the density of the molecules per unit volume, $t$ is the time, and $P$ is the polarization vector. The polarization vector is related to the transition probability through the time-dependent coefficient for the eigenfunctions of the solutions to Schrödinger's equation. Helmer and Lamb [25a] have applied these results to the solution of Maxwell's equations in a beam-loaded cavity to obtain values for the frequency and amplitude of oscillation with a velocity distributed beam as shown below.

$$-\frac{1}{2}\frac{\Omega_c-\Omega_c^2}{\Omega_c}=\frac{\delta\sqrt{\pi}T_0S(x)}{6Q_c}$$

$$\text{or } \delta\approx\frac{(\Omega_c-\omega_{kn})}{\Omega_c}\frac{6Q_c}{\sqrt{\pi}T_0S(x)} \qquad (6)$$

$$\frac{1}{Q_c}=\frac{nT_0}{\sqrt{\pi}\epsilon\hbar}\,|\mu|^2G(x) \qquad (7)$$

where

$\delta=\Omega-\omega_{kn}$,

$|\mu|$ is the matrix element,

$T_0$ = the most probable flight time through the cavity,

$S(x)$ = the function shown in Fig. 6,

$n$ = net density of active molecules entering the cavity for the transition of interest,

$G(x)$ = function shown in Fig. 7,

$x=T_0\sqrt{\delta^2+E\mu/\hbar^2}$,

$J=1/G(x)$ = the beam current normalized to the starting flux.

Shimoda, Townes, and Wang [43] found the frequency and amplitude of oscillation for the case of a uniform beam velocity and a cavity operating in the $TM_{010}$ mode to be given by

$$\delta=\left(\frac{\Omega_c-\Omega}{\Omega_c}\right)\frac{2Q_c}{T_0}\left\{\frac{1-\cos 2\theta}{1-\dfrac{\sin 2\theta}{2\theta}}\right\} \qquad (8)$$

$$\frac{1}{Q_c}=\frac{4n\hbar}{E^2}\sin^2\theta \qquad (9)$$

where

$$\theta=\frac{E|\mu|T_0}{2\hbar}.$$

The amplitude of oscillation as a function of the beam current predicted by the two theories is shown in Fig. 8. These curves are obtained when the cavity is tuned to $f_{kn}$ or line center. The beam current needed to start oscillation is increased as the cavity is detuned from $f_{kn}$.

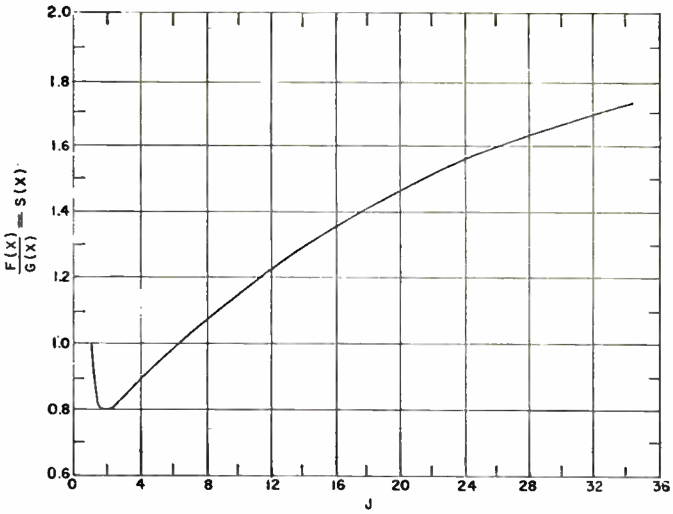


Fig. 6—Frequency stabilization factor $S(x)$ as a function of the normalized beam current $J$.

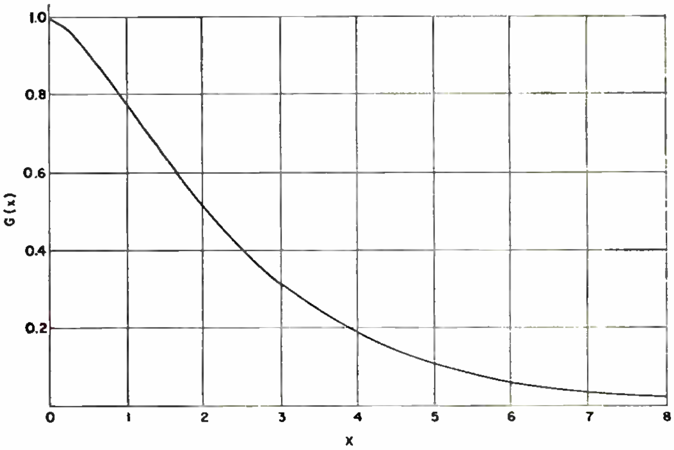


Fig. 7—The function $G(x)$ vs $x$.

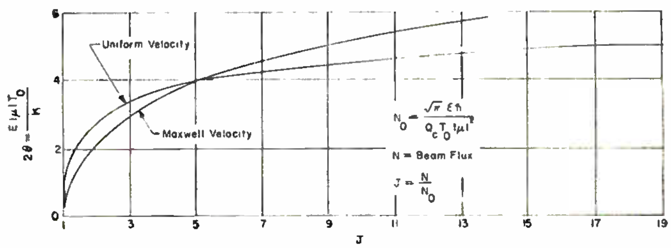


Fig. 8—The amplitude of oscillation as a function of beam current $J$.

The variation in frequency as a function of beam current is shown in Fig. 9 for the Maxwell velocity theory and in Fig. 10 for the uniform velocity theory. A comparison of these curves with the experimental results in Fig. 16 shows that this description is inadequate, and the unresolved hyperfine structure of the $J=3$, $K=3$ line must be considered.

The variation in intensity of the hyperfine components of the $J=3$, $K=3$ line with variation in beam current is treated in considerable detail by Shimoda

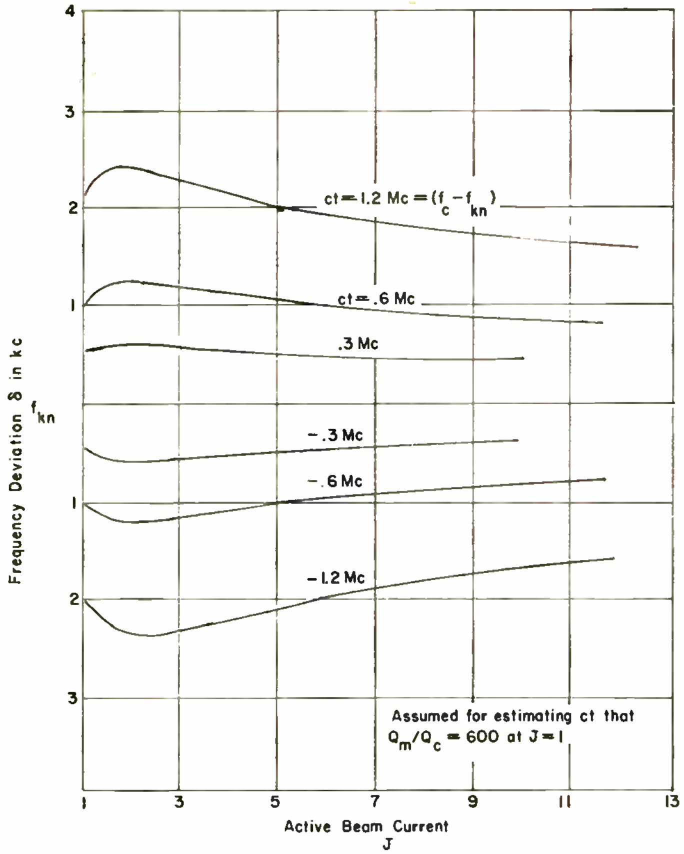


Fig. 9—Frequency of oscillation vs beam current as a function of $(f_c - f_{kn})$ for Maxwell velocity distributed beam.

[44]. He shows that each of the three hyperfine components may be treated separately with equations of the form of (8) and (9). The resulting characteristics are obtained from the sum of these components with the appropriate weight factors, which account for the differences in the hyperfine state populations and the efficiency of the focuser. These calculations predict the asymmetric characteristic of the amplitude vs cavity tuning characteristics shown in Fig. 11, and a variation in the effective line center, as a function of focusing voltage, as shown in Fig. 12.

Other terms which are important in determining the frequency of oscillation of the maser cavity include unbalanced traveling waves in the cavity and molecular collisions. The shift due to unbalanced traveling waves may be as large as a few parts in $10^9$ and is at least par-

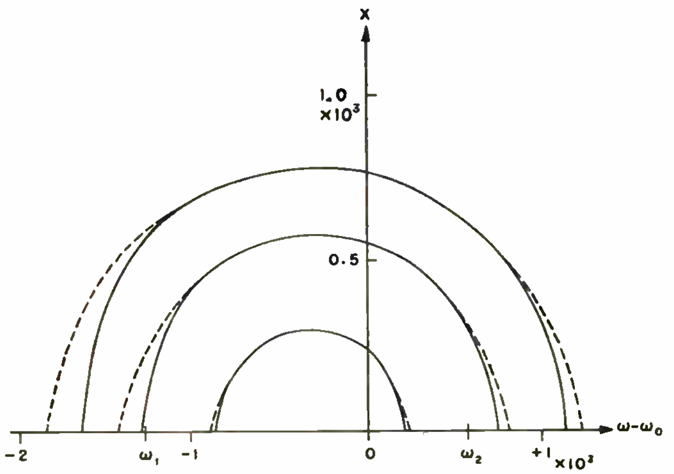


Fig. 11—Amplitude vs frequency characteristics. Dotted curves show plausible modifications for the hyperfine structure (Shimoda).

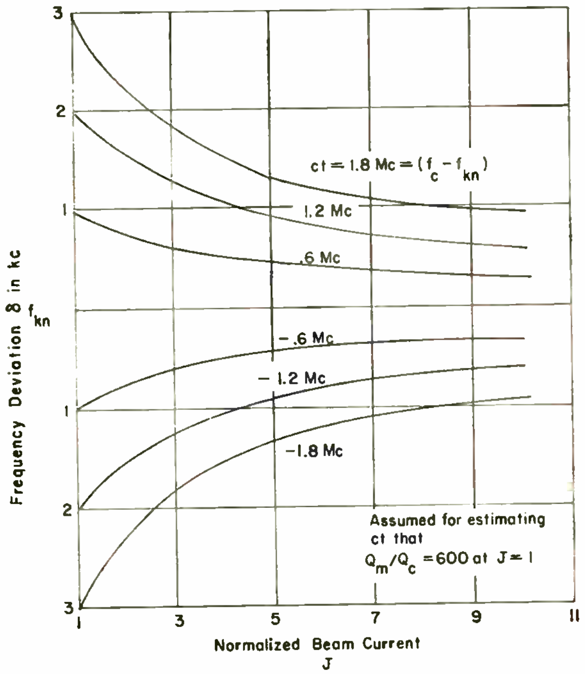


Fig. 10—Frequency of oscillation vs beam current as a function of $(f_c - f)$ for a uniform velocity beam.

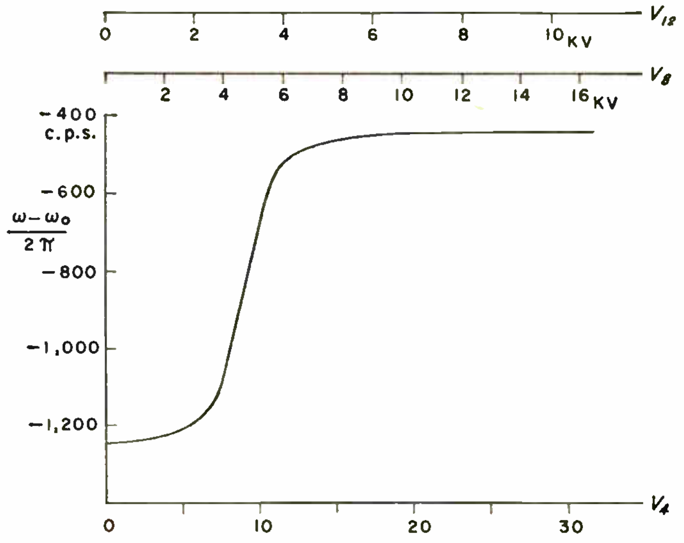


Fig. 12—Calculated frequency shift of the 3.3 line due to unresolved hyperfine structure. Changes of relative intensities by saturation effect are neglected. $V_4$ $V_8$ $V_{12}$ refer to the potentials on Shimoda's four-, eight- and twelve-pole focusers [44].

tially unavoidable. The physical location for the point of the maximum probability for the emission of radiation changes with the electric field strength and, thus, the beam current. The shift due to molecular collision may amount to as much as a few parts in $10^9$. The molecules which make collisions either with the cavity wall or other molecules may be induced to radiate with a phase constant which is not coherent with the electromagnetic field in the cavity. Shifts as large as 2 parts in $10^9$ have been measured at the Bureau of Standards by reversing the direction of the travel of the beam through the cavity [33]. The relative importance of these and other smaller sources of frequency shifts is treated by Shimoda, Townes, and Wang [43]

The density of molecules in the cavity resulting from the divergence of the beam may be calculated from the formula given by Dushman [18] for the ratio of the rate at which a gas enters and leaves a long tube. For the case of the 6-inch Stanford cavities, this ratio is about 0.17, and about 30 per cent of the molecules entering the cavity are sufficiently divergent to strike the wall. Thus, the density of molecules in the cavity is about twice that of the entering beam.

The effective range over which a maser oscillator may be tuned by varying the resonant frequency of the cavity is largely determined by the flight time of the ammonia molecules through the cavity and the resonant mode in which the cavity is operating. For the operation of the Stanford masers in the $TM_{011}$ mode, the resulting tunable range of operation is about 3000 cycles.

If the cavity is operated in the $TM_{012}$ mode or other modes with more than a half a sine wave, the variation of the field seen by the molecules resolves the ammonia line into two components [22], [25c]. This effect can be most easily visualized by considering the ammonia molecules to interact with first one and then the other of two traveling waves in the cavity, or when

$$f_{kn} = \frac{|v \pm v_p|}{\lambda_g}, \tag{10}$$

where $v$ is the velocity of the molecule, $v_p$ is the phase velocity of the electromagnetic waves, and $g$ is the guide wavelength. At these two values of the phase velocity, or cavity tuning, the moving molecules are influenced by the electromagnetic energy in the cavity. The separation between these frequencies is given by

$$\Delta f = \frac{2v}{\lambda g} = \frac{n'v}{L} \tag{11}$$

where $n'$ is the number of half wavelengths along the cavity, and $L$ is the length of the cavity.

The frequency and amplitude response for operation in the $TM_{012}$ are predicted for small signal operation by Helmer [25c] by equating the resistance in the reactance of the cavity to the equivalent resistance and reactance of the beam, as computed by the solution of the time-dependent Schrödinger equation. These results are plotted in Fig. 13. The bandwidth of the cavity is so much broader than the effective bandwidth of the molecule that the reactance of the cavity appears as a nearly straight line with the slope of the order of 0.001 of that of the beam reactance. When the intersection of the two reactances passes through $f_{kn}$, the mode in which the transition probability is largest changes, and there is a discontinuity in the frequency of oscillation with the change in cavity tuning. This discontinuity, or jump, in frequency provides a means for estimating the average velocity of the beam and, in addition, provides a possible means for establishing line center or the natural transition frequency of the molecule.

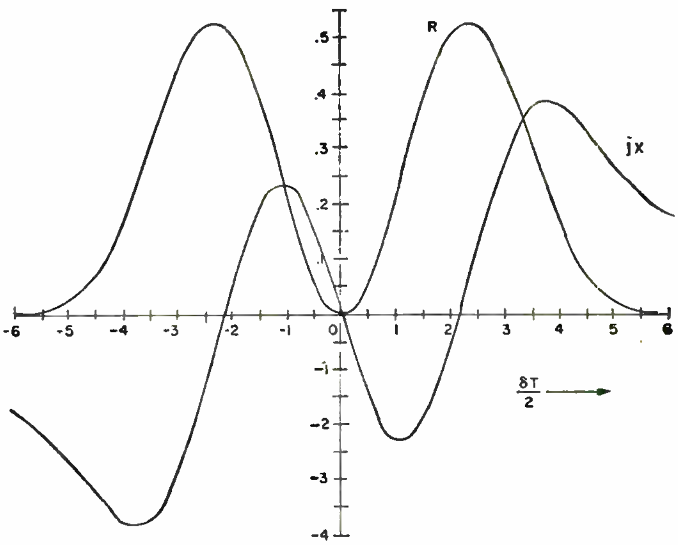


Fig. 13—The equivalent resistance $R$ and reactance $jX$ of the beam as a function of the product of the detuning $\delta$ and the average flight time $T$ for operation in the $TM_{012}$ mode (taken from Varian Assoc. Rept. 25c).

## Results of Recent Experiments at Stanford

Fig. 14 shows the relative frequency of oscillation as a function of cavity tuning obtained during the recent Stanford tests for various focusing voltages at a nearly optimum source pressure. Both the uniform and Maxwellian velocity distribution theories predict a linear relation between the frequency of oscillation and the cavity tuning; and, the slope $\partial\Omega/\partial\Omega_c$ is determined by the length of the cavity, the velocity of the molecules, and the active beam current.

The relation of $\partial\Omega_c/\partial\Omega$ to focusing voltage, as obtained during the tests, is shown in Fig. 15. According to the Maxwellian velocity theory, $\partial\Omega_c/\partial\Omega$ should vary as $S(x)$. Note that the reversal of sign of the $S(x)$ at small currents is not observed.

Fig. 16 shows the relative frequency of oscillation as a function of focusing voltage at successive cavity tunings

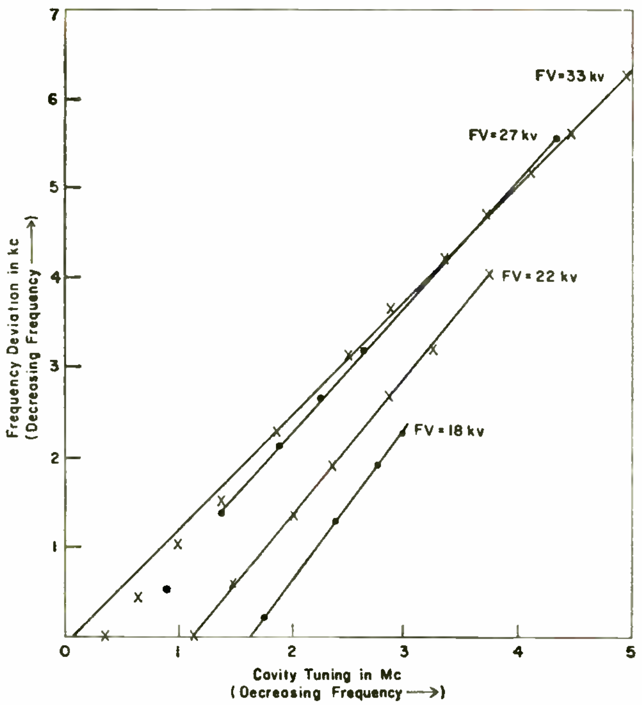


Fig. 14—The frequency of oscillation vs cavity tuning for various focusing voltages ($FV$) and source pressure $P=2.7$ mm of Hg.

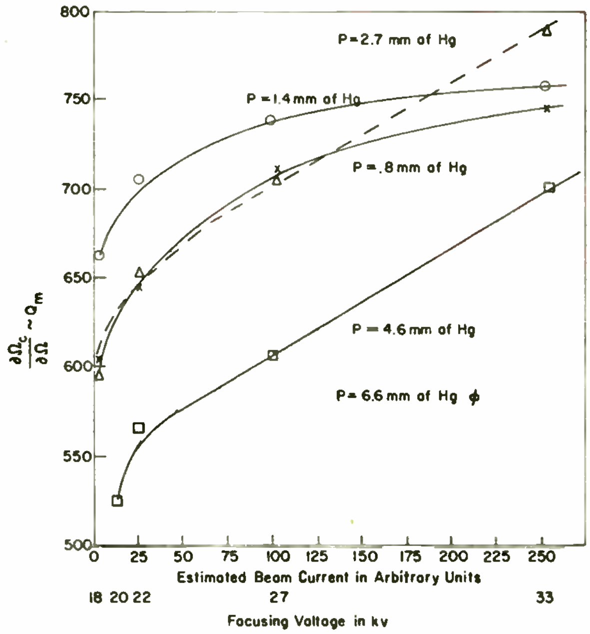


Fig. 15—The variation of the $\partial\Omega_c/\partial\Omega$ is plotted as a function of the beam current where it is assumed that the beam current increases as the square of the focusing voltage.

for nearly optimum source pressure. This graph may be compared with the predicted curve for the frequency as a function of the beam current in Fig. 9. When the cavity is widely detuned from the natural transition frequency of the molecules, the results agree quite well with the theory at large currents. However, the predicted

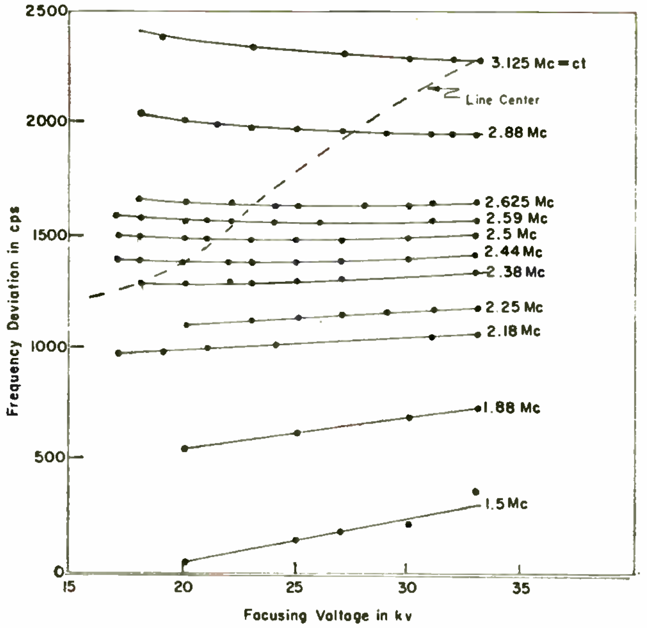


Fig. 16—The frequency of oscillation vs focusing voltage as a function of cavity tuning at source pressure $P=1.2$ mm of Hg.

reversal in direction of the frequency pulling again fails to appear at low currents.

A second and more important deviation from the simple theory is the movement of line center (or the position of cavity tuning for which the frequency is independent of focusing voltage) to higher frequencies with increasing focusing voltage. This effect is of the general form predicted by Shimoda [44] upon accounting for the hyperfine structure of the $J=3$, $K=3$ line.

Fig. 17 shows the frequency as a function of source pressure. At large pressures this frequency tends to move away from any position which might be called line center with increasing beam flux. This indicates that the beam current decreases with increasing beam flux for values greater than about $2\times10^{15}$ molecules/cm$^2$. As the $\partial\Omega/\partial P=0$ for a reasonable range of $CT$ at this beam flux density, it could be a useful operating point for a frequency standard.

The curves showing the amplitude of oscillation as a function of cavity tuning in Fig. 18 are sufficiently asymmetric to indicate that the ellipse predicted by (7a) must be modified, as suggested by Shimoda [43], to account for the hyperfine structure of the $J=3$, $K=3$ line. The curves for the maximum amplitude of oscillation as a function of focusing voltage (see Fig. 19) agree in general form with those predicted by (7) and (9). The measurements of the maximum amplitude as a function of source pressure in Fig. 20 definitely indicate a decrease in the active beam current for source pressure greater than 2 mm of mercury.

In order to obtain a better estimate of the change in beam current with changes in source pressure and focusing voltage, a gauge holder was built to permit

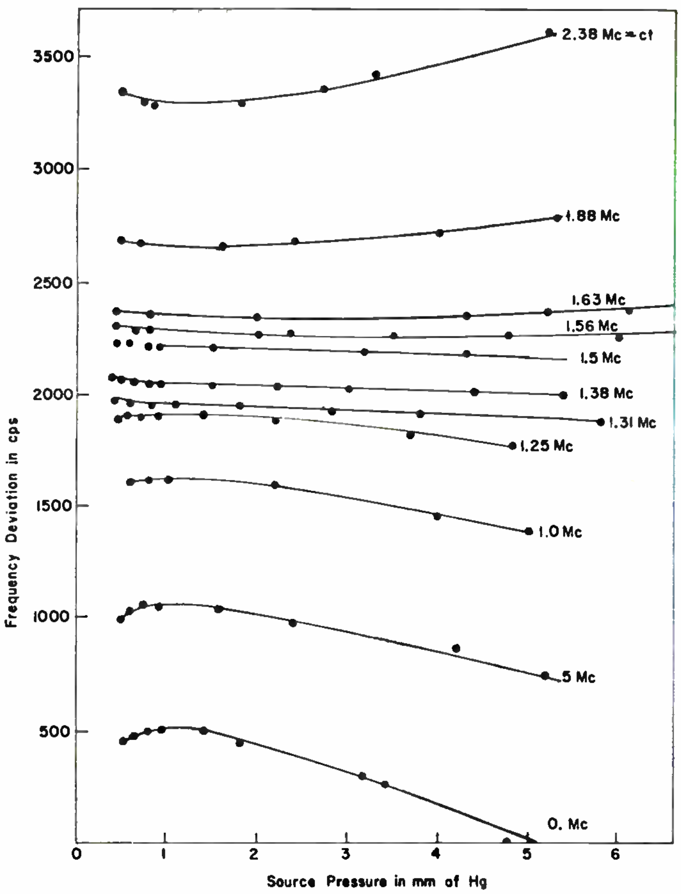


Fig. 17—Frequency of oscillation vs source pressure as a function of cavity tuning at a focusing voltage of 37 kv.

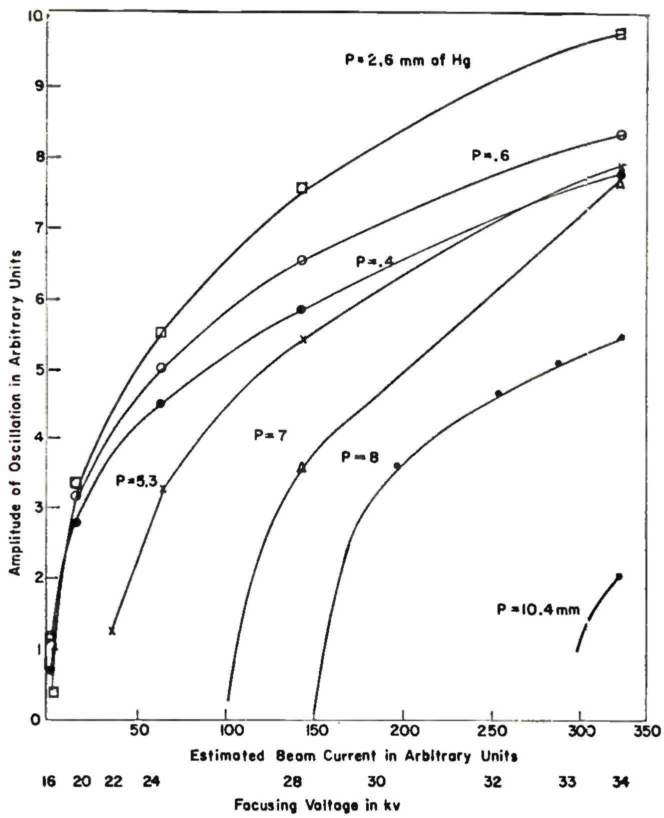


Fig. 19—Measured amplitude of oscillation vs estimated beam current as a function of source pressure.

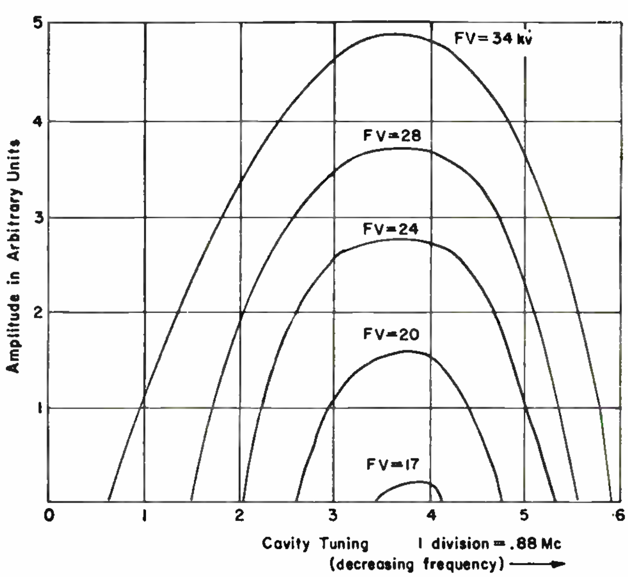


Fig. 18—Amplitude of oscillation vs cavity tuning as a function of focusing voltage at a source pressure $P=2.6$ mm of Hg.

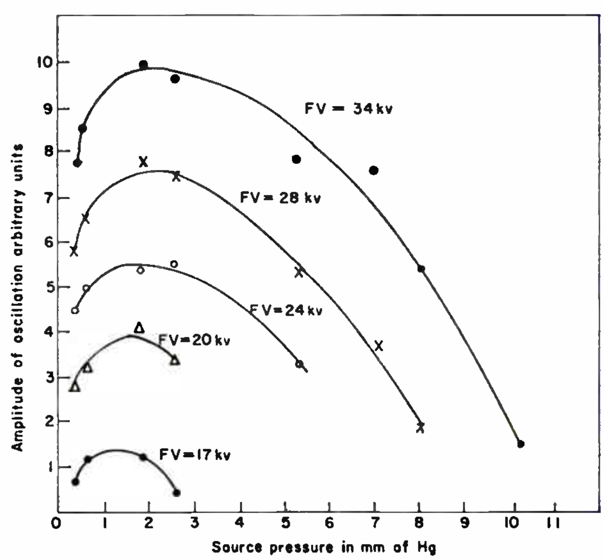


Fig. 20—Maximum amplitude of oscillation vs source pressure as a function of focusing voltage.

replacement of the maser cavity with either an ion or a Pirani gauge. These gauges provided the measurements in Figs. 21 through 24.

The plot of the beam flux vs source pressure in Fig. 21 shows that the beam flux is a monotonically increasing function of the source pressure over the maser operating range. This is in contrast to the measurements in Fig. 20, and must be accounted for in the difference between the dipole to dipole interaction cross section and the kinetic cross sections of the ammonia molecule. The ion gauge measurements in Fig. 22 show that a beam collimator pressure of 2 mm of mercury corresponds to a beam density in the cavity of about $1.6\times10^{11}$ molecules/cm²/sec and a mean-free-path of 26 cm. The maximum beam current indicated in Fig. 20 therefore occurs when the mean-free-path of the molecules in the cavity becomes approximately equal to the dimensions of the focuser.

The minimum beam flux at the cavity entrance for which the Stanford masers will oscillate is approximately $2\times10^{14}$ molecules per second. About 6 per cent of these molecules ($1.7\times10^{13}$ per sec) should be in the high inversion level of the $J=3$, $K=3$ rotational state. This is in excess of the $5\times10^{12}$ molecules per second which are necessary to start oscillation, as indicated by calculations from (7). The difference between these two numbers probably results from disregarding the divergence of the beam.

The application of the focusing voltage produces an increase in the beam flux at the cavity entrance, which varies approximately as the square of the focusing voltage and has a maximum of about 10 per cent of the initial flux. At low focusing voltages nearly equal numbers of molecules are expected to be focused and defocused. However, at high focusing voltages nearly all the low-state molecules which would enter the gauge have been defocused, and the density of molecules increases with the number of focused high-state molecules. The square law increase shown by the experimental data in Fig. 23 is in close agreement with the theory.

Fig. 24 shows that the beam flux decreases rapidly as the distance from the beam collimator increases. It should, therefore, be advantageous to use as short a focuser as will give adequate separation of states, and to mount the cavity as close to the focuser as possible. Measurements of the beam flux density at the entrance to the cavity showed the intensity to be practically constant across the cavity entrance, and that approximately 30 per cent of the molecules in the beam diverge sufficiently to collide with the cavity walls.

The graphs of the amplitude as a function of cavity tuning in Fig. 25 clearly demonstrate the Doppler splitting of the molecular resonance line into two components for operation in the $TM_{012}$ mode. The frequency separation of the peaks varies from 5 to 8 kc. and the simple theory predicts a corresponding velocity of 3 to 4 times $10^4$ cm/sec. These velocities indicate that the average velocity of the beam is considerably less than the average thermal velocity of 6 times $10^4$ cm/sec but greater than the 2 times $10^4$ cm/sec predicted by the preliminary calculations. The asymmetry of the $J=3$, $K=3$ line is also clearly demonstrated.

The discontinuity or jump in the frequency of oscillation predicted by the first-order theory for operation in the $TM_{012}$ mode is shown in Fig. 26. The size of this

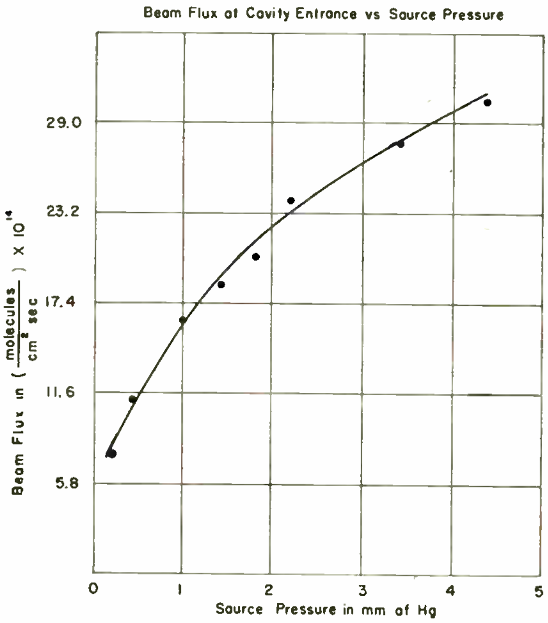


Fig. 21—The beam flux density at the cavity entrance as a function of the source pressure.

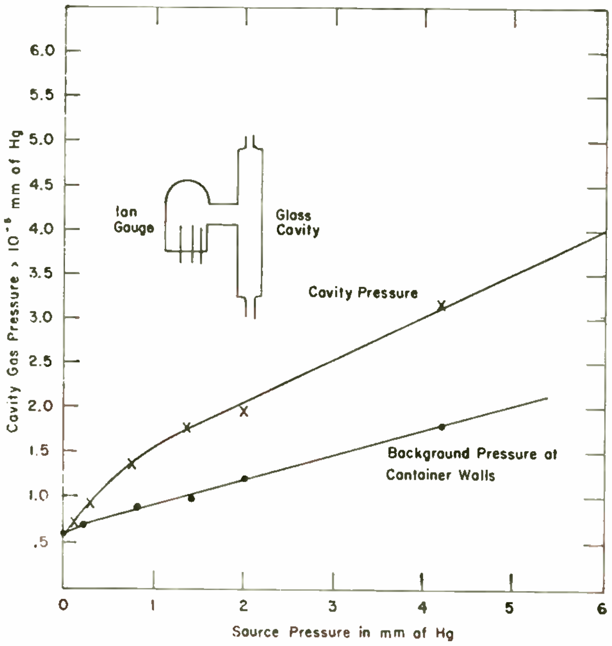


Fig. 22—The pressure of the gas in the cavity as a function of source pressure.

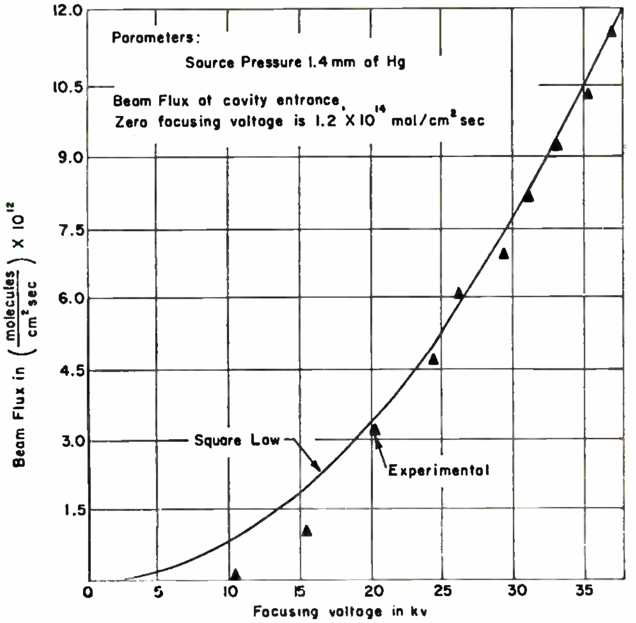


Fig. 23—Experimental measurement of the increase in beam flux at the cavity entrance as a function of focusing voltage.

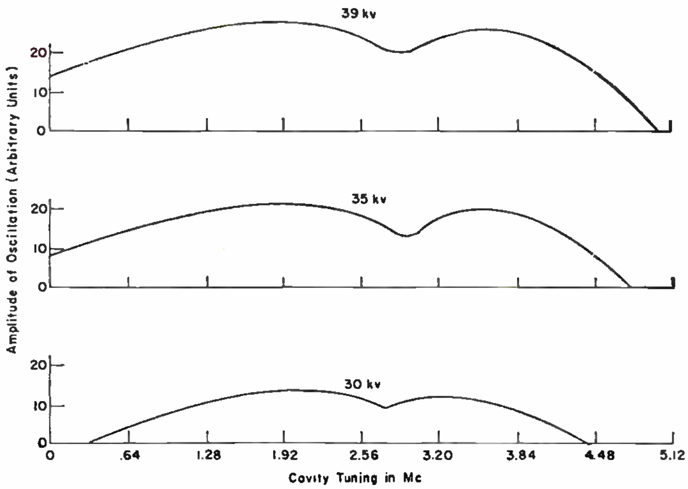


Fig. 25—The amplitude of oscillation vs cavity tuning as a function of focusing voltage for $TM_{012}$ mode operation at source pressure $P=2$ mm.

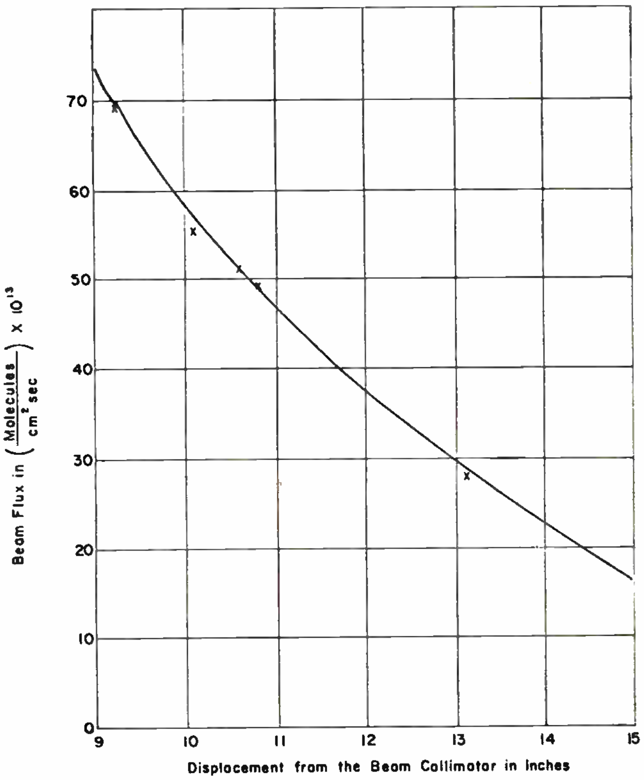


Fig. 24—Beam flux vs distance from the collimator along the axis at $P=1$ mm of Hg, $FV=25$ kv.

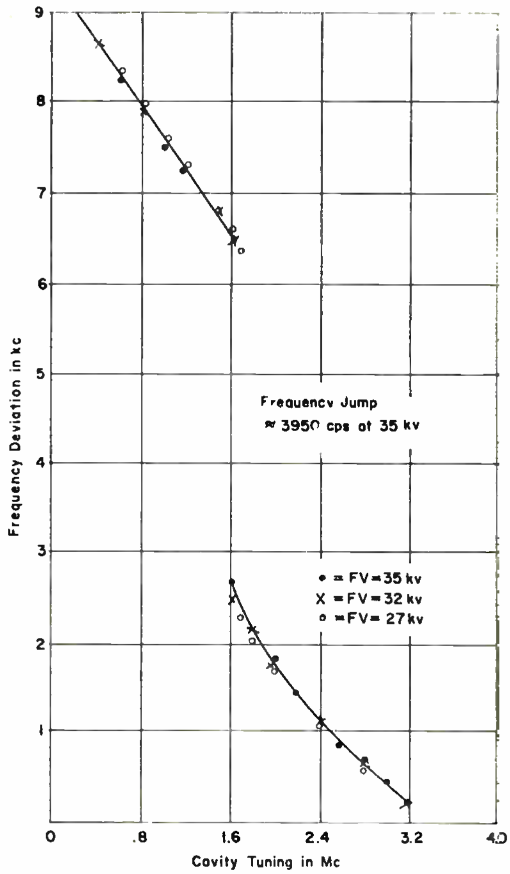


Fig. 26—Frequency of oscillation vs cavity tuning as a function of focusing voltage at a source pressure $P=1.8$ mm of Hg.

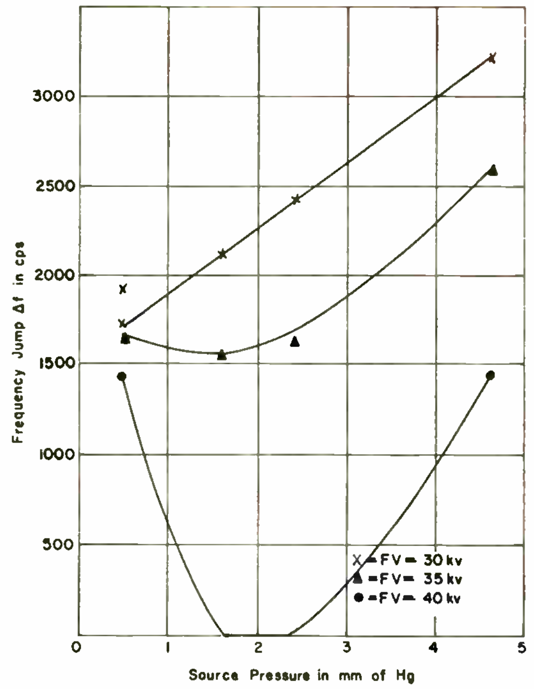


Fig. 27—The frequency discontinuity as a function of source pressure and focusing voltage for operation in the $TM_{012}$ mode.

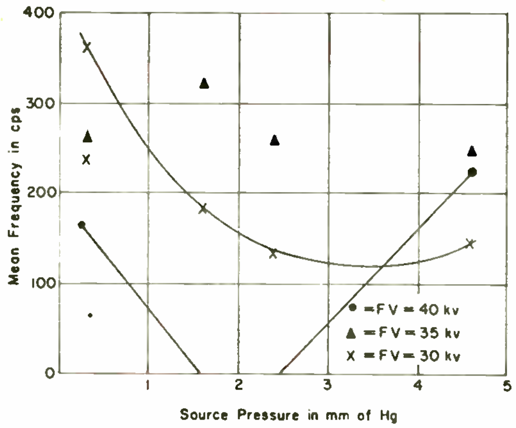


Fig. 28—The mean frequency of the $TM_{012}$ mode jump vs source pressure as a function of focusing voltages, second maser.

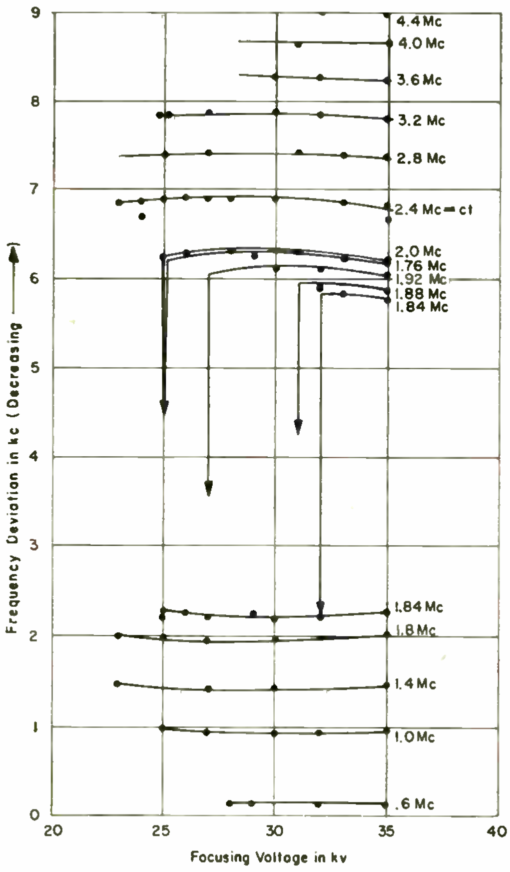


Fig. 29—Frequency of oscillation as a function of cavity tuning at source pressure of $P = 1.2$ mm of Hg for $TM_{012}$ mode.

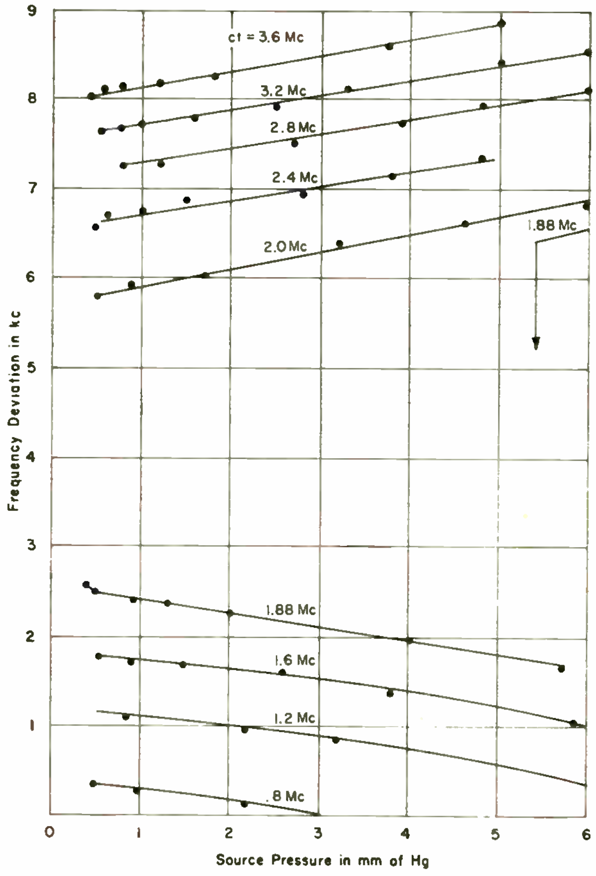


Fig. 30—Frequency vs source pressure as a function of cavity tuning at $FV = 37$ kv.

frequency jump varies with focusing voltage and source pressure, as shown in Fig. 27. Additionally, the mean frequency of this jump changes, as shown in Fig. 28.

The variation in the average velocity of the molecules, predicted from the small signal theory from the changes in the size of the velocity jump, is unreasonably large, and it is suspected that the variations in velocity are masked by more important changes in the beam current.

Another significant variation from the theory is the absence of a zero in the amplitude of oscillation at the natural transition frequency of the molecule. This indicates an asymmetry in the operation of the cavity which is probably caused by the divergence of the beam. It is also possible that some of the variation with focusing voltage of the location in the mean value of the frequency discontinuity is caused by a varying divergence of the beam current.

The mean frequency of the frequency jump has been proposed as a possible parameter for establishing the natural frequency of the molecule $f_{kn}$ for use as a frequency standard independent of the particular system design. However, the results of Fig. 28 show that this mean frequency may be varied over a range of about 400 cps or 2 parts in $10^8$ by changing the beam current.

Fig. 29 shows the frequency as a function of focusing voltage. The reversal in the sign of the $\partial\Omega/\partial FV$ with increasing focusing voltage, the dependence of the frequency of oscillation on the past history, and the divergence of the frequency with increasing beam pressure (Fig. 30) are features which have yet to be explained by large-signal theory.

## Conclusion

In the development of an atomic frequency standard there are at least two important problems. The first of these is the development of an extremely stable oscillator which, once started, will maintain a given frequency to very high precision. The second problem is to find a unique reproducible frequency. These requirements are at least partly conflicting. In order to obtain an extremely stable source of oscillation, one wishes to make the oscillator as independent of as many operating parameters as possible. In the second case, it is desirable to make some property of one frequency as different as possible from all other frequencies.

Experimental results shown in Figs. 16 and 17 make it appear that it is possible to select a source pressure, cavity tuning, and focusing voltage such that variations in frequency due to changes in focusing voltage and source pressure are minimized. The existence of these minimums in the partial $\partial\Omega/\partial p$ and $\partial\Omega/\partial FV$ should be useful in determining the operating conditions for a frequency standard. Recent work at the National Bureau of Standards by R. Mockler and J. Barnes [23] on a carefully constructed temperature control circuit for the cavity has greatly reduced the principal source of frequency instability. With temperature stabilities of about 0.001°C, their initial results indicate that frequency stabilities better than 1 parts in $10^{12}$ should eventually be maintainable for indefinitely long periods. Bononami, *et al.* [12], have shown that a flat spot in a frequency vs cavity tuning curve may be obtained by critical-coupling two cavities. The use of these critically-coupled cavities reduces the stability requirements on the temperature control circuit for a given frequency stability by about an order of magnitude.

The foregoing experimental results also place some limits on the accuracy of several methods of establishing a unique frequency which is independent of the operating parameters. First, the location of line center by setting the $\partial\Omega/\partial FV=0$ may be varied over a range of about 1500 cycles with changes in operating parameters. A similar variation of approximately 1000 cycles is obtained for using the $\partial\Omega/\partial p=0$ as a means of establishing line center, even after the elimination of the region in which the changes in beam current change sign. Second, the mean frequency of the discontinuity for operation in the $TM_{012}$ mode may be varied over a range of about 450 cycles with changes in operating parameters.

These variations in resetability are all orders of magnitude larger than the frequency drifts with time for a carefully constructed oscillator. It is suspected that the major causes of these variations in resetability are due to changes in the amplitude of the hyperfine components and the asymmetries in the radiation pattern due to the divergence of the beam.

A possible means for reducing this problem in resetability would appear to be to operate a maser on the $J=3$, $K=2$ line at 22.8 kmc [10]. This line has no hyperfine structure, and it is expected that operation on this line would reduce the variations in the foregoing methods for locating line center by an order of magnitude. Another possible means of eliminating the hyperfine structure is to use ammonia made from $N^{15}$.

## Acknowledgment

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# Coaxial Resonators with Helical Inner Conductor*

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*Summary*—**The use of coaxial or reentrant resonators is practical at frequencies down through the high-frequency band and even lower. By introducing a helical inner conductor, a $Q$ of several thousand can be achieved in relatively small volume. Design equations are simple and are the basis for an alignment chart. The unloaded $Q$ is equal to 50 times shield diameter in inches times square root of resonance frequency in megacycles. Shield length is about 30 per cent greater than its diameter. Experimental results confirm the accuracy of the predicted $Q$. The method is also applicable to miniaturized UHF resonators, and to the design of high-$Q$ radio-frequency inductors and LC resonators. Additional formulas and a chart relate frequency, $Q$, volume, voltage gradient and power rating.**

## List of Symbols

$b$ = axial length of coil, inches.
$B$ = inside length of shield, inches.
$C$ = capacitance, micromicrofarads per axial inch.
$D$ = inside diameter of shield, inches.
$d$ = mean diameter of turns, inches.
$d_0$ = diameter of conductor, inches.
$f_0$ = resonance frequency, megacycles.
$I_{sc}$ = current at connection of coil to shield.
$k$ = dissipation factor at surface of shield, watts per square inch.
$L$ = inductance, microhenries per axial inch.
$N$ = total number of turns of winding.
$n$ = turns per inch.
$P_c$ = power converted into heat in the resonator, watts.
$P_m$ = maximum power available from a generator into a load, watts.
$P_s$ = power rating of zero- or infinite-impedance generator, watts.
$Q_d$ = doubly-loaded $Q$.
$Q_s$ = singly-loaded $Q$.
$Q_u$ = unloaded $Q$.
$R_c$ = resistance due to coil conductor, ohms per axial inch.
$R_s$ = resistance appearing in a coil due to the losses in the shield, ohms per axial inch.
$V_{oc}$ = voltage at open-circuited end of coil.
(vol) = inside volume of shield, cubic inches.
$Z_0$ = characteristic impedance, ohms.
$\alpha$ = attenuation constant, nepers per unit length.
$\beta$ = phase constant, radians per unit length.
$\delta$ = skin depth, inch.
$\tau = 1/n$ = pitch of winding, inches.
$\phi$ = proximity factor.

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## Introduction

Resonators of practical size with $Q$ in excess of 1000 can be built for the hf and VHF ranges. They resemble the familiar coaxial-line quarter-wave resonator except that the inner conductor is wound in a helix. The technique can be extended even through the UHF range and beyond, where subminiature helical resonators can be built in smaller sizes than conventional ones when $Q$ values between several hundred and 1000 suffice.

As an example of the saving of space and the much better shape factor, a helical resonator for 10 mc with unloaded $Q = 1000$ is about six inches in diameter by eight inches in length. In contrast, a TEM-mode coaxial-line resonator would be 25 feet in length by three inches in diameter. As an alternative solution, it might be possible to build a lumped (electrically short) inductor and capacitor tuned circuit with $Q = 1000$. However, it would tax one's ingenuity to fabricate it in a six- by eight-inch cylindrical shield.

Again, consider a subminiature resonator with $Q = 200$ for operation at 2000 mc. The helical type would be about one-tenth inch in diameter by one-eighth inch in length. A TEM-mode unit would be 1.5 inches in length by 0.05 inch in diameter.

Fig. 1 shows a series of resonator coils and their shield. The caption gives the resonance frequency and measured unloaded $Q$ of each coil when mounted in the shield.


Fig. 1—Group of helical resonators. Shield inside diameter = 1.63 inches. Coils, from left to right: $f_0 = 55$ mc, $Q_u = 600$; $f_0 = 78$ mc, $Q_u = 720$; $f_0 = 101$ mc, $Q_u = 840$; $f_0 = 145$ mc, $Q_u = 880$; $f_0 = 215$ mc, $Q_u = 1000$.

The helical resonator (see Fig. 2) consists of a coil within a shield, one end of the coil being solidly connected to the shield. The other end is open-circuited, except possibly for a trimming capacitor. The resonator thus resembles an ordinary radio-frequency tuned circuit with the omission of the tuning capacitor. How-

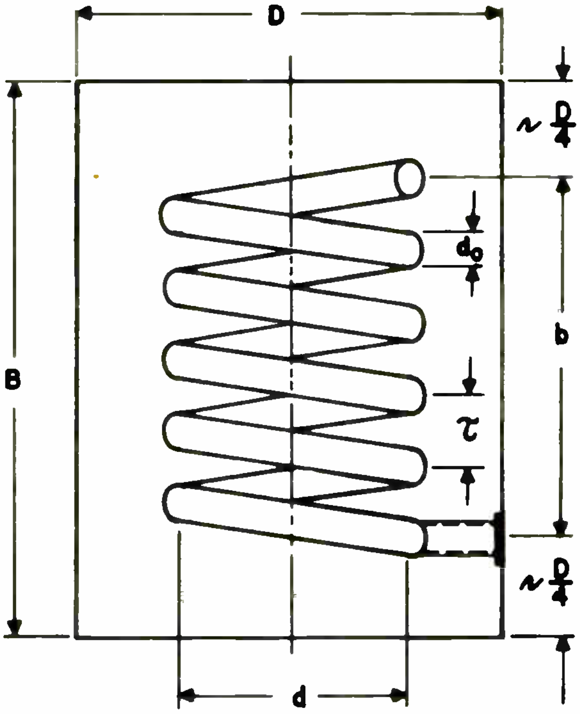


Fig. 2—Outline sketch of resonator.

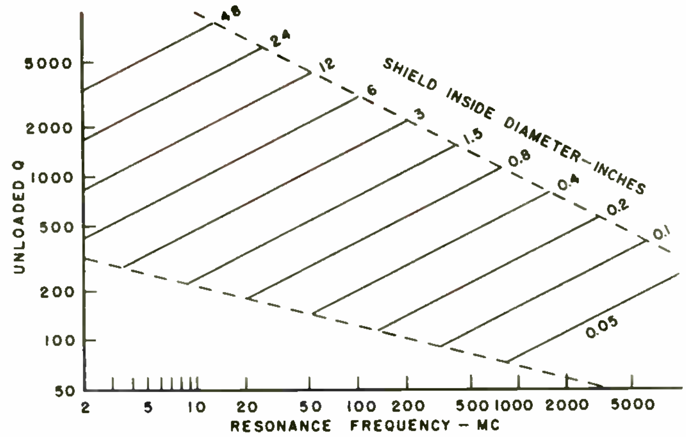


Fig. 3—Helical resonator unloaded $Q$.

ever, instead of being a lumped-constant device, its operation can be described in terms of its distributed inductance, capacitance, and resistance. The clearance at the top between the end of the helix and the shield is required to prevent voltage flashover, and the clearance at the bottom allows for passage of the magnetic field, thus reducing losses in the conductors. Resonance frequency and $Q$ are about the same when the top and/or bottom are open as when they are closed. Probe, loop or aperture coupling can be used for the input and output circuits.

An idea of the size of the helical resonator for typical unloaded $Q$ and resonance frequency can be gained from Fig. 3, which is plotted from (1), (5) and (7). The optimum range lies between the upper and lower dashed lines. At higher $Q_u$ and $f_0$ a conventional coaxial resonator is frequently more desirable than the helical type. At lower $Q_u$ and $f_0$ than the indicated range, a lumped LC circuit is often to be preferred.

A shielded inductor below its quarter-wave resonance frequency also has $Q$ predicted by (1). Then a lumped LC resonant circuit has like $Q$, provided losses in the capacitor and connecting leads are reduced to a negligible value.

A similar problem has been developed by a somewhat different method than that used herein.[1] A report[2] of extensive experimental work on the resistance and $Q$ of unshielded single-layer solenoids includes tables and charts. This leads to a simple formula for the $Q$ of an inductor similar to that given here for a resonator. A convenient compilation[3] of formulas for resonant lines in general has been made.

[1] W. Sichak, "Coaxial line with helical inner conductor," PROC. IRE, vol. 42, pp. 1315–1319; August, 1954.

[2] R. G. Medhurst, "HF resistance and self capacitance of single-layer solenoids," *Wireless Engineer*, vol. 24, pp. 35–43, 80–92, 185, 281; February, March, June and September, 1947.

## Design Chart

The alignment chart of Fig. 4 gives practical design and performance information. Due to the wide range of the parameters covered by the chart, and the latitude of possibilities in actual design and contruction of resonators, it is easily possible in specific cases to have variations of $\pm 10$ per cent. The chart is drawn for the approximate optimum range of the parameters $d/D$, $b/d$ and $d_0/\tau$.

The equations and conditions for the scales of the chart are developed in later sections hereof. Summarizing:

Unloaded $Q$ of a resonator consisting of a single-layer coil of copper conductor on a low-loss form, and enclosed in a copper shield:

$$Q_u = 50Df_0^{1/2}$$
$$0.45 < d/D < 0.6$$
$$b/d > 1.0$$
$$0.4 < d_0/\tau < 0.6 \text{ at } b/d = 1.5$$
$$0.5 < d_0/\tau < 0.7 \text{ at } b/d = 4.0$$
$$d_0 > 5\delta \text{ where } \delta = \text{skin depth.} \quad (1)$$

Total number of turns:

$$N = 1900/(f_0 D) \text{ turns}$$
$$d/D = 0.55$$
$$b/d > 1.0. \quad (2)$$

[3] "Reference Data for Radio Engineers," fourth ed., ITT Corp., New York, N. Y., pp. 574–582, 600–603; 1956.

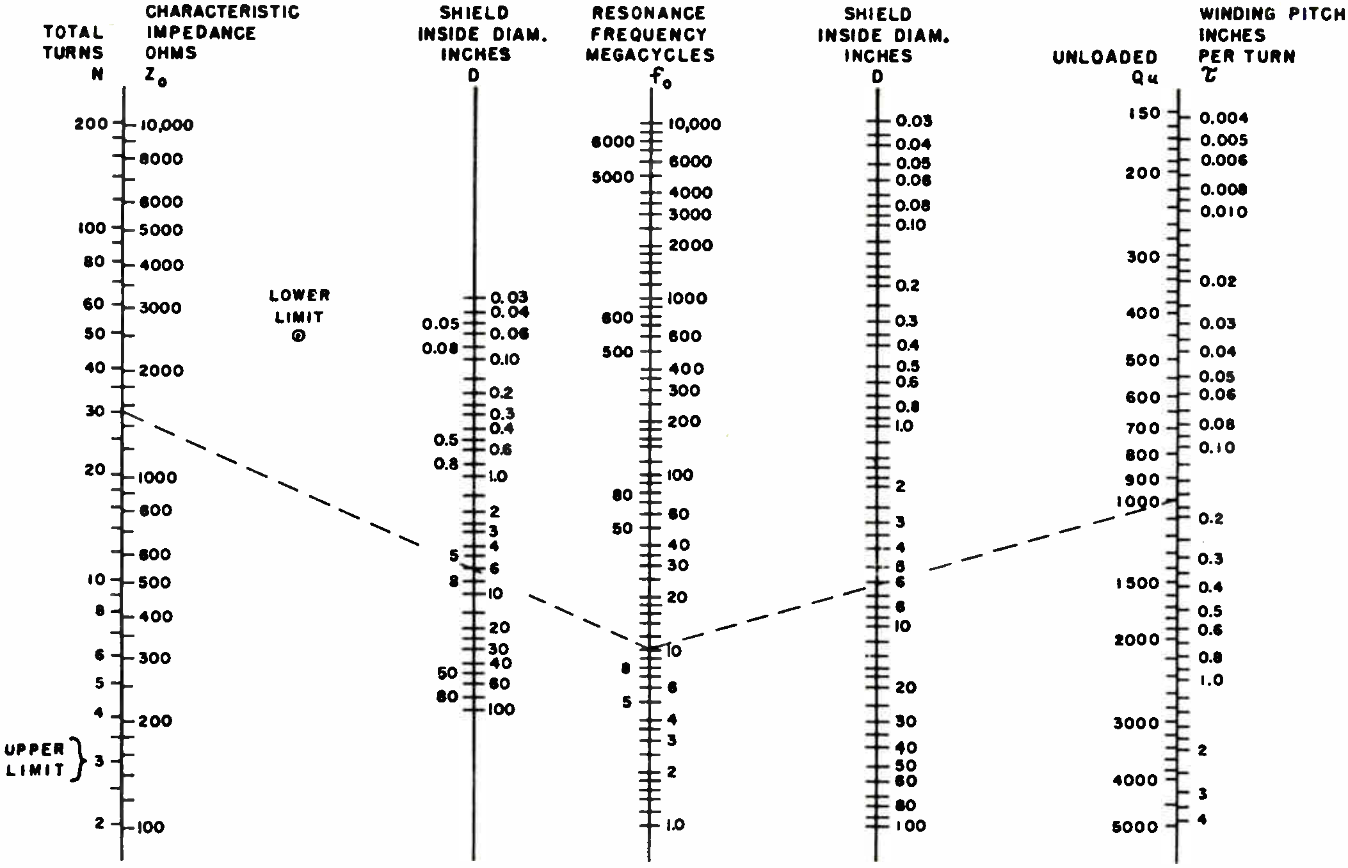


Fig. 4—Design chart for quarter-wave helical resonators.

Pitch of winding and characteristic impedance:

$$\tau = 1/n = (f_0 D^2)/2300 \text{ inches per turn} \quad (3)$$

$$Z_0 = 98{,}000/(f_0 D) \text{ ohms}$$

$$d/D = 0.55$$

$$b/d = 1.5. \quad (4)$$

General conditions for all charts are:

$$B \approx (b + D/2)$$

$$\tau < d/2.$$

The usual precautions for fabricating high-$Q$ coils must be observed. A protective silver plating on the surface of the copper wire and shield is recommended. A silver-clad or solid silver conductor increases the $Q$ about 3 per cent over that for silver-plated copper. A tinned conductor can be substituted for a silver-plated one up to about 100 mc without seriously affecting the $Q$. The shield should not have a seam parallel to the axis; any seam must be effectively soldered for a low-resistance joint. It is desirable to carry the lower end of the coil over to the side of the shield as directly as possible. A minimum amount of dielectric material should be used in the coil form, and it should be eliminated entirely when possible.

## Region of Usefulness

The region where straight coaxial resonators are preferable is separated from that where the use of a helical inner conductor is desirable by a rather broad transition zone. A resonator with about three turns lies within the transition zone. On the chart of Fig. 3 the upper dashed line represents this boundary. In the region near and above the line a straight coaxial resonator should be considered, while below it the helical one is usually preferred. The choice is affected by the shape factor. A coaxial resonator is long and relatively small in diameter. In the helical resonator the length is not much greater than its diameter.

This number, $N = 3$, can be derived from either of two basic concepts. The first is the locus of points where equal unloaded $Q$ vs frequency is obtained with the two types of resonators having equal volumes. For the straight inner conductor type[4] the theoretical $Q$ is derated about 10 per cent for a practical working value. This is compared with (22) for the helical type. The second basic concept is the limitation that $\tau < d/2$, or the pitch of the helix be less than its radius (other-

[4] F. E. Terman, "Radio Engineers Handbook," McGraw-Hill Book Co., Inc., New York, N. Y., 1st ed., p. 192; 1943.

wise it almost ceases to be helical). When $b/d=1.5$, $N=bn=b/\tau>2b/d=3$ turns. The result in either case is

$$Q_u f_0^{1/2} < 32,000 \text{ or } N > 3 \text{ turns,} \tag{5}$$

as the more desirable criterion for the helical resonator.

The demarkation between the relative desirability of a helical resonator vs a lumped-constant tuned circuit is also broad. The lower dashed line on Fig. 3 and the point marked "lower limit" on Fig. 4 are drawn for the condition that the diameter of conductor be greater than five times the skin depth (otherwise the helical-resonator $Q$ will be lower than predicted by the charts). If the alignment on Fig. 4 lies above the "lower limit" point an LC circuit may be preferable. The skin depth is[5]

$$\delta = 2.60 f^{-1/2} \times 10^{-3} \text{ inch.} \tag{6}$$

Utilizing (1) and (3) there results

$$Q_u f_0^{1/4} > 385 \text{ or } f_0^{3/4} D > 7.75, \tag{7}$$

as the condition for the helical resonator being more desirable than the LC circuit. Below this region, for a given volume and $Q$ it becomes advantageous to use fewer turns of larger diameter conductor along with an added capacitor for resonance.

## Example

Design a resonator with $Q_u=1000$ at resonance frequency $f_0=10$ mc. By the charts and formulas, $D=6.3$ inches and $N=30$ turns, $\tau=0.174$ inch per turn and $Z_0=1550$ ohms, provided $d/D=0.55$ and $b/d=1.5$, approximately. Let $n=6$ turns per inch in round numbers. Other dimensions are $d=3.5$ inches, $b=5$ inches, $B=5+(6.3)/2=8.2$ inches. The conductor size can be No. 14 to No. 10 B&S gauge ($d_0=0.064$ to $0.102$ inch) corresponding to $d_0/\tau$ ranging from about 0.4 to 0.6.

The power rating of the resonator can be estimated by use of (32) or (33). Suppose a matched generator is used and a doubly-loaded $Q$ of 100. Assuming a dissipation factor $k=0.4$ watt per square inch, then the generator can have an available power of $P_m=460$ watts. Of this, 20 per cent, or $P_c=92$ watts, is dissipated in the cavity.

If the generator is zero- or infinite-impedance and the singly-loaded $Q$ is 100, the loss in the resonator is 10 per cent. A generator rated at 920 watts can be accommodated.

## Experimental Results

The properties of resonators designed in accordance with the chart have been checked experimentally in a considerable variety of models. Fig. 5 shows unloaded $Q$ vs quarter-wave resonance frequency for 26 resonators in 4 size groups. Mechanical tolerance in construction resulted in deviations of up to 5 per cent from the standardized proportions. There was no particular uniformity of conductor material or surface condition. Silver-clad copper, tinned copper, bare copper, and enameled copper were used according to ready availability in the appropriate diameter. The shields consisted of lengths of commercial copper tubing, with no special attention given to surface condition except for the smallest sizes, which were silver plated.

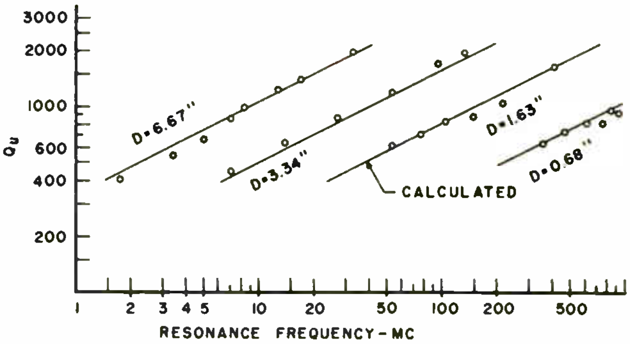


Fig. 5—Comparison of measured and computed $Q$.

Nearly all of the helices were wound on grooved tubular forms of Rexolite 1422 having wall thicknesses of one-sixteenth to one-quarter inch, depending on the depth of groove required. The helices consisting of only a few turns of heavy conductor were self supporting. In one case, a dielectric-supported helix (shown on the graph in Fig. 5 at $f_0=33$ mc, $Q_u=2000$) was duplicated without the form for comparison. The self-supported helix exhibited about 10 per cent higher $Q$ and 3 per cent higher resonance frequency.

Tests were made to check the predicted optimum $d/D$ ratio and the accuracy of the $Q$ indicated by (22). The plot in Fig. 6 shows typical data, in this case for $b/d=1.5$ and $d_0/\tau=0.5$. Ordinates give the ratio of the measured $Q$ to the predicted value. The curve confirms that the maximum $Q$ occurs when $d/D$ is in the vicinity of 0.55. The maximum value of measured $Q$ exceeds the calculated value by about 8 per cent. This is within the normal expected tolerance of predicted $Q$, due to variations of materials and construction.

The $Q$ calculated by (1) is based only on the frequency at which the helix is used, and is not restricted to the special case of quarter-wave resonance. The prediction should be valid also for the helix as a lumped inductor, where the electrical length is quite small. To test this, a typical helix was tuned downward in frequency by external capcitance. Some difficulty was experienced in finding capacitors having a $Q$ much higher than that of the helix. The desired tuning range with reasonable losses was covered by a composite array of transmitting-type vacuum capacitors and handmade parallel-plate air dielectric trimmers. The $Q$ vs frequency is shown in Fig. 7.

[5] "Reference Data for Radio Engineers," *op. cit.*, p. 129.

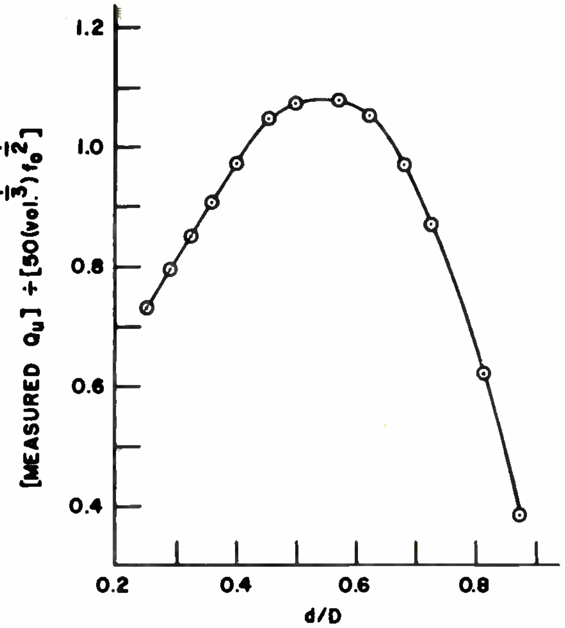


Fig. 6—Test for optimum coil-to-shield diameter ratio.

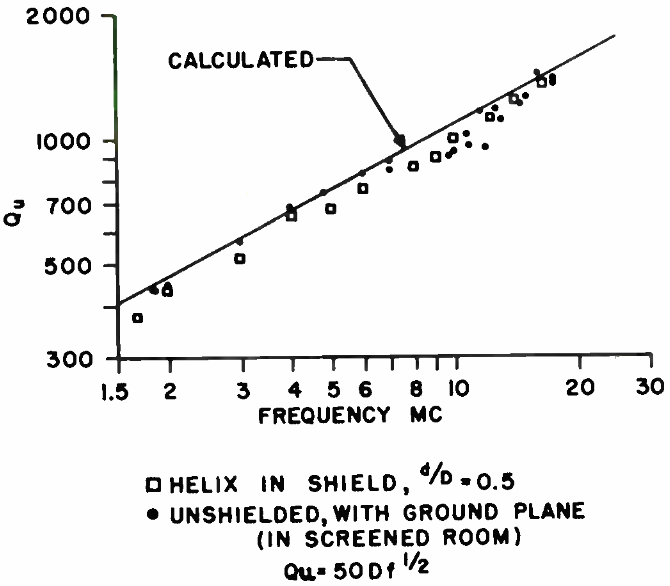


Fig. 7—Measured $Q$ of helix below quarter wave (capacitance tuned).

The data seem to confirm the predicted square-root-of-frequency variation in $Q$. The scattering of points is accounted for by losses in the external capacitors and associated leads. The uppermost points are for quarter-wave resonance with no capacitor. Those down to 12 mc were obtained by using closely-spaced copper tabs as capacitors. Below 12 mc the effect of introducing the larger, lower-$Q$ capacitors is evident.

## Theory

This elementary theory of the quarter-wave helical resonator makes no pretense of being rigorous. Rather, it is directed merely toward developing simple equations and charts for the satisfactory design of resonators.

It has been found to be practical to compute the inductance and capacitance per unit length of the resonator coils as if they were very long. The inductance of a long solenoid[6] as modified by the effect of the shield[7] is

$$L = 0.025n^2d^2[1 - (d/D)^2]\ \mu\text{h per axial inch.} \quad (8)$$

On the basis of measurements of the resonance frequency and characteristic impedance of various resonators, it appears that the effective capacitance is somewhat greater than that of two simple coaxial cylinders. Also, the electrical length of the helix is 5 to 7 per cent less than quarter wavelength. These are attributed in part to the self capacitance of the coil and the fringing field at the top of the coil. An empirical value is:

$$C = 0.75/\log_{10}(D/d)\ \mu\mu\text{f per axial inch.} \quad (9)$$

The velocity, and hence the axial length, of the resonator helix are:

$$v = f_0\lambda = 1000\,(LC)^{-1/2}\ \text{inches per microsecond,} \quad (10)$$

$$b = 0.94\lambda/4 = 235f_0^{-1}(LC)^{-1/2}\ \text{inches.} \quad (11)$$

Substituting (8) and (9) in (11):

$$1/\tau = n = \frac{1720}{f_0D^2(b/d)(d/D)^2}\left[\frac{\log_{10}(D/d)}{1-(d/D)^2}\right]^{1/2} \text{ turns per inch,} \quad (12)$$

$$N = nb = \frac{1720}{f_0D(d/D)}\left[\frac{\log_{10}(D/d)}{1-(d/D)^2}\right]^{1/2} \text{turns.} \quad (13)$$

The characteristic impedance is

$$Z_0 = 1000(L/C)^{1/2} = 235{,}000(bf_0C)^{-1}$$
$$= \frac{0.31 \times 10^6 \log_{10}(D/d)}{f_0D(b/d)(d/D)}$$
$$= 183nd\{[1-(d/D)^2]\log_{10}(D/d)\}^{1/2}\ \text{ohms.} \quad (14)$$

## Unloaded $Q$

The losses consist of conductor losses[8,9] in the winding and shield, and dielectric losses. The latter are quite small in coils of good design, but are not readily computed. The references noted give formulas for the ac resistance of a straight conductor, the proximity effect due to current in nearby turns and resistance due to currents in the shield. For copper helix and nonmagnetic shield

[6] "Radio Instruments and Measurements," Bureau of Standards circular C74, U. S. Government Printing Office, Washington, D. C., p. 252; 1937.
[7] F. E. Terman, *op. cit.*, p. 129.
[8] "Reference Data for Radio Engineers," *op. cit.*, p. 131.
[9] F. E. Terman, *op. cit.*, pp. 78–80, 129.

$$R_c = (n\pi d)\phi f^{1/2} d_0^{-1}(1/12) \times 10^{-3}$$
$$= (0.083\times 10^{-3})(\phi/nd_0)n^2\pi d f^{1/2} \text{ ohms per axial inch,} \quad (15)$$

$$R_s = \frac{9.37 n^2 b^2 (d/2)^4 (1.724 f)^{1/2}}{b[D^2(b+d)/8]^{4/3}} (\rho_s/\rho_{cu})^{1/2}$$
$$\times 10^{-4} \text{ ohms per axial inch.} \quad (16)$$

The unloaded $Q$ is given by:[10]

$$Q_u = \beta/2\alpha = 2\pi f_0 L/(R_c + R_s), \quad (17)$$

the last form being the value when dielectric losses are neglected. Note that the $Q$ is the same as that approached by a lumped LC resonant circuit as the losses in the capacitor and connections approach zero.

For the resonator with copper coil and copper shield,

$$Q_u = 600 \frac{(d/D) - (d/D)^3}{(\phi/nd_0)(1 + R_s/R_c)} D f_0^{1/2}. \quad (18)$$

Instead of determining the proximity factor $\phi$ for each case, it is sufficiently accurate to write:

$$\phi/(nd_0) = \phi\tau/d_0 = 3.7, \quad (19)$$

when $d_0/\tau$ lies within the range given in the conditions for (1).

From these there can be derived two practical formulas for $Q$ with accuracy of about $\pm 10$ per cent when $0.45 < (d/D) < 0.6$ and $(b/d) > 1.0$.

$$Q_u = 220 \frac{(d/D) - (d/D)^3}{1.5 + (d/D)^3} D f_0^{1/2}. \quad (20)$$

$$Q_u = 50 D f_0^{1/2}. \quad (21)$$

The $Q$ in these formulas has been arbitrarily reduced 10 per cent below the theoretical value to allow for imperfect surface conditions of the conductor. Tabulation of errors of (20) vs (18) (reduced 10 per cent) for the ranges of $d/D$ and $b/d$ listed for (20) shows them to give substantially equal results, and similarly for (21) vs (20).

A useful relationship is that of $Q_u$ and volume of shield. When $0.4 < d/D < 0.6$ and $1.0 < b/d < 3.0$:

$$Q_u = 50 \,(\text{vol})^{1/3} f_0^{1/2}. \quad (22)$$

## PROPORTIONAL RELATIONSHIPS

The energy considerations of resonant lines are given in a previous reference.[3] Suppose a series of resonators is considered that has various sizes and resonance frequencies, but in which the geometrical porportions are all identical. Consequently, the design parameters $d/D$, $b/d$, and $nd_0 = d_0/\tau$ are the same for all the resonators. Let the input and output loadings be equal or matched, so that there is no mismatch loss.

Then the following proportionalities and equations can be written:

$$Q_u \propto f_0^{1/2} d, \quad (23)$$
$$P_c = 2P_m Q_d / Q_u, \quad (24)$$
$$(\text{temp rise}) \propto P_c/d^2, \quad (25)$$
$$(\text{vol}) \propto d^3. \quad (26)$$

Various combinations can be made of the above expressions:

$$(\text{temp rise}) \propto P_m Q_d (\text{vol})^{-1} f_0^{-1/2}. \quad (27)$$

The voltage gradient at the open-circuited end, and similarly between turns at the short-circuited end, is:

$$(\text{volt grad}) \propto V_{oc}/d = Z_0 I_{sc}/d$$
$$\propto (P_m Q_d)^{1/2} [(\text{vol}) f_0]^{-1/2} \quad (28)$$

For a given $P_m$ and $Q_d$ there results:

A) temperature rise constant;

$$\left.\begin{aligned} (\text{vol}) &\propto f_0^{-1/2} \\ Q_u &\propto f_0^{1/3} \\ (\text{volt grad}) &\propto f_0^{-1/4} \end{aligned}\right\} \quad (29)$$

B) unloaded $Q$ constant;

$$\left.\begin{aligned} (\text{vol}) &\propto f_0^{-3/2} \\ (\text{temp rise}) &\propto f_0 \\ (\text{volt grad}) &\propto f_0^{1/4} \end{aligned}\right\}. \quad (30)$$

The proportionalities in (29) and (30) are plotted in Fig. 8. A certain frequency ratio $f_0/f_1 = 1.0$ is shown, above which the temperature rise is indicated as constant, while the relative volume, voltage gradient and $Q_u$ are plotted vs frequency ratio. In this region the unloaded $Q$ is adequate, but temperature rise is the limiting factor. The volume is chosen according to the power rating $P_m$ and the loaded $Q$.

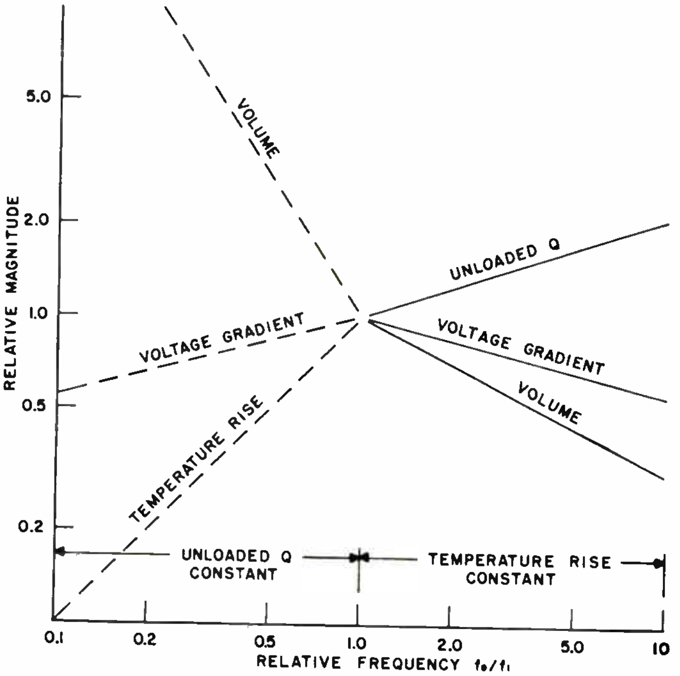


Fig. 8—Relative characteristics of helical resonators.

[10] "Reference Data for Radio Engineers," *op. cit.*, pp. 553, 575.

Below the frequency ratio $f_0/f_1 = 1.0$ the unloaded $Q$ is the limiting factor, because it cannot be allowed to decrease indefinitely. The lower the unloaded $Q$ the greater the dissipation loss. Then the efficiency of the system would become lower than is desirable, or, in other words, the transducer loss would be excessive. In this region, as shown in Fig. 8, the volume increases rapidly.

### Power Rating

The power-handling capacity can be estimated by use of (24) and the dissipation from the surface of the shield:

$$P_c = k \text{ (shield area) watts.} \tag{31}$$

When $d/D = 0.55$, $b/d = 1.5$ and $B = b + D/2$ the entire shield area is 5.8 $D^2$. Then when the top and bottom of the shield are closed and no ventilating holes are provided

$$P_m = 145kD^3f_0^{1/2}/Q_d \text{ watts.} \tag{32}$$

The value of $k$ depends on the design and materials of the resonator. A conservative value is believed to be $k = 0.4$ watt per square inch.

For a zero- or infinite-impedance generator properly loaded by the cavity and its load:

$$P_s = 290kD^3f_0^{1/2}/Q_s \text{ watts.} \tag{33}$$

# Correction

R. S. Colvin, of the Radio Propagation Laboratory, Stanford University, Stanford, Calif., has brought the following correction to the attention of Peter D. Strum, author of "Considerations in High-Sensitivity Microwave Radiometry," which appeared on pages 43–50 of the January, 1958, issue of Proceedings.

In Table I, page 46, the last line, right-hand column, should read "$1/\sqrt{2}$," not "$1/\sqrt{\pi}$," as shown.

# Digital Rate Synthesis for Frequency Measurement and Control*

T. J. REY†

*Summary*—**Digital rate synthesis is a transformation of harmonic synthesis (beat methods) from the frequency to the time domain; the synthesis of harmonics is replaced by pulse techniques.**

**The signal whose period is to be measured or controlled is in the form of a pulse train that has the repetition rate *X*. A single reference source drives a rate generator which consists of one or more dividing stages in fixed cascade; the output of the generator is a sequence of nonuniformly spaced pulses whose average repetition rate *AS* is known from the independently controllable connection between the individual stages and their output bus.**

**A rate difference detector compares the rates *X* and *AS*. The smoothed detector output has the proper sign and serves to indicate the magnitude of the difference or to reduce the difference in a closed loop, for example, by controlling a tuning motor.**

**The range of direct operation is limited by pulse techniques, but digital and harmonic synthesis can be combined with division and with phase-lock methods to stabilize an oscillator over a practically unlimited band of frequencies, the precision and purity approaching that of the reference source.**

## I. Background

THE study of digital rate synthesis (DRS) for frequency control was stimulated by limitations in conventional methods, although applications to date have been in the related fields of computing systems[1] and of motor speed control[2] only. (DRS in relation to computing techniques is discussed briefly in Appendix C.)

Conventional methods of frequency control fall into two groups, "harmonic synthesis" and "gated counts," respectively.

An example of the former[3] is the single-crystal frequency synthesizer that selects and combines harmonics and subharmonics of the crystal frequency to provide one of many possible outputs. Although crystal precision is preserved, spectral purity suffers from spurious signals generated in the combining mixers, the more so the greater the number of combinations. Spurious levels are reduced by using the selected output to lock the phase of a variable frequency oscillator (VFO), but further difficulties arise unless the VFO is pretuned closely enough; this often proves to be impossible by conventional (*e.g.*, mechanical) means.

The gated count is well known for the measurement of periodic phenomena in the form of pulse series. The number of pulses $N$ in a prescribed period $T$ is counted and displayed repeatedly. The pulse repetition rate is:

$$\frac{N_{+\epsilon}}{T}, \qquad 0 \leq \epsilon < 1;$$

the error $\epsilon$ stems from the integral nature of counting and the random phase between the unknown and the counting periods. A VFO can be tuned, manually or automatically, toward a prescribed frequency with the aid of a gated counter.

A large value of $T$ aids precision, but requires a large maximum count and affects the system stability adversely. Automatic frequency control by a gated counter[4] further necessitates the subtraction of the actual from the desired count, the conversion of the numerical difference to a control voltage and the holding of that voltage, all in a properly timed cycle.

## II. The Principle of Digital Rate Synthesis

In DRS, the stress is on the counting rate rather than on the Fourier frequency aspect of periodic phenomena; yet it can be compared both with harmonic synthesis and with the technique of the gated count. Thus, the selection and mixing of harmonics is replaced by the selection and superposition of repetition rates; again, a difference rate is measured rather than the count that accumulates in a known interval. Simplicity, resolution, range width and rapidity of response are enhanced accordingly.

Fig. 1 and Fig. 2 illustrate the principle. The uniform pulse train $X$ represents the signal whose period is to be measured or controlled, and requires a pulse-forming circuit if the signal is not of suitable form.

Pulse train $AS$ consists of nonuniformly spaced pulses; their average repetition rate is $AS$, where $S$ is the frequency of the reference source and $A$ is the number $a_0.\, a_1a_2 \cdots a_n$. The known digits $a_0, a_1 \cdots a_n$ are set up in the rate generator which comprises dividing circuits in fixed cascade connection. The output rate $AS$ is obtained by selecting and superposing pulse trains available at the various stages by means of switches or gates which determine the number $A$, digit by digit. The superposition guarantees a minimum for the spacing of the pulses,

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[1] M. A. Meyer, "Digital techniques in analog systems," IRE Trans. on Electronic Computers, vol. EC-3, pp. 23–29; June, 1954. See also M. A. Meyers, *et al.*, "An operational-digital feedback divider," IRE Trans. on Electronic Computers, vol. EC-3, pp. 17–22; March, 1954.

[2] C. I. Jones and K. Geohagen, Westinghouse Electrical Corporation, private communication.

[3] R. L. Craiglow and E. L. Martin, "Frequency control techniques for single sideband," Proc. IRE, vol. 44, pp. 1697–1702; December, 1956. See also H. J. Finden, "The frequency synthesizer," *J. IEE* (London), vol. 90, pp. 165–177; December, 1943.

[4] Northern Radio, "Variable Master Oscillator," Type 173, Model 1.

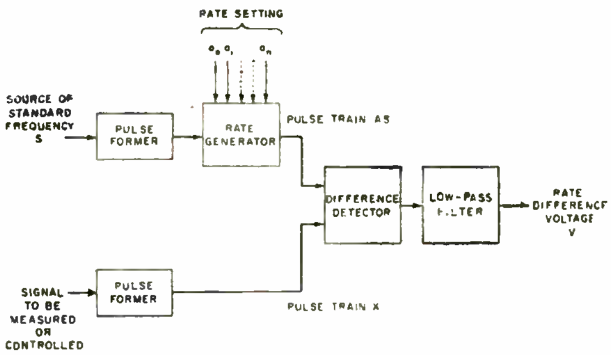
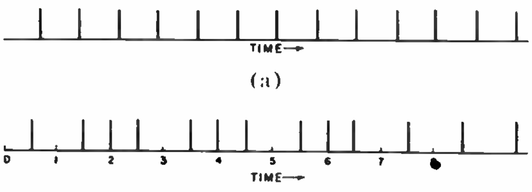



Fig. 1—System schematic.




(b)

Fig. 2—Pulse trains: (a) train $X$, (b) train $AS$.

which is nonuniform, in general. Rate generators are discussed further in the next section.

The rates $X$ and $AS$ are compared in the detector; the smoothed detector output ideally is a dc proportional to $X-AS$, in both magnitude and sign. The proportionality holds near balance, although saturation occurs at large differences.

For measurements, the detector output can be displayed or recorded and/or used for control of the rate setting $A$ by means of selector switches which operate on the digits $a_i$.

For control, the rate difference voltage serves as a wide-band error voltage; *e.g.*, if $X$ is the frequency of an oscillator, the error voltage $V$ operates a tuning device which reduces the tuning error. The residue can be reduced to zero by phase locking. DRS can be applied to frequency ranges exceeding convenient pulse rates by feeding the detector with multiples or submultiples, or by combining it with harmonic synthesis.

The further dicussion of the component blocks is facilitated by using the concepts current in digital computer design (Appendixes A and B), and by dealing with only a few of the many possible arrangements.

## III. Rate Generation

### A. Counting Rates

Rate synthesis is based on the simple properties of counters; both of these will be considered briefly.

A counter stage whose successive counts are 0, 1, 2, $\cdots$, $N$-1, 0, 1, $\cdots$, etc., is said to count "modulo $N$" and to have $N$ possible "states." Given a counter input of rate $S$, each state changes at the rate $S/N$. When a stage of modulus $M$ is fed at the rate $S/N$, every one of its states changes at the rate $S/MN$. Similarly, $n$ cascaded stages, all of modulus $N$, generate the lowest rate $N^{-n}S$ from the last stage. Moreover, pulses can be derived from any stage whenever any one of its states arises. Excluding one state, say zero, it follows that the individual stage can deliver 0 or 1 or $\cdots$ or $(N-1)$ pulses for every $N$ pulses fed into it. As will be shown next, any or all of these contributions from the $n$ stages can be combined with each other and with the pulse train of rate $S$ without losing a pulse, hence any average repetition rate in the range 0, $N^{-n}S$, $(2-N^{-n})S$ can be obtained. The combined rates have the shortest common period $N^n/S$, hence the average is always obtained in that period, which may be quite short.

The requirement that no pulse be lost in combining the contributory rates is met on noting that the addition of unity to an integer in digital representation increases one digit at most.[5] It follows that the pulse contributions must be taken when the relevant state is arising and not at its cessation. Where delay times in the generator are negligible, all changes of state coincide with a pulse of the train $S$, hence the latter must be shifted if it is to be combined with the counter contributions. A suitable delay is $1/2S$; the intervals between the pulses in the compound train are then equal to or integral multiples of $1/2S$, in accordance with the fact that the average value of the combined rate is always less than $2S$.

The combination rule can be stated thus: Given a fixed frequency $S$, the instants allocated to the pulses of average rate $AS$ are spaced by $1/2S$; the instants allocated to the contribution of any one digital place are those left after deducting for any higher digital places and for every $N$th pulse.

$N$ is the radix or base of the digital place under consideration, hence the rule also applies to mixed radix representation of the number $A$.

### B. Binary Generator

A cascade of triggers forms a binary counter ($N=2$). Reference to Fig. 3, in which $n=4$, shows that the "beginning" element, switch contacts, gates, and a time delay complete the rate generator schematic. The $\div 2^1$ trigger is fed with the pulse train $S$ after its polarity has been reversed; the $\div 2^i$ trigger is fed from the $\div 2^{i-1}$ trigger for $i>1$. The $n$ binary stages form a counter modulo $2^n$.

When the $i$th trigger goes to 1, the beginning element at its output delivers a pulse to the switch contact $a_i$; this is open if $a_i=0$ and no contribution is made to the output. If $a_i=1$, a pulse is delivered to the coincidence gate whenever the $i$th trigger goes to 1. As shown in Fig. 3, the coincidence gate is also fed with the original pulses $S$ for the purpose of reshaping the differentiated trigger outputs. This renders their performance less critical, but the reshaping pulse may have to be delayed to match the lags of the trigger and beginning circuits.

[5] Example: In decimal notation, given 3 digits: in 909+1=910 the digit 0 increases to 1, in 999+1=000 no digit increases.

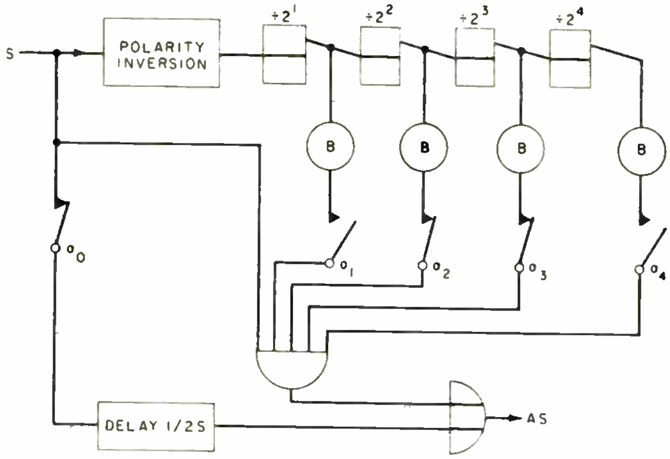



Fig. 3—Binary rate generator.

The switch contact $a_0$ allows $S$ to be added with the aid of the delay unit 1/2$S$ and the "and" gate.

One "beginning" element can be shared between two or more triggers by rearranging the circuit somewhat. Also, the polarity inversion and delay units can be replaced by feeding the rate $2S$ to a trigger followed by two "beginning" elements. Switches can be replaced by gates for control by electric signals.

### C. Decade Generator

The decimal notation is desired in most applications; a binary generator can be modified accordingly, or it can be replaced by cascaded stages of decade rings.

An example of such rings is the decade counter tube of the multicathode type. The decimal digit $a_i$ is set up by joining $a_i$ cathodes of the $i$th tube; *e.g.*, by a cumulative switch (see Fig. 4). The selection of $a_i$ states in the natural order is not necessary; the nonuniformity of the pulse spacing in the output is reduced to 2:1 (as in the binary case) if the cathodes are joined as indicated in the pulse-spacing scheme below.

| Cathode / Digit $a_i$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | × | | | | |
| 2 | | | | × | | | | × | | |
| 3 | | | × | | | × | | | × | |
| 4 | | | × | | × | | × | | × | |
| 5 | | × | | × | | × | | × | | × |
| 6 | Complementary with 4, etc. | | | | | | | | | |

More economical designs are offered by techniques that may be termed "pseudodigital." A sawtooth generator is triggered by every tenth pulse of the input, and delivers a sawtooth and a pulse at a tenth of the input rate. The contribution of $a_i$ pulses is taken from a coincidence circuit fed with the input and an enabling voltage; the latter consists of the sawtooth and a bias set according to the chosen digit $a_i$. A two (decimal) digit generator of this type is shown in Fig. 5. It will be noted that every stage operates at its fixed rate, and this fact can be used to enhance reliability.

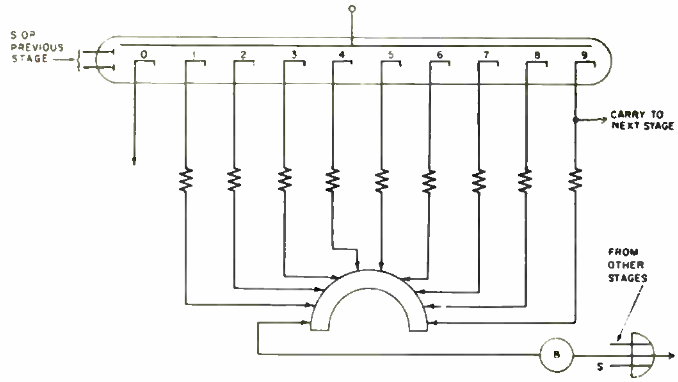



Fig. 4—Dekatron for rate generation.

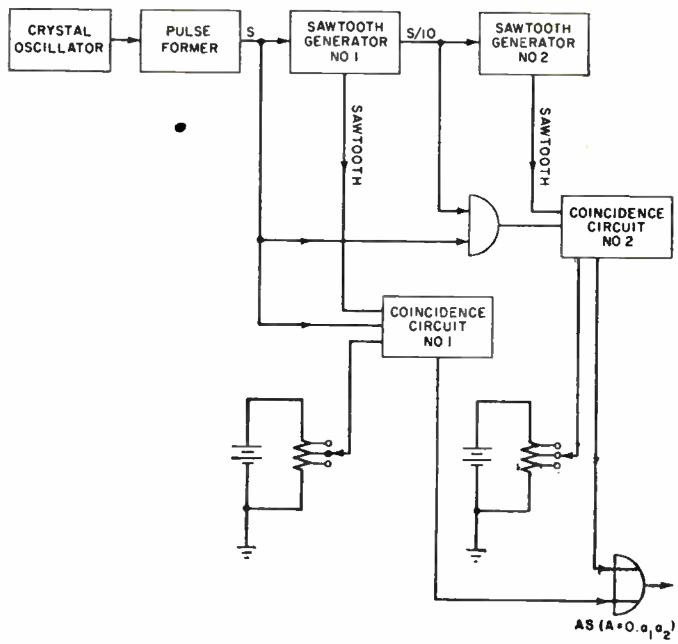



Fig. 5—Two decade generator (pseudodigital).

## IV. Detection

### A. Superposition and Pairing-Off

The basic method of rate error detection is superposition (see Fig. 6). When a unidirectional current pulse is repeated $X$ times per second, the dc component of the pulses is proportional to $X$; thus, if trains $X$ and $AS$ are superposed after inverting the polarity of $AS$, for instance, and then passed through a low-pass filter, this supplies a dc difference voltage $V$ (Fig. 6). In practice, the individual pulses are not identical and $V$ fails to vanish when $X = AS$. This zero error is reduced greatly if the filter is fed at the rate difference $X - AS$ rather than with the rates $X$ and the polarity inverted $AS$. The rate difference is generated by a pairing-off circuit [Fig. 7(a)] comprising a bistable trigger or flip-flop and two coincidence gates. Pulses $X$ are applied to one control terminal and pulses $AS$ to the other. For definiteness, it is convenient to assume tubes in the flip-flop and nega-

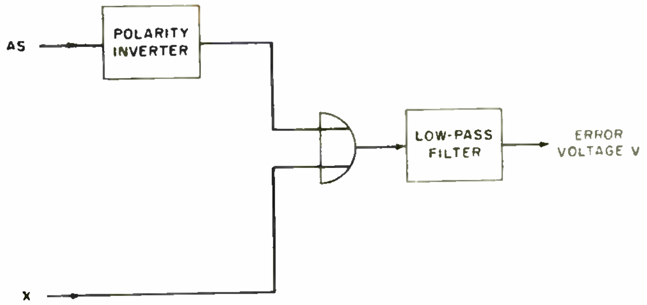



Fig. 6—Detection by superposition.

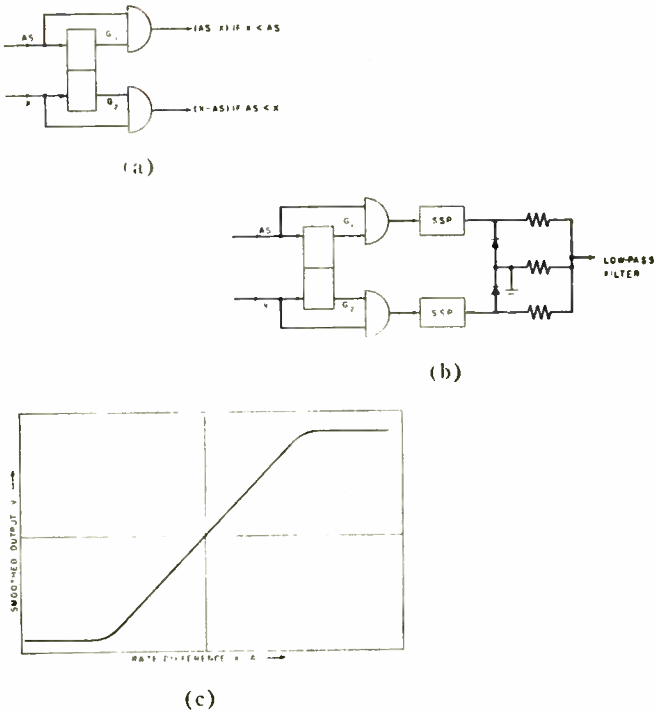



Fig. 7—Simple rate difference detection: (a) pairing-off circuit, (b) simple detector, (c) detector characteristic.

tive-going pulses in the pulse trains applied to their grids. The plates are coupled to AND gates $G_1$ and $G_2$. These are also fed with the pulses in such a way that the gate $G_1$ has an output if the flip-flop is at "one" when an $X$ pulse arrives at the flip-flop, whereas gate $G_2$ has an output if the flip-flop is at "zero" when an $AS$ pulse arrives; otherwise the gates have no output. Because of finite response speeds, the coincidence of the present $X$ or $AS$ pulse and the slightly earlier trigger state actuate the gates.

If it is assumed, for the moment, that the pulses are uniformly spaced in each train and that these have equal repetition rates, no pulse is emitted if the trigger is at "zero" prior to the arrival of an $X$ pulse; similarly, there is no emission if this is at "one" prior to an $AS$ pulse arriving. However, a pulse is emitted if $X$ exceeds $AS$ and continues to be emitted at the difference rate. (One error pulse is generated if the flip-flop is at "zero" when an $AS$ pulse arrives or if it is at "one" when an $X$ pulse arrives. This difference pulse is false, but it is not repeated.)

If the difference output is to be single-ended, the polarity of the output of one of the gates, $G_1$ or $G_2$, must be reversed. This can be done with the aid of two single-shot pairs (SSP), each of which delivers a balanced pulse when it receives an input. The SSP outputs are combined in a mixing unit [see Fig. 7(b)], a simple form of which is a resistive pad fed from the SSP with the aid of dc restoring diodes. The mixer output is a train of pulses, the repetition rate is the difference rate and the polarity is the sign of the frequency error. The dc component is the desired error signal. The characteristic [see Fig. 7(c)] saturates at a level proportional to the peak value of the pulses from the SSP and at a difference rate whose period is about equal to the width of the pulses from the SSP.

The detector could malfunction whenever an $X$ pulse almost coincides with an $AS$ pulse. Such pairs are suppressed in a simple "pulse antifouling circuit" (Fig. 8), which tests for coincidence of the broadened pulses in one with those of the other; the AND gate output controls the anticoincidence gates fed with the delayed but unbroadened pulses, as required for well-spaced outputs $X'$ and $(AS)'$ that conserve the difference rate $X-AS$.

The nonuniformity of the synthetic pulse train $AS$ has been ignored so far; its nature and implications will be considered next.

### B. Uneven Spacing

The synthetic rate $AS$ is generally subject to nonuniform spacing [*e.g.*, Fig. 2(b)]. Hence, even when the rate difference is zero, the simple detector of Fig. 7(b) is not quiescent, and its mean output fails to vanish unless the output pulses are matched perfectly. The problem is understood better on considering the response of a difference counter[6] fed with $X$ and $AS$ [or $X'$ and $(AS)'$] (see also Appendix B); when $X=AS$, the count vacillates by a certain amount. The maximum $\Delta y$ of these excursions has been estimated as a function of the number of digits $n$ in $A$, with the following result.

The Binary Case

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $n$ | 2 | 4 | 8 | 10 | 14 | 16 | 20 |
| $\Delta y$ | 1 | 2 | 2 | 3 | 3 | 4 | 4 |
| $M$ | 1 | 2 | 2 | 2 | 2 | 3 | 3 |

The last row ($M$) denotes the least number of binary stages in the difference counter which are required to accommodate the difference count $\Delta y$.

The Decimal Case

| | | | | | |
|---|---|---|---|---|---|
| $n$ | 1 | 2 | 3 | 4 | 5 |
| $\Delta y$ | 3 | 5 | 8 | 10 | 13 |
| $M$ | 3 | 3 | 4 | 4 | 4 |

[6] K. H. Barney, "The binary quantizer," *Elec. Engrg.*, vol. 68, pp. 962–977; November, 1949.

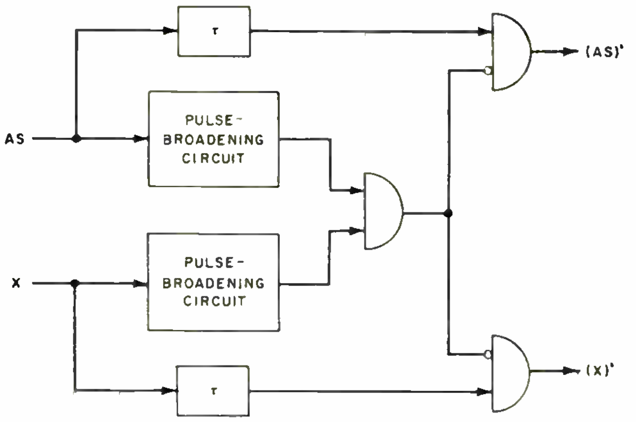



Fig. 8—Pulse antifouling circuit.

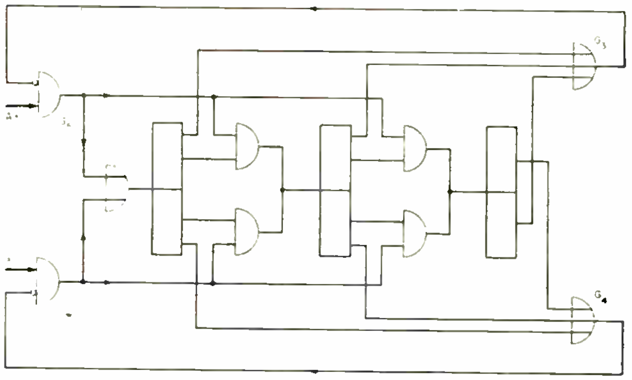


Fig. 9—Difference counter with overflow guard.

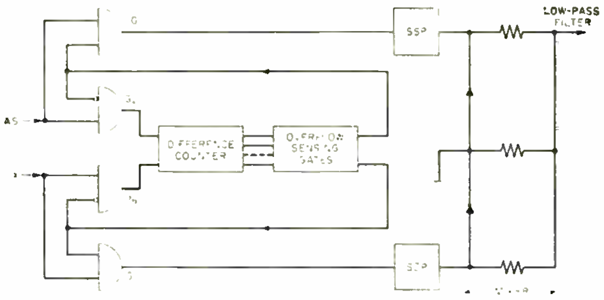



Fig. 10—Balanced difference detector.

Synthesis of $A$ is assumed in the natural order, and with the possible addition of 1.

The difference counter cannot register $\Delta y$ correctly unless overflow is prevented. The most positive number it can indicate is of type 011, *i.e.*, a "zero" in the trigger of greatest digital significance and a "one" in all other triggers; similarly the most negative number is of type 100. As shown in Fig. 9, the counter is guarded against overflow by means of coincidence gates $G_3$ and $G_4$ that sense the extremal counts, and by anticoincidence gates $G_5$ and $G_6$; the $AS$ pulses are blocked from the counter when the count 011 has been reached by means of $G_5$, and $G_6$ blocks the $X$ pulses when the count 100 has been reached.

The discussion of the rate difference detector will now be resumed.

### C. The Balanced Detector

The desired zero output in the case $X = AS$ can be approximated in several ways; it is assured by quiescence on applying the principles of subsections B and C above.

The circuit is shown as Fig. 10, and differs from that of Fig. 9 only in the gates $G_1$ and $G_2$; gates $G_3$ and $G_4$ are now indicated by the box labeled "Overflow Sensing Gates." When the difference counter has reached its positive maximum (due to an $X$ pulse) and the next pulse is an $X$, gates $G_2$ and $G_6$ divert this from the counter to the relevant SSP and thence to the output. The first $AS$ pulse subtracts unity from the maximum count but does not reach the output. The circuit is symmetrical with regard to the two pulse trains, except for the mixer that feeds the low-pass filter. This is also true of the simple detector [see Fig. 7(b)], but the desired balance is achieved by quiescence rather than by critically adjusted components and operating conditions. The detection characteristic [see Fig. 7(c)] must pass through the origin now, but with abrupt change of slope if there is any SSP unbalance. In the close vicinity of the origin, the actual output approximates a train of unidirectional impulses.

## V. System Properties

### A. Resolution

The resolution of the above detection process is not limited by the cycle of a "clock" as in the gated count technique. However, a time equal to the reciprocal of the rate error must elapse before this becomes known; *e.g.*, if $X$ exceeds $AS$ by $10^{-1}$ cps, the SSP that contributes positively fires once every 10 seconds, on average. Because of nonuniform spacing, a nonrecurring group of pulses ($\leq \Delta y$) is emitted, and the firing rate is modulated at a rate depending on $a_n 10^{-n}S$ (the lowest contribution to $AS$). A graver effect stems from detector malfunction by badly spaced pulse pairs; although a simpler circuit [see Fig. 7(a) or Fig. 8] than the balanced detector can be assigned to deal with bad pairs, only one of the partners will still be suppressed occasionally. Resolution is limited to the extent that faulty suppressions have a (fluctuating) mean in a time of the order of the post-detection smoothing period; the effective mean should be very small when pulse trains $X$ and $AS$ are randomly related and when the circuits are well balanced.

### B. The Closed System

A closed-loop control system will now be considered. The detector output is the error signal[7] and controls the tuning motor of a VFO for frequency control, or the settings of the digit switches in the rate generator for the automatic measurement of the rate $X$.

[7] A "fine control" can be provided by a bias in series with the error signal.

The system is of position-control type, since the mean error signal is proportional to the position error (of tuning motor) near balance. Balance is independent of the initial error, and convergence is speeded up if the low-pass filter is of the swinging-choke type. However, balance tends to be unstable owing to the intermittent nature of the control signal; stabilization may be provided by hysteresis (by Coulomb friction) or, in the case of a measurement loop, by the discrete nature of $A$.

A superior method of stabilization is available for frequency control, since the frequency $AS$ is always some integral multiple of the lowest contributory rate that can be drawn from the rate generator. A system of this type is illustrated by Fig. 11, in which the VFO tuning motor is driven by the error voltage. A loop for locking the VFO phase is also provided; the uniform pulse train of rate $10^{-n}S$ (or $2^{-n}S$ in binary synthesis) serves as the reference signal for periodic clamping of the controlled oscillation; the clamped voltage controls the frequency modulator (*e.g.*, a reactance tube) across the VFO tank circuit. The properties of a well-designed phase loop are such that both the stability and the spectral purity of the reference signal $S$ are preserved in the locked oscillator. Jitter in the reference rate ($10^{-n}S$) must be kept low by retiming with the signal $S$. The design of the phase loop is simplified further by restricting its pull-in range to a small tuning error.

The DRS loop is quiescent at lock unless a simple rate error detector is used or activity arises from badly spaced pairs in the now-phase-related pulse trains $X$ and $AS$; the DRS loop can be opened at lock by using the fact that ac is then absent from the output of the phase clamp.

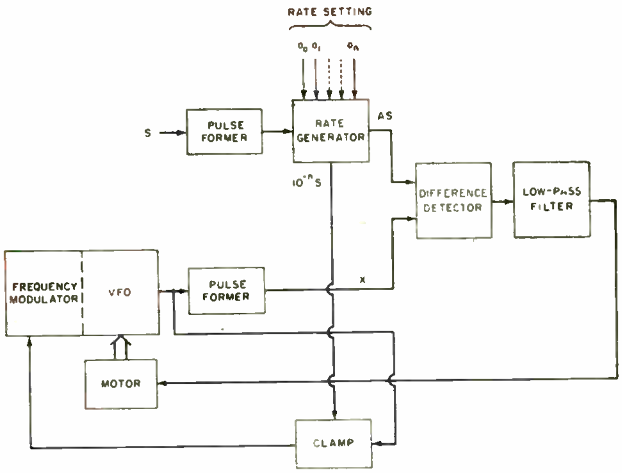
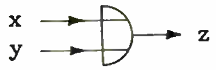
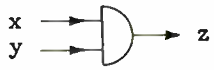
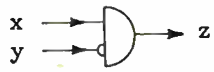
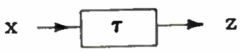
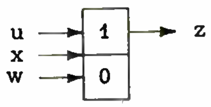
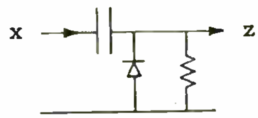



Fig. 11—Frequency control system with phase stabilization.

## Appendix A
## Logical Symbols

Logical symbols are the elements of circuits which operate in on-off fashion, such as 0 or 1 volt (this implies step functions, or impulses of finite width). The symbols represent functions of Boolean algebra and/or of time.

| Name | Symbol | Function | Note |
|---|---|---|---|
| OR gate |  | $z=(x \text{ or } y)=(x \vee y)$ | Output exists when there is at least one input |
| AND gate, coincidence gate |  | $z=(x \cdot y)=(x \wedge y)$ | Output exists when both inputs exist |
| NOT gate, anticoincidence gate |  | $z=(x \cdot \sim y)$ | Output exists when $x$ but not $y$ exists |
| Delay element |  | $z=x(t-\tau)$ | Output equals input after delay $\tau$ |
| Trigger, flip-flop |  | $z=1$ if the last input was $u$ or $x$ when $z$ was 0; $z=0$ if the last input was $w$ or $x$ when $z$ was 1. | The trigger is "on" ($z=1$) if the output is at high potential. A brief delay (of the same order as the pulse width) is associated with the response |
| "Beginning" element |  | $z=1$ only when $x$ rises positively | Output is a pulse, input is usually a step. Physical prototype is a capacitor-fed leaky diode  |

## Appendix B

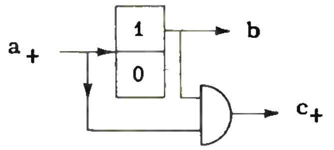
### Binary Addition, Subtraction and Counting

#### Addition

The possibilities are exhausted by the truth table; the rule and the circuit follow.

| Resident Digit $b$ | Addend $a_+$ | Resultant Digit $b'$ | Carry $c_+$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 1 | 0 | 1 | 0 |
| 0 | 1 | 1 | 0 |
| 1 | 1 | 0 | 1 |

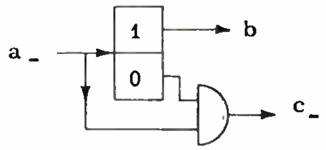
$$b' = (a_+ \mathbin{\dot{\neq}} b), \quad c = (a_+ \cdot b)$$




#### Subtraction

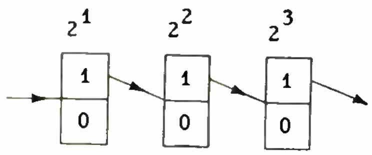
| Resident Digit $b$ | Subtrahend $a_-$ | Resultant Digit $b'$ | Carry $c_-$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 1 | 0 | 1 | 0 |
| 0 | 1 | 1 | 1 |
| 1 | 1 | 0 | 0 |

$$b' = (a_- \mathbin{\dot{\neq}} b), \quad c_- = (a_- \cdot \sim b)$$




#### Counters

Binary counting is performed by cascading flip-flops if these respond to signals of one polarity only, *e.g.*, negative going. (The input is also assumed to be negative going.)




With suitable gate connections, the circuit becomes a difference ("add-subtract" or "forward and backward going") counter, *i.e.*, it will add the $X$ pulses and subtract the $AS$ pulses. (A difference counter is shown in Fig. 9, together with gates $G_4$, $G_5$, $G_6$, and $G_7$ that prevent overflow.)

## Appendix C

### DRS for Computation

The digital nature of pulse rates and their self-decoding property commend their use in a variety of control systems. Precision, simplicity, speed and stability are enhanced on discarding the clock that has been held essential previously,[1] and on introducing rate difference detectors.

Methods for operating mathematically on the variable $X/S$ represented by the pulse rate $X$ will be considered briefly.

To add is to superimpose; a pulse antifouling circuit is devised readily to avoid loss by pulse coincidence. Subtraction is performed by means of a rate difference detector [Fig. 7(a), or Fig. 10 without the SSP and mixer]. Negative numbers are represented by a "minus" sign, *i.e.*, by the "negative" twin of the pulse-carrying line pair. Scale factors are provided by dividing circuits.

Multiplication of rates $X$ and $Y$ requires that one of them be staticized first, as in the measurement of the rate ratio $X/S$ by the digitally represented no. A. Figure 12(a) shows the closed-loop arrangement; the two rate generators are similar, and their digit switches are ganged.

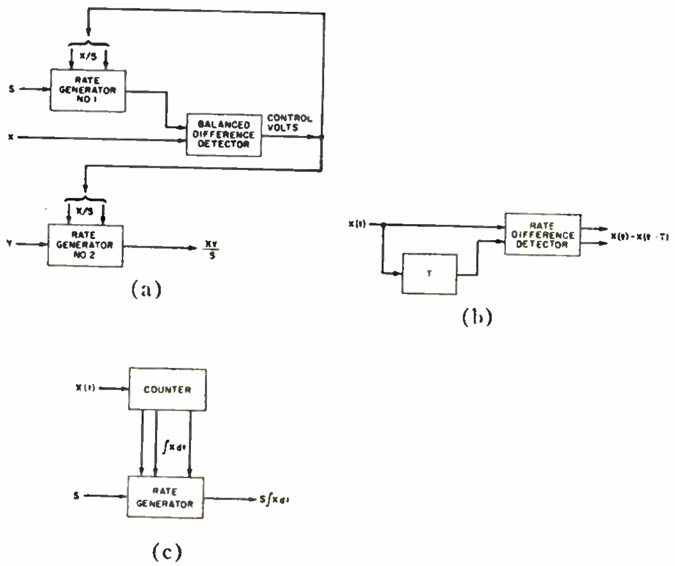



Fig. 12—Computing methods based on DRS: (a) multiplication, (b) differentiation, (c) integration.

Division is effected by the same scheme if the fixed rate $S$ and the divisor rate $Y$ are interchanged.

Differentiation is instrumented by a rate difference detector and a delay element [Fig. 12(b)].

Integration requires a counter (with overflow guard); the count controls a rate generator [Fig. 12(c)].

# Correspondence

## WWV Standard Frequency Transmissions*

Since October 9, 1957, the National Bureau of Standards radio stations WWV and WWVH have been maintained as constant as possible with respect to atomic frequency standards maintained and operated by the Boulder Laboratories, National Bureau of Standards. On October 9, 1957, the USA Frequency Standard was 1.4 parts in $10^9$ high with respect to the frequency derived from the UT 2 second (provisional value) as determined by the U. S. Naval Observatory. The atomic frequency standards remain constant and are known to be constant to 1 part in $10^9$ or better. The broadcast frequency can be further corrected with respect to the USA Frequency Standard, as indicated in the table; values are given as parts in $10^{10}$. This correction is *not* with respect to the current value of frequency based on UT 2. A minus sign indicates that the broadcast frequency was low.

WWV Frequency†

| 1959 | | #1 | #2 | #3 |
|---|---|---|---|---|
| September | 1 | −27 | −30 | −26 |
| | 2 | −27 | −30 | −26 |
| | 3 | −27 | −29 | −25 |
| | 4 | −27 | −29 | −25 |
| | 5 | −27 | −30 | |
| | 6 | −27 | −30 | |
| | 7 | −27 | −29 | |
| | 8 | −27 | −29 | −25 |
| | 9 | −27 | −29 | −26 |
| | 10 | −27 | −29 | −25 |
| | 11 | −27 | −29 | −25 |
| | 12 | −27 | −29 | |
| | 13 | −27 | −29 | |
| | 14 | −27 | −30 | −24 |
| | 15 | −27 | −29 | −25 |
| | 16 | −28 | −28 | −25 |
| | 17 | −29 | −29 | −26 |
| | 18 | −34 | −34 | −31 |
| | 19 | −34 | −33 | |
| | 20 | −34 | | |
| | 21 | −34 | −34 | −31 |
| | 22 | −33 | −34 | −31 |
| | 23 | −31 | −34 | −31 |
| | 24 | −30 | −32 | −27 |
| | 25 | −30 | −29 | −25 |
| | 26 | −28 | −27 | |
| | 27 | −27 | −33 | |
| | 28 | −26 | −27 | −24 |
| | 29 | −25 | −26 | −23 |
| | 30 | −24 | −27 | −23 |
| October | 1 | | −29 | −26 |
| | 2 | | −24 | −20 |
| | 3 | | −23 | |
| | 4 | | −19 | |
| | 5 | | −29 | −24 |
| | 6 | | −19 | −17 |
| | 7 | | −31 | −27 |
| | 8 | | −32 | −28 |
| | 9 | | −35 | −31 |
| | 10 | | −39 | |
| | 11 | | −36 | |
| | 12 | | −35 | −29 |
| | 13 | | −35 | −30 |
| | 14 | | −35 | −31 |
| | 15 | | −35 | −30 |
| | 16 | | −35 | −30 |

† WWVH frequency is synchronized with that of WWV.

Column #1 Vs NBS‡ atomic standards, Boulder, Colo., 30-day moving average seconds pulses at 15 mc.

Column #2 Vs atomichron at WWV, measuring time one hour at 2.5 mc.

Column #3 Vs atomichron at the U.S. Naval Naval Research Laboratory, Washington, D.C., measuring time 56 minutes at 2.5 mc.

‡ Method of averaging is such that an adjustment of frequency of the control oscillator appears on the day it is made. The following frequency adjustments were made:

September 17—minus $5 \times 10^{-10}$
October 2—minus $3 \times 10^{-10}$
October 4—minus $9 \times 10^{-10}$
October 6—minus $7 \times 10^{-10}$

The WWV and WWVH time signals are synchronized; however, they may gradually depart from UT 2 (mean solar time corrected for polar variation and annual fluctuation in the rotation of the earth). Corrections are determined and published by the U. S. Naval Observatory.

WWV and WWVH time signals are maintained in close agreement with UT 2 by making step adjustments in time of precisely plus or minus twenty milliseconds on Wednesdays at 1900 UT when necessary; a retarding time adjustment was made on September 30, 1959.

NATIONAL BUREAU OF STANDARDS
Boulder, Colo.

* Received by the IRE, October 28, 1959.

## Low-Noise Parametric Amplifier Using Germanium *p-n* Junction Diode at 6 KMC*

In this correspondence, the authors report low-noise performance obtained for a parametric amplifier using a refrigerated germanium *p-n* junction diode for 6 kmc. The noise figure measured at 87°K for degenerate operation (double sideband) was 0.60±0.05 db (excess noise temperature of 44°K). This is equivalent to a 3.6-db noise figure for ordinary single sideband operation. However, the sky temperature in this frequency range is so low that when the idler noise is radiated to a cold portion of the sky by use of an appropriate antenna, the noise contribution from the idler frequency is only slightly more than 44°K. The noise figure for the same amplifier measured at 296°K was 1.8 db (150°K) with 13 db of gain and a single sideband frequency bandwidth of 25 mc. For sake of comparison, it may be noted that at 3.1 kmc, Knechtli and Weglein[1] reported an excess noise temperature of 100°K (1.3-db double sideband noise figure) at room temperature, and 50°K at liquid nitrogen temperature for an amplifier utilizing a gold-bonded germanium diode. At higher frequencies, however, a higher noise figure is to be expected, since the minimum obtainable noise figure of a parametric amplifier is primarily determined by the $Q$ of the diode,[2,3] $1/\omega CR_s$, where $C$ is the average capacitance of the diode at the operating point, $R_s$ is the spreading resistance of the diode, and $\omega$ is the angular frequency of the signal. As a matter of fact, at 6 kmc one of the authors measured a double sideband noise figure of 4.0 db at room temperature and 1.7 db at 80°K by utilizing the same gold-bonded diode. This result, while fairly good, is not as good as that already reported by the same author,[3] for a silicon *p-n* junction diode (1.4 db of double sideband noise figure at room temperature). The superior performance of the silicon *p-n* junction diode is due to its higher cutoff frequency. Recent advances in semiconductor diode technology have now made it possible to produce a high-quality *p-n* junction germanium diode which has extremely low noise temperature.

The new diode utilizes the diffused mesa-type *p-n* junction structure reported elsewhere,[4] and it is mounted in a modified version of a standard microwave diode cartridge. The zero bias capacitance is 0.79 $\mu\mu$f and the series resistance is 6.8 ohms. The dc resistance of the diode is higher than 50 megohms over the range from +0.15 volt to −2 volts. The reverse current is 20 $\mu$a at −4 volts, at which point the diode capacitance is 0.48 $\mu\mu$f.

The double sideband noise figures measured at various bias voltages are plotted in Fig. 1. Noise figures were measured with argon discharge lamp and they were double checked by reference to the noise from a matched load cooled to liquid nitrogen temperature. The gain of the amplifier was maintained constant at 13 db by adjusting the pump power, and the coupling between the waveguide and the cavity was adjusted for minimum noise output at each bias condition. The pump power, iris size, and the rectified current are also plotted in the same figure. The rectified current is negligibly small from zero bias to −1.4 volts, with no noise contribution expected in this range other than the thermal noise arising from the series resistance of the diode. The noise figures calculated theoretically agree very well with the measured values for reverse bias voltages less than 1.4 volts. For larger reverse bias voltages, the rectified current increases very rapidly as a result of the diode being driven into breakdown. A consequence of this is that the measured noise figures exceed the calculated values, the difference being attributed largely to contributions from shot noise as well as noise of the microplasm type.

To enable theoretical calculation of the noise figure, the pump voltage across the junction was graphically determined from the experimental results. The pump voltage for maintaining constant gain was found to be almost linearly proportional to the bias voltage, and the operating $Q$ of the diode was calculated.

The optimum negative bias was around −1.1 volt for this particular diode, and so this was chosen as the bias voltage when the

* Received by the IRE, August 26, 1959.

[1] R. C. Knechtli and R. D. Weglein, "Low noise parametric amplifier," PROC. IRE, vol. 47, pp. 584–585; April, 1959.

[2] M. Uenohara, "Parametric Amplifier at 6 kmc Using Semiconductor Diodes," Reported at Sixteenth Annual Conference on Electron Tube Research, Quebec, Canada; June, 1958.

[3] M. Uenohara, "Noise consideration of the variable capacitance parametric amplifier," PROC. IRE, to be published.

[4] A. Uhlir, Jr., "The potential of semiconductor diodes in high-frequency communications," PROC. IRE, vol. 46, pp. 1099–1115; June, 1958.

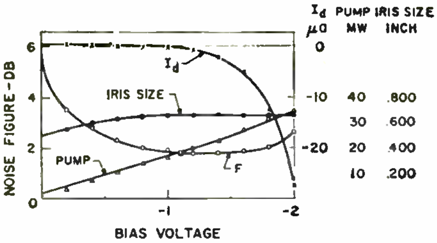



Fig. 1—Double sideband noise measured at various bias voltages. The gain of the amplifier is maintained constant at 13 db by adjusting pump power.

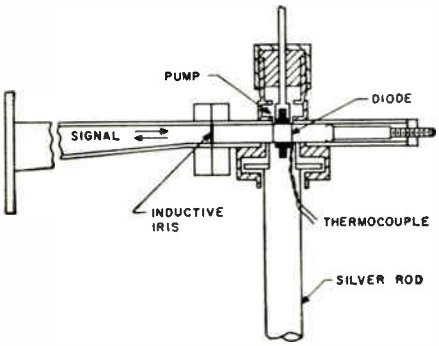



Fig. 2—Cross section of parametric amplifier with refrigeration arrangement.

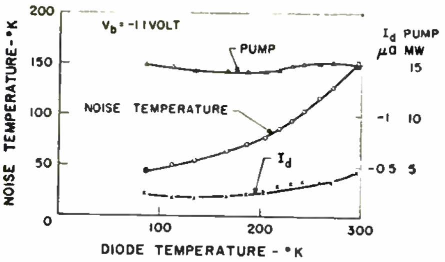



Fig. 3—The dependence of excess noise temperature upon diode temperature.

diode was refrigerated. The amplifier cavity used for the refrigeration experiment is shown in Fig. 2. The diode is refrigerated through the silver rod on which the diode is mounted. The temperature was measured at the top surface of the silver rod by an alumel-chromel thermocouple, so that the actual temperature of the junction may be slightly higher than that measured. However, the germanium crystal is soldered on the heavy metal block, which is mounted in the silver rod, while at the other end a very small area (about 1 mil²) of the crystal is in contact with a nickel pin. It is therefore expected that the temperature of the junction is very close to that measured. Dried nitrogen gas is circulated to avoid the condensation of moisture on the junction.

The experimental results are shown in Fig. 3. In this case, excess noise temperature is plotted instead of noise figure. The noise temperature decreased from 150°K to 44°K as the diode was refrigerated from 296°K to 87°K. Down to about 200°K, the fractional decrease of noise temperature exceeds that of the diode, but from 200°K down to the lowest temperature used, the fractional decrease of noise temperature is less than that of the diode. Similar characteristics have been observed for most of the germanium diodes (*p-n* junction and point contact), but the details of the characteristic differ from diode to diode depending on the amount of doping. The detailed characteristics of noise output of germanium, silicon, and gallium-arsenide diodes as a function of temperature will be reported later.

The authors wish to express their appreciation to Mrs. M. S. Boyle for her excellent work in connection with the diode fabrication.

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A. E. BAKANOWSKI
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Murray Hill, N. J.

## An Extremely Low-Noise 6-kmc Parametric Amplifier Using Gallium Arsenide Point-Contact Diodes*

In a recent paper[1] one of the authors reported that gallium arsenide (GaAs), one of the III–V intermetallic compounds, appeared to be an excellent semiconductor for use in high-frequency point-contact devices. The purpose of the present letter is to describe the extremely low noise performance obtained with a parametric amplifier using a refrigerated GaAs point-contact diode at 6 kmc. The noise figure measured at 90°K for double sideband operation was about 0.3 db (excess noise temperature of 21°K). We believe that about 10°K of the noise temperature was contributed from the circuit which had an operating temperature of about 270°K. The excess noise temperature evidently could be further reduced by complete refrigeration of the circuit. The noise figure of the amplifier operating as a degenerate single sideband device will be 3.3 db if the idler or image impedance is at room temperature. It is obvious, however, that the idler termination may also be refrigerated either by the use of liquid nitrogen or helium, or else the idler noise may be radiated directly to a cold portion of the sky by use of an appropriate antenna. If this is done, it is to be expected that the single sideband excess noise temperature of the GaAs amplifier will closely approach 42°K (twice the excess noise of the double sideband operation).

GaAs diodes used as parametric devices have several advantages over those made with either silicon or germanium. The high electron mobility, together with a higher energy gap and lower dielectric constant are favorable in obtaining the desired high $Q$ over a large operating range of applied voltages. Further, the dissociation energy is low enough in GaAs so that the diodes may be operated at low temperatures. The GaAs diodes used in our parametric amplifier have the same physical dimensions as the microwave rectifiers described in the previous paper,[1] but are given special processing to prepare them for parametric applications. The cutoff frequency has been increased to 100 kmc or possibly higher by reducing the capacitance and resistance to a minimum. This has been accomplished by using heavily doped single crystal material having resitivities near 0.002 ohm cm. At the operating bias, the total capacitance of the point-contact and the diode case is reduced to approximately $\frac{1}{3}$ μμf. To minimize the noise, the GaAs surfaces are very highly polished and both the semiconductor surface and the sharp phosphor-bronze points are thoroughly cleaned immediately before assembly. The dc characteristics of this type of diode, after forming, are shown in Fig. 1.

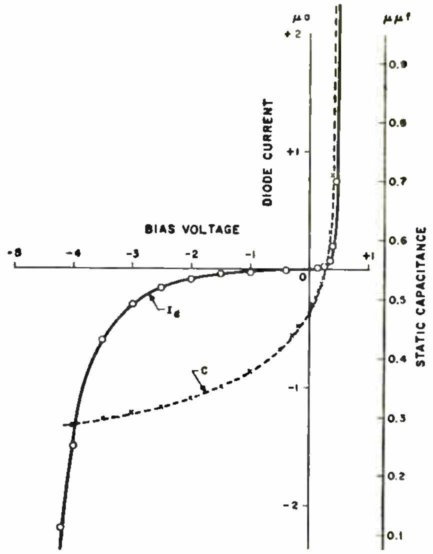


Fig. 1—Static characteristics of a GaAs point-contact diode.

The amplifier cavity used is exactly the same as that reported in a previous letter,[2] and the same technique is used to measure the noise figure. The accuracy of the measurements is believed to be ±3°K. The double sideband noise figures measured at 5.84 kmc while pumping at 11.7 kmc at various bias voltages are plotted in Fig. 2. These measurements were made at room temperature. To maintain consistent experimental conditions, the gain of the amplifier was maintained at 16 db by appropriately setting the pump power level. The single sideband bandwidth at this gain was about 25 mc. The minimum noise figure at room temperature was 0.9 db, with the diode biased 1.2 volts negatively. The noise at this bias is nearly pure thermal noise as the dc diode current is very nearly zero, precluding shot noise and noise due to internal microplasm.

The excess noise temperature of the amplifier was also measured as a function of the diode temperature. The results of this test are shown in Fig. 3. The excess noise

* Received by the IRE, September 1, 1959.
[1] W. M. Sharpless, "High frequency gallium arsenide point-contact rectifiers," *Bell Sys. Tech. J.*, vol. 38, pp. 259–269; January, 1959.

[2] M. Uenohara and A. E. Bakanowski, "Low noise parametric amplifier using germanium *P-N* junction diode at 6 kmc," PROC. IRE, this issue, p. 2113.

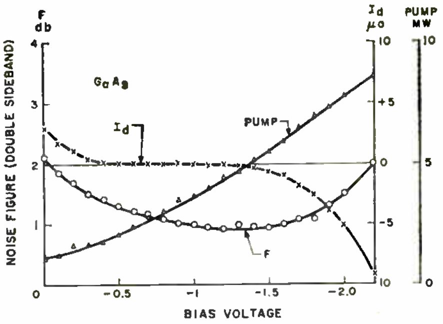


Fig. 2—Double sideband noise figure measured at various bias voltages. The gain of the amplifier is maintained constant at 16 db by adjusting pump power.

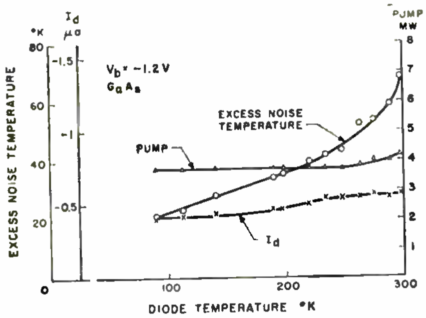


Fig. 3—The dependence of excess noise temperature upon diode temperature.

temperature decreased from 68°K at room temperature to 21°K at a diode temperature of 90°K. The pump power required for constant gain was almost constant over the entire temperature range. The excess noise temperature decreased almost linearly with the diode temperature from 220°K to 90°K. By extending the curve to the left, one can estimate that the noise contribution from the circuit is about 10°K. The justification for this construction stems from the presumption that the linear region of the characteristic implies a strict thermal representation of the diode noise source.

It is interesting to note that the excess noise temperature range obtained with the cooled GaAs parametric amplifier is of the order of that for a maser operating at this frequency. Because of its simplicity, such a parametric amplifier becomes a reasonable competitor of the maser from a systems point of view, considering the relatively large noise contribution from other portions of the system. It is possible that point-contact parametric amplifiers may be made to operate at frequencies well above the highest that have been reported to date.[3]

The authors wish to express their appreciation to T. W. Mohr for his valuable assistance in the measurements performed during the course of this study.

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[3] B. C. DeLoach and W. M. Sharpless, "An X band parametric amplifier," Proc. IRE, vol. 47, pp. 1664–1665; September, 1959.

## X-Band Parametric Amplifier Noise Figures*

Noise figure measurements have been made on the X-band parametric amplifier previously reported.[1] The circuit has been slightly modified and two general types of gallium arsenide point-contact diodes have been examined. Typical capacity vs bias plots for these diodes are presented in Fig. 1.

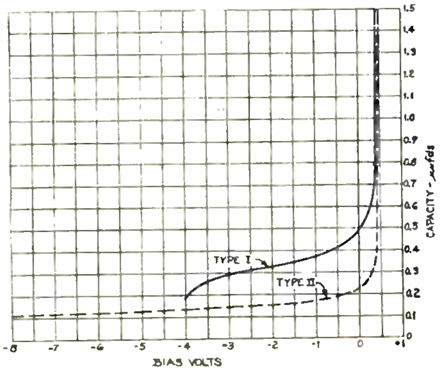


Fig. 1—Capacity vs. bias voltage for typical Type 1 and Type 2 diodes.

The continuous curve is representative of diodes made with 0.002–0.003 ohm-cm material and the dashed curve is representative of diodes made with 0.02–0.03 ohm-cm material. These two general types will be referred to as Types 1 and 2, respectively.

Table I presents data obtained for room temperature operation of these diodes. Degenerate amplification was employed with a center frequency of 11.55 kmc with a K-band pump frequency of 23.10 kmc.

TABLE I

| Type | Gain (db) | Bandwidth (mc) | Double Sideband Noise Figure |
|---|---|---|---|
| 1 | 10 | 53 | 3.2 |
| 1 | 15 | 26 | 3.3 |
| 1 | 15 | 20 | 3.7 |
| 1 | 10 | 20 | 3.8 |
| 1 | 10 | 38 | 3.8 |
| 2 | 10 | 80 | 4.0 |
| 2 | 10 | 50 | 4.5 |

The X-band circulator employed in conjunction with these measurements had an input path transmission loss of 0.18 db, the effect of which was not included in the noise figures presented.

The diodes of Type 2 were slightly worse in noise figure performance. There does, however, seem to be an advantage in gain bandwidth product associated with this general type. Several of these diodes (not included in the noise figure table above) have produced bandwidths on the order of 80 mc and 10-db gain. However, the 53-mc figure with 10-db gain included in Table I for a Type 1 diode represents the best gain bandwidth product obtained to date for a diode of this type. This greater gain-bandwidth product has tentatively been ascribed to a better circuit match to the lower average capacity of Type 2 diodes and suggests that circuit refinements may lead to better noise figures and gain-bandwidth products for both types of diodes.

Significant improvement in noise figure performance is to be expected as the operating temperature of the diodes is reduced, as has been demonstrated for similar diodes at 6 kmc.[2]

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* Received by the IRE, September 24, 1959.

[1] B. C. De Loach and W. M. Sharpless, "An X-band parametric amplifier," Proc. IRE, vol. 47, pp. 1664–1665; September, 1959.

[2] M. Uenohara and W. M. Sharpless, "An Extremely low noise 6-kmc. parametric amplifier using gallium arsenide point-contact diodes," this issue, p. 2114.

## General Energy Relations in Nonlinear Reactances*

The purpose of this paper is to discuss in some detail an alternate derivation for the general energy relations for nonlinear reactors.[1] This alternate method does not appear to be simpler or more straightforward than the original analysis.[1] This paper has been prompted by several similar derivations which have recently appeared.[2–4]

To first summarize several equations from Manley and Rowe,[1] consider a nonlinear capacitor with a single-valued characteristic defined by

$$v = f(q). \tag{1}$$

The charge $q$ and voltage $v$ may be written as double Fourier series:

$$q = \sum_{m=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} Q_{m,n} e^{j(mx+ny)} \tag{2}$$

$$v = \sum_{m=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} V_{m,n} e^{j(mx+ny)} \tag{3}$$

$$x = \omega_1 t \qquad \omega_1 = 2\pi f_1$$
$$y = \omega_0 t \qquad \omega_0 = 2\pi f_0. \tag{4}$$

The current $i$ is similarly

$$i = \frac{dq}{dt} = \sum_{m=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} I_{m,n} e^{j(mx+ny)}, \tag{5}$$

where

$$I_{m,n} = j(m\omega_1 + n\omega_0) Q_{m,n}. \tag{6}$$

The average power flowing into the nonlinear capacitor at the frequencies $\pm|mf_1 + nf_0|$ is

* Received by the IRE, April 29, 1959.

[1] J. M. Manley and H. E. Rowe, "Some general properties of non-linear elements—Part I. general energy relations," Proc. IRE, vol. 44, pp. 904–913; July, 1956.
[2] C. H. Page, "Frequency conversion with nonlinear reactance," J. Res. NBS, vol. 58, pp. 227–236; May, 1957.
[3] B. Salzberg, "Masers and reactance amplifiers—basic power relations," Proc. IRE, vol. 45, pp. 1544–1545; November, 1957.
[4] P. A. Clavier, "On the Manley-Rowe relations," Proc. IRE, vol. 47, pp. 1781–1782; October, 1959.

$$W_{m,n} = 2 \operatorname{Re} V_{m,n} I^*_{m,n}$$
$$= -(mf_1 + nf_0)4\pi \operatorname{Re} j V_{m,n} Q^*_{m,n}. \quad (7)$$

Now since the nonlinear capacitor is assumed lossless, we have from conservation of energy

$$\sum_m \sum_n W_{m,n} = 0. \quad (8)$$

where the region of the summations is taken to include the power corresponding to each frequency only once. Eq. (8) may be rewritten, following Page,[2] by dividing and multiplying each term by its corresponding frequency.

$$\sum_m \sum_n \frac{W_{m,n}}{mf_1 + nf_0}(mf_1 + nf_0) = 0. \quad (9)$$

Splitting into two terms, and writing the appropriate ranges for the summations, we have

$$f_1 \sum_{m=0}^{\infty} \sum_{n=-\infty}^{\infty} \frac{mW_{m,n}}{mf_1 + nf_0} + f_0 \sum_{m=-\infty}^{\infty} \sum_{n=0}^{\infty} \frac{nW_{m,n}}{mf_1 + nf_0} = 0. \quad (10)$$

We observe that if each of the two terms of (10) may be separately set equal to zero, we will have the general energy relations of Manley and Rowe.[1] This has been shown in the three-frequency case by Salzberg.[3] We present here a somewhat different discussion which is suitable for the general case.

Consider an ensemble of systems with identical nonlinear elements and identical $Q_{m,n}$'s and $V_{m,n}$'s, but having all possible different fundamental frequencies $f_1$ and $f_0$. The external impedances and generators will have to be changed as $f_0$ and $f_1$ change in order to accomplish this. Then from (7) the quantities $W_{m,n}(mf_1+nf_0)$ appearing in the summations of (10) are independent of the fundamental frequencies $f_1$ and $f_0$. Since (10) must hold for each member of the ensemble, *i.e.*, for all values of $f_1$ and $f_0$, each of the two terms of (10) must be separately equal to zero, thus yielding the general energy relations of Manley and Rowe.[1]

The original analysis[1] established that each of the summations in (10) is identically equal to zero by direct calculation. The present analysis obtains these results by examining their functional dependence. In either case the general energy relations are obtained not from conservation of energy alone, but depend also on the properties of the particular device. These are: 1) it is a capacitor with a nonlinear charge-voltage characteristic, thus causing new frequencies to arise whose charge and voltage components are determined by this characteristic; 2) since it is a capacitor, expressions for real power in terms of these charge and voltage components must contain the frequency factors shown in (7).

The present discussion of course applies equally well to nonlinear inductors.

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## Monotonicity and Maximally Flat Rational Functions*

For many applications of equipment with filter-like properties it is required that the pass band exhibit no peaks or ripples; that is, the system transmission must decrease smoothly up to the cutoff frequency. If the system transmission function is described by the reciprocal of a polynomial, it is well known that the so-called maximally flat function[1] (among others[2]) will accomplish this objective. On the other hand, if the transmission function must be described by a more general rational function,[1,3] the matter is not so obvious. It will be shown that for a number of common cases in loss-free filter design, where the transmission zeros are found either on the real or on the imaginary axis, or in mixed combinations, the maximally flat design still provides a function with a transmission which diminishes smoothly (monotonically) up to the first zero on the $s$-plane $\omega$ axis, for $\omega > 0$.

It will be remembered that a maximally flat design results when as many successive derivatives as possible are equated to zero, at $\omega = 0$. In other terms, as many successive coefficients as possible (in ascending powers of $\omega^2$) of the numerator and denominator of the transmission function should be equated.[1] As a particular example, if the degree of the denominator polynomial (in $\omega^2$) exceeds that of the numerator polynomial by one, the (maximally flat) squared-magnitude transmission function may be expressed as

$$|t|^2 = \frac{N(\omega^2)}{D(\omega^2)} = \frac{N(\omega^2)}{N(\omega^2) + b_K \omega^{2(2K+1)}}, \quad (1)$$

where

$$N(\omega^2) = \prod_{k=1}^{K} \left[ 1 + (2 \cos 2\theta_k) \left(\frac{\omega}{\omega_k}\right)^2 + \left(\frac{\omega}{\omega_k}\right)^4 \right]. \quad (2)$$

The parameter $\omega_k$ is the magnitude of each of the four transmission zeros associated with each $k$th factor of (2), and $\theta_k$ is the angular displacement of these transmission zeros from the real axis in the complex frequency plane, $s = \sigma + j\omega$, as shown in Fig. 1. If the function $|t|^2$ is monotone with respect to $\omega$, it will be also with respect to $\omega^2$. Therefore, differentiating with respect to $\omega^2$ gives

$$\frac{d|t|^2}{d\omega^2} = -\frac{\omega^{4K} b_K}{D^2}\left[(2K+1)N - \omega^2 N'\right], \quad (3)$$

where

$$N' = \frac{dN}{d\omega^2} = \frac{2N}{\omega^2} \sum_{h=1}^{K} \cdot \left[ \frac{\cos 2\theta_h \left(\frac{\omega}{\omega_h}\right)^2 + \left(\frac{\omega}{\omega_h}\right)^4}{1 + 2\cos 2\theta_h \left(\frac{\omega}{\omega_h}\right)^2 + \left(\frac{\omega}{\omega_h}\right)^4} \right]. \quad (4)$$

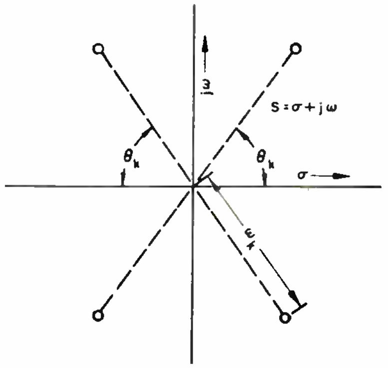


Fig. 1.

Substituting (4) into (3) gives

$$\frac{d|t|^2}{d\omega^2} = \frac{-b_K N \omega^{4K}}{D^2}\left[2K + 1 - 2\sum_{h=1}^{K} F_h\right] \quad (5)$$

where

$$F_h = \frac{\cos 2\theta_h \left(\frac{\omega}{\omega_h}\right)^2 + \left(\frac{\omega}{\omega_h}\right)^4}{1 + 2\cos 2\theta_h \left(\frac{\omega}{\omega_h}\right)^2 + \left(\frac{\omega}{\omega_h}\right)^4} \le 1 \quad (6)$$

if

$$\theta_h \le 45° \text{ (for all } h) \quad (7a)$$

or

$$\omega < \frac{\omega_h}{\sqrt{-\cos 2\theta_h}} \text{ (for all } h \text{ where } \theta_h > 45°). \quad (7b)$$

Consequently, one obtains

$$2\sum_{h=1}^{K} F_h \le 2K, \quad (8)$$

and, as $b_K$, $N$, $D^2$ and $\omega^{4K}$ in (5) are all positive it follows that,

$$\frac{d|t|^2}{d\omega^2} < 0 \quad (9)$$

for all $\omega$ satisfying (7b), and perhaps beyond. If (7a) holds, note that the transmission function is monotone decreasing for all (real) $\omega$ greater than zero. As a special case, if all of the zeros are located on either the real or the imaginary axis or in combinations thereof, then $\theta_h = 0°$ or $90°$ and the restriction of (7b) becomes

$$\omega \le \omega_h \text{ (for all } h). \quad (10)$$

Thus, the transmission function is monotone decreasing up to the first zero on the $\omega$ (or imaginary) axis in the $s$ plane and *not beyond.*

Consider an "almost maximally flat," squared-magnitude transmission function of the form

$$|t|^2 = \frac{N(\omega^2) + a_K\omega^{2(2K+1)}}{N(\omega^2) + b_K\omega^{2(2K+1)}} = \frac{\overline{N}(\omega^2)}{\overline{D}(\omega^2)} \quad (11)$$

where it is assumed that $a_K$ and $b_K$ may not be equated for physical reasons. Differentiating with respect to $\omega^2$ gives

$$\frac{d|t|^2}{d\omega^2} = -\frac{(b_K - a_K)\omega^{4K}}{\overline{D}^2(\omega)} \cdot \left[(2K+1)N - \omega^2 N'\right] \quad (12)$$

As there can be no power gain at infinity with passive networks ($|t|^2 \le 1$),

$$b_K - a_K \ge 0 \quad (13)$$

* Received by the IRE, June 15, 1959.

[1] W. A. Lynch, "The role played by derivative adjustment in broadband amplifier design," *Proc. Symp. on Modern Network Synthesis*, Polytechnic Institute, Brooklyn, N. Y., pp. 193–201; April, 1952.

[2] A. Papoulis, "Optimum filters with monotonic response," PROC. IRE, vol. 36, pp. 606–609; March, 1958.

[3] J. L. Stewart, "Flatness and symmetric lowpass lossless filters," IRE TRANS. ON CIRCUIT THEORY, vol. CT-5, pp. 128–132; June, 1958.

and the same arguments which followed (3) will also hold in this case.

Next, consider a form for $|t|^2$:

$$|t|^2 = \frac{N(\omega^2)}{N(\omega^2) + R(\omega^2)} = \frac{N(\omega^2)}{\bar{\bar{D}}(\omega^2)} \qquad (14)$$

where $N(\omega^2)$ is as defined in (2) and $R(\omega^2)$ represents additional denominator terms (not equatable to the numerator):

$$R(\omega^2) = \sum_{j=K}^{K+M} b_j \omega^{2(2j+1)}. \qquad (15)$$

Thus,

$$\frac{d|t|^2}{d\omega^2} = \Big[ -b_K \frac{\omega^{4K}}{\bar{\bar{D}}^2} [(2K+1)N - N'\omega^2]$$
$$- b_{K+2} \frac{\omega^{4K+2}}{\bar{\bar{D}}^2} [(2K+2)N - N'\omega^2] \qquad (16)$$
$$\cdots\cdots\cdots\cdots\cdots$$
$$- b_{K+M} \frac{\omega^{4K-M}}{\bar{\bar{D}}^2} [(2K+M)N - N'\omega^2] \Big] < 0$$

(if $b_K$ through $b_{K+M}$ are all positive and equations (7) are satisfied) and again the function is monotone decreasing.

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## Parametric Amplification and Conversion in Propagating Circuits Using Nonlinear Reactances*

Tien has presented an analysis of parametric amplification and conversion in propagating circuits by using a time-varying reactance as the coupling element between two propagating circuits.[1] The purpose of this note is to show that similar results can be obtained by using a nonlinear reactance to couple three propagating curcuits. To the writer's knowledge, this approach has been used in studying resonant-circuit parametric devices but not for propagating circuit models. This method can lead to the large-signal theory.

The transmission line equation, neglecting the series resistance of the wires and the shunt conductance, can be written in the following form:

$$\partial V(z, t)/\partial z = -\partial\phi(z, t)/\partial t$$
$$\partial I(z, t)/\partial z = -\partial q(z, t)/\partial t \qquad (1)$$

where $t$ is time, $z$ is distance, $V(z, t)$ is the potential along the line, $I(z, t)$ is the current, $\phi(z, t)$ is flux linkage per unit length, and $q(z, t)$ is the charge per unit length.

In the model shown in Fig. 1 only nonlinear inductive coupling is used. $\partial q/\partial t$ becomes the ordinary $C\partial V/\partial t$ and $\partial\phi/\partial t$ will contain coupling terms in addition to the ordinary $L\partial i/\partial t$.

* Received by the IRE, June 8, 1959.

[1] P. K. Tien, "Parametric amplification and frequency mixing in propagating circuits," *J. Appl. Phys.*, vol. 29, pp. 1347–1357; September, 1958.

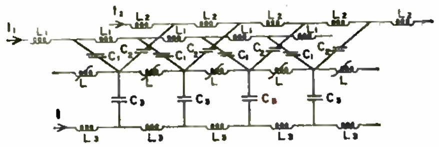

Fig. 1—An equivalent circuit of a traveling-wave parametric circuit.

In the nonlinear inductance, the voltage and flux relation is

$$V = -\partial\phi/\partial t = -(\partial\phi/\partial i)(\partial i/\partial t)$$
$$= -L(i)\partial i/\partial t \qquad (2)$$

and

$$\partial\phi/\partial t = L_0(\partial \mathcal{I}/\partial t) + L_0'\mathcal{I}(\partial\mathcal{I}/\partial t)$$
$$+ \tfrac{1}{2}L_0''\mathcal{I}^2(\partial\mathcal{I}/\partial t) + \cdots \qquad (3)$$

where $L_0$, $L_0'$, $L_0''$ $\cdots$ are the values of $L$ and its derivatives (with respect to current) evaluated at $I_0$; the dc part of the current $i(z, t)$, $\mathcal{I}(z, t)$ is the ac part of $i(z, t)$.

Referring to Fig. 1,

$$\mathcal{I}(z, t) = I_1(z)\cos(\omega_1 t - \beta_1' z + \theta_1)$$
$$+ I_2(z)\cos(\omega_2 t - \beta_2' z + \theta_2)$$
$$+ I(z)\cos(\omega t - \beta z + \theta). \qquad (4)$$

Substituting (4) in (3), we can obtain the components of $\partial\phi/\partial t$ at $\omega_1$, $\omega_2$ and $\omega$.

$$(\partial\phi/\partial t)_1 = -\omega_1\left[L_0 + \frac{1}{2}L_0''\frac{I_1^2 + 2I_2^2 + 2I^2}{4}\right]$$
$$\cdot I_1 \sin(\omega_1 t - \beta_1' z + \theta_1)$$
$$- \tfrac{1}{2}\omega_1 L_0' I_2 I \sin(\omega_1 t - \beta_1' + \theta \mp \theta_2). \qquad (5)$$

Similar equations can be written for $(\partial\phi/\partial t)_2$ and $(\partial\phi/\partial t)$. Here the upper sign is for case a) where $\omega = \omega_1 + \omega_2$, and the lower sign is for case b) where $\omega = \omega_1 - \omega_2$. $\theta_1$, $\theta_2$, and $\theta$ are initial phases. Most of the notations employed here follow those used by Tien.[1]

Neglecting the current-dependent inductance term in the first term at the right-hand side of (5) as being small compared to $L_0$, we can write the transmission line equation for the $\omega_1$-circuit as

$$\partial V_1/\partial z = \omega_1(L_{11} + L_0)I_1 \sin(\omega_1 t - \beta_1' z + \theta_1)$$
$$+ \tfrac{1}{2}\omega_1 L_0' I_2 I \sin(\omega_1 t - \beta_1' z + \theta \mp \theta_2)$$
$$\partial I_1/\partial z = -C_1 \partial V_1/\partial t, \qquad (6)$$

and similar equations for the $\omega_2$ and $\omega$ circuits. $L_{11}$ is the inductance per unit length of $\omega_1$ circuit.

Combining the pair of equations of (6) and similar pairs for the $\omega_2$ and $\omega$ circuits, we finally obtain

$$\frac{\partial I_1}{\partial z} - jk_1\Delta\beta I_1 = -j\frac{1}{4}\frac{\omega_1 B_1 L_0'}{\beta_1'} I I_2 e^{j(\theta \mp \theta_2 - \theta_1)},$$
$$\frac{\partial I_2}{\partial z} - jk_2\Delta\beta I_2 = -j\frac{1}{4}\frac{\omega_2 B_2 L_0'}{\beta_2'} I_1 I e^{j(\pm\theta \mp \theta_1 - \theta_2)},$$
$$\frac{\partial I}{\partial z} = -j\frac{1}{4}\frac{\omega B L_0'}{\beta} I_1 I_2 e^{j(\pm\theta_2 + \theta_1 - \theta)}. \qquad (7)$$

Notice the similarity and difference between these equations and those of Tien. For small signal theory, the second term on the right-hand side of the expression $\partial V/\partial z$, similar to that in (6), is neglected. Then $I(z)$ becomes a constant and (7) becomes identical to that in Tien's work, if a substitution $I_1'(z) = I_1(z)e^{j\theta_1}$, $I_2'(z) = I_2(z)e^{j\theta_2}$ and $I'(z) = I(z)e^{j\theta}$ is used. The expression for $\xi$ given by Tien becomes

$$\xi^2 = \frac{\omega_1\omega_2 B_1 B_2 L_0'^2 |I|^2}{4\beta_1'\beta_2'}. \qquad (8)$$

The exact solution of (7) without the small-signal assumption is difficult to obtain. However, if $\Delta\beta = 0$, some useful results can be obtained. Using (7) and its complex conjugates, one can have for case a),

$$-|I_1|^2 Z_{01}/\omega_1$$
$$= -|I_2|^2 Z_{02}/\omega_2 = |I|^2 Z_0/\omega; \qquad (9)$$

and for case b)

$$|I_1|^2 Z_{01}/\omega_1$$
$$= -|I_2|^2 Z_{02}/\omega_2 = -|I|^2 Z_0/\omega. \qquad (10)$$

The above relations are simply Manley and Rowe's power relation. From (7) one can also obtain the first-order large-signal solution from the following:

$$\frac{d^2 I_1}{dz^2} = \pm\left[\frac{1}{16}\frac{\omega_1\omega_2 B_1 B_2 L_0'^2 |I|^2}{\beta_1\beta_2}\right.$$
$$\left.\mp \frac{\omega B\beta_1}{\omega_1 B_1 \beta}\left|\frac{1}{1}\frac{dI_1}{dz}\right|^2\right] I_1. \qquad (11)$$

The second term in the brackets shows the saturation effect.

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## Noise Figure for a Traveling-Wave Parametric Amplifier of the Coupled-Mode Type*

The theoretical noise figure for a traveling wave parametric amplifier of the continuously-coupled transmission line type has been calculated. This theory is applicable to the traveling-wave parametric amplifier employing discrete diodes insofar as the particular structure can be treated as a distributed network.

The calculation employs the normal coupled-mode equations for weak coupling and introduces distributed thermal noise sources, $n_s(z)$ and $n_i(z)$, at signal and idler frequencies, respectively. Noise sources at different positions of the structure are considered to be uncorrelated, hence $\overline{n_i^*(z_1)n_i(z_2)} = \overline{n_i^2}\delta(z_1 - z_2)$ and $\overline{n_s^*(z_1)n_s(z_2)} = \overline{n_s^2}\delta(z_1 - z_2)$. The mean square values, $\overline{n_s^2}$ and $\overline{n_i^2}$, are related to the attenuation constant (nepers-per-unit length) for idler, $\alpha_i$, and for signal $\alpha_s$, by

$$\overline{n_i^2} = 2\alpha_i kT\Delta f \qquad \overline{n_s^2} = 2\alpha_s kT\Delta f. \qquad (1)$$

* Received by the IRE, June 8, 1959.

where

$k$ = Boltzmann constant,
$T$ = ambient temperature of the device,
$\Delta f$ = bandwidth of the device.

The relationships in (1) are obtained by considering an element $dz$ of the device which is at a temperature $T$ and at thermal equilibrium. A power $kT\Delta f$ enters the element and is attenuated, and noise power is added from the thermal noise $\overline{n^2}$; hence the output is $(1-2\alpha dz)kT_0\Delta f+\overline{n^2}dz$. This total output power must equal $kT\Delta f$, since the system is at a constant temperature $T$ and thermal equilibrium. Consideration of this equality leads to the relationships expressed in (1).

For the case of no coupling between the idler and signal modes, the $z$ and time dependencies for the idler and signal modes, respectively, are given by $\exp(-\gamma_i z+j\omega_i t)$ and $\exp(-\gamma_s z+j\omega_s t)$, where $\gamma_i=\alpha_i+j\beta_i$ and $\gamma_s=\alpha_s+j\beta_s$ are the propagation constants. It is presumed that the coupling coefficients, $C_{si}$ and $C_{is}$, between the signal and idler modes have a dependency of $\exp(-j\beta_p z+j\omega_p t)$, where subscript $p$ refers to pump signal and no loss is assumed. The angular frequencies are related by $\omega_i=\omega_p-\omega_s$.

Consider the case of weak coupling between the signal and idler frequencies. These signals may be propagating in the same mode or in different modes of the structure. Represent the amplitudes of the forward wave of the idler and signal frequencies by $a_i$ and $a_s$, respectively. The amplitudes are so normalized that $a_i a_i^*$ and $a_s a_s^*$ are the powers carried by the waves.

In absence of coupling, the wave amplitudes satisfy

$$\frac{da_s}{dz} = -\gamma_s a_s, \qquad \frac{da_i}{dz} = -\gamma_i a_i, \tag{2}$$

where $\gamma_s$ and $\gamma_i$ are the propagation constants of the unperturbed waveguide for the signal and idler frequencies, respectively.

If the coupling is introduced between the waves, the presence of one wave affects the rate of change of the amplitude of the other. For weak coupling, it presumed that $\gamma_i$ and $\gamma_s$ are unaffected and that the coupling is properly taken into account by setting

$$\begin{aligned} \frac{da_s}{dz} &= -\gamma_s a_s + C_{si}a_i^* + n_s, \\ \frac{da_i^*}{dz} &= C_{is}a_s - \gamma_i^* a_i^* + n_i. \end{aligned} \tag{3}$$

The distributed thermal noise sources have been included in the equations. (Compare (4.3) of Haus.[1]) Here, we interpret the lower sideband frequency, $\omega_i=\omega_p-\omega_s$, as positive as opposed to the convention of Haus.[1] This necessitates complex conjugate signs on all amplitudes pertaining to $\omega_i(>0)$. As $\omega_i+\omega_s=\omega_p$, the time dependencies cancel in the above equations.

Consideration of the power relationship given by Manley and Rowe[2] [1] yields the relationship between the amplitude coupling coefficients

$$\frac{C_{si}}{\omega_s} = \frac{C_{is}^*}{\omega_i}. \tag{4}$$

The solution for $a_s$ in terms of the noise sources, $n_i$ and $n_s$, is achieved by the method of undetermined coefficients (see Hildebrand[3]). The solution is

$$\begin{aligned} a_s = &- k_a e^{-j\beta_1 z}\int_0^z e^{j\beta_1 z_1} n_s(z_1)dz_1 \\ &+ k_b e^{-j\beta_1 z}\int_0^z C_{si}e^{j\beta_1 z_1} n_i(z_1)dz_1 \\ &+ k_c e^{-j\beta_2 z}\int_0^z e^{j\beta_2 z_1} n_s(z_1)dz_1 \\ &- k_b e^{-j\beta_2 z}\int_0^z C_{si}e^{j\beta_2 z_1} n_i(z_1)dz_1, \end{aligned} \tag{5}$$

where

$$\beta_{1,2} = -j\,\frac{\gamma_s+\gamma_i^*+\gamma_p}{2} \pm \sqrt{-\frac{(\gamma_s-\gamma_i^*-\gamma_p)^2}{4} - \frac{\omega_i}{\omega_s}\,|C_{si}|^2} \tag{6}$$

$$k_a = \frac{\beta_2 - j\gamma_s}{\beta_1-\beta_2} \quad k_b = \frac{j}{\beta_1-\beta_2} - k_c = \frac{\beta_1 - j\gamma_s}{\beta_1-\beta_2}.$$

If the real part of the quantity under the square-root sign is negative, $\beta_1$ is a growing wave and $\beta_2$ is an attenuating wave.

For a lossless structure, this condition is given by

$$\frac{(\beta_s+\beta_1-\beta_p)^2}{4} - \frac{\omega_i}{\omega_s}\,|C_{si}|^2 < 0.$$

For a given coupling $|C_{si}|^2$, this gain term is maximized by requiring

$$\beta_s = \beta_i - \beta_p = 0. \tag{7}$$

Eq. (7) is the synchronism condition derived by Tien.[4]

The exact solution for a short-length or moderate-gain device involves both of these waves, $\beta_1$ and $\beta_2$. This complete solution is omitted here and consideration is given to the high-gain solution. Hence, $a_s$ may be represented by the first two terms of (5), which are the growing wave terms. The power at the signal frequency at the position $z$ caused by the noise generators $n_i$ and $n_s$ is given by

$$\begin{aligned} P_s(z) = a_s a_s^* = &\,|k_a|^2 e^{-j\beta_1 z}e^{+j\beta_1^* z} \\ &\cdot \iint_0^z e^{j\beta_1 z_1}e^{-j\beta_1^* z_2}\overline{n_s^*(z_2)n_i(z_1)}\,dz_2dz_1 \\ &+ |k_b|^2 e^{-j\beta_1 z}e^{+j\beta_1^* z} \\ &\cdot \iint_0^z C_{si}C_{si}^* e^{j\beta_1 z_1}e^{-j\beta_1^* z_2}\overline{n_s^*(z_2)n_i(z_1)}\,dz_2dz_1. \end{aligned} \tag{8}$$

The excess noise figure is given by

$$F - 1 = \frac{N_{ns}+N_{ni}+N_i}{N_s}, \tag{9}$$

where

$N_{ns}$ = output noise power at the signal frequency due to the distributed thermal noise source, $n_s(z)$,

$N_{ni}$ = output noise power at the signal frequency due to distributed thermal noise source, $n_s(z)$,

$N_i$ = output noise power at the signal frequency due to thermal noise power at idler input terminals $T_i$ = idler input temperature,

$N_s$ = outout noise power at the signal frequency due to the thermal noise at signal input terminals, which is taken to be at room temperature for reference, $T_0$.

The terms $N_i$ and $N_s$ are evaluated from (8) by having $\overline{n_i^*(z_2)n_i(z_1}=kT_i\Delta f\ \delta(z_2)\delta(z_1)$ and $\overline{n_s^*(z_2)n_s(z_1)}=kT_0\Delta f\ \delta(z_2)\delta(z_1)$. The $N_{n_i}$ and $N_{n_s}$ terms are evaluated from (8) by considering that the thermal noise generators at different positions along the structure are uncorrelated; hence $\overline{n_i^*(z_2)n_i(z_1)} = \overline{n_i^2}\delta(z_1-z_2)$ and $\overline{n_s^*(z_2)n_s(z_1)} = \overline{n_s^2}\delta(z_1-z_2)$, where $\overline{n_i^2}$ and $\overline{n_s^2}$ are related to the attenuation (nepers per unit length) for idler and signal by (1), where $T$ is taken as the ambient temperature $T_0$.

Putting these results in (9) and ignoring the constant terms in comparison with the exponentially increasing terms, one obtains

$$F - 1 = \frac{\alpha_s}{\alpha_1} + \frac{|k_b|^2}{|k_a|^2}\,|C_{si}|^2\left[\frac{\alpha_i}{\alpha_1}+\frac{T_i}{T_0}\right], \tag{10}$$

where

$\alpha_s$ = loss (nepers per unit length) for the signal frequency,

$\alpha_i$ = loss (nepers per unit length) for the idler frequency,

$\alpha_1$ = gain (nepers per unit length) for the signal frequency when the structure is active; *i.e.*, being pumped. This is the imaginary part of the growing wave propagation constant, $\beta_1$.

If the device is cooled to a temperature, $T_a$, then a $T_a/T_0$ term should appear in the nontemperature terms in (10).

For a lossless sytem, $\alpha_i=\alpha_s=0$, (10) becomes

$$F - 1 = \frac{\omega_s}{\omega_i}\,\frac{T_i}{T_0}. \tag{11}$$

Use has been made of (6) to evaluate $k_a$ and $k_b$ for the lossless case in order to derive (11) from (10). Eq. (11) is the result reported by Tien.[4]

If the structure is matched to the antenna at the input of idler and signal, then the noise of the second stage will be radiated out of the input and may be ignored. This connection would also put $T_i=T_a$, the antenna temperature, and, hence, a lower noise figure would be achieved if the antenna were pointed into free space.

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[3] F. B. Hildebrand, "Advanced Calculus for Engineers," Prentice-Hall, Inc., New York, N. Y., pp. 27–31; 1949.
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## Antenna Power Densities in the Fresnel Region*

### Introduction

The large average powers used in some current radar and communications systems have raised the problem of personnel safety, particularly irreversible eye damage. This letter presents calculations and curves of maximum power density as a function of distance from the antenna for several typical aperture distributions.

Two factors are of interest: 1) maximum power density envelope, and 2) gain reduction, which is also approximately the beamwidth broadening factor. The apertures considered are: a) square with uniform illumination, b) circular with uniform illumination, and c) circular with $(1-\rho^2)$ taper. Let $R$ be the distance to the aperture.

### Square Aperture with Uniform Illumination

The on-axis power (field squared) is given by[1]

$$P = 16.4[C^2(1/2\sqrt{x}) + S^2(1/2\sqrt{x})]^2 \quad (1)$$

where $C$ and $S$ are Fresnel integrals and

$$x = \frac{R}{2L^2/\lambda}$$

is the distance as an inverse fraction of the distance $2L^2/\lambda$. The choice of coefficient normalizes the power density to unity at $R=2L^2/\lambda$ for a square of side $L$.

Fig. 1 shows that the greatest power density is 12.7 times the density at $2L^2/\lambda$. As the observation distance moves in closer to the antenna, the main beam alternately divides and reforms to produce an oscillating curve. The dashed line is the envelope of maximum power density vs distance. Close to the antenna, the density oscillates about a value of four.

Because the antenna gain and beamwidth are both degraded in the Fresnel region, a gain reduction factor is obtained by comparison of the (on-axis) intensity about a spherical surface for the focused aperture with that of the unfocused aperture. The gain is reduced by $1/\gamma$,[2] where

$$\gamma = \frac{y}{4[C^2(\sqrt{y}/2) + S^2(\sqrt{y}/2)]}$$

and

$$y = \frac{2L^2/\lambda}{R}. \quad (2)$$

The beamwidth is broadened approximately by $\gamma$, which is plotted in Fig. 2. For large apertures the asymptotic value is $\gamma=(1/2)y$. In addition $\gamma$ is also called a defocusing factor.

### Circular Aperture with Uniform Illumination

For an aperture of diameter $D$ the Fresnel field squared is given by[2]

* Received by the IRE, May 18, 1959.

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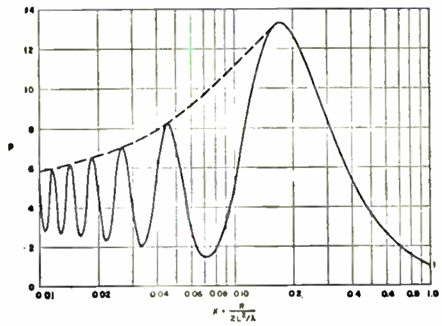

Fig. 1—On-axis power density, uniform square aperture.

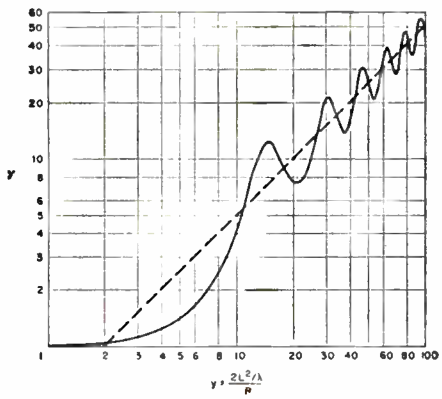

Fig. 2—Defocusing factor, uniform square aperture.

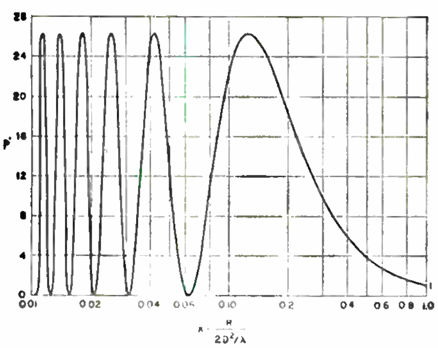

Fig. 3—On-axis power density, uniform circular aperture.

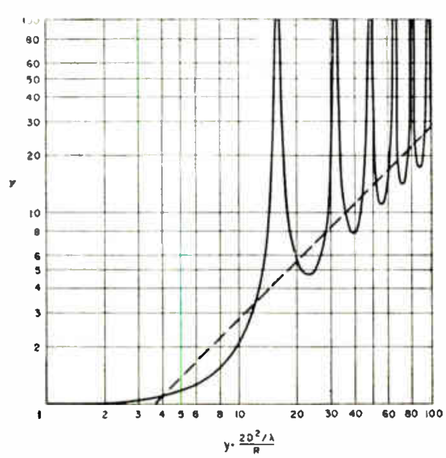

Fig. 4—Defocusing factor, uniform circular aperture.

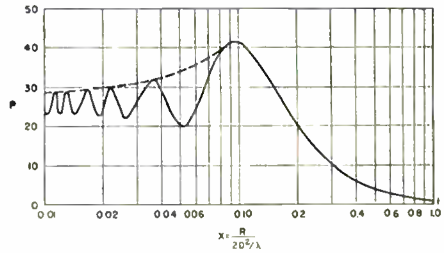

Fig. 5—On-axis power density, tapered circular aperture.

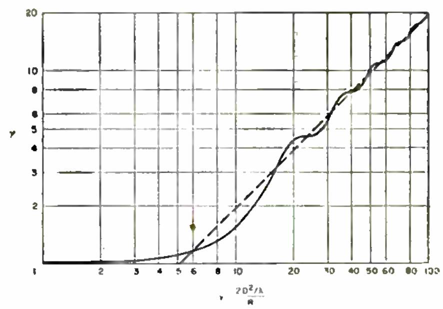

Fig. 6—Defocusing factor, tapered circular aperture.

$$P = \frac{16.2}{x^2}\left|\int_0^1 \exp\left[j\frac{\pi}{8x}(1-\xi^2)\right]\xi d\xi\right|^2 = 13.14\left(1-\cos\frac{\pi}{8x}\right) \quad (3)$$

which is plotted in Fig. 3 in fractions of $2D^2/\lambda$ with the power normalized to unity at $2D^2/\lambda$. The defocusing factor is

$$\gamma = \frac{\pi y}{8\sqrt{2}\sqrt{1-\cos\frac{\pi y}{8}}} \quad (4)$$

and is plotted in Fig. 4. Now

$$x = \frac{R}{2D^2/\lambda} \quad \text{and} \quad y = \frac{2D^2/\lambda}{R}.$$

At the points where the aperture subtends nearly an even number of Fresnel zones, the on-axis gain and power density both are zero.

### Circular Aperture with $(1-\rho^2)$ Taper

This aperture is of most practical interest because it corresponds most closely with actual dish antennas. The power on-axis is given by

$$P = \frac{16.1}{x^2}\left|\int_0^1 (1-\xi^2)\exp\left[j\frac{\pi}{8x}(1-\xi^2)\right]\xi d\xi\right|^2 = 26.1\left[1 - \frac{16x}{\pi}\sin\frac{\pi}{8x} + \frac{128x^2}{\pi^2}\left(1-\cos\frac{\pi}{8x}\right)\right]. \quad (5)$$

A power density curve plotted from this equation is shown in Fig. 5. It may be noted that the peak power density occurs at about 0.1 $(2D^2/\lambda)$ and is nearly 42 times the $2D^2/\lambda$ density. The asymptotic value is 26.1. Similarly the defocusing factor is

$$\gamma = \frac{\pi y}{16\sqrt{1 - \frac{16}{\pi y}\sin\frac{\pi y}{8} + \frac{128}{\pi^2 y^2}\left(1-\cos\frac{\pi y}{8}\right)}} \quad (6)$$

which is given in Fig. 6. Here the asymptotic value is

$$\gamma = \pi y/16.$$

The asymptotic curves of $\gamma$ are useful in determining a Fresnel-Fraunhofer transition point which is defined[1] as the value of $y$ at which asymptotic $\gamma$ goes to unity. Note the following values:

$$\text{Square, uniform} \quad R = L^2/\lambda$$

$$\text{Circular, uniform} \quad R = \frac{\pi D^2}{4\sqrt{2}\lambda}$$

$$\text{Circular, tapered} \quad R = \frac{\pi D^2}{8\lambda}.$$

The power density on-axis in the Fraunhofer field at a distance of $2D^2/\lambda$ may be found from

Power Density

$$= \frac{PG}{4\pi(2D^2/\lambda)^2} = \begin{cases} \dfrac{P}{4L^2} & \text{uniform square} \\ \dfrac{3\pi P}{64D^2} & \text{tapered circular} \\ \dfrac{\pi P}{16D^2} & \text{uniform circular} \end{cases} \quad (7)$$

where $P$ = power and $G$ = conventional gain.

Because the gain at $2D^2/\lambda$ is slightly smaller than the computed value which exists an infinite distance away, a small error of about 1 per cent is evident. For more accurate work (7) should be divided by the gain factor, $\gamma$, at $2D^2/\lambda$; this can be found from the appropriate Figs. 2, 4, or 6. (Note that this error may not be small[3] for other aperture distributions, particularly those with appreciable phase errors.) As an example, take an $X$-band dish with 25-db sidelobes, $\lambda = 3$ cm, $D = 20\lambda$, $G = 34.71$ db $= 2960$, and $2D^2/\lambda = 24$ m $= 78.75$ feet. Assume $P = 1000$ watts average.

Power Density

$$= \frac{10^3 \times 2.96 \times 10^3}{4\pi \times (2.4)^2 \times 10^6} = 0.0408 \text{ watt/cm}^2. \quad (8)$$

Even this figure, for the maximum power density (on-axis) at the Fraunhofer distance of 79 feet, is well over the ARDC maximum[4] of 0.01 watt/cm². In the example the power density, from the envelope curve of Fig. 5, reaches a peak of $41.7 \times 0.0408 = 1.7$ watts/cm² at a distance of $0.096 \times 78.75 = 7.6$ feet. The gain reduction factor at 7.6 feet is $1.6^2 = 2.56$. The Fraunhofer beamwidth is 3.64°; at 7.6 feet it is approximately $3.64 \times 1.6 = 5.8°$.

The power density on the axis can be found from Fig. 6 by dividing $\gamma^2$ into $[(2D^2/\lambda)/R]^2$, because the Fraunhofer power density increases as $R^2$ while the gain reduction factor is $\gamma^2$. Thus, this is exactly equivalent to Fig. 5. Of course, the maximum power density only exists at a spot; for the example the peak power density is nearly 3 db down at an angle of $1/2(5.8°) = 2.9°$.

To summarize, the maximum power density is found by computing the density at $2D^2/\lambda$ from (7), and multiplying this value by the power factor from the envelope curves of Figs. 1, 3, or 5.

ACKNOWLEDGMENT

Data were computed by Carol Hasson.

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## Spin-Spin Energy Transfer and the Operation of Three-Level Masers*

The original experiments on the three level maser[1] demonstrated the importance of the role played by spin-spin energy transfers. These occur whenever there is equality between two energy intervals, whether they belong to the same level scheme or to the level schemes of different spin species present in the material, and they may, by equalizing spin temperatures in the two intervals, profoundly modify the operation of the maser. In the course of recent experiments on paramagnetic relaxation in ruby ($Cr^{+++}$ in $Al_2O_3$), we have observed a new type of transfer phenomenon which takes place when one energy interval is twice as large as another. This process is independent of temperature in the hydrogen-to-helium range and depends approximately on the square of the concentration. With 0.05 per cent $Cr^{+++}$ the transfer times are of the order of a millisecond, which is long compared with the usual spin-spin times, but considerably shorter than lattice relaxation times at helium temperatures. The experimental evidence indicates that three spins are involved in the energy exchange, as compared with two in the usual type of spin-spin transfer. Consideration of the physical model suggests that this may be only the first in a sequence of higher order processes which become effective as concentration increases.

Spin energy transfers between intervals of different sizes introduces new difficulties and new possibilities in the design of solid state masers. In ruby, for instance, there are eleven ways in which one interval can be twice another (excluding the cases of equal adjacent intervals), and at an arbitrarily chosen setting there is an appreciable chance of working in the vicinity of a two-to-one frequency point. In this case, the two intervals concerned with tend to assume the same spin temperature, resulting in the imposition of a spurious load on the inverted spin group or the accidental cross pumping of levels and the destruction of the negative temperature. We have observed that the transfer effect spreads further to each side of the exact two-to-one setting as the concentration is raised, and it seems likely that this, complemented by higher order processes, may explain some of the difficulties encountered in the attempt to operate masers at higher spin concentrations.

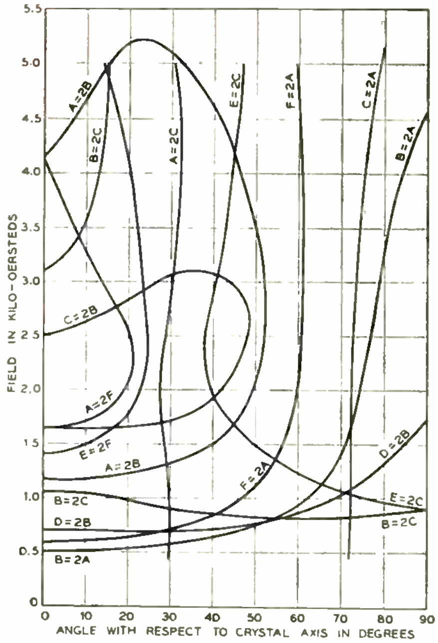


Fig. 1.

In other circumstances an advantage may be gained by communicating spin temperatures from one interval to another, particularly where the frequencies concerned are near the upper limit of those which can be generated by existing signal sources. For instance, a pumping temperature may be passed from a smaller to a larger gap; in the specially favorable case of $h\nu$ and $2h\nu$ intervals which are adjacent in the same level scheme, a signal at a frequency $\nu$ would serve to pump a $3h\nu$ gap. Spin mixing or "double doping" of the host lattice offers more complex possibilities such as two-stage multiplication of the effective pumping frequency, accelerated lattice relaxation, or the transfer of a negative temperature from a smaller to a larger interval. (Ordinary first order spin-spin transfer does not require that both spins belong to the same species, and there seems to be no reason why such a restriction should apply to higher order processes either.)

Fig. 1 shows angles to the crystal axis and magnetic fields for which there exists a two-to-one ratio between intervals in the ruby level scheme. If we number the ruby levels 1 to 4, starting with the lowest in energy the six intervals are designated by the following letters: A (1, 2), B (2, 3), C (3, 4), D (1, 4), E (1, 3), F (2, 4). The diagram was prepared from level schemes given by E. O. Schulz du Bois,[2] to whom the authors would like to express gratitude for the loan of the original graphs.

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* Received by the IRE June 25, 1959.
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## Ridge Waveguide Impedance*

Consider single ridge waveguide of overall width $a_1$, overall height $b_1$, ridge width $a_2$, and ridge height $b_2$. Cohn[1] has shown that the cut-off wavelength $\lambda_c'$ of the $TE_{10}$ mode is determined by the lowest root (in $\theta_1+\theta_2$) of

$$\cot\theta_1 - (b_1/b_2)\tan\theta_2 = B_c/Y_1 \qquad (1)$$

where the phase angles $\theta_1$ and $\theta_2$ are defined by

$$\theta_1 = \pi(a_1 - a_2)/\lambda_c' \qquad (2a)$$

$$\theta_2 = \pi a_2/\lambda_c' \qquad (2b)$$

and $B_c/Y_1$ is the normalized equivalent susceptance at cutoff of the discontinuity. Cohn[1] has also given a formula for the characteristic impedance (voltage/current definition) of ridge waveguide, but he has partially neglected the effects of the discontinuity. Mihran[2] has shown how to correct Cohn's results to allow for the extra current flowing at the discontinuity, and his formula can be recast into a form that is more revealing and gives a simple, direct calculation of the characteristic impedance. Mihran's formula for the impedance at infinite frequency is

$$\frac{120\pi}{Z_{vi\infty}} = \frac{2C}{\epsilon_0}\cos\theta_2 + \frac{\lambda_c'}{\pi b_2}\left[\sin\theta_2 + \frac{b_2}{b_1}\cos\theta_2\cdot\tan\frac{\theta_1}{2}\right] \qquad (3)$$

where $C$ is the capacity per unit length equivalent to the discontinuity. The term in $C$ is that neglected by Cohn. This capacity may be related to the normalized susceptance of (1) by the result:

$$\frac{C}{\epsilon_0} = 120\pi cC = 120\pi\cdot\omega_c'C\cdot\frac{\lambda_c'}{2\pi} = \frac{1}{2\pi}\frac{B_c}{Y_1}\frac{\lambda_c'}{b_1}. \qquad (4)$$

Eliminating $B_c/Y_1$, (3) becomes:

$$Z_{vi\infty} = 120\pi(\pi b_1/\lambda_c')\sin\theta_1\cdot\sec\theta_2. \qquad (5)$$

Similarly, Mihran's formula for the characteristic impedance (power/voltage definition),

$$\frac{120\pi}{Z_{pr\infty}} = \frac{2C}{\epsilon_0}(\cos\theta_2)^2 + \frac{\lambda_c'}{4\pi b_2}\left[2\theta_2 + \sin 2\theta_2 + \frac{b_2}{b_1}\left(\frac{\cos\theta_2}{\sin\theta_1}\right)^2(2\theta_1 - \sin 2\theta_1)\right], \qquad (6)$$

may be simplified to

$$\frac{120\pi}{Z_{pr\infty}} = \frac{\lambda_c'}{4\pi b_2}\left[2\theta_2 - \sin 2\theta_2 + \frac{b_2}{b_1}\left(\frac{\cos\theta_2}{\sin\theta_1}\right)^2(2\theta_1 + \sin 2\theta_1)\right]. \qquad (7)$$

As a check we see that both (5) and (7) lead to the correct result for ordinary rectangular waveguide.

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* Received by the IRE, July 29, 1959.

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[2] T. G. Mihran, "Closed- and open-ridge waveguide," Proc. IRE, vol. 37, pp. 640–644; June, 1949.

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He held a teaching assistantship at Syracuse University from 1949 to 1951 and a research assistantship from 1951 to 1954. In 1954, he joined the Research Division of Philco Corporation, Philadelphia, Pa., as a project engineer, and became research section manager in 1956 and manager of applied physics research in 1958. Initially, he worked on semiconductor surfaces and then infrared detectors, and is now directing several different infrared programs, an electrochemical and photochemical study, and a study of fast time constant electro-optical materials.

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Mr. Leeson is a member of Tau Beta Pi, Eta Kappa Nu, and Sigma Xi.

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William W. Macalpine (A'29–M'38–SM'43) was born in Kilmacolm, Scotland, on September 2, 1900. He received the B.Sc. degree in electrical engineering from Carnegie Institute of Technology, Pittsburgh, Pa., in 1922, and the Ph.D. degree in physics in 1930 from Columbia University, New York, N. Y., where he was Assistant in the Graduate Laboratory of Optics and Electricity.

W. W. Macalpine

He has been associated with the International Telephone and Telegraph system since 1929, having been for the most part with Federal Telegraph Co. and Federal Telephone and Radio Co. until 1947. Since then he has been with Federal Telecommunication Labs., now called ITT Labs., in Nutley, N. J. At various times, he has been engaged in the development of marine and point-to-point radio receivers and related equipment, low-frequency radio range goniometer, etc., and in special studies on transmitters, receivers and transmission lines.

Dr. Macalpine is a Fellow of the AAAS, and a member of the AIEE and Sigma Xi.

❖

Thomas J. Rey was born on January 1, 1918, in Berlin Germany. He was educated at the College Francais in Berlin, and at the University of London, England, where he received the B.S. degree in engineering in 1938, the B.A. degree in mathematics in 1947, and the M.A. degree in mathematics in 1950.

T. J. Rey

He was a Development Engineer at Murphy Radio, Welwyn Garden City, England, and at the United Insulator Company, London, between 1939 and 1941; from 1941 to 1944, he trained radio engineers and officers under the Hankey Scheme at Northampton Polytechnic, London. During 1944 to 1948, he investigated spark discharges at the Laboratories of the British Electrical Research Association in Middlesex. As a Senior Engineer at E.M.I. ("His Masters' Voice") in Hayes, Middlesex, from 1948 to 1955, he worked on circuits, digital computers, microwave plumbing and classified projects. He came to this country in October, 1955, and joined Westinghouse Electric Corporation, Baltimore, Md., where he was concerned with methods of frequency control and microwave problems. He has been doing similar work since joining the staff of Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Mass., in May, 1957.

Mr. Rey is a Corporate Member of the IEE and was a founder and first chairman of the E.M.I. Mathematical Society.

❖

Raymond O. Schildknecht (S'49–A'51–SM'56) was born in Sedalia, Mo., on January 8, 1924. He received the B.S. degree in electrical engineering from the University of Missouri, Columbia, in 1950.

R. Schildknecht

Since 1950, he has been employed by ITT Laboratories and is a project engineer in the Radio Communication Laboratory at Nutley, N. J. His work has included a number of system, circuit, and component studies in the field of radio communication. He is presently engaged in the development of a helically loaded monopole antenna system for VLF megawatt transmission.

Mr. Schildknecht is a member of Eta Kappa Nu.

❖

Sander Weinreb (S'57) was born in New York, N. Y., on December 9, 1936. He received the B.S. degree in electrical engineering in 1958 from the Massachusetts Institute of Technology, Cambridge, where he is presently a graduate student doing part-time teaching and research.

S. Weinreb

In 1958, he received the Boston Section IRE Student Award to the most outstanding E.E. senior at M.I.T. He is the recipient of a National Science Foundation graduate fellowship for the year 1959–1960. He has engaged in part time employment with Raytheon Manufacturing Company, Radiation Inc., and the Ewen Knight Corporation, doing work primarily in communication receiver and radiometer development.

Mr. Weinreb is a member of Sigma Xi, Tau Beta Pi, and Eta Kappa Nu.

# Scanning the Transactions

**Is space exploration economically justified?** There is no question that the scientific gains from our exploits in space will be tremendous, but what is this going to cost in dollars and cents? Before answering that question, however, one must also consider what it would cost *not* to probe space. In this connection one authority has the following to say: "First, the success of the early Sputniks has probably cost the United States at least five billion dollars which will be paid for in lost contracts on the world market, additional military and economic aid to our allies, and increased demonstrations of the United States military and economic might. Second, it can be shown that it is more economic to use communication satellites for world communications than to use any other technique when the channel capacity desired approaches that of television or greater. The capital investment involved for such communications is about three hundred million dollars. Third, during the past year there has been increasing interest by commercial organizations in sponsoring their own satellite program for purely commercial gain. The concerns would even buy the vehicles."

His somewhat surprising conclusion: Space exploration will probably pay for itself. (E. Rechtin, "Communication techniques for space exploration," IRE Trans. on Space Electronics and Telemetry, September, 1959.)

**Transatlantic radio via airborne relays?** Midst all the current discussion of using earth satellites for long range communication comes the following interesting alternative, proposed in a guest editorial in a recent issue of the PGCS Transactions. "The development of a transmission facility for spanning distances of 400 to 2400 miles or greater is required for carrying multichannel information of the type now transmitted on transcontinental radio relay links. Both the high-powered tropo and the communications satellite pose partial solutions to this problem; however, the attendant problems, including that of interference, make some other solution desirable. One such approach would be the development of a high-altitude airborne relay platform capable of sustained operation for periods of days on location. The manpower requirement for such an operation should be less than that required for equivalent number of tropo stations, and at the same time, the lower transmitted powers required plus the use of directional antennas should provide a facility which is much less susceptible to causing or receiving radiated interference. In this case, the solution probably lies in the labs of the nuclear powered air frame designer and provision of this capability must await advances in this field." (C. A. Strom, Jr., "Editorial," IRE Trans. on Communications Systems, September, 1959.)

**With Information Theory a little over 10 years old** what assessment can be given past accomplishments and future prospects in this field? One distinguished observer sums it up as follows. For one thing, Information Theory has now become mathematically respectable. At the same time, practical achievements have fallen short of what could be expected ten years ago. Most progress has been made where communications were already near-perfect. On the other hand, hardly any progress has been made in the filtering of speech, or in the transmission of speech or pictures in reduced wavebands, where the potential saving is not measured in percents but in orders of magnitude. But until we know more exactly what it is that a human ear picks out in a conversation with a noisy background, or what the eye picks out at a glance in a picture, no serious progress is possible, except perhaps by lucky inventions. There is a gap of a million or so between the 20 bits per second which the human eye is capable of taking in, and what we offer it in a television picture. It would seem that at least the first two orders of magnitude out of the six ought to be relatively easy going, and could be overcome on the basis of such elementary knowledge as that the eye fixes in the first line on contours, and samples what is in between. This is a challenging problem for the signal analyst, who must first pioneer the field before statistical communication theory can start. If more effort is directed into the No-Man's Land between raw sensory data and the distinguishable signals which are the starting point of the statistical theory, the second decade of Information Theory will be as rich in practical improvements in communication techniques as the first was in intellectual clarification. (D. Gabor, "Guest editorial," IRE Trans. on Information Theory, September, 1959.)

**Recent developments in FM signal-processing** techniques have removed a basic limitation of FM—the stronger-signal capture effect whereby the desired signal is blotted out by a stronger cochannel or adjacent-channel signal. The two techniques of "feedforward" across a limiter and "dynamic trapping" now make it possible to extract the weak signal, as well as the strong one, opening up a number of interesting possibilities. A weak signal and a strong signal could be sent on separate carriers within the same FM channel, thus doubling the number of messages that can be sent over one channel. For example, a stereo program could be broadcast, or a simultaneous exchange of voice messages could be carried on, in one channel. In telemetry, the presently wasted frequency guard spaces could be put to use. In addition, the weaker-signal booster can be changed into a weaker-signal suppressor, thus greatly improving the stronger-signal capture characteristics of FM receivers. (E. J. Baghdady, "New developments in FM reception and their application to the realization of a system of power-division multiplexing," IRE Trans. on Communications Systems, September, 1959.)

**Automatic diagnosis of heart conditions** has been shown to be possible with a new electrocardiographic recording and data reduction system. The system provides for the taking of simultaneous measurements at as many as 100 points on the body, instead of just the usual three or four, to give a more nearly complete picture of the electrical activity of the heart. These readings, in addition to being recorded, are compared with records of known heart conditions by means of cross-correlation techniques. A chart reading system feeds the information being recorded to a cross correlator. At the same time, a continuous loop motion picture film containing records of prediagnosed heart conditions is run and scanned electronically to provide a second input signal to the cross correlator. The signals are compared and, unless the readings are insufficient, a diagnosis is thus established entirely automatically. (J. Martinek, G. C. K. Yeh and R. Carnine, "A new system for electrocardiographic recording, analysis, and diagnosis," IRE Trans. on Medical Electronics, September, 1959.)

**The prospect of manned space flight** poses some challenging problems for those who must design the space communication system. A noted space biologist, who will be remembered for his suggestion that for better efficiency a space crew might comprise two men and one woman, reminds us that the presence of passengers on board a space vehicle will greatly increase the amount of information that must be telemetered to earth. Not only must the crew and ground personnel be able to communicate back and forth, but a wide variety of environmental and behavioral data must be transmitted to earth. For example, earthlings will want to measure: cabin pressure, oxygen and carbon dioxide content of cabin atmosphere, cardiac activity of the crew, respiratory rate and volume, blood pressure, electroencephalographic data, muscle activity, reflex activity, galvanic skin response, body temperature, activity of the gastrointestinal tract, food and water intake, and urine and feces excretion. It seems clear that the design of space communication systems of the future will require the talents of biophysicists as well as electronics engineers. (T. C. Helvey, "Telemetered parameters of primates and humans from space capsules," IRE TRANS. ON SPACE ELECTRONICS AND TELEMETRY, September, 1959.)

**The pioneers in circuit theory** are beginning to stake out boundaries marking substantial advances in the analysis and synthesis of linear networks with time-varying parameters. The growing use of time division as a means of switching and multiplexing has made the problem of efficient transmission from source to load through a variable intermediate path one of great practical interest. The September, 1959 issue of the PGCT TRANSACTIONS includes two contributions to this field. One paper analyzes a general linear network containing a single periodically varying element. The steady-state modulation theory approach is combined with techniques of impedance matching, circuit tearing, and iterative procedures. The other paper deals with a periodically operated switch in a linear circuit. It differs from earlier work in this field by concentrating on the system function rather than on the network structure. (C. A. Desoer, "Steady-state transmission through a network containing a single time-varying element," and A. Fettweis, "Steady-state analysis of circuits containing a periodically-operated switch," IRE TRANS. ON CIRCUIT THEORY, September, 1959.)

**The value of advertisements** in the PROCEEDINGS is, in the eyes of our advertising manager, unquestionable and irrefutable. They are also technically informative, widely read and frequently acted upon, he is always happy to explain. And we are happy to agree. Just how valuable, informative, etc., is now attested to in a most singular fashion. An ad has been cited as a technical reference in a technical paper—in fact, two ads. The ads in question deal with the timely subject of noise temperature and appeared on page 2A of the January and May, 1958 issues of the PROCEEDINGS as part of a series of informative technical discussions which now appear monthly on page 4A. We strongly suspect that this is the first time in the history of any engineering periodical that an ad has served, and ably so, as a footnote reference. (S. Perlman, *et al.*, "Concerning optimum frequencies for space vehicle communication," IRE TRANS. ON COMMUNICATIONS SYSTEMS, September, 1959.)

# Books

### Paris Symposium on Radio Astronomy, Ronald N. Bracewell, Ed.

Published (1959) by Stanford University Press, Stanford, Calif. 601 pages+10 index pages+xii pages. Illus. 6¾×9¼. $15.00.

The Paris Symposium on Radio Astronomy was held in Paris in August, 1958, and was jointly sponsored by the International Astronomical Union and the International Scientific Radio Union. All astronomical aspects of radio astronomy were covered except those pertaining to meteors and the ionosphere. Instrumentation and techniques were not specifically treated since they were covered in 1957 at the General Assembly of the International Scientific Radio Union in Boulder, Colo.

In the words of its able editor, R. N. Bracewell, "This book records the research results reported at the symposium as subsequently submitted with benefit of revision; and, together with the several introductory surveys, the extremely good discussions, and the concluding assessments, it forms a comprehensive account of the current state of development of the basic aspects of radio astronomy."

Over 100 invited papers from 13 countries were presented to 162 astronomers and other scientists from 17 countries. These papers were given in six nonconcurrent sessions (totaling 60 hours) under the following subjects and session organizers:

1) Radio emission and reflections from planets, comets and the moon: A. C. B. Lovell.
2) Solar radio emission and the quiet and active sun: J. F. Denisse.
3) Radio study of individual objects (external to solar system): H. C. van de Hulst.
4) Radio evidence on the large-scale structure of our own and external galaxies: J. L. Pawsey.
5) Source surveys, identifications, and other studies related to cosmological problems: R. Minkowski.
6) Theory, mechanisms of solar and cosmic radio emission: Fred Hoyle.

The over-all planning of the Symposium was under the direction of the following committee: R. N. Bracewell, editor; J. F. Denisse, local organizer; F. T. Haddock, secretary; F. Hoyle; H. C. van de Hulst; A. C. B. Lovell; R. Minkowski; J. L. Pawsey, chairman; V. V. Vitkevich.

Each session was opened with an introductory speaker (F. G. Smith, J. F. Denisse, J. S. Hey, J. L. Pawsey, R. H. Brown, and G. R. Burbidge, respectively) who made a survey of the field to be covered by his session. In addition, at the end of each session a summary talk was given by an astronomer (A. C. B. Lovell, M. G. J. Minnaert, H. C. van de Hulst, A. Blaauw, R. Minkowski, and F. Hoyle, respectively) who attempted to point out the highlights of the papers presented in his session, and to point out the areas of agreement and of disagreement in the topics discussed. These introductory and summary papers can be read by the nonspecialist for an up-to-date review of the astronomical side of radio astronomy.

The discussion following each paper, or group of related papers, was written down on the spot, then later checked and edited. This is a valuable feature and gives the reader the kind of information not usually available in the literature.

Other outstanding features of this book are its speed of publication and its excellent and copious illustrations. It appeared in less than one year after the Symposium in spite of the 137 separate authors of 106 papers, including 8 in French. The editor and Stanford University Press are to be commended for this achievement.

Some 500 recent papers cited in this volume comprise an up-to-date bibliography on radio astonomy. A list of participants with their addresses, an author key to all references, and a detailed index of subject and authors are also included.

This volume will be a constant reference for the active radio astonomer for a number of years and will serve the interested engineer as an introduction to the astronomical side of the subject.

FRED T. HADDOCK
The Univ. of Michigan
Ann Arbor, Mich.

### From Microphone to Ear: Modern Sound Recording and Reproduction Technique, 2nd Rev. Edition, by Gerard Slot

Published (1959) by The Macmillan Co., 60 Fifth Ave., N. Y. 11, N. Y. 246 pages+4 index pages+8 appendix pages. Illus. 5½×8. $4.50.

This book presents a survey of the entire field of high-fidelity sound recording and reproduction from an engineer's point of view, but in language intelligible to the layman. The writing and organization are excellent, and the book may be "read through" with pleasure.

It should be of primary value to the high-fidelity hobbiest. However, it may also be of great value to professional workers in a small area of this broad field who wish to become better acquainted with other areas.

A rather minor complaint is the lack of a satisfactory description of the coordinates of several graphs. Fortunately, the text is usually sufficiently clear to enlighten the reader when the coordinate functions are missing.

The author is in charge of technical publications for the Philips Apparatus Division, Eindhoven, Holland. The book is translated from Dutch.

David L. Klepper
Bolt Beranek and Newman Inc.
Cambridge, Mass.

### Technical Reporting Revised, by Joseph N. Ulman, Jr., and Jay R. Gould

Published (1959) by Henry Holt and Co., 383 Madison Ave., N. Y. 17, N. Y. 246 pages+6 index pages+3 bibliography pages+12 Appendix pages +xvii pages. Illus. 6¼×9¼. $5.00.

Effective technical reporting is a vital necessity if we are to continue our rapid advances in science and technology. It is, therefore, refreshing to examine a book which can lead the reader to report on his technical findings in a clear, lucid manner. Here is a book which gives detailed help and instructions on all the many aspects of communications, whether such communications are by means of written or spoken words, or by means of visual presentations.

Designed as a basic text for courses in technical writing for students of engineering and the sciences, it has been through the proving ground of extensive classroom use. It is a revised and expanded version of a previous text.

There are three main parts to the book—Basic Issues, The Report, and Tools and Methods. Each of these in turn is divided into numbered and titled sections and subsections, making it easy to select rapidly a specific topic of interest.

Under the main heading "Basic Issues" appear such subjects as fundamental principles, which presents very completely and in considerable detail the main points to keep in mind when preparing a written report. Included are very helpful hints on such matters as how to be brief, the use of headings and subheadings, organization, and the like. Also in this first part are suggestions as to the various steps to follow in preparing a report.

The second portion of the book discusses various types of reports—informal, formal, and laboratory reports, the thesis, technical articles, instructional writing, and oral presentations. Again, each type is covered in detail, and much helpful information is presented—including warnings of the pitfalls normally encountered in such presentations.

Part three, titled "Tools and Methods," might easily be called the "handbook" portion of the book. Here are specific, detailed instructions on style, grammar and punctuation. Here can be found the answer to many of the problems that arise in the preparation of written or oral presentations—split infinitives, the dangling modifier, proper use of commas, etc. Extensive use is made of examples to illustrate various points.

Also included in part three is a section on the mechanics of writing—use of abbreviations, quotations, page numbering, margins, etc. A section on tables tells how they can best be presented and where they are most useful. Then there is an important section on visual aids, with lots of "how to" information to obtain maximum effectiveness from the use of such aids.

The Appendix contains a number of specimen reports of various kinds to show the many possible ways of presenting technical information. A bibliography is included for those who wish to pursue the subject further.

Scattered throughout the book are many exercises which, if worked out, will aid the reader in applying the principles outlined in the text material. Thus, these principles become a part of his stock in trade, and he gradually learns to use them automatically.

Here, then, is a book which can be of tremendous help to the beginner in the field of technical writing, and can be a valuable reference to the many "professionals" in the field.

H. S. Renne
Bell Telephone Labs.
New York, N. Y.

### Elements of Solid State Theory, by Gregory H. Wannier

Published (1959) by Cambridge University Press, 32 E. 57 St., N. Y. 22, N. Y. 258 pages+12 index pages+12 index pages+vii pages. Illus. 5½×8½. $6.50.

This book is designed as an introduction to the theory underlying solid state physics. It is intended for advanced students and scientists who have had no previous exposure to this specialty. Actually, this slim volume should appeal to a much wider audience than this, since it treats the rudiments of solid state theory in a highly individualistic manner, with a degree of maturity and sophistication rarely found in introductory textbooks.

Wannier's book is less comprehensive but more thought-provoking than such standard texts as "Solid State Physics" by Dekker, "Introduction to Solid State Physics" by Kittel, or "Electronic Semiconductors" by Spenke. The present book is most similar in spirit and coverage to "Quantum Theory of Solids" by Peierls.

Among the several topics treated are the following: geometry of the crystalline state; dynamics of lattice vibrations (with just a touch of group theory and topology added for taste); co-operative phenomena in solids; the one-electron approximation; electronic energy bands; bound carrier states; carrier dynamics; electronic transport processes; and solid cohesion and chemical bonding. Each chapter concludes with an excellent choice of problems and references for further reading.

Wannier is admirably successful in sketching the "broad picture;" he never gets bogged down in the details. His discussion is generally lively and physically motivated. There is a very happy balance between mathematical exposition and straight narrative.

As a typical example of Wannier's physical insight, we might mention his treatment of the electrical conductivity tensor of pages 208 and 209. While most texts[1] end up with the following expression:

$$\sigma = -e^2 \int \partial f_0/\partial E \tau(p) \operatorname{grad}_p E(p) \operatorname{grad}_p E(p) dp, \tag{1}$$

Wannier goes one step further, and, integrating by parts, obtains the equivalent result:

$$\sigma = +e^2 \int f_0(p) \operatorname{grad}_p [\tau(p) \operatorname{grad}_p E(p)] dp. \tag{2}$$

With this form, it is possible to determine the contribution of the carriers in an arbitrary volume element $dp$ to the conductivity tensor, since here $\sigma$ is expressed as an average over the equilibrium distribution $f_0$, rather than as an average over the derivative of this distribution. For simplicity, let us specialize to a universal relaxation time $[\tau(p)=\tau$ for all $p]$. Then (2) reduces to:

$$\sigma = e^2\tau \int f_0(p) \operatorname{grad}_p [\operatorname{grad}_p E(p)] dp$$
$$= e^2\tau \langle [m^*(p)]^{-1} \rangle, \tag{3}$$

where $\langle\ \rangle$ denotes an average over the equilibrium distribution, and $[m^*(p)]^{-1}$ is the reciprocal effective mass tensor, It is now easy to see that particles in negative mass states give negative contributions to the conductivity tensor. In this reviewer's opinion, the above demonstration is more straightforward than several others that have recently appeared.

Summing up, Wannier's book is a valuable addition to the literature on solid state physics, particularly from the standpoint of the more discriminating reader. It seems well suited as a textbook for use in introductory courses for students and scientists having good mathematics and physics backgrounds.

Frank Herman
RCA Labs.
Princeton, N. J.

### Fundamentals of Electron Devices and Circuits, by Herman R. Weed and Wells L. Davis

Published (1959) by Prentice-Hall, Inc., 70 5th Ave., N. Y. 11, N. Y. 584 pages+7 index pages+xii pages. Illus. 6¼×9¼. $9.50.

This very readable, easily understood book on electron devices and circuits is sufficiently advanced for undergraduate electrical engineers, yet well within the grasp of nonelectrical engineering students. One may wonder whether both these goals can indeed be realized in a single text. The secret of doing so lies in introducing each topic in terms of its broad fundamental concepts before developing its more complex details. When done in proper balance, this makes for understanding that is "broad" for nonelectricals, "complete" for electricals.

The authors have applied good logic not only to the sequence of thoughts in each topic, but also to the sequence of topics in each chapter and the sequence of chapters in the book. For example, in the chapter entitled "the Triode," the progression of

[1] See, for example, A. H. Wilson, "The Theory of Metals," Cambridge University Press, second edition, page 196, 1953.

topics is as follows: triode construction, potential distribution in a diode without space charge, potential distribution in a diode with space charge, potential distribution in parallel plane triode, the triode as a circuit element, plate resistance, amplification factor, transconductance, relation between the parameters, etc. Those familiar with triode theory will recognize the logical order of these topics. The same comment applies to the chapter progression: Electric Circuits, Electron Emission and Acceleration, The Diode, Single-Phase Rectifier Circuits, Polyphase Rectifiers, Semiconductor Diodes, The Triode, Class A Amplifiers, Multigrid Tubes, Direct Coupled, Push-Pull, and Feedback Amplifiers; Transistor Circuits, Magnetic Amplifiers, Gas Tube Characteristics, Basic Gaseous Tube Circuits, Controlled Rectifiers, Back-to-Back Circuits and Inverters, Industrial Timing Circuits, Regulators, Operational Amplifiers, Oscillators, Electronic Instruments, and Phototubes and Applications. Such an integrated sequence is particularly valuable to the reader with minimum preparation (say a working knowledge of calculus and elementary college background in electrical physics). Yet the degree of integration practiced in this book does not prevent the more advanced reader from "spot-reading" its contents effectively. Suffice it to say that the flow pattern of the material presented in the text is excellent.

Various improvements could be made in the text, one of which would be to add a more comprehensive list of references. The book would then attract an additional audience, namely, the practicing engineer who often desires a quick introduction or review of some subject plus convenient references to more advanced works. The chapter on semiconductor diodes could be improved by expanding the section on germanium and silicon diodes, even if this required some reduction in the material on copper-oxide and selenium diodes. Also, somewhat further use of semiconductor diodes and transistors in circuit examples would make the text more in keeping with present trends in the art. In the sections on feedback, the reader is led to the general belief that inverse feedback may be used only to increase, not decrease, the input impedance of an amplifier. This fallacy should be cleared up in future editions of the book. By and large, these criticisms, and others that might be made, are rather trivial matters, many of which are controversial.

All in all, the book offers a clear and concise treatment of a broad range of topics. It should find effective use, particularly in the instruction of undergraduate engineers.

HAROLD M. STRAUBE
Bell Telephone Labs., Inc.
Murray Hill, N. J.

## RECENT BOOKS

Carroll, John M., ed., *Modern Transistor Circuits.* McGraw-Hill Book Co., Inc., 330 W. 42 St., N. Y. 36, N. Y. $8.50.

Champion, F. C. and N. Davy, *Properties of Matter*, 3rd ed. Philosophical Library, N.Y. $10.00. The important change in this new edition is the gradual orientation of the subject from a largely phenomenological treatment to atomic interpretations.

Eichner, Hans and Hans Hein, *Reading German for Scientists.* John Wiley and Sons, Inc., 440 Fourth Ave, N.Y. 16, N.Y. $5.25. This book is designed to serve the needs of the student who wants to be able to read German scientific texts and wishes to reach this limited aim by the shortest route.

Evans, Ralph M., *Eye, Film and Camera in Color Photography.* John Wiley and Sons, Inc., 440 Fourth Ave., N.Y. 16, N.Y. $8.95. Considers the optical photographic and physical bases, the psychological facts that apply in using a camera, and the way in which they may be combined to aid the various purposes of the photographer.

Gillie, Angelo C., *Transistors.* Prentice-Hall, Inc., 70 5th Ave., N. Y. 11, N. Y. $7.95. From general linear and nonlinear conduits, to nonlinear resistive control devices, to the transistor and its applications. Requires a minimum of mathematics.

Kiver, Milton S., *Transistors in Radio, Television and Electronics, 2nd ed.* McGraw-Hill Book Co., Inc., 330 W. 42 St., N. Y. 36, N. Y. $7.95. A revised edition of the original text, which was reviewed earlier in the PROCEEDINGS.

Levens, Alexander, F., *Nomography*, 2nd ed. John Wiley and Sons, Inc., 440 Fourth Ave. N. Y. 16, N. Y. $8.50. Provides a modern working knowledge of the basic theory and construction of charts involving straight line scales, curved scales, and combination of the two.

Mark, David, *R-L-C Components Handbook.* John F. Rider Pub., Inc., 116 W 14 St. N. Y. 11, N. Y. $3.50. The purpose of this book is to inform the reader about various factors of importance in selecting a resistor, capacitor, inductor, or transformer and to acquaint him with the various types of available components and their special features.

*Proceedings of the Fourth National Conference on Tube Techniques.* New York University Press, Washington Sq., N. Y., N. Y. $7.50.

Ritchie, Ralph W., *Microwave Measurements for the Technician.* Wm. C. Brown Co., Dubuque, Iowa. $3.50. A comprehensive, simplified manual on basic microwave measuring techniques, especially helpful to electronics engineers and technicians with little or no previous indoctrination in the field.

Smith, Charles V. L., *Electronic Digital Computers.* McGraw-Hill Book Co., Inc., 330 W. 42 St. N. Y. 36, N. Y. $12.00. A study based on the Institute of Advanced Studies computer, of value to the newcomer to the computer field.

Warfield, John W., *Introduction to Electronic Analog Computers*, Prentice-Hall, Inc., Englewood Cliffs, N. J. $6.00.

Williams, Samuel B., *Digital Computing Systems.* McGraw-Hill Book Co., Inc., 330 W. 42 St., N. Y. 36, N. Y. $7.75. Describes the structure of modern computing systems selected "hardware" and application in simple terms.

# Abstracts of IRE Transactions

**The following issues of TRANSACTIONS have been recently published, and are now available from the Institute of Radio Engineers, Inc., 1 East 79th Street, New York 21, N. Y., at the prices indicated. The contents of each issue and, where available, abstracts of technical papers, are given herewith.**

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## Circuit Theory

### Vol. CT-6, No. 3, September, 1959

**Abstracts** (p. 242)

**Steady-State Transmission through a Network Containing a Single Time-Varying Element**—C. A. Desoer (p. 244)

This paper presents a method of steady-state analysis of a linear network, of arbitrary degree of complexity, containing a single periodically-varying element. The proposed method makes full use of circuit theoretical ideas, such as impedance matching and tearing apart, and of teration techniques which are particularly suitable for automatic computation. The proposed method has the additional feature of leading to the amplitude and phase of *all* sidebands and of giving a bound on the error if the iterations are stopped at any particular point. More precisely, it is shown that, provided the impedance seen by the time-varying element becomes capacitive at very high frequencies, the complete solution can be found within an arbitrary amount of accuracy.

**Steady-State Analysis of Circuits Containing a Periodically-Operated Switch**—Alfred Fettweis (p. 252)

The exact conversion functions are calculated for networks containing one periodically operated switch, using familiar pole-zero and Fourier methods of analysis. It is first assumed that the switch is alternately open and closed during equally long time intervals. Circuits whose driving-point impedance $Z(p)$ seen from the switch has neither pole nor zero at infinity are treated in detail. The analysis is then extended in order to allow for impedances $Z(p)$ having either a pole or a zero at $p=\infty$. Complete results are also given for circuits whose switch is alternately open during time intervals of duration, $T_1$, and closed during intervals of duration, $T_2 \neq T_1$.

The general analysis is applied to a series modulator and the realization of a given function of frequency as conversion function of such a modulator is investigated.

Throughout this paper, the impedance $Z(p)$ is assumed to have only simple poles and simple zeros.

**On a Problem of Network Topology**—Toshio Fujisawa (p. 261)

In mesh-basis analysis of networks with mutual and active elements, it is necessary to list all possible trees or cotrees and signs of cotree determinants. This paper provides a computational method for obtaining them.

Computations are based on fundamental circuit matrices. A transformation from one tree to another tree may be performed by elementary transformations on circuit matrices. By this method, all the trees and fundamental circuit matrices may be determined. Signs of cotree determinants and their minor determinants of a fundamental circuit matrix also may be easily determined.

**The Path Matrix and Its Relizability**—O. Wing and W. H. Kim (p. 267)

This paper presents in one listing those properties of the path matrix of a graph which are fundamental and interesting in nature. Included are 1) a relation between the path matrix and the incidence matrix, 2) the rank of the path matrix, 3) relations between paths and cut sets, and 4) relations between paths and circuits (Ashenhurst's lemmas). Also included are a number of necessary conditions for the realizability of a matrix as a path matrix of a graph.

**The Problem of Phase Equalization**—G. Szentermai (p. 272)

The equalization of the insertion-phase vs frequency characteristics of low-pass filters and low-pass like networks is considered in the article. A method is described for maximally-flat equalization by minimum-pass or all-pass equalizers. The method can be readily extended to a nearly equal-ripple approximation by using Darlington's method of Tchebycheff polynomial series.

**Optimum Filters of Even Orders withMonotonic Response**—Minoru Fukada (p. 277)

Recently, Papoulis has developed a new class of filters, which has the maximum cutoff rate under the condition of a monotonically-decreasing response. These new filters are based on the optimum monotonically-increasing polynomials of odd degrees. In this paper, the optimum polynomials of even degrees are presented in general forms, from which the optimum filters with monotonic response are derived. Characteristics of these filters are illustrated by several examples which include frequency response, pole locations and the ladder realizations.

**A Note on Zeros of Reflection and Transmission in a Cascade of Lossless Two-Terminal-Pair Networks**—Daniel C. Fiedler (p. 282)

Certain properties of cascade-connected, two-terminal-pair lossless networks are investigated. Particular reference is made to the duo-cascade (two-terminal-pair networks) and the trio-cascade (three two terminal-pair networks).

In the first part of the paper, theorems and proofs pertaining to inter-relations among the reflection and transmission coefficients of the complete cascade and the two-terminal-pair networks are presented. In the second part of the paper, a discussion of degenerate transmission zeros is presented. In the third section, the effects on transmission coefficients of adding various right-half $s$-plane zeros of reflection are investigated. Reflection zeros are added so that the real frequency magnitude of a reflection coefficient is invariant under the addition of reflection zeros.

**Network Realizability in the Time Domain**—Armen H. Zemanian (p. 288)

Two network-realizability theorems on the unit-impulse response matrix of a multiterminal network are developed. They present necessary and sufficient conditions which are satisfied by the unit-impulse response matrix of certain classes of fixed, linear, and passive networks.

**Envelope and Angle Response of Asymmetrical Narrow-Band Networks**—Julius J. Hupert (p. 292)

This paper outlines a general approach to the evaluation of envelope and angle response of narrow-band networks including asymmetrical networks. From a known constellation of poles and zeros of a network in the $s$-plane, approximate linearized transfer functions are developed which relate envelope and angle response of the network to the amplitude modulation of the forcing function for small signal conditions (shallow modulation). The transfer functions are expressed in terms of two auxiliary constellations in the $p$-plane, where $p$ is equivalent to the complex frequency of modulation.

**Optimization of Negative-Impedance Conversion Methods of Active RC Synthesis**—Isaac M. Horowitz (p. 296)

Negative-impedance conversion methods of active RC synthesis lead to networks which are highly sensitive to active and passive parameters. In the design of such networks there is some freedom available, which may be used to minimize the sensitivity of the structure to both the active and passive parameters. In most cases, the problem is that of decomposing a polynomial with real coefficients into the differences of two polynomials with negative real zeros such that the latter two polynomials have coefficients which are as small as possible. The optimum design is presented.

**DC Design of Resistance-Coupled Transistor Logic Circuits**—W. J. Wray, Jr. (p. 304)

Worst-case dc design equations for resistance coupled transistor logic circuits are presented and discussed. A solution is chosen in a form which provides for setting switching transient times in advance of calculating the dc design. All constants are discussed, and the algebraic solution is obtained for values of the unknown resistors and voltages. A numerical example illustrates a typical design with five inputs and five outputs, using the type GT-759 transistor.

**RC Constant-Argument Driving-Point Admittances**—Ralph Morrison (p. 310)

This paper deals with a class of RC driving-point immittances characterized by nearly constant argument over an extended frequency range. These arguments may have an average value between the limits zero and $\pi/2$ radians. Networks having near constant argument are of importance in shaping the phase character of the forward gain in feedback systems. These networks have arguments that oscillate about a mean value and the nature of this oscillation is discussed. The poles of admittance are geometrically spaced along the negative-real frequency axis, and consequently the elements of the network can be thought of as "spaced." The immitance functions and argument oscillations for the $22\frac{1}{2}°$, 45° and $67\frac{1}{2}°$ cases as a function of spacing are fully discussed. An application to a feedback amplifier design is given.

**Correction to "Bounded Real Scattering Matrices and the Foundations of Linear Passive Network Theory"**—D. C. Youla, *et al.* (p. 317)

**Reviews of Current Literature** (p. 318)

**Correspondence** (p. 321)

**PGCT News** (p. 326)

## Communications Systems

### Vol. CS-7, No. 3, September, 1959

**Frontispiece and Guest Editorial** (p. 145)

**New Developments in FM Reception and Their Application to the Realization of a System of "Power Division" Multiplexing**—Elie J. Baghdady (p. 147)

Two techniques—*feedforward* across a limiter and *dynamic trapping*—are described to show how the message carried by the weaker of two cochannel FM signals can be extracted with negligible distortion even when its amplitude is much smaller than that of the stronger signal. The development of these techniques marks the end of the stronger-signal capture limitation of FM systems and ushers in more efficient spectrum utilization, as well as new applications for frequency modulation.

**Probability Distribution of Noise Due to Fading on Multisection FM Microwave-Systems**—Harold E. Curtis (p. 161)

The probability distribution of expected baseband noise during fading at the end of a multisection microwave radio system is an important consideration in the engineering of a long system.

This paper gives measurements of fading on a single path, and derives an estimate to the probability distribution of expected noise due to fading on a particular 68-section system of which the single path is a typical part. A comparison is shown with a measured cumulative distribution curve of noise at baseband subsequently obtained on the long system under operating conditions. A numerical method of combining distribution curves was used in this case and the so-called "breaking effect," due to deep fades, is included. This method is described in the Appendix. While this paper is directed specifically to a particular microwave system, the principles described can be applied equally well to others.

**Concerning Optimum Frequencies for Space Vehicle Communication**—S. Perlman, *et al.* (p. 167)

Optimum frequencies for the varied needs of space vehicle communication can best be determined from the estimated system performance. Each of the contributing equipment and propagation factors over the range of the radio frequency spectrum affects the minimum tolerable signal-to-noise power ratio at the receiver. Over the range of the radio frequency spectrum, the behavior of the individual building blocks, as factors, will vary so as to exhibit a preponderance of either desirable or undesirable characteristics.

Some of the newer technical developments that increase sensitivity to weak signals are evaluated for their potential increase in the distance of communication. Then the individual building blocks are married to each other in operating systems that determine the optimum portions of the frequency spectrum. The equipment factors are examined first, both as to their individual characteristics and their dependence on each other. Next, the propagation factors are examined for their effect over the range of the radio frequency spectrum in providing windows for communication through the earth's atmosphere, troposphere, and ionosphere to outer space. Some consideration is given to the effects of auroral displays, water vapor and gaseous absorption, Faraday rotation of polarization, and radio star scintillations. In addition, there is a discussion of noises arising from various causes. Measurements by radio astronomers demonstrate that equivalent noise temperature is a more useful measure of signal-to-noise ratio of receiver performance than the standard noise figure definition.

**Effects of Frequency Cutoff Characteristics on Spiking and Ringing of TV Signals**—A. D. Fowler and J. C. Igleheart (p. 173)

The spiking and ringing of TV signals depend upon amplitude and delay characteristics associated with frequency cutoff of transmission. The effects of a variety of cutoff characteristics of both ideal and practical systems on rectangular and sine-squared pulses are illustrated by computed waveforms.

The illustrations are arranged to show a) waveform of input pulse, b) amplitude and delay characteristics of transmission path, and c) waveform of output pulse. Included here is a discussion of inferences that can be drawn from certain output wavesforms on the reductions in transient response that are achieved by inband delay equalization and amplitude roll-off.

**A 2500-Baud Time-Sequential Transmission System for Voice Frequency Wire Line Transmission**—G. Holland and J. C. Myrick (p 180)

The Sebit-25 is a full duplex terminal equipment designed to transmit digital data at rates up to 2500 baud. The equipment has been completely transistorized and thoroughly evaluated under environmental conditions.

In operation, binary information at 2500 baud is converted to minimum bandwidth and used to amplitude modulate a 2500-cycle carrier. The resulting signal is converted to vestigial sideband prior to transmission, to further compress the bandwidth.

At the receiver terminal, amplitude and delay compensation are provided to correct for distortion introduced by the transmission line. Synchronous sampling of the recovered signal by a slaved time standard reproduces the original binary information even though line distortion may be severe.

Excellent performance results were obtained from a series of laboratory tests conducted on the Sebit-25 to determine error probability vs noise, level changes, delay distortion, carrier frequency shift, and line filter variations.

**An Experimental Equipment to Reduce Teleprinter Errors in the Presence of Multipath**—James L. Hollis (p. 185)

Multipath propagation between radio terminals employing binary signalling elements produces a catastrophic rise in teleprinter error rate when the difference in path delay time becomes appreciable compared to the duration of a bit. A commonly used four-channel multiplex system has a bit length of 6.7 milliseconds and is thus seriously affected by differences in path delay greater than approximately 3 milliseconds.

This paper describes a method of preventing the rise in errors when multipath propagation is present, by synchronously shifting the frequency of the transmitter and receiver following transmission of each bit. The receiver is thus responsive to the signalling element propagated by the shortest path and rejects the long path signals by filter selectivity. Spectrum occupancy and receiver bandwidth considerations which determine the magnitude and number of frequency changes are discussed, and a practical system is described. The general features of equipment used in testing this device are illustrated and discussed.

The compatability of the anti-multipath equipment with existing equipment and the ability to reduce the error rate substantially, under conditions of ground-scatter multipath propagated by the *F* layer, have been successfully demonstrated.

**Impulsing of Linear Networks in Integrated Data Systems**—Gerald K. McAuliffe (p. 189)

Waveforms useful in data transmission may be obtained by impulsing suitable linear networks, and these same networks may be used, in certain cases, as receiving matched filters. A filter design for certain low-pass waveforms is described, together with a procedure for realizing band-pass analogs of these low-pass waveforms. The latter avoid the use of modulators. Practical results are described.

**Angular Diversity Reception at 2290 MC Over a 188-Mile Path**—J. H. Chisholm, *et al.* (p. 195)

Experiments were performed over the 188-mile Round Hill-Crawfords Hill path at 2290 mc to determine the feasibility of using angular diversity reception in a tropospheric scatter system. Using a 28-foot reflector, two beams were produced with two separate feed systems. The correlation of the signals received on one of the two beams with that received on the other was determined for various spacing of the beams, as well as for the azimuthal position of the antenna.

These experiments show that angular diversity techniques can be effective depending on the proper choice of frequency, antenna size, and beam separation for paths in the neighborhood of 200 miles in length. A substantial "diversity gain" can be achieved even though partial correlation exists. These results also appear to be in good agreement with theoretical predictions for equal means and for the short periods of time applicable to obtaining reliable voice and high speed teletype communications.

**Real Time Data Transmission System**—C. R. Scott and W. H. Butler (p. 201)

A real-time data transmission system was designed for and installed at the Atlantic Missile Range. This system is used to transmit the digital range, azimuth, and elevation coordinates from remotely located ANF/PS-16 radars into the Range Safety IBM 704 Computer at Cape Canaveral, Fla. The radar data is transmitted at a 10PPS rate and is used in the computation of a predicted impact point ten times a second within the computer. The predicted impact point is displayed on vertical plotting boards or use by the Range Safety Officer.

**Tropospheric Scatter Path Loss Tests, Florida Bahamas**—Kenneth P. Stiles (p. 205)

Telephone service between the United States and the Bahama Islands is now provided by means of high-frequency radio systems working in the 2–7 mc range. To handle properly the large volume of traffic during the peak winter season requires that more than the present nine circuits be provided. The lack of available frequencies in the 2–7 mc range, together with the comparatively poorer grade of facility obtained from these radio systems, makes it desirable to investigate other methods of providing telephone facilities. The fact that the present Miami-Havana tropospheric scatter system is performing so well, and that the distance from Miami to Nassau is the same as that to the Cuban terminal, made this type of system very attractive. At the time the Cuban system was being developed, klystron tubes capable of high outputs above 1000 mc were not available. For this reason, the Cuban system was designed to operate in the 700–900 mc range. Since that time tubes capable of high output levels at frequenices above 2000 mc have been developed and it was considered desirable to operate at these higher frequencies rather than in the lower.

**Applicability of Multipath Protection to Meteor Burst Communications**—T. G. Knight (p. 209)

This paper investigates past methods of improving the duty cycle of meteor scatter communications links in the presence of multipath distortion and suggests using a technique, for further improvement, which has proved useful at HF frequencies. It notes also, that use of this technique in conjunction with improved end-of-message error detection techniques should yield an improved duty cycle for meteor burst communications.

**A Formalized Procedure for the Prediction Analysis of Multichannel Tropospheric Scatter Circuits**—Charles A. Parry (p. 211)

In order to evaluate the potentialities of the scatter link and to minimize the financial risk involved in its implementation, examination of many combinations of path, sites, and system configurations is desirable. To assist this process, and to minimize the financial risks involved in uncertainties, a formal analytical procedure for the study of these circuits is desirable. The essential structure for such a procedure is outlined. A step-by-step process is involved, commencing with determination of an objective weighting factor for site evaluation. Data are presented for resolution of further steps dealing with median path loss, design accuracy, traffic loading, instantaneous fading, SNR, error rates, bandwidth and power. A performance index for path evaluation is used so that an optimum path-site combination may be selected. An index for comparison of various paths carrying different traffic leads with different reliabilities is suggested. Equations for use of this data in specific design situations are also given.

**Contributors** (p. 222)

## Electron Devices

### Vol. ED-6, No. 3, July, 1959

**Electron Beams in Axially-Symmetric Crossed Fields**—John A. Bradshaw (p. 257)

*M*-type traveling-wave tubes use electron beams that drift in crossed electric and magnetic fields. One such tube, the axiotron described by Warnecke and Doehler in 1950, used a hollow beam drifting parallel to the tube axis in a radial electric field crossed by an aximuthal magnetic field. The addition of an axial magnetic field to the azimuthal one adds another degree of complication and flexibility to the beam equations, yet maintains their symmetry about the tube axis. It gives, in effect, a helical magnetic field crossed by a radial electric field.

This report examines the behavior of hollow electron beams drifting in laminar flow through fields of the latter configuration. It defines a stability index for electron paths, and four fairly general types of beam. It determines the stability index and the distribution of space charge obtainable in each type as functions of the amplitudes and directions of the fields and drift velocities. In general, the density tends to be greatest at the inner beam radius, but it is possible to approach uniform density in stable beams.

This report does not consider beam launching nor the "gun" problem; nor does it consider over-all beam instabilities such as scalloping.

**Laminar Flow in Magnetically-Focused Cylindrical Electron Beams**—James L. Palmer (p. 262)

The behavior of a cylindrical electron beam in a magnetic field is discussed in terms of a laminar-flow model. By numerical integration of the equations of motion, the maximum and minimum radii of excursion and the wavelength of the undulations for each electron are presented in graphical form for various boundary conditions on the electron beam. By the proper selection of the boundary conditions, *e.g.*, magnetic field strength at the cathode, the graphs are utilized to describe Brillouin flow, space-charge-balanced flow, immersed flow, confined flow, and, in fact, any electron flow which satisfies the laminar flow criterion. The perturbations introduced by improper injection conditions for any of the flows mentioned can be read directly from the graphs. A study of the wavelength and the amplitude of such perturbations as a function of radial position in the beam determines if a given type of flow with given injection conditions satisfies the laminar flow criterion. The sensitivity of the various types of electron flow to misadjustments of the boundary conditions is clearly revealed by the graphs; *e.g.*, the amplitude of the undulations in Brillouin flow is very sensitive to the adjustment of the magnetic field strength whereas, for immersed flow, a similar deviation in magnetic field strength has very little effect on the amplitude of the undulations.

**Point-Contact Diodes in Terms of *p-n* Junction Theory**—Robert E. Nelson (p. 270)

A "*formed*" *n*-type germanium point-contact diode is qualitatively reminiscent of an idealized model that comprises an abrupt hemispherical *p-n* junction, both regions of which may have moderate resistivity, terminated on the inner (*p*) and outer (*n*) sides by hemispherical ohmic contacts. The extent to which this model can be justified quantitatively is investigated. Low-injection analyses of the static and small-signal, frequency-dependent properties suggest that the model is capable of predicting the corresponding experimentally-observed behavior. Consideration of space-charge-layer widening with reverse bias allows the computation of breakdown and punch-through voltages, which correspond in magnitude range to the observed peak inverse voltages of formed germanium point contacts. A high-injection analysis of the static forward characteristic indicates approximate agreement between theory and experiment, even for the nonlinear spreading resistance.

**The Nesistor—A Semiconductor Negative Resistance Device**—Robert E. Nelson (p. 278)

A semiconductor device similar in principle to the injecting-drain-field-effect transistor, having wide ranges of controllable negative resistance which can be used in counting, flip-flop, amplifying, and oscillator circuits, is described. The negative resistance arises from the modulation of the current between two ohmic contacts of circular symmetry, on a flat semiconductor wafer, by the effect of the collection of minority carriers on the pinching potential of a collector electrode. Families of negative resistance, of either the shunt or series type, are obtainable depending upon the mode of operation. Power gains of 60 and thermal dissipation of 1/4 watt have been achieved in liquid cooled units the size of high-frequency transistors. An improved sandwich-type base tab for mounting semiconductor wafers is shown. A theoretical analysis of the operation of the device permits prediction of the effect of various physical parameters upon the static electrical characteristics.

**Super-Radiation and Super-Regeneration**—C. Greifinger and G. Birnbaum (p. 288)

The transient behavior of a two-level spin system coupled to an electric circuit is investigated by using the equations of Bloembergen and Pound. The equations are solved, in the limit where the circuit ringing time is very short compared with all other characteristic times, for two cases: 1) the spin-lattice and spin-spin relaxation times both infinite, with an externally applied driving field, and 2) the spin-lattice relaxation time infinite but the spin-spin relaxation time finite, in the absence of an external field. In case 1), it is shown that the motion of an initially inverted magnetization under the action of an applied signal consists roughly of two stages: in the first stage, the effect of radiation damping is unimportant and the motion of the system is determined principally by the applied signal via the ordinary Bloch equations, whereas in the second stage, the motion is essentially the same as if the applied signal had been turned off and only radiation damping were present. In case 2), it is shown that a delayed peak in the emitted radiation should be observed under certain conditions. The delayed peak condition is identical with that derived by Bloom. Curves are presented showing the peak power and the time at which the delayed peak occurs as functions of the relevant parameters. In connection with the ordinary maser behavior of a two-level spin system, it is shown that for values of the parameters typical of steady-state maser amplification, the effects of radiation damping should be unimportant. Finally, systems are examined for which the radiation damping time is much shorter than all other characteristic times (super-regenerative systems). It is indicated how such systems might be operated as one-shot multivibrators or as linear amplifiers. For the latter type of operation, an expression for the gain is derived which is found to be similar to that encountered in ordinary circuit theory.

**A Low Potential Collector Employing an Asymmetrical Electrode in an Axially-Symmetric Magnetic Field**—D. A. Dunn, *et al.* (p. 294)

A collector for a beam-type tube with an axial magnetic focusing field can be made to operate at a potential near cathode potential without returning secondary electrons, if the beam is deflected and caused to pass an asymmetrical electrode properly positioned in the axially symmetric magnetic focusing field. Collection takes place in a region of radial electric field. Experimental results on such a device indicate successful operation, provided the velocity spread in the beam is not too large.

**Electrostatic Optics for Camera Tubes**—R. W. Redington (p. 297)

Two versions of an electrostatic focusing and deflection system suitable for camera tube applications are described. Focusing properties, resolution and aberrations are discussed.

**Thermally-Induced Cracking in the Fabrication of Semiconductor Devices**—Theodore C. Taylor (p. 299)

The literature bearing on the cracking of semiconductor devices due to thermally induced strains is reviewed. A model is developed to describe in qualitative terms, the stress distribution and mechanics of cracking and the significant variables of the cracking process are summarized. The remedial measures which have been proposed as solutions to the cracking problem are discussed. An analytical model is given which describes the stress distribution in the chip of a semiconductor device, and predicts a location of maximum stress which is in agreement with experimental results. A formula is derived for the calculation of the maximum semiconductor tensile stress in an elastic model. The modifications requires of the model in cases of inelastic behavior are discussed.

Three appendixes are given to present: 1) experimental methods of crack detection, 2) analytical design methods for tabbed device structures, and 3) references for some structural properties of germanium and silicon.

**Medium Power High-Speed Germanium Alloy Transistors**—H. E. Hughes, *et al.* (p. 311)

A complementary pair of medium-power high-speed switching transistors was required to satisfy the needs of an electronic switching system. Units have been designed and produced which exhibit a median cutoff frequency of 7 mc and a punch-through voltage of 70 volts.

High yields have been achieved on established production lines by very close manufacturing controls of the critical alloying variables, namely, germanium wafer thickness, alloyed junction area, concentricity, mass of alloying material, alloying temperature, and special material properties such as orientation and etch-pit density.

A vacuum-tight transistor structure has been designed to permit the dissipation of one-half watt of power at 25°C in free air. The structure embodies an all-copper cold-welded encapsulation for efficient heat removal. Important techniques concerning the cold-welding process will be discussed, and the particular die contour used will be illustrated in some detail. Additional cleanliness advantages are obtained by the use of the cold welded seal.

**New Methods for the Measurement of Cathode Interface Impedance**—H. B. Frost (p. 315)

Two improved methods for the measurement of cathode interface impedance have been developed, and their limitations have been analyzed. One of these, the complementary network method, is an improvement of a technique disclosed at the IRE National Convention in 1952. The other, the shunt admittance bridge, has not been described previously. Both methods allow the measurement of impedance with both small resistance and short time constant, well below the limit, 50 ohms at 0.1 $\mu$sec, of most present equipments. With the development of improved cathode alloys, the measurement of interface impedances having short time constants and low resistances has become important to control this parameter in manufacture and to obtain further improvement.

For the complementary-network bridge, the theoretical analysis has shown the extreme importance of minimizing stray inductance in the complementary network. When corrections are applied, the complementary-network bridge has good accuracy, with less than one-ohm error at 10 ohms and 0.05 $\mu$sec and lower relative errors for higher resistances.

The shunt admittance bridge is most satisfactory when tubes with transconductances greater than 10,000 $\mu$mho are to be measured. An impedance transformation is used which allows much easier physical realization of the measurement network than in other interface measurement methods. For tubes with transconductances greater than 10,000 $\mu$mho, the shunt admittance bridge will provide accurate time constant and resistance data down to 0.02 $\mu$sec and 5 ohms.

**Maximum Rapidly-Switchable Power Density in Junction Triodes**—J. M. Early (p. 322)

The maximum power density which may be switched at (switching time/current gain) quotients comparable to $1/2\pi f_\alpha$ is shown to be $10^5-4\times10^5$ watts/cm²for *p-n-p* germanium transistors. This result is derived first for junction triodes in which the collector depletion layer at peak reverse voltage lies largely in a collector body of conductivity type opposite to that of the base; *e.g.*, diffused base transistors of the mesa type. The limitation arises from the linear dependence of maximum (scattering limited) current density ($J_{max}$) on collector-body impurity concentration ($N_{Ac}$) and from the approximately reciprocal dependence of breakdown voltage ($BV_{CB}$) on the same parameter.

It is shown that space-charge limitation of current density leads to a somewhat lower limit for intrinsic collector barriers of the same maximum width and, *a fortiori*, to a lower value for collector barriers lying largely in material of the same conductivity type as the base layer. Similar limits for *n-p-n* germanium and for silicon transistors are higher but generally comparable.

**On the Periodic Coupling of Propagating Structures**—Nathan Rynn (p. 325)

An analysis of two propagating structures periodically coupled together, based on a method developed by J. R. Pierce, is presented. A periodic structure that supports a backward wave may be coupled to a structure that supports a forward wave by coupling to alternate cells of the former. The coupling is completely analogous to the case of continuously coupled waves, *i.e.*, energy is transferred back and forth between the two guides periodically and the period of the transfer is inversely proportional to the strength of the coupling. The period of the transfer is also a function of the number of couplers per unit length. A method of measuring the coupling coefficient is presented and application to a coupled-structure attenuator is discussed.

**The Effects of Electrode Resistance in Electroluminescent Cells**—Henry F. Ivey (p 335)

The effects of electrode resistance on the voltage drop, the power dissipation, and the equivalent circuit constants of electroluminescent cells have been calculated by means of linear transmission line theory. In practice, electroluminescent cells have nonlinear characteristics which make the actual problem very difficult to solve. It is believed, however, that the present considerations serve to give a qualitative picture of the effects of electrode resistance in actual cells.

**Semiconductor Diode Amplifiers and Pulse Modulators**—W. Ko and F. E. Brammer (p. 341)

The reverse recovery characteristic of a semiconductor diode depends not only on the crystal properties and the physical dimensions of the diode but also on the circuit in which it is used. The effects of the circuit parameters, namely, forward current, reverse voltage and reverse loop impedance, on the diode recovery characteristics were studied experimentally on germanium and silicon junction diodes. The results are given in curves which illustrate the relationships between these circuit parameters and the maximum reverse current, as well as the constant current duration. Based on these curves, circuit applications were developed. The experiments on a pulse amplifier performed by the National Bureau of Standards, were repeated. The results showed a maximum power gain of 22 db per stage. Four pulse modulator circuits were designed. They are amplitude modulator, sampler, pulse duration and position modulators. Linearity and frequency response tests on these modulator circuits were conducted. The results indicated that they have small distortion and flat frequency response from dc up to several tens of kilocycles per second. Modifications of the pulse amplitude modulator provides amplifiers for continuously varying signals. Four such circuits are given.

**A Design Theory for the High-Frequency *p-n* Junction Variable Capacitor**—C. J. Spector (p. 347)

One of the more significant uses of the *p-n* junction variable capacitor is as an HF (>100 mc) tuning element. Structures which have been available have had rather low $Q$ at these frequencies. In order to determine the limits imposed on $Q$ by the physics of the device, a fundamental study has been made of the problems of the HF junction capacitor. Equations have been developed for the prediction of $Q$ in alloyed and diffused structures. Optimization criteria are proposed which permit design of capacitors in which $Q$ is no longer a significant limitation. In support of the theory, experimental results are presented on units designed and fabricated in accordance with the optimization criteria. $Q$'s in excess of 500 have been observed at 100 mc.

**The Radio-Frequency Current Distribution in Brillouin Flow**—M. Chodorow and L. T. Zitelli (p. 352)

It has been shown that in an electron beam with Brillouin focusing, two pairs of space-charge waves are possible. One pair has the peculiar property of having no RF charge density in the volume of the beam, with most of the current being caused by ripples of the boundary. This paper shows that, in the case of modulation by the gridless gap of a klystron, it is only these space-charge waves which are excited in the electron beam. This result has also been verified elsewhere by experiment. In addition to the detailed calculation, a simple proof is given which demonstrates why one gets the particular behavior predicted by the detailed theory, namely, a modulated beam with no RF charge density in the volume. This effect arises from the fact that the modulation is produced by an electric field with zero divergence, and therefore the RF velocity produced also has zero divergence. Zero divergence of the velocity is the condition for an incompressible fluid; *i.e.*, constant density. In the case of modulation by a grid, the electric field does not have zero divergence and this kind of behavior does not occur.

**Experimental Notes and Techniques**

**Technique for Making Crack-Free Alloyed Junctions in Silicon**—Theodore C. Taylor (p. 358)

**Contributors** (p. 360)

## Engineering Management

### Vol. EM-6, No. 3, September, 1959

**A Profitability Criterion for Measurement and Decision-Making**—John C. Fisher (p. 65)

Consideration of the legal structure of corporations, and of long-term price and dividend trends of industrial stocks, leads to the conclusion that a corporation achieves its maximum profitability when the discounted value of the over-all flow of cash associated with its various activities is a maximum. The appropriate discount rate is somewhere near 6 per cent. Since each project, individually, must have its maximum possible discounted value, the profitability criterion serves as a criterion for decision-making.

**Production Selction—Witchraft or Wisdom**—Charles S. Roberts (p. 68)

This paper develops the thesis that marketing research can make a significant contribution to new product conception and development. A discussion of new product development is presented within the framework of meeting the challenge of changing needs of the market and the competition of companies who are market-oriented and working to anticipate the needs of their customers. Companies engaged in research and development work are committing important resources in new product and new concept development in order to survive, yet there is a risk of failure that is inherent in such activities. Although it is agreed that the risk of failure cannot be eliminated, it is recommended that this risk can be reduced by utilizing the discipline of marketing research.

**Group Contracting**—James D. McLean (p. 71)

The pattern of military electronics procurement in recent years has shifted away from large-scale production of relatively simple systems—black boxes, they may be called—and toward the development and production of fewer systems of increasing complexity. To meet the challenges imposed by this change, the industry has found it necessary, in many cases, to form teams of specialist organizations, each possessing one or more of the capabilities necessary for the task in question.

Although the structure of the relationships which bind the team together may vary, the basic attributes are the same. In this paper, the characteristics of team contracting are revealed and the advantages of this form of solving specific military problems are discussed.

**The Management of Research and Development**—Abraham Katz (p. 75).

Our intensive search for knowledge, basic and applied, must be accompanied by a corresponding search for the principles underlying the management of research and development. An attempt has been made here to seek out the factors of major importance and to organize them into a meaningful whole. Basic to this analysis have been the views of product value and cost as streams in time, and of managerial capabilities as probabilities of project completion, also varying in time. A simple model based on these concepts has been developed for a business in which the products are characterized by great complexity and by rapid change. The model is simply a tool to understanding—a way of looking at a business. Rational procedures have been derived for making certain of the major project decisions.

**Management Control of Professional Operations—Actuality or Illusion?**—P. S. Schmidt (p. 81)

Whether management has effective control of professional operations such as Research and Development is difficult to judge because the required level of creativity varies from project to project. To eliminate this variable, patent operations, which require specialized creativity of constant intensity, were chosen for study. Results of a questionnaire sent to 100 electronics companies indicate that quantity, quality and cost controls in most corporate patent programs are rudimentary or nonexistent. This raises a question as to whether management control (in the cybernetic sense) is achievable in any area of professional operations.

**Magazine Review Section** (p. 87)

**For Your Bookshelf** (p. 89)

## Information Theory

### Vol. IT-5, No. 3, September, 1959

**Frontispiece** (p. 96)

**Guest Editorial**—D. Gabor (p. 97)

**Note on Unique Decipherability**—E. T. Jaynes (p. 98)

We consider an alphabet of $a$ letters, used under the restrictions: 1) messages uniquely decipherable into words by use of one of the letters as a space mark, and 2) words limited to a maximum length of $L$ letters. Although imposing these constraints simultaneously may cause a large reduction in the channel capacity of the alphabet, neither by itself causes any reduction. Accordingly, in the absence of constraints other than 1), an inequality of McMillan pertaining to uniquely decipherable messages can be made to be an equality.

Defining "semi-optimal" transmission by the condition that the mean transmission time per word is minimized for a given entropy per word, we find the attainable rate of information transmission under semi-optimal conditions. Transmission at full channel capacity is a special case of semi-optimal transmission. Some generalizations and analogies to statistical mechanics are discussed.

**On the Use of Laguerre Polynomials in Treating the Envelope and Phase Components of Narrow-Band Gaussian Noise**—Irving S. Reed (p. 102)

The joint probability density of the envelope of a Gaussian process at two different times is expanded by the use of Hardy's identity into a series involving Laguerre polynomials. It is shown how this result may be used to estimate the cross-correlation function of the output of two quite general envelope-distorting filters. A generalization of this result, involving the use of the associated Laguerre polynomials, is obtained and applied to the calculation of a cross-correlation function which involves both the phase and envelope of the process at two points in time.

**Interchannel Correlation in a Bank of Parallel Filters**—Janis Galejs and William M. Cowan (p. 106)

The first-order effects of interchannel noise correlation on the false alarm and incorrect dismissal probabilities are computed for a bank of parallel RLC filters by expanding the envelope distribution of the $n$ filter outputs in a power series.

The correction to the false alarm probability due to noise correlation is found to decrease with increasing threshold-to-rms-noise ratios. If the filter-separation-to-filter-band width ratios are larger than 0.2, it is less than 15 and 0.2 per cent for threshold-to-rms-noise ratios exceeding 12 and 14 db respectively.

The correction to the incorrect dismissal probability, which is computed by considering the signal output of three contiguous filters, increases with increasing threshold-to-rms-noise and signal-to-threshold ratios. Even for filter separations larger than the filter bandwidth, it may be in excess of 100 per cent if the threshold-to-rms-noise ratio exceeds 12 db and the signal-to-threshold ratio is larger than 1.2.

**Application of Modular Sequential Circuits to Single Error-Correcting $p$-nary Codes**—Thomas E. Stern and Bernard Friedland (p. 114)

**Some Spectral Properties of Weighted Random Noise**—H. S. Shapiro and R. A. Silverman (p. 123)

We studied the power spectrum and, more generally, the spectral covariance of weighted stationary processes. It is found that if the power spectrum of the underlying stationary process is suitably well behaved and properly matched to the weight function, then the high-frequency behavior of the power spectrum and spectral covariance is especially simple. Asymptotic theorems describing this behavior precisely are given.

**Extremal Coding for Speech Transmission**—Max V. Mathews (p. 129)

A digital coding and its application to speech transmission is described. The coder determines the amplitudes and times of successive extremes (relative maxima and minima) of the signal. This information is decoded at the receiver by interpolating a function between extremes so as to connect them smoothly and preserve the extremes of the original signal in the reconstructed wave. Thus, the coding is a nonlinear sampling technique. It is related to clipped speech encoding which effectively transmits only the times of the extremes.

The properties of the coding for speech signals have been studied by digital simulation on an IBM 704 computer. Information rate, statistics of the extremes data, and quality of the resulting signal have been evaluated. The buffer size necessary to receive the randomly ocurring data and transmit at a constant rate was measured.

**Correspondence** (p. 136)
**Contributors** (p. 144)

## Medical Electronics

Vol. ME-6, No. 3, September, 1959

**A Multichannel Analyzer for Heart Potentials**—C. V. Nelson, *et al.* (p. 107)

**Computers Applied to Ballistocardiography**—S. A. Talbot (p. 109)

**A New System for Electrocardiographic Recording, Analysis, and Diagnosis**—J. Martinek, *et al.* (p. 112)

**A Study of the Advantages of Displaying the Heart's Electrical Activity as Linear Time-Scale Curves of Spacial Magnitude and Orientation**—J. A. Abildskov, *et al.* (p. 116)

**An Automatic Pressure Regulator for Extracorporeal Circulation**—O. Z. Roy (p. 118)

An automatic pressure regulator for controlling venous pressure during extracorporeal heart operations is described. The controller is used in procedures where a pressure is maintained in the venae cavae; *i.e.*, where gravity flow is not used to drain the venous blood.

A differential pressure transducer produces an error signal which controls the field current in a dc shunt motor and, consequently, the rate of pumping. The sensitivity of the controller can be varied in eight steps; on the most sensitive range, an error of less than 0.20 mm Hg can be detected and corrected. The total change in motor speed and hence pumping rate is ±20 per cent.

**The Computation of Muscle Activity from the Integrated Electromyogram**—B. R. Fink and M. L. Scheiner (p. 121)

The integration of a signal of varying pulse amplitude and frequency is discussed. Several solutions are considered, and a method is described in which an accurate integration is obtained with a circuit of short time constant and virtually infinite decay time.

**Automatic Reading and Recording of Digital Data in the Analysis of Primate Behavior**—D. McConnell (p. 123)

**The Human Being as a Link in an Automatic Control System—Part I**—T. J. Higgins and D. B. Holland (p. 127)

**Adaptive Servomechanisms**—Charles W. Johnson (p. 136)

A discussion is given on some of the current ideas behind the control engineer's approach to the problem of developing servomechanisms which exhibit some degree of adaptive behavior. Several categories of adaptive systems are discussed and an attempt is made to associate the operating principle of the systems in each category with the behavior of the human being when he acts as a controlling device. A particular system developed for application in the field of automatic flight control is discussed from a functional point of view. The controller, using an analog model which operates on the input information, determines a "standard of performance" for the controlled element which closely approximates the performance desired by an experienced operator. The remainder of the controller, using a very simple passive network as a switching function computer to determine the state of a bistable device, forces the controlled element to operate in such a manner as to minimize continuously the error between the desired performance and the actual performance. The controller exhibits adaptive behavior in the sense that it operates in such a manner as to keep the actual performance of the system practically invariant, although the parameters of the controlled element change over a relatively wide range of values.

**The Ultraviolet Flying-Spot Television Microscope**—P. O'B. Montgomery and W. A. Bonner (p. 143)

**Transmission of Ultrasound Through Living Human Thorax**—H. D. Crawford, *et al.* (p. 146)

Experiments are described demonstrating the passage of one-mc/sec continuous wave ultrasound through the heart and lungs at power levels of 100 mw/cm² at the tranducer terminals (a total of 1.25 watts). When the sound was directed through the region of the heart, the ultrasound was modulated by the moving intra-thoracic structures in synchonism with the heart beat. The records obtained were modified both by exercise and by amyl nitrite administered to the subject, but remained synchronous with the heart rate. Modulation of the ultrasound did not occur in two warm corpses. Sonic energy at the levels used to traverse the thorax did not affect a simultaneously recorded electrocardiogram. No deleterious effects have been observed on a subject whose heart was irradiated at 1 watt/cm² and 3 watts/cm² (totals of 12.5 and 37.5 watts, respectively) applied to transducer terminals at intervals over a period of one year (Appendix I). When continuous wave ultrasound was directed through a lung field clear of the heart, it was found that the attenuation varied 50 db between full inspiration and a lung emptying of 3400 cubic cm (0 db = full inspiration). In addition to direct transmission, sound is scattered throughout the thorax. The mechanics of the ultrasonic phenomena are described.

**Problems in Electroencephalograph Analysis**—M. G. Saunders (p. 152)

**The Analysis of Electroencephalograms by the Use of a Cross-Spectrum Analyzer**—Ezra S. Krendel (p. 154)

**An Automatic Digital Recorder for Timing Sequential Events**—Stanley M. Block (p. 162)

**A Method of Measuring the Dynamic Characteristics of Muscle Rigidity, Strength, and Tremor in the Upper Extremity**—David D. Webster (p. 164)

**Computational Aspects of Brain Function**—Reginald G. Bickford (p. 169)

**Digital Recording of Electrocardiographic Data for Analysis by a Digital Computer**—L. Taback, *et al.* (p. 172)

A corrected orthogonal 3-lead system has been used to record electrocardiograms directly from patients at Veterans Hospitals, using three FM channels of magnetic tape. A pilot facility has been designed and assembled by NBS to permit a medical technician to inspect these on an oscilloscope and select a significant cardiac cycle. This is automatically sampled at millisecond intervals and the numerical values are stored in digital form on magnetic tape acceptable to an electronic computer. Upon writing various programs for the digital computer, the cardiac researcher will have a flexible tool for objective analysis of large quantities of biological data by a variety of possible criteria.

**Possible Approaches to Multiple-Channel Tape Recording for Biomedical Purposes**—D. H. Smith, *et al.* (p. 176)

**A Statistical Study of the Effects of Electric Fields on the Movements of Mammalian Sperm Cells**—John W. Trank (p. 179)

A micro technique has been developed to facilitate the study of electric field effects on the swimming pattern of sperm cells. The instrumentation for this technique, a microelectrophoresis vessel, a metering motion picture projector, and a simple analog computer for data handling, are briefly described. It is shown experimentally that 1) an electric field imposed on a cell suspension acts primarily to direct the cells to the anode without appreciably changing their swimming speed, and 2) the field effects are not linear functions of field strength. It is postulated that the field effect is primarily galvanotaxis and that the cells seek a position of minimum stimulation and therefore must have a transverse sensitivity axis.

**Autocorrelation and Cross Correlation Analysis in Electroencephalography**—John S. Barlow (p. 184)

Autocorrelation and cross correlation analysis, which have been used extensively in statistical communication theory in the past few years, can be applied, with certain limitations, to the study of the EEG (electroencephalograph). Autocorrelograms for normal subjects can be classified in several categories, according to the dominant frequency, or frequencies, present, and other parameters. Cross correlograms of EEG recordings from different locations on the head permit a comparison of the electrical activity at the two locations. Correlation functions and power-density spectra contain equivalent information because the one may be obtained from the other by Fourier transformation; but, because of the squaring and multiplication that appear in the computation process, the data so obtained are not exact equivalents of the frequency spectra derived from tuned resonators. A special case of cross correlation analysis (cross correlation of a repetitive signal with a synchronously occurring brief pulse) can be applied to the detection of electric responses evoked by sensory stimulation. This process is equivalent to averaging a large number of individual responses. Illustrative examples, obtained from semi-automatic computers especially designed for the purpose, are given.

**PGME Applications for Affiliates** (p. 189)

## Military Electronics

### Vol. MIL-3, No. 4, October, 1959

**Frontispiece** (p. 127)

**Guest Editorial**—Bernard A. Schriever (p. 128)

**Scientific Objectives of the Able-3 Program**—Applied Physics Dept., Space Technology Labs., Inc. (p. 129)

The purpose of the Able-3 program is to place a scientific observatory in a highly elliptic satellite orbit. A scintillation counter, ion chamber, Geiger counter, and proportional counter telescope in the payload permit comprehensive mapping of corpuscular radiation over a large volume of the geomagnetic region, including the Van Allen radiation belts. Simultaneously, the fundamental static quantities, electron density, and vector magnetic intensity are to be measured. A VLF experiment is included to measure upper atmosphere VLF noise and to study the propagation characteristic of VLF between the ground and the satellite. A radio scintillation experiment using radio telescopes will measure the effects of ionospheric irregularities on amplitude and phase. Micrometeorite detection equipment in the payload provides a two-point momentum spectrum of micrometeorites encountered, and an image scanner is included to examine reflection characteristics of the earth.

**Able-3 Payload Design**—John E. Taber (p. 143)

This paper discusses the Able-3 payload instrumentation. The design parameters and functional characteristics of this instrumentation are discussed in terms of the two goals of this program: to build a payload which gathers as much scientific information as possible concerning the space environment about the earth, and to develop and check out communications, power supply, and temperature control systems suitable for subsequent interplanetary space probes. The basic electronics of the satellite and their relationship with the experimental equipment as well as with structural and other aspects of the satellite are discussed in some detail. Particular emphasis is placed on the communications system, and, in particular, on the new digital telemetry system and its value to deep space exploration.

**Three-Dimensional Interplanetary Trajectories**—A. B. Mickelwait, *et al.* (p. 149)

Developments in guided missiles and related scientific areas have reached a state where ballistic flights to the planets Venus and Mars are feasible and imminent with existing hardware. This paper discusses considerations involved in making an actual ballistic flight to Venus. Conventional two-dimensional analysis is compared to the actual three-dimensional case. Burn-out conditions required to minimize the problems of guidance, payload, range safety booster aerodynamics, midcourse guidance, and capture are established. Problems relating to launch times, launch latitude, and interplanetary communications are also discussed.

**Detection and Evaluation of Space Radiations**—dePaul T. Corkhill and R. A. Hoffman (p. 162)

In the very near future man will escape from his terrestrial environment and venture into space. The first flights will be limited space voyages circling the earth only one or several times at altitudes from 100 to 500 miles. As technological advances permit, these space journeys will become longer in duration and farther from earth until travel between planets in our solar system is accomplished. Ultimately of course, travel outside our solar system is envisioned.

The hazards of space flight are numerous. An environment paralleling that of the earth's must be simulated as closely as possible inside the space capsule. In providing such an environment, those problems of air regeneration, temperature control, pressure control, etc., are overcome. One potential hazard from which man in space cannot be effectively protected is radiation. Therefore, the intensity of space radiations and their biological effects must be evaluated prior to prolonged space journeys if such journeys are to be accomplished without undue risk.

The aeromedical field laboratory is now studying a space radiation detection system which would be capable of detecting and identifying the several forms of space radiation and the intensity of each form. Once the types and intensities of radiation prevalent in space are ascertained, it will be possible to study, in earth laboratories, the biological effects of most of these radiations. Radiobiological studies should lead to realistic RBE (relative biological effectiveness) values for these radiations, and thus biological dose rates (rem/hr) can be established.

A radiation survey system such as described will be a very intricate electronic assembly. The biological studies to determine RBE values will require careful study. The unit must be compact, rugged, and lightweight if it is to be adaptable to satellite flights.

Presently, a feasibility study is underway to determine the most practical and efficient electronic assembly. Then follows the fabrication of the complete detection system. Orbital flights of this system must then be made to evaluate the types and intensities of space radiations. Biological studies of these radiations must then be made so that biological dose rates may be established. Once the biological studies have been completed, the RBE factors can be incorporated in the radiation detection system, *i.e.*, a system which will be capable of giving the space passenger a biological dose rate in rem/hr on a dial type instrument as well as his total accumulated radiation dosage during the flight. Admittedly, such a system may not be a prerequisite for the first toddling steps of man into space, but it must certainly form an integral part of future space vehicles when bolder journeys farther from earth are made.

**High-Accuracy Electronic Tracking of Space Vehicles**—P. F. von Handel and F. Hoehndorf (p. 162)

It is the purpose of this paper to show that optical accuracies can be reached with electronic tracking if the refractive index is known at the site of the radar, as well as at the site of the target. This is the case in tracking space vehicles with microwaves. The index can be measured at the tracking site and it is unity beyond the denser atmosphere. Ionospheric influences can be neglected in the higher kilomegacycle range. It is also shown that the uncertainty of the course of any particular profile between the surface of the earth and the target has only minute effects on range and angular errors. Accuracy limits are determined and presented numerically. The inherent high precision of modern electronic tracking systems can be fully utilized under these conditions; this is not the case in tracking vehicles flying in the atmosphere.

**Some Reliability Aspects of Weapon and Other Space Systems Using Ballistic Missile Boosters**—Henry Triwush (p. 173)

This paper shows that there is a need to differentiate, at least on occasion, between weapon and nonweapon space systems where their reliability is concerned. Three criteria are offered as a means of determining whether this differentiation need be made in the case of any particular nonweapon space system. Where this differentiation should be made, possible reliability approaches for the nonweapon space system are suggested.

**Radar Beacons for IRBM/ICBM**—F. J. Clark (p. 175)

This paper summarizes problems which confront engineers who are responsible for the design of radar beacons and beacon antennas used in IRBM and ICBM test vehicles. The most important factors which affect compatibility between the beacon and tracking radars at the test range are enumerated. Cited also are several design areas which should be correlated with the test range prior to finalization of beacon design criteria.

**Design Studies for a Rubidium Gas Cell Frequency Standard**—J. M. Andres, *et al.* (p. 178)

A description is given of several studies undertaken in the design of a small, gas cell stabilized atomic frequency standard making use of the field-independent hyperfine resonance of rubidium 87 at 6834 mc. In the standard considered, light from a rubidium vapor lamp is used to enhance the population differences between the atomic levels involved in the resonance and also to provide a means of detecting the microwave resonance. One of the studies described is concerend with the generation of requisite microwave energy at the resonant frequency, another with the choice of an optimum length for the gas cell, and the last with the optimization of parameters for the modulation process used.

**Some Considerations in the Design of the Guidance and Control System for Discoverer**—John J. Schmitt, Jr. (p. 184)

The limited number of flight tests to date has indicated that the Discoverer satellite will be a highly reliable and effective system from which the ARPA and the Air Force expect to gain valuable additional knowledge of outer space. The achievement of this high degree of reliability and effectiveness of the satellite means that each of its subsystems must, in fact, be even more reliable and effective. The Discoverer guidance and control system is meeting their specifications because of the simplicity of the over-all design—simplicity for reliability with sufficient sophistication to accomplish its mission effectively.

The mission of the guidance system is that of providing adequate attitude, velocity, and time references to guide the satellite into a desired orbit, to control its attitude on orbit, and to provide switching in the proper sequence for certain principal satellite functions. The mission of the control system is simply that of positioning the vehicle in the proper attitude commanded by guidance. The investigations that were made and those which are being continued in the determination of the optimum configuration for the desired performance are described in some detail. The present system, consisting of an inertial reference device, a horizon scanner, and a computer for guidance, and of both pneumatic and hydraulic control systems, are discussed.

In summary, a typical flight of the Discoverer, from separation from the Thor booster until stabilization on orbit, is outlined and the functions of the guidance and control systems are described.

**Contributors** (p. 185)

**Annual Index 1959** (follows p. 187)

## Space Electronics and Telementry

### Vol. SET-5, No. 3, September, 1959

**Communication Techniques for Space Exploration**—Eberhardt Rechtin (p. 95)

This article was first given in a symposium at the California Institute of Technology on "Realities of Space Exploration," showing as graphically as possible that space communication is practical, that the extrapolation of the state of the art is straight forward, and that the real limitations are those of: 1) external noise, 2) handling an extreme volume of data, 3) certain relativistic effects (more distant future), 4) time, and 5) economics and money. These limitations, at present, indicate frequencies between 500 and 5000 mc, automatic data handling, an awareness that communications outside the solar system is presently impossible, an appreciation that time scales of many years are expected in development and flight times, and a surprising conclusion that space exploration will probably pay for itself.

**Telemetered Parameters of Primates and Humans from Space Capsules**—T. C. Helvey (p. 99)

**A Circularly Polarized Feed for an Automatic Tracking Telemetry Antenna**—R. C. Baker (p. 103)

Characteristics of a feed that utilizes a unique method to produce a conically scanning main beam are discussed. Model and full scale test data are included to make the feed operation more clearly understood.

Certain criteria such as gain, side lobe level, and polarization must be considered when designing a primary feed for a paraboloid reflector. Also, the automatic tracking requirement calls for some means of producing an error signal for given off-target angles.

The feed discussed is a circular waveguide excited by orthogonal probes fed 90° out of phase to produce circular polarization. The electrical phase center of the feed is shifted around the focal point of the 60-foot diameter paraboloid reflector by rotating a hemispherical tapered-dielectric prism at the aperture of the waveguide. A ground plane around the waveguide mouth controls the illumination taper across the paraboloid aperture to yield equal *E* and *H* plane secondary beamwidths.

**The Dynamic Analysis of the Averaging Type FM Discriminator**—I. Cederbaum and S. Rozenstein (p. 111)

The dynamic response of an averaging type FM discriminator to a general FM input is analyzed on the assumption that the zero crossing of the input signal initiates impulses which are applied to a low pass filter. The boundaries between which the output voltage of that filter is varying are evaluated. The faithful decoding may start after an initial settling-down period which is often found to be short compared with the actual period of the measurement.

In order to show the practical use of the result obtained, two examples are given which deal with a linear and a parabolic change of the frequency with time.

**A High-Speed, Airborne Digital Data Acquisition System**—S. Cogan and W. K. Hodder (p. 117)

This paper describes a transitorized airborne PCM/FM data acquisition system. The prototype version of this system has, in the past few months, been subjected to a flight evaluation program, and the final version is now in the process of assembly and test. The system is primarily digital; however, the technical areas of switching and amplification of low-level analog signals will be emphasized and system aspects will be discussed.

The airborne system is part of a larger system designed to provide an accurate and reliable means of collecting information from a large number of transducers during aircraft flight testing, and to transfer this information in the most efficient manner to a digital computer for final data reduction. The Airborne portion collects, stores, and transmits flight-test data in digital form to the ground control record station trailer which monitors the progress of the flight test. The recorded data is then carried to the computer station which organizes and controls the selection of data in a form compatible with the requirements of an IBM type 704 computer.

**A System for Editing and Computer Entry of Flight Test Data**—S. F. Higgins (p. 123)

This paper describes a system of data editing with provisions for computer entry of flight test data as acquired by an integrated digital data system. Also described are system concepts that must be dealt with in solving problems incident to these activities.

The computer station described is provided with editing control facilities that permit selection of the desired prime and commutated channels which are essential for data reduction. The editing facilities provide for the most economic use of computer and manpower effort and are so designed that they permit convenient access to all instrumented channels.

In addition, peripheral equipment is described as an aid in the editing process for examining the raw data in terms of analog, quick-look, and permanent record equipment.

**The Use of a Fractional Bi-Stable Multivibrator Counter in the Design of an Automatic Discriminator Calibrator**—M. W. Williard and G. F. Anderson (p. 131)

This paper discusses the approach used in the design of an automatic discriminator calibrator system. This design led to analysis of the use of bi-stable multibrators to obtain a fractional countdown of the output frequency of a crystal oscillator. The final counter waveform is filtered to extract only a sinusoidal component of the square wave from the counters. Some properties of fractional counters are discussed, including the use of a 382.5/1 counter in the calibrator system.

**Analysis of Multiplex Error in FM/FM and PAM/FM/FM Telemetry**—J. Schenck and W. F. Kennedy (p. 138)

The primary object of the work described in this paper is to establish and delineate a procedure for the calculation of certain errors associated with the performance of FM/FM and/or PAM/FM/FM multiplex telemetry systems. The errors considered are those that are produced in a channel of the multiplex resulting from arbitrary frequency and phase selective networks, and those resulting from the interference of adjacent channel sidebands with respect to an arbitrary channel center frequency separation. To find these errors, a straightforward spectral analysis and synthesis is developed for practical models of standard FM/FM and PAM/FM/FM systems. Expressions are obtained for the outputs of a multiplex for given inputs, and for nonlinear distortion and adjacent channel interference, in terms of the conventional parameters of such systems. This method of analysis is entirely quantitative, and an effort has been made to develop it from a definite theoretical basis.

Because the FM process is nonlinear, and since the purpose of this investigation has been the evaluation of system performance rather than analytical insight per se, automatic digital computation is contemplated throughout. Nevertheless, it has been found that the results of the work involved in 1) the justification of a system model, 2) the derivations of functions defining the operations of the components of the model, 3) programming the functions for numerical analysis, and finally 4) performing relatively economical experimental numerical adjustments of the model parameters, lead to a valuable physical appreciation of the system behavior with respect to prescribed conditions.

Nonlinear distortion present in the demodulated output of a subcarrier channel is produced by a band limiting filter or the band-selection filter. This distortion is determined by comparing the demodulated output signal with a known modulating input signal. The input may be sinusoidal, which is of interest in the specification of distortion in FM/FM, or rectangular, which simulates the modulation in PAM/FM/FM. The output signal is obtained by a numerical computation signal of the derivative of the phase of the recovered FM subcarrier. A derivation is given for this phase derivative through the representation of the recovered subcarrier signal by a phasor whose instantaneous length and angle have been modified with respect to time by interference, and by the amplitude and phase characteristics of the transmission networks. Graphic results are given for both sinusoidal and rectangular modulating signals, for a range of modulation indexes, and for band-pass filters of the Butterworth type having various bandwidths and rates of attenuation.

The criterion for error in PAM/FM/FM is a deviation of the average, over a predetermined interval of the pulse, from the average value which would have been measured on an undistorted pulse over that interval. Curves are presented showing the maximum permissible duration, for 0.1 per cent and 0.5 per cent, error, of this predetermined interval in terms of bandwidth and band edge attenuation. Error resulting from sinusoidal modulation is presented in terms of harmonic distortion. These distortion results are exact in that they involve no approximations based on assumptions such as quasi-stationary conditions or small phase variations.

**Comments Relative to the Application of PCM to Aircraft Flight Testing**—Robert S. Djorup (p. 148)

The pending widespread use planned for PCM telemetry has caused some confusion in the area of PCM or digital standards. It is the purpose of this paper to discuss proposed PCM standards on a realistic basis and to show by example the organization of an integrated digital flight test system using these standards. Consideration is given to the variety of testing applications and ultimate usage of digital flight test data.

**Contributors** (p. 153)

# Abstracts and References

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**NOTE: The Institute of Radio Engineers does not have available copies of the publications mentioned in these papers, nor does it have reprints of the articles abstracted. Correspondence regarding these articles and requests for their procurement should be addressed to the individual publications, not to the IRE.**



The number in heavy type at the upper left of each Abstract is its Universal Decimal Classification number. The number in heavy type at the top right is the serial number of the Abstract. DC numbers marked with a dagger (†) must be regarded as provisional.

**The Index to the Abstracts and References published in the PROC. IRE from February, 1958 through January, 1959 is published by the PROC. IRE, May, 1959, Part II. It is also published by *Electronic and Radio Engineer*, incorporating *Wireless Engineer*, and included in the March, 1959 issue of that journal. Included with the Index is a selected list of journals scanned for abstracting with publishers' addresses.**

## ACOUSTICS AND AUDIO FREQUENCIES

**534.213-8:539.2** **3536**
**Absorption of Compressional Waves in Solids from 100 to 1000 Mc/s**—J. Lamb, M. Redwood and Z. Shteinshleifer. (*Phys. Rev. Lett.*, vol. 3, pp. 28-29; July 1, 1959.) Experimental data are given for dependence of the amplitude absorption coefficient on frequency for crystal quartz, fused silica, Ge and Si.

**534.231:534.88** **3537**
**Studies on the Near Fields of Monopole and Dipole Acoustic Sources**—C. W. Horton and A. E. Sobey, Jr. (*J. Acoust. Soc. Amer.*, vol. 30, pp. 1088-1099; December, 1958.) When an observer is not farther than one wavelength from an acoustic source, he can determine the distance to the source from measurements of the pressure and particle velocity of the medium. Expressions are developed which are exact in the case of a monopole source. Measurements made using a dipole source are described.

**534.522.1** **3538**
**Determination of the Form of Finite-Amplitude Ultrasonic Waves by Light Refraction**—M. A. Breazeale, B. D. Cook and E. A. Hiedemann. (*Naturwiss.*, vol. 45, p. 537; November, 1958. In English.) The refraction method (see 1050, April, Breazeale and Hiedemann) has been perfected so that the phase relation between harmonic components can be determined.

**534.7** **3539**
**Signal Detection as a Function of Frequency Ensemble: Part 2**—F. A. Veniar. (*J. Acoust. Soc. Amer.*, vol. 30, pp. 1075-1078; December, 1958.) Further experimental investigation of the detection of a signal in noise as a function of signal ensemble size and frequency range. Part 1:1052, April.

**534.75** **3540**
**Detection of Multiple-Component Signals in Noise**—D. M. Green. (*J. Acoust. Soc. Amer.*, vol. 30, pp. 904-911; October, 1958.) Experimental results are analysed by comparison with three mathematical models; for predicting the detectibility of a complex signal the most acceptable is a statistical summation model in which it is assumed that two or more critical bands may be linearly combined.

**534.75** **3541**
**What is Masking?**—W. P. Tanner, Jr. (*J. Acoust. Soc. Amer.*, vol. 30, pp. 919-921; October, 1958.) Three experiments are described and analysed in terms of a conventional definition of masking and a masking index conforming to this definition.

**534.75:621.391** **3542**
**Definitions of $d'$ and $\eta$ as Psychophysical Measures**—Tanner and Birdsall. (*See* 3854.)

**534.78** **3543**
**Prediction of Speech Intelligibility at High Noise Levels**—J. M. Pickett and I. Pollack. (*J. Acoust. Soc. Amer.*, vol. 30, pp. 955-963; October, 1958.) An extension of the work described in a previous paper (2286 of 1958) to cover a wide range of speech and noise spectra. To predict the deterioration in intelligibility at high noise levels, a correction based upon a change in the over-all speech/noise ratio is acceptable at moderate intelligibility levels but, at low levels, secondary corrections are necessary.

**534.79** **3544**
**On Psychological and Systematic Bases of Loudness**—E. Zwicker. (*Akust. Beihefte*, no. 1, pp. 237-258; 1958.) Loudness measurements made using 1-kc tone and noise are discussed in relation to loudness level comparisons. A basic "loudness function" is defined and a graphical method of evaluating loudness is described.

**534.844** **3545**
**Apparatus for Automatic Evaluation of Successive Sound Reflections**—W. Junius. (*Akust. Beihefte*, no. 1, pp. 266-272; 1958.) Details are given of an electronic apparatus for measuring the sound pressure of successive reflections and recording the number of reflections according to their intensity and delay time.

**534.844** **3546**
**Characteristics and Evaluation of Reverberation Curves**—H. Kuttruff. (*Akust. Beihefte*, no. 1, pp. 273-280; 1958.) The initial slope of a reverberation curve is shown to be proportional to the weighted arithmetic mean of the damping factors of all the relevant natural vibrations.

**534.845** **3547**
**Experimental Investigations on the Sound Insulation of Cylinders**—M. Heckl. (*Akust. Beihefte*, no. 1, pp. 259-265; 1958.) Two characteristic frequencies are defined relating to the sound insulation of hollow cylinders. Between these two frequencies marked transmission bands are observed in the case of narrow-band noise; with wide-band noise the sound insulation is largely independent of frequency.

**534.845** **3548**
**Reflections from Gradual-Transition Sound Absorbers**—N. B. Miller. (*J. Acoust. Soc. Amer.*, vol. 30, pp. 967-973; October, 1958.) Reflections are treated theoretically by considering the propagation of compressional waves in stratified media, and results are compared with experimental data obtained from structures suitable for use underwater.

**534.845** **3549**
**On the Relation between the Reverberant Sound Absorption Coefficient and the Normal-Incidence Absorption Coefficient of Fibrous Materials**—M. Koyasu. (*J. Acoust. Soc., Amer.*, vol. 30, pp. 1163-1164; December, 1958.)

**621.395.625:681.84.083.82** **3550**
**Multitrack and Stereo Heads for Studio and Home Equipment**—H. Haar. (*Radioschau*, vol. 9, pp. 224-225; June/July, 1959.) The design and construction of modern tape-recording heads are described.

## ANTENNAS AND TRANSMISSION LINES

**621.315.212:621.372.54** **3551**
**A Broad-Band Microwave Coaxial Connector with Capacitive R.F. Coupling and Isolated D.C. Returns**—C. M. Lin and R. W. Grow. (IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-6, pp. 454-455; October, 1958.) Description of the construction and characteristics of a modified Type-N connector which serves as a high-pass filter in the range 1.5 to 10 kmc.

**621.315.212:621.372.62** **3552**
**An Analysis of a Broad-Band Coaxial Hybrid Ring**—V. J. Albanese and W. P. Peyser. (IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-6, pp. 369-373; Octo-

ber, 1958. Abstract, PROC. IRE, vol. 47, p. 112; January, 1959.)

621.372.8.002.2 3553
**Manufacture of Waveguide Parts by Investment Casting from Frozen-Mercury Patterns**—H. H. Scholefield, H. H. H. Green and R. E. Gossett. (*Proc. IEE* (*London*), Part B, vol. 106, pp. 431–434; July, 1959.) A discussion of the merits and limitations of the frozen-mercury process.

621.372.82 3554
**The Cutoff Wavelength of Trough Waveguide**—K. S. Packard. (IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-6, pp. 455–456; October, 1958.)

621.372.821 3555
**A Method of Calculating the Characteristic Impedance of a Strip Transmission Line to a Given Degree of Accuracy**—R. G. de Buda. (IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-6, pp. 440–446; October, 1958. Abstract, PROC. IRE, vol. 47, p. 113; January, 1959.)

621.372.821:621.372.832.43 3556
**Coupled- Transmission-Line Directional Couplers**—J. K. Shimizu and E. M. T. Jones. (IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-6, pp. 403–410; October, 1958. Abstract, PROC. IRE, vol. 47, p. 113; January, 1959.)

621.372.826 3557
**The Estimation of the Reactance of a Loss-Free Surface Supporting Surface Waves**—K. P. Sharma. (*Proc. IEE* (*London*), Part B, vol. 106, pp. 427–430; July, 1959.) A transmission-line analogue technique is applied in the calculation of the reactance of a loss-free flat surface, and the results are compared with experimental data.

621.372.826:537.226 3558
**The Excitation of a Dielectric Rod by a Cylindrical Waveguide**—C. M. Angulo and W. S. C. Chang. (IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-6, pp. 389–393; October, 1958. Abstract, PROC. IRE, vol. 47, p. 113; January, 1959.)

621.372.832 3559
**The Multiple-Branch Waveguide Coupler**—J. Reed. (IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-6, pp. 398–403; October, 1958. Abstract, PROC. IRE, vol. 47, p. 113; January, 1959.)

621.372.832.6 3560
**Hybrid Junctions**—R. Levy. (*Electronic Radio Eng.*, vol. 36, pp. 308–312; August, 1959.) 90° hybrids are not only compact and easy to construct but they retain their 90° phase-shift property over a wide band and are excellent when used as duplexers. The disadvantages of 180° hybrids, such as the hybrid-T, and of hybrid rings are pointed out.

621.372.852.1 3561
**A Unified Discussion of High-Q Waveguide Filter Design Theory**—H. J. Riblet. (IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-6, pp. 359–368; October, 1958. Abstract, PROC. IRE, vol. 47, p. 112; January, 1959.)

621.372.852.1 3562
**High-Power Microwave Filters**—J. H. Vogelman. (IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-6, pp. 429–439; October, 1958. Abstract, PROC. IRE, vol. 47, p. 113; January, 1959.)

621.372.852.323:621.318.134 3563
**Development of a High-Power L-Band Resonance Isolator**—E. O. Schulz-Dubois, G. J. Wheeler and M. H. Sirvetz. (IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-6, pp. 423–428; October, 1958. Abstract, PROC. IRE, vol. 47, p. 113; January, 1959.)

621.372.852.4:621.317.34 3564
**Equipment for the Investigation of Polarization Properties of Transmission Elements in the 4-Gc/s Region**—K. Baur. (*Arch. elekt. Übertragung*, vol. 12, pp. 371–379, 407–413 and 447–456; October, 1958.) The theory and design of *a*) a polarization converter for obtaining any desired elliptical polarization, and *b*) a polarization discriminator are described in detail. The application of these units to the measurement of the polarization characteristics of a waveguide element is detailed.

621.396.67:061.6.055 3565
**U.R.S.I. Report on Antennas and Waveguides, and Annotated Bibliography**—H. V. Cottony, R. S. Elliott, E. C. Jordan, V. H. Rumsey, K. M. Siegel, J. R. Wait, and O. C. Woodyard. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-7, pp. 87–98; January, 1959. Abstract, PROC. IRE, vol. 47, pp. 610–611; April, 1959.)

621.396.67.09 3566
**The Radiansphere around a Small Antenna**—H. A. Wheeler. (PROC. IRE, vol. 47, pp. 1325–1331; August, 1959.) Defines the radius (1 "radianlength" $=\lambda/2\pi$) at which the near and far fields of a small antenna are equal. The concept assists in visualizing the properties of small lossy antennas which are evaluated.

621.396.673.012.12 3567
**On the Radiation Diagram of Linear Antennas**—A. Bruaux. (*Rev. HF, Brussels*, vol. 4, no. 5 pp. 107–118; 1959.) Expressions are derived for calculating the radiation diagram of an asymmetrically energized cylindrical antenna. Results obtained at frequencies of 150 and 185 mc with an experimental antenna 1 m long and 81 mm in diameter, fed at a point several cm from one end are in good agreement with theoretical diagrams. See also 286 of 1951 (King).

621.396.676:621.318.57 3568
**Optimizing Antenna Switches and Phasers**—I. Dlugatch. (*Electronics*, vol. 32, pp. 55–57; August 14, 1959.) An automatic antenna switching circuit for aircraft is described, that can give a maximum increase of signal/noise ratio of 3 db and has a reduced tendency to lock on reflected or distorted signals.

621.396.677 3569
**Travelling-Wave Cylindrical Antenna Design.—A Graphical Synthesis Method**—P. Foldes. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-7, pp. 74–80; January, 1959. Abstract, PROC. IRE, vol. 47, p. 610; April, 1959.)

621.396.677 3570
**The Theory of Helical Antennas**—W. Peters. (*Nachrichtentech. Z.*, vol. 11, pp. 405–410; August, 1958.) The characteristics are calculated and methods of increasing the gain are discussed.

621.396.677:621.397.61 3571
**Transmitting Antennas for Television Broadcasting in the United Kingdom**—A. Brown. (*J. Brit. IRE*, vol. 19, pp. 389–399; July, 1959.) The permissible variation of reflection coefficient and of radiation pattern with frequency are considered and problems that arise in the design and testing of UHF antennas are discussed.

621.396.677.3 3572
**The Superdirectivity of an Aerial for Tranverse Radiation**—J. C. Simon, G. Broussaud and E. Spitz. (*Compt. Rend. Acad. Sci., Paris*, vol. 248, pp. 2309–2311; April 20, 1959.) Superdirective antennas can only be obtained by grouping several independent sources in a volume which is small relative to the wavelength. Using an array of five slots concentrated in a length $3\lambda/4$ and fed from the same oscillator at 3 cm $\lambda$, a main-lobe width of 24° was obtained. The classical limit is 69°.

621.396.677.3:523.164.32 3573
**16-Antenna Array operating at 9,300 Mc/s**—Pick-Gutmann and Steinberg. (*See* 3659.)

621.396.677.3:621.376.5 3574
**Improving Antenna Directivity for Pulsed Signals**—V. G. Welsby. (*Electronic Radio Eng.*, vol. 36, pp. 313; August, 1959.) The usual antenna array designs are based on the amplitude and phase characteristics of the carrier wave. When pulse modulation is used, the pulse envelope delay between the outputs from two elements is disregarded. The utilization of this additional information requires further study.

621.396.677.31 3575
**Suppressed Sidelobe Antenna of 32 Elements**—G. Reber. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-7, p. 101; January, 1959.) Results are given for an array designed to operate at medium wavelengths with a 23 db sidelobe suppression.

621.396.677.43 3576
**On the Design of some Rhombic Antenna Arrays**—A. A. de C. Fernandes. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-7, pp. 39–46; January, 1959. Abstract, PROC. IRE, vol. 47, p. 610; April, 1959.)

621.396.677.45 3577
**Radiation Field of an Elliptical Helical Antenna**—J. Y. Wong and S. C. Loh. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-7, pp. 46–52; January, 1959. Abstract, PROC. IRE, vol. 47, p. 610; April, 1959. See also 1776 of June.

621.396.677.47 3578
**On the Optimum Radiation from a Sawtooth Antenna used at Microwave Frequencies**—M. Anastassiades, C. Caroumbalos and C. Bouloheris. (*Ann. Télécommun.*, vol. 13, pp. 83–89; March/April, 1958.) A study of the antenna developed from V-antenna theory, shows that the optimum V-angle is 120°. The directivity is comparable with that of a parabolic mirror of equal surface area.

621.396.677.5 3579
**The Rectangular Loop Antenna as a Dipole**—R. King. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-7, pp. 53–61; January, 1959. Abstract, PROC. IRE, vol. 47, p. 610; April, 1959.)

621.396.677.71 3580
**Conical Radiation from a Travelling-Wave Slot**—J. Ernest. (*Compt. Rend. Acad. Sci., Paris*, vol. 248, pp. 2463–2465; April 27, 1959.) A demonstration that the radiation field has the symmetry of a half cone is confirmed by experiments at 3.15 cm $\lambda$.

621.396.677.71.015.5 3581
**Voltage Breakdown Characteristics of Microwave Antennas**—J. B. Chown, W. E. Scharfman and T. Morita. (PROC. IRE, vol. 47, pp. 1331–1337; August, 1959.) Measurements made at X-band frequencies on a 20 db slot antenna are described. Voltage swr pulse shape, radiation pattern and radiated power all vary with pulse width and peak power.

**621.396.677.73** 3582
**The Effect of Flanges on the Radiation Patterns of Waveguide and Sectoral Horns**—P. C. Butson and G. T. Thompson. (*Proc. IEE (London)* Part B, vol. 106, pp. 422–426; July, 1959.) Radiation patterns are given for open-end rectangular waveguide (WG10) with conducting flanges attached to the long edges of the aperture. Some *E*-plane patterns of flanged *H*-plane sectoral horns are also given, and the results show differences between these patterns and those of similarly flanged waveguide.

**621.396.677.85** 3583
**Spherically Symmetric Lenses**—A. F. Kay (IRE Trans. on Antennas and Propagation, vol. AP-7, pp. 32–38; January, 1959. Abstract, Proc. IRE, vol. 47, p. 610; April, 1959.)

**621.396.677.85:537.226** 3584
**Properties of Slotted Dielectric Interfaces**—R. E. Collin. (IRE Trans. on Antennas and Propagation, vol. AP-7, pp.62–73; January, 1959. Abstract, Proc. IRE, vol. 47, p. 610; April, 1959.)

## AUTOMATIC COMPUTERS

**681.142** 3585
**Testing High-Speed Digital Computer Circuits**—R. G. Norquist. (*Electronics*, vol. 32, pp. 50–51; July 17, 1959.) A word generator providing 16-bit serial binary words at a rate of 10 mc is described. Any one of $2^{16}$ words can be selected manually. High-*gm* tetrodes are used to obtain high-speed operation.

**681.142** 3586
**Automatic Input Equipment for Commercial Data Processing Systems**—K. R. Eldredge, F. J. Kamphoefner and P. H. Wendt. (*Nachrichtentech. Z.*, vol. 11, pp. 393–397; August, 1958.) Magnetic equipment for "reading" documents with characters and symbols printed in magnetic ink is described. With a high-speed transporation arrangement, 5000 characters can be read and 50 documents handled per second.

**681.142:621.318.042** 3587
**A Fast Method of Reading Magnetic-Core Memories**—H. J. Heijn and N. C. de Troye. (*Philips Tech. Rev.*, vol. 20, pp. 193–207; February 10, 1959.) Description of a 1024-word, 44-bit storage system using a method of core-threading suggested by Renwick (2481 *f* of 1958). The system includes a circuit which prevents parasitic pulses from blocking the output amplifiers, reducing the cycling time to $3\mu s$.

**681.142:621.372.44** 3588
**The Parametron, a Digital Computing Element which Utilizes Parametric Oscillation.**—E. Goto. (Proc. IRE, vol. 47, pp. 1304–1316; August, 1959.) Japanese research and applications of parametric oscillation are described. A parametron element is essentially a resonant circuit with a nonlinear reactive element oscillating at half the driving frequency. The oscillation is used to represent a binary digit by the choice between two stationary phases $\pi$ radians apart.

**681.142:621.372.45** 3589
**A Negative Resistance for D.C. Computers**—Indiresan. (*See* 3605.)

**681.142:621.373.029.6:621.372.44** 3590
**Microwave Parametric Subharmonic Oscillators for Digital Computing**—F. Sterzer. (Proc. IRE, vol. 47, pp. 1317–1324; August, 1959.) The oscillation is used to represent a binary digit by the choice between the stationary phases $\pi$ radians apart. A variable capacitance oscillator with output frequency 2 kmc is described, and its use for amplifying, scaling and performing logic functions is discussed. The advantages of carrier over baseband systems for high-speed computing are mentioned. (*See* 3588 above.)

**681.142.001.4:621.373.44** 3591
**Dynamic Testing of Computer Building Blocks**—R. W. Buchanan and B. Kautz. (*Electronics*, vol. 32, pp. 66–68; August 14, 1959.) A variable-frequencing pulse source with repetition frequency up to 18 mc is described.

## CIRCUITS AND CIRCUIT ELEMENTS

**621.3.049:621.314.7** 3592
**Transistorizing Electronic Equipment**—R. K. Jurgen. (*Electronics*, vol. 32, pp. 53–64; July 31, 1959.) A general discussion of semiconductor devices giving tabulated data on Ge and Si diodes and transistors, specifications of associated thermistors, capacitors and batteries, and a note on the construction of solid circuits.

**621.314.2:621.372.51** 3593
**Some Broad-Band Transformers**—C. L. Ruthroff. (Proc. IRE, vol. 47, pp. 1337–1342; August, 1959.) Describes the construction, theory and performance of transmission-line transformers, which take the form of twisted pairs having distributed interwinding capacitors. Bandwidth ratios as high as 20000:1 in the range 50 kc—1 kmc can be obtained, with transformation ratios of unity or 4:1.

**621.314.2:621.372.51** 3594
**Some Notes on the Optimum Design of Stepped Transmission-Line Transformers**—L. Solymar. (IRE Trans. on Microwave Theory and Techniques, vol. MTT-6, pp. 374–378; October, 1958. Abstract, Proc. IRE, vol. 47, p. 112; January, 1959.)

**621.314.2:621.372.512** 3595
**Double-Tuned Transformers — Steady-State and Transient Response**—J. B. Rudd. (*AWA Tech. Rev.*, vol. 10, pp. 175–214; December, 1958.) A general analysis applicable to both wide- and barrow-band cases. All degrees of coupling are examined and expressions are derived for insertion loss, phase shift, envelope delay, rise time and overshot.

**621.316.86** 3596
**Current Noise and Nonlinearity in Pyrolytic Carbon Films**—T. R. Williams and J. B. Thomas. (*Rev. Sci. Instr.*, vol. 30, pp. 586–590; July, 1959.) A high correlation exists between noise and nonlinearity when the variations in film dimensions are taken into account. A balanced-bridge method for measuring nonlinearity is described.

**621.318.57:621.314.63** 3597
**Microwave Semiconductor Switching Techniques**—R. V. Garver, E. G. Spencer and M. A. Harper. (IRE Trans. on Microwave Theory and Techniques, vol. MTT-6, pp. 378–383; October, 1958. Abstract, Proc. IRE, vol. 47, p. 112; January, 1959.)

**621.318.57:621.314.7** 3598
**Switching Circuits for Missile Count-Downs**—D. W. Boensel. (*Electronics*, vol. 32, pp. 76–78; July 31, 1959.) A transistor circuit is described which produces a switching pulse if its input differs by more than a predetermined amount from a given reference level. The use of nonlinear negative feedback ensures stable operation over a wide temperature range.

**621.319.43.076.7** 3599
**Voltage-Variable Capacitor Selection Guide**—T. W. Butler, Jr., and G. A. Roberts. (*Electronics*, vol. 32, pp. 52–53; July 24, 1959.) Tabulated information is presented to facilitate the choice of the best component for the circuit requirements.

**621.372.01** 3600
**Elements of Electronic Circuits: Part 5—Amplitude Selection and Amplitude Comparison**—J. M. Peters. (*Wireless World*, vol. 65, pp. 411–413; September, 1959.) Part 4: 3221 of October.

**621.372.012** 3601
**Signal Flow Graphs**—M. Boisvert. (*Ann. Télécommun.*, vol. 13, pp. 50–77; March/April, 1958.) An article in three parts covering basic theory, topological relations for network synthesis, and applications to feedback theory.

**621.372.012** 3602
**Signal Flow Graphs**—R. F. Hoskins. (*Electronic Radio Eng.*, vol. 36, pp. 298–304; August, 1959.) A discussion of the application of Mason's technique of circuit analysis (2985 of 1956 and 3531 of 1953.)

**621.372.413/.414:621.372.54** 3603
**Dissipation Loss in Multiple-Coupled Resonator Filters**—S. B. Cohn. (Proc. IRE, vol. 47, pp. 1342–1348; August, 1959.) A simple approximate formula enables center-frequency loss to be computed, and elsewhere loss may be computed from the prototype (low-pass) filter after suitable circuit modification. Unsymmetrical and symmetrical designs are considered.

**621.372.414** 3604
**Miniature Resonators for U.H.F.**—I. Dlugatch. (*Electronic Equipm. Engng.*, vol. 7, pp. 35–37; January, 1959.) An investigation of the extent of miniaturization possible in coaxial resonators.

**621.372.45:681.142** 3605
**A Negative Resistance for D.C. Computers**—P. V. Indiresan. (*J. Brit. IRE*, vol. 19, pp. 401–410; July, 1959.) A nomogram is presented for the design of a circuit using transistors and resistors to give any required value of negative resistance.

**621.372.5** 3606
**Some Applications of Non-Euclidean Geometry in Quadripole Theory**—E. F. Bolinder. (*Arch. elekt. Übertragung*, vol. 12, pp. 357–361; August, 1958.) A survey of literature and an attempt to correlate the work of various authors. The treatment of impedance and noise transformations by means of the Poincaré and Cayley-Klein models of non-Euclidean hyperbolic space is discussed. 50 references.

**621.372.54** 3607
**Novel Expression for the Relationship between the Real and Imaginary Parts of the Transfer Function of a Linear Filter**—D. M. Lipkin. (Proc. IRE, vol. 47, p. 1383; August, 1959.)

**621.372.543.2** 3608
**Theory and Design Data for the Synthesis of Tchebycheff Parameter Filters**—W. Milort. (*Philips Telecommun. Rev.*, vol. 20, pp. 158–185; May, 1959.) 54 references.

**621.373.029.6:621.372.44:681.142** 3609
**Microwave Parametric Subharmonic Oscillators for Digital Computing**—Sterzer. (*See* 3590.)

**621.373.029.65:621.314.63** 3610
**Experiment indicating Generation of Submillimetre Waves by an Avalanching Semiconductor**—Schleimann-Jensen. (*See* 3875.)

**621.373.4** 3611
**Ultraharmonic and Subharmonic Resonance in an Oscillator**—B. R. Nag. (*J. Brit. IRE*, vol. 19, pp. 411–416; July, 1959.) Experimental results, using a differential analyser, are compared for an oscillator with cubic non-

linearity with theoretical curves obtained by Van der Pol's method.

621.373.431.1.076 3612
**Frequency Control of Magnetic Multivibrators**—W. A. Geyger. (*Electronics*, vol. 32, pp. 54–56; July 24, 1959.) A basic circuit is developed allowing output frequency to be controlled continuously or in steps over a wide frequency range. Variations of the circuit provide similar controls of output amplitude.

621.374:621.314.7 3613
**Designing Transistor Circuits—Sequential Circuits: Parts 1 and 2**—R. B. Hurley. (*Electronic Equipm. Engng.*, vol. 6, pp. 40–45; December, 1958. and vol. 7, pp. 54–58; February, 1959.) Bistable flip-flop, a stable and monostable multivibrator, blocking-oscillator, and negative-resistance circuits and transistor-reactor combinations are discussed.

621.374.44 3614
**Stepping Up Frequency with Counter Circuits**—W. O. Brooks. (*Electronics*, vol. 32, pp. 60–62; July 17, 1959.) Precise frequency multiplication is achieved with digital feedback, counter (divider) circuits, and a phase comparator. The circuit described multiplies frequencies between 900 and 1100 cps by a factor of 1000 with an error of 0.1 per cent.

621.375.2.078 3615
**Reducing Errors caused by Power-Supply Variations**—J. Holtzman. (*Electronics*. vol. 32, pp. 54–55; July 17, 1959.) Differential amplifiers in cascade cancel the errors.

621.375.227 3616
**Concertina Phase - Splitter** — (*Electronic Radio Engr.*, vol. 36, pp. 271–274 and 295–297; July and August, 1959.) The performance of the circuit is analysed with particular regard to the frequency range of operation.

621.375.3 3617
**Graphical Determination of the Operating Characteristic of a Magnetic Amplifier**—E. Pio. (*Compt. Rend. Acad. Sci., Paris*, vol. 248, pp. 1960–1961; April 1, 1959.) A method of constructing a performance characteristic for a magnetic amplifier is described, based on the equivalent circuit derived earlier (3237 of October, Bernard and Pio) taking account of the nonlinearity of the associated rectifier and expressing output current as a function of current in the control circuit.

621.375.4 3618
**Q-Multiplication with Transistors**—A. E. Bachmann. (*Arch. elekt. Übertragung*, vol. 12, pp. 368–370; August, 1958.) Two transistor circuits are described with negative impedance stable to within 1 per cent over a temperature range −30° to +60°C. See also *Proc. NEC, Chicago*, vol. 12, pp. 469–480; 1956 (Karp).

621.375.432 3619
**Feedback Design for Transistor Amplifier Stages**—T. R. Hoffman. (*Electronics*, vol. 32, pp. 52–54; August 14, 1959.) Equations are given for realizing a specific input impedance, or maximum feedback for a given gain.

621.375.9:537.311.33 3620
**Avalanche-Controlled Semiconductor Amplifier**—L. J. Giacoletto. (Proc. IRE, vol. 47, pp. 1379–1381; August, 1959.) The theory of a particular avalanche-controlled semiconductor amplifier is given; its hf operation should be good.

621.375.9:538.569.4 3621
**Three-Level Spin Refrigeration and Maser Action at 1500 Mc/s**—Geusic, Shulz-Du Bois, De Grasse and Scovil. (*See* 3654.)

621.375.9:538.569.4 3622
**Method for Calculating Simultaneous Resonance Conditions in a Three-Level Ruby Maser**—M. A. Garstens. (*J. Appl. Phys.*, vol. 30, pp. 976–977; July, 1959.)

621.375.9:538.569.4.029.64 3623
**Multilevel Pulsed-Field Maser for Generation of High Frequencies**—S. Foner, L. R. Momo and A. Mayer. (*Phys. Rev. Lett.*, vol. 3, pp. 36–38; July 1, 1959.) The maser has been operated at 4.2°K as an oscillator at both 12.61 kmc and 1915 kmc with a pumping frequency of 12.61 kmc. Principles of operation and characteristics are discussed.

621.375.9:538.569.4.029.64 3624
**Low-Field *X*-Band Ruby Maser**—F. R. Arams. (Proc. IRE, vol. 47, pp. 1373–1374; August, 1959.) The signal frequency used was 9540 mc and the pump frequency 10850 mc. The low pump-frequency and low magnetic-field requirements are attractive although the achievable gain-bandwidth product is lower than with other masers.

621.375.9:621.3.011.23 3625
**A Surface-Wave Parametric Amplifier**—E. S. Cassedy, Jr. (Proc. IRE, vol. 47, pp. 1374–1375; August, 1959.) The proposed amplifier would take the form of a slab of ferroelectric material between two conducting planes. The slab would be pumped with high power. It is shown that useful gain would be achieved at X-band frequencies even with present ferroelectric materials. With new materials the amplifier could be used at mmλ.

621.375.9:621.3.011.23 3626
**Relaxation Phenomena in Diode Parametric Amplifiers**—H. Endler, A. D. Berk and W. L. Whirry. (Proc. IRE, vol. 47, pp. 1375–1376; August, 1959.) Oscillations have been observed in parametric amplifiers under certain conditions with CW pump sources. The effect varies with pump power, being a relaxation oscillation at low pump power, and a stable oscillation when this is increased.

621.375.9:621.383:535.376 3627
**Lumistors: Amplifiers of the Future**—Spitzer. (*See* 3884.)

## GENERAL PHYSICS

535.13 3628
**Criterion of Uniqueness for the Solutions of Maxwell's Equations**—P. Poincelot. (*Compt. Rend. Acad. Sci., Paris*, vol. 248, pp. 2182–2184; April 13, 1959.) A linear medium characterized by the absence of dielectric or magnetic hysteresis is considered.

535.62 3629
**Two-Coordinate Colour**—(*Electronic Radio Engr.*, vol. 36, pp. 292–295; August, 1959.) A short discussion of the subjective and objective characteristics of a color and their relation to color vision. The two color experiments of Land (*Sci. Amer.*, vol. 200, pp. 84–94, 99; May, 1959.) are summarized and their bearing on Goethe's two color theory of 1808 and Granit's recent experiments.

537.291 3630
**Grapho-analytical Plotting of Trajectories of Charged Particles in Variable Electric and Constant Magnetic Fields**—N. I. Shtepa. (*Zh. Tekh. Fiz.*, vol. 28, pp. 178–187; January, 1958.) Two techniques are described based on a) addition of velocities, and b) radius of curvature. Examples of plotting using these two methods are shown. Errors and means of correcting them are indicated.

537.311.33:538.569.2 3631
**The Phenomenon of Depolarization in Small Conducting Bodies in an Extensive Electromagnetic High-Frequency Field**—H. Stols. (*Ann. Phys.* (*Lpz.*), vol. 1, pp. 334–343; June 2, 1958.) Continuation of earlier investigations (see 2117 of 1958). Current density and internal field are calculated as a function of the external field. The results are discussed with reference to measurements on Ge in the temperature range 0–200°C at 1.24 cmλ.

537.311.33:539.2 3632
**Role of Negative Effective Mass in Negative Resistance**—P. Kaus. (*Phys. Rev. Lett.*, vol. 3, pp. 20–23; July 1, 1959.) A theoretical investigation of the relations between negative effective mass, carrier distribution and negative resistance.

537.312.62 3633
**Impurity Scattering in Superconductors**—H. Suhl, and B. T. Matthias. (*Phys. Rev.*, vol. 114, pp. 977–988; May 15, 1959.) Perturbation theory is used to determine the reduction in superconducting transition temperature due to scattering by impurities dissolved in the superconductor.

537.533.7:538.561 3634
**The Radiation from a Charged Particle Passing through a Plate**—G. M. Garibyan and G. A. Chalikyan. (*Zh. Eksp. Teor. Fiz.*, vol. 35, pp. 1282–1283; November, 1958.) Expressions are derived for the Fourier components of the radiation field in the space before and after a dielectric plate in vacuum.

537.533.7:538.561 3635
**Motion of a Charged Particle in an Anisotropic Medium**—G. A. Begiashvili and E. V. Gedalin. (*Zh. Eksp. Teor. Fiz.*, vol. 35, pp. 1513–1517; December, 1958.) Expressions are derived for the em field components, and the total energy losses are determined for a charged particle moving in an anisotropic gyroelectric and gyromagnetic medium.

537.533.79:538.221 3636
**Magnetic Perturbation of Cathode Rays**—S. Yamaguchi. (*Nuovo Cim.*, vol. 10, pp. 714–717; November 16, 1958. In English.) The splitting of an electron beam when it penetrates a magnet was observed with electron-diffraction apparatus. An explanation is given in terms of polarization of free electrons.

537.534.9 3637
**Ion-drag Pressure Generation**—O. M. Stuetzer. (*J. Appl. Phys.*, vol. 30, pp. 984–994; July, 1959.) "A theory of pressure build-up under unipolar ion conduction is presented and verified experimentally. Constriction of the current flow leads to sizeable pressures in insulating liquids."

537.56:534.1–8 3638
**On Acoustic-Electrical Phenomena in a Degenerate Electron-Ion Plasma**—P. S. Zyryanov and G. G. Taluts. (*Zh. Eksp. Teor. Fiz.*, vol. 36, pp. 145–148; January, 1959.) A calculation of the absorption coefficient for ultrasonic waves travelling in a plasma.

537.56:538.56 3639
**Low-Frequency Oscillations of Plasma in a Magnetic Field**—K. N. Stepanov. (*Zh. Eksp. Teor. Fiz.*, vol. 35, pp. 1155–1160; November, 1958.) Mathematical analysis of small oscillations of a plasma consisting of electrons and singly charged ions. Some limiting cases are discussed for which a solution of the dispersion equation can be found.

537.56:538.56 3640
**On the Behaviour of a Conducting Gaseous Sphere in a Quasistationary Electromagnetic Field**—V. V. Yankov. (*Zh. Eksp. Teor. Fiz.*, vol. 36, pp. 560–564; February, 1959.) Investigation by the perturbation method of the sta-

bility of a homogeneous plasma sphere with an external field.

537.56:538.566 3641
**Statistical Derivation of the Dispersion Formula of a Lorentz Plasma of Finite Temperature**—K. Rawer and K. Suchy. (*Ann. Phys.* (*I.pz.*), vol. 2, pp. 313–325; November 11, 1958.)

537.56:538.63 3642
**An Investigation on Plasmas in External Magnetic Fields: Part 1—Steady State, Part 2—Varying Fields**—G. Schmidt. (*Nuovo Cim.*, vol. 10, pp. 55–67 and 659–674; October 1, and November 16, 1958. In English.)

537.562:538.63 3643
**Dependence of Electron Mobility on Magnetic Field in a Fully Ionized Gas**—M. S. Sodha and Y. P. Varshni. (*Phys. Rev.*, vol. 114, pp. 946–947; May 15, 1959.) Analysis, with tabulations and illustrative graphs, of the variation of drift and Hall mobilities with magnetic field.

538.1 3644
**A System of Magnetic Moments in a Weak Variable Magnetic Field**—G. V. Skrotskiĭ and A. A. Kokin. (*Zh. Eksp. Teor. Fiz.*, vol. 36, pp. 169–175; January, 1959.) A mathematical analysis of a system of magnetic moments which possesses electric exchange and weak magnetic dipole-dipole interactions and which is located in an external magnetic field. The equation of matron of the magnetization vector is derived and the limits of its applicability are discussed.

538.221 3645
**On Magnetic Permeability for the Case of Magnetization under the Action of a Circular Alternating Field in the Presence of a D.C. Longitudinal Field**—V. Tutovan. (*Compt. Rend. Acad. Sci., Paris*, vol. 248, pp. 940–943; February 16, 1959.) A method is described for measuring the permeability of a torsion-free iron wire. Results are given for various values of the circular alternating field, the longitudinal field and the wire tension.

538.221:538.569.4 3646
**Ferromagnetic Resonance in a Circularly Polarized Electromagnetic Field of Arbitrary Amplitude**—G. V. Skrotskiĭ and Yu. I. Alimov. (*Zh. Eksp. Teor. Fiz.*, vol. 35, pp. 1481–1484; December, 1958.) The exact solution of the magnetization equations of motion is examined. The dependence of the magnetization components on the amplitudes of the magnetizing field and RF field is determined.

538.561:537.122 3647
**Cherenkov Radiation from Dipoles**—V. L. Ginzburg and V. Ya. Eĭdman. (*Zh. Eksp. Teor. Fiz.*, vol. 35, pp. 1508–1512; December, 1958.) Mathematical analysis of the Cherenkov radiation from electric and magnetic dipoles moving in a continuous medium in a channel or a slit.

538.561:537.122 3648
**On the Cherenkov Radiation of an Electron Moving in a Medium with Spatial Dispersion**—V. N. Agranovich, V. E. Pafomov, and A. A. Rukhadze. (*Zh. Eksp. Teor. Fiz.*, vol. 36, pp. 238–243; January, 1959.) An examination of the Cherenkov radiation in an isotropic medium including a consideration of spatial dispersion. The angular distribution of the radiation intensity and the escape of the radiation through the surface of the medium are discussed.

538.561:539.17 3649
**Radio Emission from an Atomic Explosion**—A. S. Kompaneets. (*Zh. Eksp. Teor. Fiz.*, vol. 35, pp. 1538–1544; December, 1958.) In an atomic explosion which is accompanied by asymmetric emission of $\gamma$ quanta, radio waves are emitted due to the presence of a current in the ionized air. The duration of the oscillation in each half-wave is of the order of 10 $\mu$s. For a given asymmetry in emission of the $\gamma$ rays, the amplitude of the oscillations depends weakly on the total number of quanta.

538.561:662.2 3650
**Emission of Radio Waves from Detonations**—B. Koch. (*Compt. Rend. Acad. Sci., Paris*, vol. 248, pp. 2173–2175; April 13, 1959.) Transient em waves giving a field strength of about 600$\mu$v/m close to an explosion of 750g of high explosive were recorded using a receiver tuned to 24.1 mc. They are attribtued to ionic rather than thermal effects. See 1741 of 1954 (Kolsky).

538.566.2:539.32 3651
**Discussion of the Influence of Frequency in the Problem of the Investigation of the Optimum Absorption Thickness for a Metallic Thin Film**—M. Gourceaux. (*Compt. Rend. Acad. Sci., Paris*, vol. 248, pp. 2461–2462; April 27, 1959.) The absorption of em waves by films so thick as to be equivalent to the solid material and by very thin films is considered.

538.569.4:538.222 3652
**Spectral Diffusion, Phonons, and Paramagnetic Spin-Lattice Relaxation**—P. W. Anderson. (*Phys. Rev.*, vol. 114, pp. 1002–1005; May 15, 1959.) Discussion of paramagnetic relaxation phenomena at low temperatures, by analogy with Holstein's theory of trapping of resonance radiation in gases.

538.569.4:[538.222+537.311.33 3653
**On the Overhauser Stationary Effect in Paramagnetic Salts and Semiconductors**—G. R. Khutsishvili. (*Nuovo Cim.*, vol. 11, pp. 186–197; January 16, 1959. In English.) Discussion of the problem of obtaining stationary nuclear polarization in nonmetals by means of a complete or partial saturation of one or more components of the para-magnetic-resonance hyperfine structure.

538.569.4:621.375.9 3654
**Three-Level Spin Refrigeration and Maser Action at 1500 Mc/s**—J. E. Geusic, E. O. Shulz-Du Bois, R. W. De Grasse and H. E. D. Scovil. (*J. Appl. Phys.*, vol. 30, pp. 1113–1114; July, 1959.) It is shown that positive and negative signal spin temperatures, both small compared to the ambient temperature, can be realized through three-level excitation.

538.569.4:621.375.9:535.61–1/2 3655
**Optical Maser Design**—J. H. Sanders. (*Phys. Rev. Lett.*, vol. 3, pp. 86–87; July 15, 1959.) Excitation by electron impact is suggested for a maser working in the visible region. See 1857 of June (Schawlow and Townes).

538.569.4:621.375.9:537.52 3656
**Possibility of Production of Negative Temperature in Gas Discharges**—A. Javan. (*Phys. Rev. Lett.*, vol. 3, pp. 87–89; July 15, 1959.) The production of negative temperature by the excitation of atomic levels is suggested and the difficulties of obtaining sufficient excited atoms for maser action are considered.

537/538 3657
**Handbuch der Physik (Encyclopedia of Physics). Vol. 16: Electric Fields and Waves.** [Book Review]—S. Flügge (Ed.). Publishers: Springer-Verlag, Berlin-Göttingen-Heidelberg, 753 pp., DM 158, 1958. (*Naturwiss.*, vol. 45, no. 17, p. 427; Spetember, 1958.) The volume comprises the following five parts:

a) **Static Fields and Stationary Currents**—G. Wendt (In German).

b) **Quasi-Stationary and Nonstationary Currents in Electric Circuits**—R. King (In English).

c) **Electromagnetic Waveguides and Resonators**—F. E. Borgnis and C. H. Papas (In English).

d) **Propagation of Electromagnetic Waves**—H. Bremmer (In English).

e) **The Dispersion and Absorption of Electromagnetic Waves**—L. Hartshorn and J. A. Saxton (In English).

## GEOPHYSICAL AND EXTRATERRESTRIAL PHENOMENA

523.164.3 3658
**Angular Diameter Measurements of the Radio Sources Cygnus (19N4A) and Cassiopeia (23N5A) on a Wavelength of 10.7 cm**—B. Rowson. (*Monthly Notices Roy. Astron. Soc.*, vol. 119, no. 1, pp. 26–33; 1959.) Results, given in each case for two directions at right angles, show that Cassiopeia is circularly symmetrical and approximately the same size at 10.7 cm as it is at metre wavelengths, while Cygnus is markedly asymmetrical, with a major axis which may be slightly larger at the shorter wavelength. The position angle of this major axis is 109°±2°. Measurement equipment is described.

523.164.32:621.396.677.3 3659
**16-Aerial Array operating at 9,300 Mc/s**—M. Pick-Gutmann and J. L. Steinberg. (*Compt. Rend. Acad., Sci., Paris*, vol. 248, pp. 2452–2464; April 27, 1959.) An array of mirrors 1.10 m in diameter mounted at equal intervals on a beam 23 m long has been erected at Nançay for the study of RF solar radiation by interferometry. Centers of RF emission are found closely associated with optical centers.

523.164.4 3660
**The Radio Emission from the Direction of the "Supergalaxy"**—J. R. Shakeshaft and J. E. Baldwin. (*Monthly Notices Roy. Astron Soc.*, vol. 119, No. 1, pp. 46–53; 1959.) An analysis of observations made at 1.9 m$\lambda$ suggests that the band of radio emission running perpendicular to the galactic plane, at about $12^h$ R. A. is not associated with the "local supergalaxy."

523.165 3661
**Theory of the Cosmic-Ray Equator**—R. Ingraham. (*Nuovo Cim.*, vol. 12, pp. 356–368; May 16, 1959. In English.) The 45° westward shift of the cosmic ray equator from the geomagnetic equator is explained by assuming that there exist ionized atmospheric layers which rotate more slowly than the earth. The resultant magnetic field beyond the layers is then a dipole field whose magnetic north pole is west of the geomagnetic north pole.

523.165:550.38 3662
**Effect of Magnetic Anomaly on Particle Radiation Trapped in Geomagnetic Field**—A. J. Dessler. (*J. Geophys. Res.*, vol. 64, pp. 713–715; July, 1959.)

523.165:550.389.2:629.19 3663
**Investigation of Variations in Cosmic Radiation**—S. N. Vernov, Yu. I. Logachev, A. E. Chudakov and Yu. G. Shafer. (*Uspekhi Fiz. Nauk*, vol. 63, pp. 149–162; September, 1957.) The phenomena which can be investigated and the measuring instruments which can be installed in an artificial earth satellite are described.

523.72 3664
**Investigation of Ultraviolet Solar Radiation**—S. L. Mandel'shtam and A. I. Efremov. (*Uspekhi Fiz. Nauk*, vol. 63, pp. 163–180; Sept., 1957.)

523.746 3665
**On the Structure and Mechanism of Sunspots**—A. Dauvillier. (*Compt. Rend. Acad.*

*Sci., Paris*, vol. 248, pp. 1084–1086; February 23, 1959.)

**523.75 3666**

**On a Possible Mechanism of Solar Non-Stable Processes leading to Neutron Eruptions**—V. A. Petukhov. (*Ann. Géophys.*, vol. 14, pp. 425–432; October/December, 1958. In English.) The hypothesis is proposed that the formation within the sun of a nucleus with increased lithium concentration may be the initial cause of nonstable processes of all kinds and, in particular, the formation of sunspots.

**550.38:551.510.535:621.396.11 3667**

**The Geometry of the Earth's Magnetic Field at Ionospheric Heights**—Millman. (*See* 3849.)

**550.385 3668**

**Induced Electromagnetic Fields in the Earth**—J. Carstoiu (*Proc. Nat. Acad. Science, Wash.*, vol. 45, pp. 204–208; February, 1959.) A general theoretical study of the effect of geomagnetic variations in the earth.

**550.385:539.16 3669**

**Geomagnetic Effects of Nuclear Explosions**—(*Tech. Bull. Nat. Bur. Stand.*, vol. 43, pp. 121–122; July, 1959.) Report of an analysis of changes in the earth's magnetic field which occurred when two bombs were exploded at night at a high altitude on Johnston Island, August 1 and 12, 1958. Results indicate that the upper atmosphere at a distance of 2000 km was ionized to near daytime intensity. Field changes were detected up to 3400 km away. For a shorter account see *Electronics*, vol. 32, p. 72; August 14, 1959.

**550.385:539.16 3670**

**Geomagnetic Disturbances due to Nuclear Explosion**—H. Maeda. (*J. Geophys. Res.*, vol. 64, pp. 863–864; July, 1959.) Possible reasons for the observed effects at Honolulu on August 1 and 12, 1958, are discussed.

**550.385:539.16 3671**

**Magnetic Effects resulting from Two High-Altitude Nuclear Explosions**—J. A. Lawrie, V. B. Gerard and P. J. Gill. (*Nature*, vol. 184, pp. B.A. 34, B.A. 52; September 5, 1959.) An examination of vector diagrams of geomagnetic variations in a horizontal plane due to explosions on August 1 and 12, 1958, indicates that the effects may be classified into four phases; initial, second, main and final.

**550.385:539.16 3672**

**Some Geomagnetic Phenomena associated with Nuclear Explosions**—R. G. Mason and M. J. Vitousek. (*Nature*, vol. 184, pp. B.A. 52–B.A. 54; September 5, 1959.) Magnetograms recorded at three stations in the immediate area of the explosion on April 28, 1958, show no disturbance of the *H* component of the earth's field at the time of major disturbances in *Z* and *D* components. Vector diagrams of the disturbance in the vertical plane at the three stations are compared with those for the explosion on August 1, 1958, and are found to be markedly similar despite the different geographical positions and altitudes of the two events; in the latter event changes in the *H* component were comparable with those in *Z* and *D*.

**550.385.37:551.510.536 3673**

**Geomagnetic Pulsations and the Earth's Outer Atmosphere**—T. Obayashi. (*Ann. Géophys.*, vol. 14, pp. 464–474; October/December, 1958. In English.) Hydromagnetic oscillations of the ionized outer atmosphere are considered as a possible cause of geomagnetic pulsations. Observational results are applied to this model and the distribution of ionic density is determined.

**550.389.2:061.3 3674**

**Important Contribution to International Scientific Collaboration**—V. V. Belousov and B. I. Silkin. (*Priroda*, pp. 65–73; February, 1959.) A brief report on the Fifth Assembly of the Special I.G.Y. Committee which took place in Moscow, August 1958. 400 delegates from 35 countries were present and some preliminary results were discussed.

**550.389.2:629.19 3675**

**Some Dynamic Problems of Flight to the Moon**—V. A. Egorov. (*Uspekhi. Fiz. Nauk*, vol. 63, pp. 73–117; September, 1957.) Trajectories for reaching the moon or for flying round the moon and returning to the earth are considered. The initial rocket velocities and the distances from the earth and moon of four different orbits are tabulated. A periodic orbit passing near the moon and earth seems to be unpractical because an error in the initial velocity of 1 mm/sec would be enough to allow the rocket to escape into space after only four revolutions. For a shorter account see *Priroda*, pp. 3–9; February, 1958.

**550.389.2:629.19 3676**

**The Launching of a Cosmic Rocket towards the Moon**—(*Priroda*, pp. 1–4; January, 1959.) A short account of the day-to-day progress of the cosmic rocket from January 2–5, 1959. In the first 62 hours it travelled to a distance of 597,000 km passing the moon and entering an orbit around the sun between those of the earth and Mars.

**550.389.2:629.19 3677**

**The Launching of Cosmic Rockets and Astronomical Problems**—B. V. Kukarkin. (*Priroda* pp. 7–8; March, 1959.)

**550.389.2:629.19 3678**

**Soviet Cosmic Rocket**—(*Priroda*, pp. 17–30; February, 1959.) A description of the 1472-kg rocket which was fired on January 2, 1959, and which passed within a distance of 5000–6000 km of the moon. The orbit round the sun lies between the earth and Mars and has a period of 15 months. The minimum and maximum distances from the sun will be 146 and $197 \times 10^6$ km. Signals were emitted from the rocket on 19.997, 19.995 and 19.993 mc. The eccentricity of the orbit is 0.148 as compared with 0.017 for the earth. A photograph of the sodium cloud released at a distance from the earth of 113,000 km is shown.

**550.389.2:629.19 3679**

**Satellites and Space Probes Launched in U.S. and U.S.S.R.**—(*Electronics*, vol. 32, pp. 46–47; July 24, 1959.) A tabulated summary of launching dates, instrumentation and results.

**550.389.2:629.19 3680**

**Some Variational Problems connected with the Launching of an Artificial Earth Satellite**—D. E. Okhotsimskiĭ and T. M. Eneev. (*Uspekhi. Fiz. Nauk*, vol. 63, pp. 5–32; September, 1957.) A mathematical analysis of the best angle of elevation for a rocket which is required to put a satellite into an orbit with minimum fuel consumption and allowing for a variable gravitational field and the rotation of the earth.

**550.389.2:629.19 3681**

**Determination of the Lifetime of an Artificial Earth Satellite and Study of the Secular Perturbations of Its Orbit**—D. E. Okhotsimskiĭ., T. M. Eneev and G. P. Taratynova. (*Uspekhi. Fiz. Nauk*, vol. 63, pp. 33–50; September, 1957.) A general mathematical method is described which is valid for any satellite and which takes account of the distribution of atmospheric density with altitude. This method is based on single-parameter series of integral curves of a first-order equation. From graphs and tables the satellite's lifetime and the variation of the orbital parameters with time are rapidly calculated. The effect of atmospheric rotation on the secular variations of the satellite's orbit are found to be small.

**550.389.2:629.19 3682**

**The Motion of an Artificial Satellite in the Noncentral Field of Terrestrial Gravitation in the Presence of Atmospheric Resistance**—G. P. Taratynova. (*Uspekhi. Fiz. Nauk*, vol. 63, pp. 51–58; September, 1957.) The orbit of a fictitious satellite of weight 10 kg and diameter 0.5 m has been calculated in four hours using an electronic computer. The period of rotation of the perigee is 11 times in 700 days. The ascending node regresses in the direction opposite to the earth's rotation at a rate of about 5° per day.

**550.389.2:629.19 3683**

**Effect of Geophysical Factors on the Motion of a Satellite**—I. M. Yatsunskiĭ. (*Uspekhi. Fiz. Nauk*, vol. 63, pp. 59–71; September, 1957.) The orbital calculations based on the use of differential equations in terms of elliptical osculating elements depend on the accurate estimation of geophysical factors such as air resistance and gravitational anomalies. The determination of these factors from satellite is considered.

**550.389.2:629.19 3684**

**Use of Artificial Earth Satellites for the Verification of the General Theory of Relativity**—V. L. Ginzburg. (*Uspekhi. Fiz. Nauk*, vol. 63, pp. 119–122; September, 1957.) Three main points could be examined: a) the rotation of the perigee of Mercury which, according to the theory, should revolve 43.03 inches in a century, b) the deflection by 1.75 inch of light rays in passing near the sun, c) the gravitational shift of spectral lines.

**550.389.2:629.19 3685**

**The Orbit of Satellite 1958δ 2**—G. Hergenhahn. (*Naturwiss.*, vol. 45, pp. 434–435; September, 1958.) Orbital period as a function of the number of revolutions completed is plotted for the period May 15 to July 2, 1958. Orbital data are calculated and certain discrepancies with observations are discussed.

**550.389.2:629.19 3686**

**An Experimental and Indirect Method for Determining the High Atmosphere's Density**—C. Casci and V. Giavotto. (*Nuovo Cim.*, vol. 11, pp. 291–297; January 16, 1959. In English.) An approximate method is described for calculating the density of the atmosphere above 130 km, using, as data, observed lifetimes of artificial satellites no longer in orbit. Calculated densities are compared with those measured by means of rocket probes.

**550.389.2:629.19 3687**

**New Approach in the Theory of Satellite Orbits**—J. P. Vinti. (*Phys. Rev. Lett.*, vol. 3, p. 8; July 1, 1959.) A proposed co-ordinate system is useful for investigating the motion of an earth satellite.

**550.389.2:629.19 3688**

**Short-Time Measurement of Time Dilation in an Earth Satellite**—R. S. Badessa, R. L. Kent and J. C. Nowell. (*Phys. Rev. Lett.*, vol. 3, pp. 79–80; July 15, 1959.) A method for measuring the gravitational red shift based on the variation of the frequency difference between two oscillators as a function of altitude.

**550.389.2:629.19 3689**

**Air Density in the Upper Atmosphere from Satellite Orbit Observations**—G. V. Groves. (*Nature*, vol. 184, Suppl. No. 4, pp. 178–179; July 18, 1959.) The results given agree with those of King-Hele (2955 of September).

550.389.2:629.19:523.165 3690

**Investigation of Cosmic Rays by Means of Artificial Earth Satellites**—N. A. Dorbrotin. (*Priroda*, pp. 57–64; January, 1959.) These investigations led to the discovery of a belt of charged particles round the earth which, at a height of 1600 km, passed at the rate of $10^8$–$10^9$ particles per second through an area 1cm². This radiation would be very dangerous to unprotected living beings.

550.389.2:629.19:523.165 3691

**Ionizing Radiation at Altitudes of 3500 to 36000 Kilometres: Pioneer I**—A. Rosen, C. P. Sonett, P. J. Coleman, Jr., and C. E. McIlwain. (*J. Geophys. Res.*, vol. 64, pp. 709–712; July, 1959.) "The total ionizing component of cosmic radiation was measured on October 11, 1958, by means of an ionization chamber mounted on the Pioneer I lunar probe vehicle. Data were taken over an altitude range of 3500 to 36000 km and a latitude range of 35°N to 5°N. The calibration procedure and the analysis of the telemetered data are described."

550.389.2:629.19:523.165 3692

**Satellite Observations of Solar Cosmic Rays**—P. Rothwell and C. McIlwain. (*Nature*, vol. 184, pp. 138–140; July 18, 1959.) On three occasions during August, 1958, large increases in the intensity of charged particles outside the Van Allen radiation zones were detected by 1958 E at high magnetic latitudes and low satellite altitudes. It is suggested that these increases are due to solar protons associated with large solar flares.

550.389.2:629.19:550.38 3693

**Investigation of the Earth's Magnetic Field using an Artificial Earth Satellite**—N. V. Pushkov and S. Sh. Dolginov. (*Uspekhi. Fiz. Nauk*, vol. 63, pp. 645–656; December, 1957.) An investigation by means of magnetometers, located on the satellite, of the space distribution of the earth's magnetic field at great heights and of inhomogeneities in the ionosphere. The effect of the magnetic field on the polarization of radio waves reflected from the ionosphere, the latitude effect of cosmic rays, and auroral phenomena are considered.

550.389.2:629.19:551.510.53 3694

**Problems of Measurement of the Pressure and Density of the High Layers of the Atmosphere by means of Artificial Earth Satellites**—B. S. Danilin, V. V. Mikhnevich, A. I. Repnev and E. G. Shvidkovskiĭ. (*Uspekhi. Fiz. Nauk*, vol. 63, pp. 205–226; September, 1957.) Temperature pressure, density and composition between 100 and 300 km are tabulated. The concentrations of oxygen and nitrogen between 160 and 500 km are also shown.

550.389.2:629.19:551.510.53 3695

**The Density of the Earth's Outer Atmosphere according to Satellite Observations**—H. K. Paetzold and H. Zschörner. (*Naturwiss.*, vol. 45, pp. 485–486; October, 1958.) Orbital data of satellites 1958α and 1958β 2 are used to determine atmospheric density above 200 km. Results agree closely with those obtained from observations of satellites 1957α 2 and 1958δ 2. Retardation effects are also discussed.

550.389.2:629.19:551.510.535 3696

**Measurement of the Concentration of Positive Ions along the Orbit of an Artificial Earth Satellite**—K. I. Gringauz and M. Kh. Zelikman. (*Uspekhi. Fiz. Nauk*, vol. 63, pp. 239–252; September, 1957.) The surface potential of a satellite and the distribution of charged particles around it are discussed. Instruments for measuring the ion concentration and the transmission of results to earth by radio-telemetry are described. Graphs of the air temperature at different heights are also shown. 23 references.

550.389.2:629.19:621.396.11 3697

**Preliminary Results of Measurements on Doppler Shift of Satellite Emissions**—P. R. Arendt. (IRE Trans. on Antennas and Propagation, vol. AP-7, pp. 99–101; January, 1959.) Measurements of transmissions from 1957 α and β on 20 and 40 mc have been analyzed to investigate the influence of the propagation path on observed data. Results indicate that the 40-mc wave travels about 2 per cent slower than the 20-mc wave.

550.389.2:629.19:621.396.11 3698

**Refraction of Very-High-Frequency Radio Signals at Ionospheric Heights**—S. Weisbrod and L. Colin. (*Nature*, vol. 184, p. 119; July 11, 1959.) Calculations relevant to the radio tracking of space vehicles show that refractive errors due to the troposphere rapidly decrease with increasing elevation angle, while those due to the ionosphere initially increase with elevation angle and then decrease gradually. The elevation angle error is plotted for realistic models of the ionosphere and troposphere.

550.389.2(54) 3699

**Work Carried Out under the Auspices of the Indian National Committee for the I.G.Y. 1957–1958**—(*J. Sci. Indus. Res.* vol. 17A, Suppl., pp. 1–110; December, 1958.) The following papers and data are included:

a) **A Preliminary Report "On the Nature and Origin of Atmospherics"**—M. W. Chiplonkar, R. N. Karekar, T. A. Raju and M. S. Hattiangadi (pp. 3–23).

*b*) **Atmospheric Electricity Observations in India during the I.G.Y.—Radiosonde Techniques for Measuring Potential Gradient and Conductivity**—S. P. Venkeitshwaran (pp. 24–32).

*c*) **Geomagnetic Work at Albiag, Annamalainagar and Trivandrum during the I.G.Y.**—S. L. Malurkar (pp. 33–35).

*d*) **Atomic Nitrogen in the Thermosphere**—M. Nicolet (p. 36).

*e*) **Ionospheric Disturbances at Low Latitudes**—A. P. Mitra (pp. 37–40).

*f*) **Studies of Cosmic Radio Noise on 25 Mc/s at Ahmedabad**—R. V. Bhonsle and K. R. Ramanathan (pp. 40–45).

g) **Meteors and Es Ionization**—K. M. Kotadia (pp. 46–49).

h) **Rates of Fading of Reflected Pulses of Vertically Incident Electromagnetic Waves at Ahmedabad on 2.6 and 4.0 Mc/s**—R. Sethuraman (pp. 50–53).

i) **Observations on Galactic Radiation at 30 Mc/s**—Y. V. Somayajulu and N. N. Rao. (pp. 54–56).

j) **Diurnal Variation of Ionospheric Absorption on 5.65 Mc/s at Waltair during the I.G.Y.**—B. R. Rao and K. V. V. Ramana (pp. 56–58).

k) **Effect of Enhanced Solar Activity on the $F_2$ Region Drifts at Waltair**—B. R. Rao and E. B. Rao (pp. 59–62).

l) **A New Continuous-Wave Radio Method for the Study of Ionospheric Drifts**—B. R. Rao and D. S. Murty (pp. 63–67).

m) **Program of I.G.Y. Solar Observations in India** (pp. 68–69).

n) **Solar Control of some Unusually Remarkable Geophysical Events**—S. L. Malurkar (pp. 69–71).

o) **Radio Emission from the Sun at 30 Mc/s**—M. Krishnamurthi, G. S. Sastry and T. S. Rao (pp. 71–73).

p) **Radio Patrol of Solar Flares**—A. P. Mitra, K. A. Sarada, N. V. G. Sarma and M. N. Joshi (pp. 74–80).

q) **Optical Tracking of Artificial Satellites**—M. K. Vainu Bappu (pp. 95–98).

Appendix 3:

r) **Table 1—Solar Flares during July 1957 to September 1958** (pp. 106–108).

s) **Table 2—Sudden Enhancement of Atmospherics (SEA) during July 1957 to August 1958** (p. 109).

t) **Table 3—Sudden Cosmic Absorption (SCA) during July 1957 to July 1958** (p. 109).

u) **Table 4—Solar Flare Effects recorded during July 1957 to June 1958** (p. 110).

551.510.53 3700

**Investigation by Rockets of the Composition of the Atmosphere at Great Heights**—B. A. Mirtov. (*Uspekhi. Fiz. Nauk*, vol. 63, pp. 181–196; September, 1957.) A description of containers designed to collect samples of the atmosphere is given and results obtained between 65 and 95 km are tabulated.

551.510.53 3701

**Measurements of the Pressure in the Upper Atmosphere**—V. V. Mikhnevich. (*Uspekhi. Fiz. Nauk* vol. 63 pp. 197–204; September, 1957.) A description is given of a container with recording instruments which, after being released from a rocket, record the pressure of the upper atmosphere. A comparison is made between pressure measurements obtained in U.S.A. and U.S.S.R. at 50–100 km. Pressure and temperature variations at different heights are shown graphically.

551.510.535 3702

**Investigation of the Ionic Composition of the Ionized Layers of the Atmosphere**—B. A. Mirtov and V. G. Istomin. (*Uspekhi. Fiz. Nauk*. vol. 63, pp. 227–238; September, 1957). Rockets and artificial satellites equipped with mass spectrometers of the type described by Bennett (*J. Appl. Phys.*, vol. 21, pp. 143–149; February, 1950) automatically sending results to the earth are considered. The ionization of the atmosphere by a fast-moving satellite vehicle and the effect of the vacuum created behind it are also examined.

551.510.535 3703

**Results obtained with Rocket-Borne Ion Spectrometers**—C. Y. Johnson, J. P. Heppner, J. C. Holmes and E. B. Meadows. (*Ann. Géophys.*, vol. 14, pp. 475–482; October/December, 1958. In English.) A description of the instrumentation used and an analysis of the results obtained from three flights in which both positive and negative ion spectrometers were flown.

551.510.535 3704

**Some Studies of the Upper Atmosphere in the Auroral Zone**—S. Matsushita. (*Ann. Géophys.*, vol. 14, pp. 483–491; October/December, 1958. In English.) Observations show close correlation between blackouts, complete blanketing of $F_2$ by $E_s$, slant $E_s$ and geomagnetic bay disturbances. The height of the absorbing region responsible for the daytime polar blackout appeared to be lower than when the event occurred at night. To explain these results, the effect on the ionosphere of X-rays generated by solar particles is discussed.

551.510.535 3705

**Model of the Ionosphere**—O. Burkard. (*Naturwiss.*, vol. 45, pp. 507; November, 1958.) Electron-density data obtained by a Russian rocket can be correctly interpreted by the $F_2$-layer model proposed in *Geofis. pura appl.*, vol. 37, pp. 145–164; 1957.

551.510.535 3706

**The Worldwide Distribution of the $F_2$-Layer Electron Density: Seasonal and Nonseasonal Variations and Correlations with Solar Activity**—F. Mariani. (*Nuovo Cim.*, vol. 12, pp. 218–240; May 1, 1959. In English.) Seasonal and nonseasonal variations of the maximum electron density in the $F_2$ layer at noon are largely asymmetrical in the two hemispheres; at midnight they are symmetrical. A general circulation of the upper atmosphere is suggested as an explanation for these and other anomalies discussed. See 2444 of 1957.

551.510.535 3707

**The Diurnal Development of the Anomalous Equatorial Belt in the $F_2$ Region of the Ionosphere**—R. G. Rastogi. (*J. Geophys. Res.*, vol. 64, pp. 727–732; July, 1959.) A study is made of the latitudinal distribution of $f_0F_2$, for each hour of the day, for the equinoctial months at sunspot minimum and also of the diurnal variation of $f_0F_2$ at a number of low-latitude stations. The observed behaviour of $f_0F_2$ in both cases is suggested to be due not only to vertical drift of ionization but also to horizontal movement between the poles and the equator during the day.

551.510.535 3708

**Time and Height Variations in the Daytime Processes in the Ionosphere: Part 1**—A. P. Mitra, (*J. Geophys. Res.*, vol. 64, pp. 733–743; July, 1959.) An extension of earlier work (114 of 1955, Mitra and Jones). Variations of the decay of electron density with height are discussed for the height range 50–600 km. An expression is developed for the loss coefficients over this range for northern middle latitudes at noon.

551.510.535+550.385]:539.16 3709

**Geomagnetic and Ionospheric Pheonomena associated with Nuclear Explosions**—S. Matsushita. (*Nature*, vol. 184, pp. B.A.33–B.A.34; September 5, 1959.) Magnetograms and ionograms recorded at stations in the Central Pacific Ocean have been analyzed for the periods covering the explosions on August 1 and 12, 1958. Some geomagnetic variation could be explained by a dynamo effect associated with wind velocities of 100 miles per second and a ten-fold increase in electrical conductivity.

551.510.535:539.16 3710

**Some Effects of Nuclear Explosions on Ionospheric Vertical-Incidence Soundings**—D. Lepechinsky and C. Davoust. (*Compt. rend. Acad. Sci., Paris*, vol. 248, pp. 1203–1206; February 23, 1959.) An analysis of observations made at Tahiti (17°20′S, 149°20′W), Maui (20°N, 150°W) and Rarotonga (21°12′S, 159°46′W). At the time of an explosion on August 1, 1958. abnormal absorption, which lasted three hours, was recorded at Maui and Tahiti (for auroral effect see 1569 of May, Cullington). On August 12, 1959, the date of another explosion, the onset of abnormal absorption at Maui and Rarotonga appeared to be delayed by five hours.

551.510.535:539.16 3711

**Sudden Ionospheric Disturbances caused by an Atomic Explosion**—A. Kimpara. (*Compt. rend. Acad. Sci. Paris*, vol. 248, pp. 2117–2119; April 6, 1959.) A note on recordings of atmospherics and solar RF bursts made at Toyokawa, Japan, August 12, 1958.

551.510.535:539.16 3712

**Disturbance in the Ionospheric F Region following the Johnston Island Nuclear Explosion**—C. H. Cummack and G. A. M. King. (*Nature*, vol. 184, pp. B.A.32–B.A.33; September 5, 1959.) From a study of time delay at various observatories in the vicinity, it is assumed that the ionospheric disturbance due to the explosion on August 1, 1958, is a by-product of a gaseous shock wave propagated at a velocity considerably greater than that of sound. Anomalies in this assumption are discussed.

551.510.535:550.371 3713

**Measurement of Electrostatic Fields in the Upper Layers of the Earth's Atmosphere**—I. M. Imyanitov. (*Uspekhi. Fiz. Nauk*, vol. 63, pp. 267–282; September, 1957.) The charge acquired by a body located in a plasma is examined. An instrument measuring the field potential in the ionosphere is described. Electrostatic field variations due to moving rockets or satellites are considered.

551.510.535:621.396.11 3714

**Ionosphere Electron Densities and Differential Absorption**—J. C. Seddon and J. E. Jackson. (*Ann. Géophys.*, vol. 14, pp. 456–463; October/December, 1958.) A review of daytime ionosphere measurements made over New Mexico using a rocket-to-ground CW radio propagation method and a preliminary report of similar measurements made in the arctic ionosphere during a time of polar blackouts.

551.510.535:621.396.11 3715

**On the Measurement of Virtual Height**—I. Kay. (IRE Trans. on Antennas and Propagation, vol. AP-7, pp. 11–14; January, 1959. Abstract, Proc. IRE, vol. 47, p. 610; April, 1959).

551.510.535:621.396.11 3716

**Interpretation of the Variation of Ionospheric Absorption as a Function of Frequency**—K. Bibl, A. Paul and K. Rawer. (*Compt. rend. Acad. Sci., Paris*, vol. 248, pp. 949–952; February 16, 1959.) Errors in nondeviative absorption calculations are attributed to the presence in the *E* layer of a thin densely ionized $E_s$ layer, The expression used earlier, (985 of 1952, Bibl and Rawer) has been revised. Results obtained using the new expression indicate that it allows a more detailed study of the absorption process.

551.510.535(98) 3717

**Ionospheric Conditions in the Circumpolar Region**—V. M. Driatski and A. S. Besprozvannaya. (*Ann. Géophys.*, vol. 14, pp. 438–455; October/December, 1958. In English.) A preliminary analysis of ionospheric and magnetic-field measurements made from a drifting observatory in the Arctic Ocean during the period May 15, 1954 to April 14, 1955. Values of 5–6 mc were obtained for $f_0F_2$ during the arctic night.

551.510.536 3718

**Investigation of the Solid Component of Interplanetary Matter by means of Rockets and Artificial Earth Satellites**—S. M. Poloskov and T. N. Nazarova. (*Uspekhi. Fiz. Nauk.*, vol. 63, pp. 253–265; September, 1957.) The kinetic energy of micrometeorites is measured by an acoustic method or by a new type of sensitive photomultiplier. Results of collisions of these particles with polished plates located on rockets are shown. Tables giving values of brightness, mass, radius and estimated fall out on the earth in 24 hours are included. Particles ejected from the sun and charged cosmic dust are also considered.

551.594.6 3719

**A Preliminary Meteorological Study of the Origin of Whistlers**—C. P. Mook. (*J. Geophys. Res.*, vol. 64, pp. 745–748; July, 1959.) "A possible unique source of whistling atmospherics is found to be the presence of large cyclonic disturbances at the geomagnetic conjugate point for the whistler receiving station. The possible role of these cyclonic disturbances in producing narrow magneto-ionic duct propagating conditions is also discussed."

## LOCATION AND AIDS TO NAVIGATION

621.396.663 3720

**The Reduction of Bearing Errors due to Multiple Incidence in Long-Base-Line Systems**—F. Steiner and H. Stittgen. (*Nachrichtentech. Z.*, vol. 11, pp. 417–423; August, 1958.) The maximum bearing errors as a function of base length $d/\lambda$ are calculated for the Adcock and Doppler systems. With increasing base line the errors decrease, the Adcock, but not the Doppler system, becoming more liable to ambiguities.

621.396.93(083.74) 3721

**I.R.E. Standards on Navigation Aids: Direction-Finder Measurements, 1959**—(Proc. IRE, vol. 47, pp. 1349–1371; August, 1959.) Standard 59 IRE 12. S1.

621.396.933.1 3722

**Collision Detection without Range Data**—Y. J. Liu and J. O. Campbell. (*Electronics*, vol. 32, pp. 60–63; July 24, 1959.) A system is developed which automatically computes the relative velocity vector of two aircraft and compares it with the line of sight. Warning is given if the two parameters are within a few degrees of one another.

621.396.933.23 3723

**Blind Landing**—W. J. Charnley. (*J. Inst. Nav.*, vol. 12, pp. 115–135; April, 1959. Discussion, pp. 135–140.) A detailed account of the B.L.E.U. system briefly described earlier (1892 of June) and a discussion of the principles of the "televiewer" manual blind landing system.

621.396.963.325:621.397.24 3724

**Further Progress in Bandwidth Compression of Radar Displays**—H. Meinke and A. Rihaczek. (*Nachrichtentech. Z.*, vol. 11, pp. 398–404; August, 1958.) By varying the scanning speed in a radar-signal storage system so that short pulses and intervals are lengthened at the expense of long pulses the bandwidth of the signal can be reduced. Transmission of radar PPI displays with 4-kc bandwidth over a telephone channel has been successful. See also 3744 of 1956 (Meinke and Groll).

621.396.969.3 3725

**Checking Jitter in Moving-Target Radar**—C. Clark. (*Electronics*, vol. 32, pp. 56–58; July 17, 1959.) A circuit is described for a unit which monitors the frequency of the coherent oscillator automatically, and provides a visible indication of the amount of jitter.

## MATERIALS AND SUBSIDIARY TECHNIQUES

535.215:546.472.41 3726

**Photoconductivity of Zinc Telluride**—Y. Simon and J. Bok. (*Compt. rend. Acad. Sci., Paris*, vol. 248, pp. 2176–2178; April 13, 1959.) The conductivity of ZnTe prepared by fusion and subsequent recrystallization in hydrogen was observed in darkness and in visible light for fields up to 2000 v/cm. The enhanced conductivity at high field strengths can be attributed to shock ionization.

535.215:546.482.21 3727

**A Lamination-Type Structure of CdS Crystals**—H. Radelt. (*Naturwiss.*, vol. 45, p. 463; October, 1958.) Crystals grown from the vapor phase by Frerichs' method (450 of 1948) often exhibit a fine laminar structure. The effect is interpreted with reference to experimental investigations.

535.215:546.482.21 3728

**Measurement of the Elastic Constants of CdS Single Crystals**—E. Gutsche. (*Naturwiss.*, vol. 45, p. 566; December, 1958.) The results of mechanical tests on thin-plate and rod-shaped specimens are summarized. See also 3729.

535.215:546.482.21 3729

**Compressibility and Pressure Displacement**

**of the Absorption Edge of Cadmium Sulphide**—E. Gutsche. (*Naturwiss.*, vol. 45, p. 486; October, 1958.) Preliminary report of measurements on CdS single crystals at pressures up to 4000 kp/cm². The influence of hydrostatic pressure on the spectral distribution of photoconductivity is also investigated.

535.215:546.482.21 3730
**Effect of Deformations on the Spectrum of CdS Crystals**—E. F. Gross and B. S. Razbirin. (*Zh. Tekh. Fiz.*, vol. 28, pp. 237–239; February, 1959.)

535.215:546.482.21 3731
**The Electrostatic Charging of CdS Single Crystals under the Influence of Strong Electric Fields**—K. W. Böer and U. Kümmel. (*Ann. Phys.*, (*Lpz.*), vol. 2, pp. 217–224; November 11, 1958.) The results of measurements obtained cannot be interpreted by the theory of space-charge limitation (2566 of 1955, Smith and Rose), but they are in agreement with the assumption of inhomogeneous conductivity in CdS single crystals.

535.215:546.482.21 3732
**Diffusion of Copper in Cadmium Sulphide Crystals**—R. L. Clarke. (*J. Appl. Phys.*, vol. 30, pp. 957–960; July, 1959.) Diffusion coefficients determined using radioactive-tracer sectioning technique.

535.215:546.561–31 3733
**Influence of Molecular Adsorption on the Longitudinal Photoconductivity of Cuprous Oxide**—O. V. Snitko. (*Zh. Tekh. Fiz.*, vol. 28, pp. 35–44; January, 1958.) Report of an investigation on $Cu_2O$ plates 0.2 mm thick coated on both sides with a semitransparent gold film and illuminated by 30-μsec light pulses in a glass container a) evacuated, and b) containing ethyl alcohol vapor.

535.215:546.561–31 3734
**Time-lag of Photoeffect and Electrical Conductivity of Cuprous Oxide**—A. L. Rvachev. (*Zh. Tekh. Fiz.*, vol. 28, pp. 45–51; January, 1958.) An oscillographic examination has been made of the photocurrents in $Cu_2O$ samples with a) low and b) high specific conductance, under illumination by pulsed monochromatic light. Results show that the time-lag of the photoeffect depends not only on the wavelength of the incident light but also on the dark conductance. The spectral distribution of photosensitivity of different samples is shown and the method of preparation is described.

535.37 3735
**The System $ZnO.CdO.B_2O_3$, Phase Relationships, and Fluorescence**—D. E. Harrison and F. A. Hummel. (*J. Electrochem. Soc.*, vol. 106, pp. 24–26; January, 1959.) Two compounds have been isolated which, with Mn activator, give respectively orange and red fluorescence under cathode-ray excitation. See also 1778 of 1957.

535.37:546.472.21 3736
**Activation of ZnS and (Zn, Cd)S Phosphors by Gold and other Elements**—S. T. Henderson, P. W. Ranby and M. B. Halstead. (*J. Electrochem. Soc.*, vol. 106, pp. 27–34; January, 1959.) A study of spectral emission characteristics.

535.376 3737
**Bimolecular Electroluminescent Transitions in GaP**—E. E. Loebner and E. W. Poor, Jr. (*Phys. Rev. Lett.*, vol. 3, pp. 23–25; July 1, 1959.) A description of direct observations of bimolecular band-to-band transitions at rectifying junctions in single crystals of GaP and InP.

535.376:646.472.21 3738
**Particle Size Effects and the Distribution of Barriers in Electroluminescent Zinc Sulphide Phosphors**—P. Goldberg. (*J. Electrochem. Soc.*, vol. 106, pp. 34–38; January, 1959.) Particle size is shown to be a significant factor in empirical equations describing brightness/voltage relations.

537.226/.228 3739
**Electromechanical Properties of Lead Titanate Zirconate Ceramics with Lead Partially replaced by Calcium or Strontium**—F. Kulcsar. (*J. Amer. Ceram. Soc.*, vol. 42, pp. 49–51; January, 1959.) By partially substituting Sr for Pb, dielectric constants greater than 1300 can be obtained, with planar couplings of about 0.5. Ca also raises the dielectric constant but the planar coupling level is lower than with Sr.

537.227 3740
**Contribution to the Theory of Domain Walls in Ferroelectrics**—V. A. Zhirnov. (*Zh. Eksp. Teor. Fiz.*, vol. 35, pp. 1175–1180; November, 1958.) Investigation of the transition region in 180° and 90° boundaries of ferroelectric domains in $BaTiO_3$. Expressions are derived for the thickness and surface energy of domain boundaries and some numerical estimates are made. The 180° domain boundary of Rochelle salt crystals is briefly discussed.

537.227 3741
**Ferroelectric Properties of Colemanite**—H. H. Wieder. (*J. Appl. Phys.*, vol. 30, pp. 1010–1018; July, 1959.)

537.227 3742
**Polarization Reversal by Sideways Expansion of Domains in Ferroelectric Triglycine Sulphate**—A. G. Chynoweth and J. L. Abel. (*J. Appl. Phys.*, vol. 30, pp. 1073–1080; July, 1959.) Experiments show that when fields are applied by liquid electrodes to crystals of triglycine sulphate, polarization is accomplished by the formation and sideways expansion of a few domains.

537.227:546.321.85–841 3743
**Deuteron Magnetic Resonance Spectrum and Relaxation in $KD_2PO_4$**—J. L. Bjorkstam and E. A. Uehling. (*Phys. Rev.*, vol. 114, pp. 961–968; May 15, 1959.)

537.227:546.431.824–31 3744
**Dynamic Properties of the Polarizability in $BaTiO_3$ Crystal**—K. Husimi. (*J. Appl. Phys.*, vol. 30, pp. 978–981; July, 1959.) "The second harmonic distortion by a $BaTiO_3$ crystal of a small high-frequency sinusoidal electric field, superimposed on a low-frequency switching field, is studied by the filter method. From the phase relationship of the second harmonic distortion with respect to the measuring signal, together with the increase of the fundamental component of the capacitive current, it is concluded that the polarizability increases markedly for the backward direction during switching."

537.227:546.431.824–31 3745
**Investigation of the Temperature Dependence of Total Polarization, Coercive Force and Hysteresis Losses of (Ba, Sr) $TiO_3$, Ba(Ti, Sn)$O_3$ and Ba(Ti, Zr)$O_3$ Polycrystalline Solid Solutions**—V. A. Bokov. (*Zh. Tekh. Fiz.*, vol. 28, pp. 77–86; January, 1958.) The spontaneous polarization of Ba(Ti,Sn)$O_3$ and Ba(Ti,Zr)$O_3$ decreases with decrease of $BaTiO_3$ content. In the solid solution (Ba,Sr)$TiO_3$ it decreases with increase of $SrTiO_3$ up to 40 per cent, but with $SrTiO_3$ content over 50 per cent a considerable increase in spontaneous polarization is observed.

537.228.1:546.482.21 3746
**The Influence of the Activator and of the Storage of Radiation Energy on the Piezoelectric and Elastic Behaviour of Cadmium Sulphide Single Crystals**—H. Gobrecht and A. Bartschat. (*Z. Phys.*, vol. 153, pp. 529–554; January 8, 1959.) Investigations were made at 20°C and −180°C to determine the temperature dependence of elastic damping for various degrees of activator concentration and the effects of crystal irradiation by light and infrared rays. See also 2278 of July.

537.311.3:538.569.4:539.2 3747
**Energy Absorption by Charge Carriers of Negative Effective Mass in Crystals**—C. Kittel. (*Proc. Nat. Acad. Science*, vol. 45, pp. 744–747; May, 1959.) A theoretical examination of the negative-resistance properties of a negative-carrier system.

537.311.33 3748
**Solid-State Physics at N.B.S**—(*Tech. Bull. Nat. Bur. Stand.*, vol. 43, pp. 92–96; May, 1959.) General account of semiconductor research in progress at the National Bureau of Standards.

537.311.33 3749
**On the Theory of the Field Effect**—V. L. Bonch-Bruevich. (*Zh. Tekh. Fiz.*, vol. 28, pp. 70–76; January, 1958.) A mathematical analysis of the effect of a transverse alternating field on semiconductor conductivity for any given values of Debye length and length of the free path.

537.311.33 3750
**On the Influence of the Short-Range Order on the Type of Conductivity**—V. L. Zyazev and O. A. Esin. (*Zh. Tekh. Fiz.*, vol. 28, pp. 18–22; January, 1958.) Measurements of conductivity of binary mixtures based on $V_2O_5$ for different temperatures and compositions are shown graphically. In $V_2O_5$—PbO, $V_2O_5$—CaO and $V_2O_5$—MgO the semiconductor mechanism is transformed into the ionic one when the concentration of the second component is low. This confirms Joffe's opinion on the character of conductivity.

537.311.33 3751
**Remarks on Drift Velocity**—Yu. N. Obraztsov. (*Zh. Tekh. Fiz.*, vol. 28, pp. 245–249; February, 1959.) Reasons are examined for the apparent difference in current density calculated using a) an exact solution of the kinetic equation and b) the drift velocity. Correct application of the latter method gives good results.

537.311.33 3752
**Notes on the Theory of Semiconductors with an Excited Impurity Band**—M. I. Klinger and G. A. Makarycheva. (*Zh. Tekh. Fiz.*, vol. 28, pp. 264–266; February, 1959.)

537.311.33 3753
**Transport Phenomena in Nondegenerate Semiconductors Considering Electron-Electron Scattering**—M. S. Sodha and Y. P. Varshni. (*Z. Phys.*, vol. 153, pp. 555–562; January 8, 1959. In English.) Hall mobility and other electron transport phenomena are investigated on *n*-type semiconductors in a magnetic field. Results are given for different impurity concentrations. See also 1225 of April (Sodha and Eastman).

537.311.33 3754
**Transport Properties of Nondegenerate *n*-Type Semiconductors Considering Electron-Electron Scattering**—M. S. Sodha and Y. P. Varshni. (*Phys. Rev.*, vol. 114, pp. 717–718; May 1, 1959.) Two proposed functions permit analytical integration of integrals appearing in

ıe theory of transport phenomena. (*e.g.* 753).

37.311.33 3755

**New Semiconducting Compounds**—V. P. hıse, V. M. Sergeeva and E. L. Shtrum. (*Zh. 'ekh. Fiz.*, vol. 38, pp. 233–236; February, 959.) An investigation of $CuFeSe_2$, $CuFeTe_2$, $.gFeSe_2$ and $AgFeTe_2$. The temperature deendence of conductivity and Hall constant is ıown for $AgFeTe_2$.

37.311.33 3756

**Oxides which Show a Metal-to-Insulator 'ransition at the Néel Temperature**—F. J. ⁄Iorin. (*Phys. Rev. Lett.*, vol. 3, pp. 34–36; uly 1, 1959.) Conductivity measurements on xides of titanium and vanadium provide addiional evidence for the existence of a conducion band of nonbonding orbitals. An explanaory model is suggested.

37.311.33:535.843.3 3757

**Method of Rendering Visible the Conducivity Inhomogeneities of Semiconductors**— ∑. W. Böer, H. J. Hänsch and U. Kümmel. *Naturwiss.*, vol. 45, p. 460; October, 1958.) 'reliminary report on tests carried out on CdS ingle crystals. Micrograms taken with monohromatic light show light and dark zones vhich indicate the field or current distribution nside the crystal.

ı37.311.33:537.32 3758

**Investigation of Thermoelectric Properties ıf $Bi_2Te_3$–$Bi_2So_3$ Solid Solutions**—G. N. ɔordyakova, G. V. Kokosh and S. S. Sinani. *Zh. Tekh. Fiz.*, vol. 28, pp. 3–17; January, 1958.) The effect of the addition of impurities o 80 per cent $Bi_2Te_3$ – 20 per cent $Bi_2Se_3$ ıolid solutions is examined. Best results are ıbtained with halides of the first group of elenents or with copper. Results are tabulated ınd graphs show the temperature dependence ıf the electrical conductivity and the thermo-EMF for various impurity additions.

ı37.311.33:537.323 3759

**$InAs_{1-x}P_x$ as a Thermoelectric Material**— ₹. Bowers, J. E. Bauerle and A. J. Cornish. (*J. 4ppl. Phys.*, vol. 30, pp. 1050–1054; July, 1959.) Measurements of the electrical conduc:ivity, the thermal conductivity, and the Seeɔeck coefficient have been made at high temɔeratures with $x$ ranging from 0 to 0.4.

ı37.311.33:538.569.4 3760

**Theory of Negative-Mass Cyclotron Resoıance**—D. C. Mattis and M. J. Stevenson. (*Phys. Rev. Lett.*, vol. 3, pp. 18–20; July 1, 1959.) It is shown that except under very reıtricted conditions, re-entrant states in Ge ınd Si will add a normal positive resistivity ɔomponent to the material independently of :heir population.

537.311.33:539.23 3761

**Vapour-Deposited Films of Semiconducting III-V Compounds**—K. G. Günther. (*Naturwiss.*, vol. 45, pp. 415–416; September, 1958.) See 3349 of October.

537.311.33:546.23:537.533.8 3762

**Measurements of Secondary Electron Emission from Selenium**—G. Oertel. (*Ann. Phys.* (*Lpz*)., vol. 1, pp. 305–318; June 2, 1958.) A static and a dynamic method of measurement are used to determine the temperature dependence of secondary emission and the energy distribution of secondary electrons as a function of doping with Br and Te.

537.311.33:546.24 3763

**The Band Structure of Tellurium**—A. Pires de Carvalho. (*Compt. rend. Acad. Sci., Paris*, vol. 248, pp. 778–781; February 9, 1959.)

537.311.33:[546.28+546.289 3764

**On the Distinction between Recombination Centres and Trapping Levels**—V. L. Bonch-Bruevich. (*Zh. Tekh. Fiz.*, vol. 28, pp. 67–69; January, 1958.) This distinction which is examined for Ge and Si samples, does not appear to be of an absolute character but to depend on the properties of impurities, the temperature, the method of preparation of the sample and the condition of injection. Trapping levels seem most likely to occur near the middle of the forbidden zone.

537.311.33:[546.28+546.289 3765

**On Reflection Coefficients of Germanium and Silicon Crystals**—V. S. Vavilov, A. A. Gippins and M. M. Gorshkov. (*Zh. Tekh. Fiz.*, vol. 28, pp. 254–255; February, 1959.) A note on the optical properties of Ge and Si surfaces.

537.311.33:[546.28+546.289 3766

**Reflecting Power of Bulk Silicon and Germanium between 1000 and 3000 Å**—S. Robin-Kandare and B. Vodar. (*Compt. rend. Acad. Sci., Paris*, vol. 248, pp. 1965–1967; April 1, 1959.)

537.311.33:[546.28+546.289 3767

**Growth of Large-Diameter Silicon and Germanium Crystals by the Teal-Little Method**—W. R. Runyan. (*Rev. Sci. Instr.*, vol. 30, pp. 535–540; July, 1959.) The equipment and techniques used to grow crystals of 6 inch diameter are described, and the effect of spin, radiation, and mode of heating on crystal growth from a melt is discussed.

537.311.33:[546.28+546.289] 3768

**Distribution of Slow Traps on the Surface of Germanium and Silicon with Reference to Relaxation Time**—I. I. Abkevich. (*Dokl. Akad. Nauk SSSR.* vol. 127, pp. 1199–1202; August 21, 1959.) The time dependence of the contact potential after illumination of a freshly etched specimen and the time dependence of excess charges in slow surface traps are shown graphically. The capture of electrons in surface slow traps before illumination produces an electric field which lowers the barrier between traps and bulk of the sample decreasing the relaxation time of the traps.

537.311.33:546.28 3769

**Lifetimes and Capture Cross-Sections in Gold-Doped Silicon**—W. D. Davis. (*Phys. Rev.*, vol. 14, pp. 1006–1008; May 15, 1959.) The amplitude of the voltage pulses produced by α-particles was measured as a function of applied electric field, and the cross-sections for hole and electron capture at the gold sites deduced. The results were $2\times10^{-15}cm^2$ and $10^{-13}cm^2$ for neutral and oppositely charged sites respectively, for either holes or electrons.

537.311.33:546.28 3770

**Microplasma Fluctuations in Silicon**—K. S. Champlin. (*J. Appl. Phys.*, vol. 30, pp. 1039–1050; July, 1959.) The electrical properties of a fluctuating bistable microplasma are specified by three parameters which, in general, are functions of voltage. For an ideal low-impedance connection, these parameters are independent of time and thus yield simple forms for the pulse rate, average current differential conductance, and noise spectral density. With a high-impedance circuit the phenomenon is more complex, and only an approximate analysis is offered.

537.311.33:546.281.26:061.3 3771

**Semiconducting Silicon Carbide**—H. K. Henisch. (*Nature*, vol. 184, pp. 158–159; July 18, 1959.) Brief report of a conference held at Boston, Mass., April, 1959, to discuss the preparation, properties and applications of SiC.

537.311.33:546.289 3772

**A New Study of the L-Spectrum of Germanium**—A. Lucasson-Lemasson. (*Compt. rend. Acad. Sci., Paris*, vol. 248, pp. 1156–1158; February 23, 1959.)

537.311.33:546.289 3773

**Influence of High-Energy Electron Bombardment on the Conductivity of Germanium**—N. Van Dong, L. Koch, P. Baruch and P. Andre. (*Compt. rend. Acad. Sci., Paris*, vol. 248, pp. 788–791; February 9, 1959.) Report of an anomalous increase in the short-circuit current of a Ge junction when bombarded by high-energy electrons at 100°K. This effect may be explained by the Shockley-Read recombination theory if displacement of the Ferni level during bombardment is taken into account.

537.311.33:546.289 3774

**Microwave Techniques in Measurement of Lifetime in Germanium**—A. P. Ramsa, H. Jacobs and F. A. Brand. (*J. Appl. Phys.*, vol. 30, pp. 1054–1060; July, 1959.) "New techniques are proposed for the measurement of lifetime in semiconductors by utilizing the absorption of microwave power by charge carriers. The densities of holes and electrons are varied by irradiation with light or the conduction mechanism. Agreement is found when the microwave absorption methods are compared with the more established photoconductivity decay techniques. One of the new methods offers an advantage in that electrode attachments are no longer required."

537.311.33:546.289 3775

**Electron-Spin-Resonance Experiments on Shallow Donors in Germanium**—G. Feher, D. K. Wilson and E. A. Gere. (*Phys. Rev. Lett.*, vol. 3, pp. 25–28; July 1, 1959.) Resonances have been observed from both bound and nonlocalized electrons. Results indicate that the ground state of the As and P donors in Ge is a singlet.

537.311.33:546.289:537.32 3776

**Volume Peltier Effect in Germanium**—P. I. Baranskiĭ. (*Zh. Tekh. Fiz.*, vol. 28, pp. 225–230; February, 1959.) A method is described for investigating the Peltier effect produced by imperfections in Ge single crystals. The current characteristic is linear and it is established that the measured thermo-EMF is a voluum gradient effect.

537.311.33:546.289:538.63 3777

**Hot-Electron Behaviour in Germanium under the Influence of a Magnetic Field**—L. Gold. (*Phys. Rev.*, vol. 114, pp. 691–704; May 1, 1959.) Theory developed using a model based on individual ellipsoidal energy surfaces is extended to investigate the anistropy existing with a superposed field.

537.311.33:546.47-31 3778

**Surface Potential, Field-Effect Mobility, and Surface Conductivity of ZnO Crystals**—H. J. Krusemeyer. (*Phys. Rev.*, vol. 114, pp. 655–664; May 1, 1959.)

537.311.33:546.49.241 3779

**Some Properties of Mercuric Telluride**—H. Fumeron-Rodot and M. Rodot. (*Compt. rend. Acad. Sci., Paris*, vol. 248, pp. 937–940; February 16, 1959.) A study of the thermomagnetic properties of specimens of HgTe with an electron mobility of $2.2\times10^4 cm^2/v.sec$ at room temperature indicates that mobility is limited by collisions between electrons and acoustic phonons.

537.311.33:546.682.86 3780

**Investigation of Thin Layers of Variable Composition in the Indium-Antimony System**—G. A. Kurov and Z. G. Pinsker. (*Zh. Tekh.*

*Fiz.*, vol. 28, pp. 29–34; January, 1958.) A metastable amorphous phase of Sb has been found in a mixture with crystalline particles of InSb in layers 1–2$\mu$ thick. In such layers, investigations have been made of a) the temperature dependence of conductivity, b) the abnormally low mobility of the charge carriers.

**537.311.33:546.682.86** 3781
**Semiconductivity Experiments on Hot Electrons in InSb. Application to the Construction of an Oscillator**—J. Bok and R. Veilex. (*Compt. rend. Acad. Sci., Paris*, vol. 248, pp. 2300–2302; April 20, 1959.) "Hot" carriers which have an energy sufficient to create new carriers occur when InSb is subjected to a strong electric field. Under pulse conditions at 77°K and in the presence of a longitudinal magnetic field of ~1200 oersteds, the upper part of the $V/I$ characteristic has a negative slope. An oscillator based on this effect has been constructed, operating in the range 5–30 mc; it may be modified to give frequencies as high as 1200 mc. A second oscillation at low electric field strengths (~40 v/cm) was also observed.

**537.311.33:546.682.86:535.215** 3782
**Photoanodization of InSb**—J. D. Venables and R. M. Broudy. (*J. Appl. Phys.*, vol. 30, pp. 1110–1111; July, 1959.) It was observed that the InSb anodization process is sensitive to visible light of wavelength shorter than approximately 5200Å.

**537.311.33:546.714–31** 3783
**Influence of Foreign Ions on the Semiconductivity of the Dioxides of Manganese**—J. P. Chevillot and J. Brenet. (*Compt. rend. Acad. Sci., Paris*, vol. 248, pp. 776–778; February 9, 1959.) Measurements in the 20–80°C temperature range indicate that the influence of $Th^{4+}$ ions in the lattice does not modify the intrinsic character but greatly diminishes the semiconductivity of both $\beta$-$MnO_2$ and $\gamma$-$MnO_2$.

**537.311.33:546.817–31** 3784
**The Electrical Conductivity of Lead (II) Oxide with Additions of Higher-Valency Impurity Cations**—H. Grunewald and W. Neumann. (*Ann. Phys. (Lpz.)*, vol. 1, pp. 344–350; June 2, 1958.) Investigations were made on PbO with additions of $Cr_2O_3$, $Nd_2O_3$ and $CeO_2$ in the temperature range 200°C–500°C.

**537.311.33:546.873.241** 3785
**Stoichiometry of Bismuth Telluride and Related Compounds**—G. Offergeld and J. van Cakenberghe. (*Nature*, vol. 184, suppl. no. 4, pp. 185–186; July 18, 1959.)

**537.311.33:548.5** 3786
**X-Ray Method for the Differentiation of {111} Surfaces in $A^{III}B^{V}$ Semiconducting Compounds**—E. P. Warekois and P. H. Metzger. (*J. Appl. Phys.*, vol. 30, pp. 960–962; July, 1959.)

**537.311.33:621.314.63** 3787
**Equilibrium Distribution of Field Potential and Concentration of Charge Carriers in Fused-In Junctions**—E. I. Aditovich, Yu. S. Ryabinkin and K. V. Temko. (*Zh. Tekh. Fiz.*, vol. 28, pp. 55–66; January, 1958.) Mathematical analysis, based on a differential equation suggested by Shockley, for semiconductors with *p-n* or *p-i* junctions and in a state of thermodynamic equilibrium.

**537.311.33:621.383.5** 3788
**Transient Response of Grain Boundaries and its Application for a Novel Light Sensor**—R. K. Mueller. (*J. Appl. Phys.*, vol. 30, pp. 1004–1010; July, 1959.) The negative surface charge carried by grain boundaries in *n*-type Ge and Si constitutes a potential barrier for electrons, the height of which can be increased by applying an electrical pulse across the boundary or decreased by injecting holes. The relaxation time with which the perturbed barrier returns to its equilibrium value is, for sufficiently low temperatures, very large compared to the time necessary to change the barrier height. A theory of the transient response is given together with a description of a novel photosensor based on this phenomenon.

**537.533.8:546.74** 3789
**Secondary Electron Emission from Nickel**—A. R. Shul'man, I. R. Zakirova, Yu. A. Morozov and S. A. Fridrikhov. (*Zh. Tekh. Fiz.*, vol. 28, pp. 87–96; January, 1958.) An investigation of the energy distribution of secondary electrons emitted by Ni for primary electrons in the range 200–2000v. The number of secondary electrons with energies>100ev is >20 per cent.

**538.22** 3790
**Magnetic Investigations on Pd mixed Crystals with Transition Elements**—D. Gerstenberg. (*Ann. Phys. (Lpz)*, vol. 2, pp. 236–262; November 11, 1958.) The results of susceptibility measurements in the temperature range 90°–1100°K are discussed.

**538.22:538.569.4** 3791
**Antiferromagnetic Resonance in $MnF_2$**—F. M. Johnson and A. H. Nethercot, Jr. (*Phys. Rev.*, vol. 114, pp. 705–716; May 1, 1959.) Report and discussion of the results of measurements in the frequency range 96–247.2 kmc from 4.2° to 64°K.

**538.22:538.569.4:549.517.13** 3792
**Polarization of the $Al^{27}$ Nuclei in Ruby**—J. A. Cowen, W. R. Schafer and R. D. Spence. (*Phys. Rev. Lett.*, vol. 3, pp. 13–14; July 1, 1959.) Either enhanced absorption or strong emission is observed in components of the Al nuclear resonance by driving a microwave transition of the Cr impurity. Results can be explained in terms of a dynamic polarization process.

**538.22:538.569.4:549.517.13** 3793
**Ruby as a Maser Material**—C. Kikuchi, J. Lambe, G. Makhov, and R. W. Terhune. (*J. Appl. Phys.*, vol. 30, pp. 1061–1067; July, 1959.) "The reasons for the initial choice of ruby as a maser material are outlined and some measurements of the parameters in the spin Hamiltonian and of spin relaxation times are reported. The relative merits of single- and double-pump modes of operation of a four-level maser are discussed and measurements of the oscillator power for the two cases are included."

**538.221** 3794
**The Influence of Carbon Inclusions on the Mobility of Bloch Walls**—B. Rothenstein and J. Hrianca. (*Naturwiss.*, vol. 45, pp. 359–360; August, 1958.) Tests on iron wire show that Bloch-wall mobility increases with a reduction of carbon in solid solution.

**538.221** 3795
**The Influence of Temperature on the Law of Distribution of Ferromagnetic Domains from the Point of View of Coercive Force**—B. Rothenstein and J. Hrianca. (*Naturwiss.*, vol. 45, pp. 507–508; November, 1958.) Results of measurements on high-purity Ni specimens are discussed.

**538.221** 3796
**Measurement of the Noise from Cyclic Remagnetization of Ferromagnetic Substances at Low Temperatures**—N. N. Kolachevskiĭ. (*Zh. Eksp. Teor. Fiz.*, vol. 36, pp. 401–403; February, 1959.) An investigation in the temperature range 2 to 300°K revealed no dependence of noise on temperature.

**538.221** 3797
**Magnetic Annealing in Perminvar: Part 1—Structural Origin**—R. D. Heidenreich, E. A. Nesbitt and R. D. Burbank. (*J. Appl. Phys.*, vol. 30, pp. 995–1000; July, 1959.) A structural model is presented, based on an interpretation of electron-diffraction results, magnetic properties and oxygen content.

**538.221** 3798
**Magnetic Annealing in Perminvar: Part 2—Magnetic Properties**—E. A. Nesbitt and R. D. Heidenreich. (*J. Appl. Phys.*, vol. 30, pp. 1000–1003; July, 1959.) Faults form as a result of heat treatment in the temperature range at which magnetic annealing is effective. This is attributed to small amounts of oxygen as an impurity.

**538.221:537.311.33** 3799
**Magnetic Properties of the System $Ni_{(1-x)}Li_xO$ between 80 and 300°K**—N. Perakis, J. Wucher and G. Parravano. (*Compt. rend. Acad. Sci., Paris*, vol. 248, pp. 2306–2308; April 20, 1959.) Experimental results for $x=0.2$ and $x=0.3$ are discussed.

**538.221:537.533.7** 3800
**Electron Mirror Microscopy of Magnetic Stray Fields on Grain Boundaries**—L. Mayer. (*J. Appl. Phys.*, vol. 30, pp. 1101–1104; July, 1959.)

**538.221:537.533.73** 3801
**Magnetic and Crystallographic Analysis by Electron Diffraction**—S. Yamaguchi. (*Nuovo Cim.*, vol. 12, pp. 286–289; May 1, 1959. In English.) The diffraction patterns of a ferromagnetic specimen and of gold are superposed by a double-exposure technique and the diffraction-ring eccentricity is measured, from which the magnetization may be calculated.

**538.221:538.569.4** 3802
**Magnetic Resonance of Polycrystalline Cobalt at 3,500 Mc/s as a Function of Temperature**—G. Asch. (*Compt. rend. Acad. Sci., Paris*, vol. 248, pp. 781–784; February 9, 1959.) The resonance field is a maximum and the line width a minimum at 260°C. At this temperature the anisotropy energy is a minimum.

**538.221:538.632** 3803
**Crystal Anisotropy and Magnetostriction with the Hall Effect in Ferromagnetic Materials**—W. Jellinghaus and M. P. de Andrés. (*Naturwiss.*, vol. 45, p. 508; November, 1958.) Hall-effect measurements on 3.3 per cent-Si laminations indicate the anisotropy of carrier mobility in ferromagnetic crystals. The effect of elastic tension in the direction of current flow on the magnitude of the magnetization-dependent Hall effect is investigated for four different materials.

**538.221:539.23** 3804
**The Magnetic Properties of Electrolytically Produced Thin Nickel Films**—W. Ruske. (*Ann. Phys., (Lpz.)*, vol. 2, pp. 274–286; November 11, 1958.) Hysteresis loops were obtained for the thickness range 20–20,000Å to determine the dependence of magnetic properties on film thickness and structure, and on treatment.

**538.221:539.23** 3805
**The Temperature Dependence of the Electrical Resistance of Nickel-Copper and Nickel-Chromium Alloys and of Thin Nickel and Palladium Vapour-Deposited Films, the Ferromagnetic Resistance Anomaly and the Curie Temperature**—H. J. Bauer. (*Z. Phys.*, vol. 153, pp. 484–507; December 22, 1958.)

**538.221:621.318.124** 3806
**On the Variation of Magnetization of Uniaxial Substances as a Function of the Field; Application to $6Fe_2O_3.BaO$**—V. S. Giron and

R. Pauthenet. (*Compt. rend. Acad. Sci., Paris*, vol. 248, pp. 943–946; February 16, 1959.) A graphical method is described for determining magnetization curves for all values of field.

538.221:621.318.124:537.226 3807

**Anisotropy of the Dielectric Properties of Oriented Barium Ferrite**—J. Rupprecht and C. Heck. (*Naturwiss.*, vol. 45, p. 511; November, 1958.) Preliminary report on measurements of dielectric constant and loss factor as a function of frequency in the range 60 kc – 30 mc.

538.221:621.318.134 3808

**Effect of a Small Proportion of Cobalt on the Magnetic Dispersion of Nickel-Zinc Ferrites**—A. Marais. (*Compt. rend. Acad. Sci., Paris*, vol. 248, pp. 2303–2305; April 20, 1959.)

538.221:621.318.134 3809

**Geometrical Anisotropy of Magnetic Materials in Waveguides and Cavities**—L. A. Steinert. (*J. Appl. Phys.*, vol. 30, p. 1109; July, 1959.) A general derivation for the effective susceptibilities of ellipsoidal isotropic ferrite samples in uniform magnetic fields.

538.221:621.318.134:538.569.4 3810

**Ferrite Line Width Measurements in a Cross-Guide Coupler**—D. C. Stinson. (IRE Trans. on Microwave Theory and Techniques, vol. MTT-6, pp. 446–450; October, 1958. Abstract, Proc. IRE, vol. 47, p. 113; January, 1959.)

538.221:621.318.134:538.569.4 3811

**Effects of Rare-Earth Impurities on Ferrimagnetic Resonance in Yttrium Iron Garnet**—J. F. Dillon, Jr., and J. W. Nielsen. (*Phys. Rev. Lett.*, vol. 3, pp. 30–31; July 1, 1959.) Experimental data are given for several rare-earth-doped crystals.

538.221:621.318.134:538.569.4 3812

**Low-Temperature Line-Width Maximum in Yttrium Iron Garnet**—E. G. Spencer, R. C. LeCraw and A. M. Clogston. (*Phys. Rev. Lett.*, vol. 3, pp. 32–33; July 1, 1959.)

538.221:621.318.134:538.569.4 3813

**Identification of the Magnetostatic Modes of Ferrimagnetic Resonant Spheres**—P. Fletcher, I. H. Solt, Jr., and R. Bell. (*Phys. Rev.*, vol. 114, pp. 739–745; May 1, 1959.) A detailed comparison between the magnetostatic theory and experimental observation.

538.221:621.318.134:538.569.4.08 3814

**Direct Measurement of the Width of the Resonance Curves of Ferromagnetic Materials**—R. Vautier and A. J. Berteaud. (*Compt. rend. Acad. Sci., Paris*, vol. 248, pp. 1957–1959; April 1, 1959.) A simple method is described for determining $\Delta H$ from cavity measurements without plotting the complete absorption/field-strength curve. Its application to Y-Fe garnet is noted.

538.221:621.318.134:621.317.3 3815

**Investigation of the Properties of Ferrites at Radio Frequencies**—I. Teodorescu. (*Telecommunicatii*, vol. 2, pp. 108–113; May/June, 1958.) An experimental method for measurements in very weak RF fields is described. Certain phenomena not observed by other methods are noted.

538.569.4:534.133–8 3816

**Effects of 9.2-kMc/s Ultrasonics on Electron Spin Resonances in Quartz**—E. H. Jacobsen, N. S. Shiren and E. B. Tucker. (*Phys. Rev. Lett.*, vol. 3, pp. 81–83; July 15, 1959.) The electron-spin-resonance signal is observed as a function of the power and frequency of the ultrasonic vibrations and of the spectrometer power.

538.569.4:534.14–8 3817

**Excitation of Hypersonic Waves by Ferromagnetic Resonance**—H. Bömmel and K. Dransfeld. (*Phys. Rev. Lett.*, vol. 3, pp. 83–84; July 15, 1959.) The experimental arrangement for observing waves emitted from a Ni film deposited on a quartz surface is described. The excitation mechanism in this and other cases is considered.

621.315.616 3818

**Investigation of the Temperature Dependence of Dielectric Losses and Permittivity of Polymers in the Centimetre Range ($\lambda = 3.3 - 10$ cm): Parts 1 and 2**—G. P. Mikhaĭlov and A. M. Lobanov. (*Zh. Tekh. Fiz.*, vol. 28, pp. 267–278; February, 1959.) Report of measurements made in the temperature range −100° to +200°C using a short-circuited waveguide with the sample located at the short circuit.

## MEASUREMENTS AND TEST GEAR

621.317.337:621.372.413 3819

**Microwave Q Measurements in the Presence of Coupling Losses**—E. L. Ginzton. (IRE Trans. on Microwave Theory and Techniques, vol. MTT-6, pp. 383–389; October, 1958. Abstract, Proc. IRE, vol. 47, pp. 112–113; January, 1959.)

621.317.34:621.372.21 3820

**Measuring the Capacitance per Unit Length of Two Infinite Cones of Arbitrary Cross Section**—J. D. Dyson. (IRE Trans. on Antennas and Propagation, vol. AP-7, pp. 102–103; January, 1959. Abstract, Proc. IRE, vol. 47, p. 611; April, 1959.)

621.317.34:621.372.832.43 3821

**A Method for Measuring the Directivity of Directional Couplers**—G. E. Schafer and R. W. Beatty. (IRE Trans. on Microwave Theory and Propagation, vol. MTT-6, pp. 419–422; October, 1958. Abstract, Proc. IRE, vol. 47, p. 113; January, 1959.)

621.317.34:621.372.852.4 3822

**Equipment for the Investigation of Polarization Properties of Transmission Elements in the 4-Gc/s Region**—Baur. (*See* 3564.)

621.317.4:538.7:538.569.4 3823

**Measurement of the Terrestrial Magnetic Field by means of a Nuclear-Resonance Maser**—H. Benoit and J. Hennequin. (*Compt. rend. Acad. Sci., Paris*, vol. 248, pp. 1991–1993; April 1, 1959.) Experiments on the measurement of a field modified by an electromagnet are described and show that the weak-field maser (2548 of August, Benoit *et al.*) may be useful for measuring the geomagnetic field.

621.317.42:538.569.4 3824

**High-Precision Measurement of the Average Value of a Magnetic Field over an Extended Path in Space**—C. Sherman. (*Rev. Sci. Instr.*, vol. 30, pp. 568–575; July, 1959.) A nuclear-magnetic-resonance technique is used to measure the change in excitation of nuclei contained in a liquid flowing through the space under investigation.

621.317.729.1 3825

**Anisotropic Field Plotting in the Electrolytic Tank**—D. A. Jones. (*Rev. Sci. Instr.*, vol. 30, pp. 577–578; July, 1959.) Anisotropic field problems are simulated in an electrolytic tank by varying the resistance to motion of the electrolyte along two axes.

621.317.75:681.142 3826

**Statistical Analysis of Noise-Signal Amplitudes**—D. Hoffman and E. Schutzman. (*Electronics*, vol. 32, pp. 48–49; July 24, 1959.) A system is described which provides digital data from which the amplitude probability distribution and the probability density functions can be plotted.

621.317.755 3827

**The Use of Pre-pulse Techniques in High-Speed Oscillography**—F. E. Whiteway. (*J. Brit. IRE*, vol. 19, pp. 439–449; July, 1959.) The frequency range of conventional oscilloscopes and associated amplifiers can be extended by switching into a high-current operating condition for a very short part of the duty cycle. Pre-pulse time bases and generators are discussed and a four-valve amplifier with 140-mc bandwidth and a gain of 360 is described.

621.317.755 3828

**Sample Method displays Millimicrosecond Pulses**—W. E. Bushor. (*Electronics*, vol. 32, pp. 69–71; July 31, 1959.) Circuit details of an oscilloscope capable of displaying pulses of rise time 0.4 mμs. The sensitivity achieved is better than 3 mv/cm.

621.317.78.029.62 3829

**Measurement of Pulsed Powers at Metre Wavelengths**—A. Dumont and H. d'Hoop. (*Rev. HF, Brussels*, vol. 4, No. 5, pp. 119–123; 1959.) A description of a direct-reading transistorized peak voltmeter for the measurement of incident and reflected power. The instrument is calibrated from a calorimetric measure of the HF pulse power developed in an oil-cooled load.

631.317.794 3830

**Microwave Power Detectors**—R. Stata. (*Electronics*, vol. 32, p. 59; July 17, 1959.) Two tables summarize the basic characteristics of crystal rectifiers, barretters, and thermistors for the detection or measurementof microwave power.

621.317.794 3831

**Designing a Power Density Meter**—A. Borck. (*Electronics*, vol. 32, pp. 66–69; July 17, 1959.) Discussion of dipole and horn probes, attenuators and detectors for measurements in the near-field zone of high-power microwave transmitting antennas.

## OTHER APPLICATIONS OF RADIO AND ELECTRONICS

537.533.35(091) 3832

**Electron Microscopy**—E. Ruska. (*VDI Z.*, vol. 101, pp. 1106–1109; August 11, 1959.) A review covering developments since 1957. 56 references. See also 1512 of 1958.

537.54:629.1.03 3833

**Plasma Engine Verifies Theory**—(*Electronics*, vol. 32, pp. 86–89; July 31, 1959.) A machine has been constructed consisting of two electrodes, one opened into a nozzle, and based on the magnetic acceleration of a plasma or pinch-effect principle to obtain thrust. The performance of such a machine in a space vehicle is discussed.

616:621.3.083.7:621.314.7 3834

**The Ingestible Intestinal Transmitter for Signalling pH Values**—M. von Ardenne and H. B. Sprung. (*Naturwiss.*, vol. 45, pp. 564–565; December, 1958.) The transmitter, which is 28 mm long and 8 mm in diameter, operates at 1.9 mc; this frequency increases linearly with pH value with a maximum rise of 13 kc corresponding to 8.5 pH units. See also 1327 of April.

621.384.61 3835

**Cyclic Motion of Charged Particles in an Electric Field**—A. A. Kolomenskiĭ and Fan Shou-syan'. (*Zh. Eksp. Teor. Fiz.*, vol. 36, pp.

271–276; January, 1959.) A mathematical treatment of particle trajectories in a system of strong- or weak-focusing lenses. Resonance acceleration of the particles and their phase stability are considered. The effect of em radiation on the motion of electrons is examined.

621.384.622.2 3836
**The Multifactor Effect in a Linear Electron Accelerator**—V. J. Vanhuyse, J. L. Veshaeghe and J. Turf. (*Nuovo Cim.*, vol. 10, pp. 721–727; November 16, 1958. In English.) More detailed treatment of the effect reported earlier (1329 of April, Vanhuyse).

621.384.612 3837
**On the Maximal Energy and Intensity of the Electrons Accelerated by the Microtron**—F. Porreca. (*Nuovo Cim.*, vol. 11, pp. 283–286; January 16, 1959. In English.)

621.385.833 3838
**Spherical Aberration in Weakly Convergent Magnetic Lenses**—P. Durandeau, B. Fagot and C. Fert. (*Compt. rend. Acad. Sci., Paris*, vol. 248, pp. 946–949; February 16, 1959.) The coefficient of spherical aberration is given for a series of thin magnetic lenses both symmetrical and asymmetrical.

629.19.053:621.375.4 3839
**Guidance Systems in Manned Space Flight**—S. T. Cap and N. P. White. (*Electronics*, vol. 32, pp. 49–51; August 14, 1959.) A description of a complete inertial guidance system is given, with details of the transistorized amplifiers in the integrating circuits. Ten Si transistors are used to give a gain of 250000. Error in computation due to the amplifier is less than 0.01 per cent. Negative feedback is applied over each stage.

## PROPAGATION OF WAVES

621.396.11 3840
**On Statistic Theory of Radio Wave Propagation over an Ideally Conducting Plane**—E. A. Kaner and F. G Bass. (*Dokl. Akad. Nauk. SSSR*, vol. 27, pp. 792–795; August 1, 1959.) Computation of statistical characteristics of the em field propagating in a medium with small random fluctuations of permittivity over an ideally conducting half space, the medium above the dividing surface being statistically uniform.

621.396.11 3841
**Propagation of Radio Waves along an Inhomogeneous Surface**—E. L. Feinberg. (*Nuovo Cim.*, vol. 11, suppl. 1, pp. 60–91; 1959. In English.) From a study of classical theory a fundamental integral equation for a field at the earth's surface is derived. The equation is used as a basis for the development of formulas relevant to propagation over a flat or a spherical earth with homogeneous or inhomogeneous surfaces. Results for inhomogeneous paths are compared with those obtained by semi-empirical methods. An application of the theory was described by Boudouris (236 of 1958.)

621.396.11 3842
**Propagation of a Ground-Wave Pulse around a Finitely Conducting Spherical Earth from a Damped Sinuisoidal Source Current**—J. R. Johler and L. C. Walters. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-7, pp. 1–10; January, 1959. Abstract, PROC. IRE, vol. 47, pp. 609–610; April, 1959.)

621.396.11 3843
**Back-Scattering Measurements with a Space-Separation Method**—H. J. Schmitt. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-7, pp. 15–22; January, 1959. Abstract, PROC. IRE, vol. 47, p. 610; April, 1959.)

621.396.11 3844
**Scattering of a Surface Wave by a Discontinuity in Reactance**—A. F. Kay. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-7, pp. 22–31; January, 1959. Abstract, PROC. IRE, vol. 47, p. 610; April, 1959.)

621.396.11:550.389.2:629.19 3845
**Refraction of Very-High-Frequency Radio Signals at Ionospheric Heights**—Weisbrod and Colin. (*See* 3698.)

621.396.11:551.510.52 3846
**Theoretical Research on Tropospheric Scatter Propagation in the United States, 1954–1957**—H. Staras and A. D. Wheelon, (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-7, pp. 80–87; January, 1959. Abstract, PROC. IRE, vol. 47, p. 610; April, 1959.)

621.396.11:551.510.535 3847
**Nonlinear Interaction of Radio Waves Propagating in a Plasma**—V. L. Ginzburg. (*Zh. Eksp. Teor. Fiz.*, vol. 35, pp. 1573–1575; December, 1958.) Mathematical note on nonlinear effects in the interaction of radio waves in the ionosphere: a) the usual "quadratic" effect, giving rise to combination frequencies $\omega' \pm 2\omega$, where $\omega'$ is the frequency of a weak signal propagated in a medium which is perturbed by a strong wave at frequency $\omega$; b) effects similar to those occurring in the scattering of transverse waves on plasma waves in an isotropic medium (see *e.g.* 3047 of 1958, Akhiezer *et al.*), which give rise to combination frequencies $\omega' \pm \omega$.

621.396.11:551.510.535 3848
**New Geometrical Properties and their Usefulness for Ionospheric Radio Propagation**—K. Toman. (PROC. IRE, vol. 47, pp. 1381–1382; August, 1959.) The geometrical properties dealt with concern the intercept which a straight line passing through a fixed point $P$ makes between two concentric circles. If absorption of a signal reaching the earth from a satellite is proportional to the length of this intercept, the thickness of the absorbing layer can then be calculated. Other consequences of the geometry are discussed.

621.396.11:551.510.535:550.38 3849
**The Geometry of the Earth's Magnetic Field at Ionospheric Heights**—G. H. Millman. (*J. Geophys. Res.*, vol. 64, pp. 717–726; July, 1959.) Assuming the earth's magnetic field to be approximated by a centred magnetic dipole, the technique of matrix-coordinate transformations is used to develop a method for determining the angle between the earth's magnetic field and the direction of propagation of a radio wave for any geographic location and azimuth and elevation angle of transmission.

621.396.11.029.62 3850
**Particularities of Ultra-Short-Wave Propagation in Towns**—G. Ionescu. (*Telecomunicatii*, vol. 2, pp. 128–137; May/June, 1958.) Note of measurements made in Bucharest to determine field-strength contours at frequencies of 50, 70 and 100 mc. The minimum transmitter power for television or FM coverage is calculated with reference to the mean noise level.

## STATIONS AND COMMUNICATION SYSTEMS

621.376.3/.4 3851
**Power in an Angle-Modulated Wave**—W. C. Vaughan. (*Electronic Radio Eng.*, vol. 36, pp. 289–291; August, 1959.) Two mathematical proofs are given which confirm that a negligible amount of power is required to modulate the angle of a sinusoidal carrier by a sinusoidal signal.

621.391 3852
**The Fundamental Theorems of Information Theory Particularly in Telecommunications**—H. Wolter. (*Arch. elekt. Übertragung*, vol. 12, pp. 335–345; August, 1958.) An ambiguity in the proof of Shannon's sampling theorem and the contradictions involved in the assumption of sharp frequency limits are discussed. An equation is derived for determining the time function at the input of a communication channel of given bandwidth from the time function measured at the output. Electronic computer circuits are described which solve this equation automatically and can therefore effectively expand the channel bandwidth to any desired value.

621.391 3853
**A Physical Interpretation of Shannon's Ambiguity**—J. Loeb. (*Ann. Télécommun.*, vol. 13, pp. 78–82; March/April, 1958.) The Shannon "ambiguity" (1361 of 1949) is interpreted, for the case of Gaussian noise superposed on an AM signal, by a transitional probabilities matrix ("grille"). This method can also be applied to problems involving non-Gaussian noise or nonlinear circuit elements.

621.391:534.75 3854
**Definitions of $d'$ and $\eta$ as Psychophysical Measures**—W. P. Tanner, Jr., and T. G. Birdsall. (*J. Acoust. Soc. Amer.*, vol. 30, pp. 922–928; October, 1958.) The theory of signal detectability is reviewed to clarify the definitions of $d'$ and $\eta$. The efficiency $\eta$ is defined as the ratio of the energy required by an ideal receiver to the energy required by a receiver under study when the performance of the two is the same. The measure $d'$ is that value of $(2E/N_0)^{\frac{1}{2}}$ necessary for the ideal receiver to match the performance of the receiver under study, where $E$ is the energy of the signal and $N_0$ the noise power per unit bandwidth. The measure is extended to include the recognizability of two signals. Every set of signals is described by a Euclidean space in which distances are the square roots of the energy of the difference signal.

621.391:621.376.56 3855
**Speech Transmission with Quantization in Few Stages**—K. Küpfmüller and W. Andrich. (*Nachrichtentech. Z.*, vol. 11, pp. 389–392; August, 1958.) The optimum number and value of threshold levels on which quantization is based is determined experimentally. Four threshold levels are adequate for useful intelligibility.

621.395.741:621.3.018.78 3856
**A Contribution to the Law of Addition of Distortion Voltages in Long-Distance Communication Systems with Amplitude Modulation**—H. Zuhrt. (*Nachrichtentech. Z.*, vol. 11, pp. 424–428; August, 1958.) A numerical method of solving the formula derived by Steinbuch and Marko (2421 of 1955) is given; results obtained are better than those of the graphical method especially for systems with many repeaters.

621.396.5:534.76:621.396.82 3857
**F.M. Multiplex Spectra and Interference**—L. B. Arguimbau. (PROC. IRE, vol. 47, pp. 1372–1373; August, 1959.) Experiment shows that the theoretical widening of the transmitted spectrum brought about by the use of a subcarrier for stereophony has little effect on adjacent or alternate-channel interference.

621.396.65:621.396.812.3 3858
**Statistics of the Fading-Dependent Noise Power for Wide-Band Radio Links with Many Sections**—W. Hornuth. (*Arch. elekt. Übertragung*, vol. 12, pp. 346–356; August, 1958.) The C.C.I.R. reference circuit for wide-band radio links is considered and assumed to be divided into 45 sections of 55.6 km. Other assumptions include continental propagation conditions and

FM operation in the range 1–8 kmc. The received noise power is calculated for Rayleigh distribution of fading over the whole or part of the path, the rest of the sections being affected by fading of Gaussian distribution. A fading margin of 5 db per section is considered adequate. Theoretical results are compared with practical observations.

621.396.932 3859

**Mobile Maritime Service**—R. Gea Sacasa. (*Rev. Telecommun.* (*Madrid*), vol. 13, pp. 19–23; March, 1959.) Signal strength measurements at Cadiz of ship's transmissions at 4, 6, 8, 12 and 16 mc along the route Centa (Spanish Morocco)—Sidon (Lebanon) are analyzed with reference to forecasts by the Gea method (see *e.g.* 1339 of April).

621.396.934:621.398 3860

**Some Notes on Space Communications**—J. P. Costas. (Proc. IRE, vol. 47, pp. 1383–1385; August, 1959.) An analysis of telemetry systems is given; it is suggested that parallel data transmission (as in frequency-division multiplex) will be inferior to serial data transmission in space communication.

## SUBSIDIARY APPARATUS

621–52(047.1) 3861

**Control Techniques**—E. Krochmann. (*VDIZ.*, vol. 101, pp. 835–844; July 11, 1959.) Annual review covering investigations of control problems, methods of control, and regulating equipment. 209 references.

621.311.6:629.19 3862

**Silicon Solar Batteries as a Source of Electrical Supply in Artificial Earth Satellites**—V. S. Vavilov, V. M. Malovetskaya, G. N. Galkin and A. P. Landsman. (*Usp. Fiz. Nauk*, vol. 63, pp. 123–129; September, 1957.) Experiments using Si *p-n* junctions to convert solar radiation into electrical energy are described. Photoelements having a surface area of 5–8 $cm^2$ and a thickness of 0.7–1.0 mm were used. At sea level with the sun rays incident normally, an efficiency of 11 per cent was recorded corresponding to 100 w for an area of 1 $m^2$. With a solar constant of 0.135 w/$cm^2$, a Si plate exposed to the sun rays showed a temperature of 324° K.

621.314.63 3863

**Breakdown of Silicon Power Rectifiers**—M. A. Weston. (*Electronic Radio Eng.*, vol. 36, p. 313; August, 1959.) A description of a type of breakdown which can occur when Si junction rectifiers are used in series to rectify a high-frequency hv supply (700 v, 2400 cps). The cause was traced to minority-carrier storage effects and methods of overcoming it are described.

621.316.721.078:621.385.3 3864

**Elimination of the Effect of Thermal Delay of the Cathode on a Valve with Grid Compensation**—Y. Descamps. (*Compt. rend. Acad. Sci., Paris*, vol. 248, pp. 2076–2078; April 6, 1959.) The circuit described earlier (1369 of May, Curie and Descamps) is adapted for the compensation of transient fluctuations by means of an *RC* network which delays the application of the compensating voltage to the grid.

621.352 3865

**Magnesium-Bismuth Oxide Dry Cells**—C. K. Morehouse and R. Glicksman. (*J. Electrochem. Soc.*, vol. 106, pp. 61–63; January, 1959.) The cell construction and its performance characteristics are described. After an initial voltage drop, cells have a flat voltage discharge curve slightly above 1 v.

621.352 3866

**Zinc-Mercuric Dioxysulphate Dry Cell**—S. Ruben. (*J. Electrochem. Soc.*, vol. 106, pp. 77–78; February, 1959.) A cell is described which has the desirable characteristics of the mercuric oxide alkaline cell, the conventional construction of the dry cell and a relatively flat discharge characteristic at 1.3 v for loads within the rated current density.

## TELEVISION AND PHOTOTELEGRAPHY

621.397.5:621.395.625.3 3867

**Video Time-Delay Systems for International Television Program Exchange**—R. H. Snyder. (*J. Soc. Mot. Pic. Telev. Eng.*, vol. 68, pp. 135–136; March, 1959.) A general discussion of the use of tape recorders for the conversion of line and frame standards and for storing program material, with some details of the Ampex video tape recorder.

621.397.61:621.396.677 3868

**Transmitting Antennas for Television Broadcasting in the United Kingdom**—Brown. (*See* 3571.)

621.397.61.004.5 3869

**The Monitoring of Television Transmission Systems and Omnidirectional Transmitters**—O. Macek. (*Elektrotech. u. Maschinenb.*, vol. 76, pp. 321–327; July 1, 1959.) See also 2763 of August.

621.397.621:621.314.7 3870

**Transistorized Horizontal Deflection for Television**—M. Fischman. (*Electronics*, vol. 32, pp. 60–63; August 14, 1959.) A 90° horizontal deflection circuit and high-voltage generator using only two transistors and a diode is described.

621.397.621.2 3871

**Improvements in Television Receivers: Part 6a—Design Considerations for Stabilized Line Output Circuits**—D. Hoogmoed, A. Boekhorst and H. Heyligers. (*Electronic Applic.*, vol. 19, pp. 15–24; March, 1959.) An addendum to 3124 of September (Dammers *et al.*) giving a simplification of the procedure for plotting a combined nomogram and short notes on the influence of the beam current and the validity of the formula for anode dissipation of the line output tube.

## TRANSMISSION

621.376.3:621.396.61 3872

**A Frequency Modulator for Broadcasting Transmitters utilizing Overall Negative Feedback**—E. L. C. White. (*Proc. IEE* (London), Part B, vol. 106, pp. 408–416; July, 1959.) Existing techniques are reviewed and compared with the feedback method. A system using the latter method is described in detail.

621.396.61 3873

**A New Very-Low-Frequency C.W. Transmitter for Ionospheric Investigation—KM2XIX**—R. M. Golden, R. V. Langmuir, R. S. Macmillan and W. V. T. Rusch. (Proc. IRE, vol. 47, p. 1381; August, 1959.) An 8-mile section of a power transmission line is used as an antenna at 4–40 kc.

## TUBES AND THERMIONICS

621.314.63:546.817.221 3874

**Study of Current/Voltage Characteristics of n-p Contacts on Galena**—P. V. Khandekar and J. N. Das. (*Curr. Sci.*, vol. 26, pp. 386–387; December, 1957.) Earlier investigations (2560 of 1956, Bhide *et al.*) have been extended using an *n*-type crystal of PbS as a whisker contact on *p*-type material. The observed i/v characteristics, excluding the saturation region in the forward direction, are due to the *n-p* contact, and are in close agreement with theory for values of contact potential difference $\leq$0.25 v.

621.314.63:621.373.029.65 3875

**Experiment indicating Generation of Submillimetre Waves by an Avalanching Semiconductor**—A. Schleimann-Jensen. (Proc. IRE, vol. 47, pp. 1376–1378; August, 1959.) An embankment of semiconducting material was formed on an anode of low-melting-point metal by creating a corona discharge between it and a needle cathode 1$\mu$ distant. Eventually a steady current passes between anode and cathode, but this is subject to sudden jumps at certain voltages. This is believed to be associated with avalanche breakdown in the semiconductor and evidence is given that waves of wavelength 100$\mu$ are generated. For further notes see *Ibid.*, pp. 1378–1379.

621.314.63:621.396.822 3876

**An Investigation of the Properties of Germanium Mixer Crystals at Low Temperatures**—L. K. Anderson and A. Hendry. (IRE. Trans. on Microwave Theory and Techniques, vol. MTT-6, pp. 393–398; October, 1958. Abstract, Proc. IRE, vol. 47, p. 113; January, 1959.)

621.314.63.029.6 3877

**Recent Developments in Microwave Diodes**—E. J. Feldman. (*Sylvania Tech.*, vol. 11, pp. 71–75; April, 1958.) Specifications of several new crystal diodes are discussed including reversible-polarity and wide-band tripolar types.

621.314.7 3878

**An Investigation of the Dependence of the Current Gain of a Plane-Alloy-Junction Transistor on Emitter Current and Frequency**—F. J. Hyde. (*Proc. IEE* (London), Part B, vol. 106, pp. 391–396; July, 1959.) "The complex internal current gain, $\alpha_d$, of a diffusion-type germanium transistor has been derived from measurements of the external short-circuit current gain, $\alpha$, at frequencies up to 20 Mc/s and for emitter currents between 15$\mu$A and 3 mA, by taking account of the effects of the emitter and collector depletion-layer capacitances and the ohmic base resistance. The resulting frequency dependence of $\alpha_d$ is that expected from unidimensional diffusion theory. At low emitter currents, the flow of r.f. current in the emitter depletion-layer capacitance causes the cut-off frequency of $\alpha$ to be less than one-third that of $\alpha_d$."

621.314.7 3879

**Drift Transistors**—J. te Winkel. (*Electronic Radio Eng.*, vol. 36, pp. 280–288; August, 1959.) A development of equivalent circuits for drift transistors including approximations appropriate to limited frequency ranges and large values of the drift field. The resulting circuits are similar to those for alloy transistors.

621.314.7 3880

**An Investigation of the Current Gain of a Drift Transistor at Frequencies up to 105 Mc/s**—F. J. Hyde. (*Proc. IEE* (London), Part B, vol. 106, pp. 397–404; July, 1959.) A description of measurements of the complex internal short-circuit current gain of a Type-2N247 plane alloy-junction Ge transistor over a range of emitter current from 50 $\mu$a to 8 ma. The results are interpreted in terms of Kroemer's theoretical treatment based on the existence of a uniform drift field across the base.

621.314.7 3881

**High-Frequency Power Gain of the Drift Transistor**—F. J. Hyde. (*Proc. IEE* (London), Part B, vol. 106, pp. 405–407; July, 1959.) "Approximate expressions are derived for (*a*) the critical frequency above which the ideal transistor is unconditionally stable, and (*b*) the resulting maximum available gain, for the common-emitter configuration. These involve the internal cutoff frequency, the low-frequency emitter input conductance, the ohmic base resistance and the emitter and collector depletion-layer capacitances."

**621.314.7:546.289** 3882

**Calculation of the Dependence of the Current Amplification Factor on the Emitter Current in Germanium Transistors for Injection and Extraction at High Temperatures**—L. L. Makovskiĭ. (*Zh. Tekh. Fiz.*, vol. 28, pp. 52–54; January, 1958.) A theoretical interpretation of experimental results (599 of 1957, Stafeer *et al.*) showing that in Ge transistors the dependence of the current amplification factor on the emitter current is different at room temperature and at 90°C.

**621.314.7:621.318.57** 3883

**Two-Terminal p-n-p-n Switches**—J. M. Goldey. (*Bell Labs. Rec.*, vol. 37, pp. 223–226; June, 1959.) A note on the preparation of Si *p-n-p-n* transistors and their operation as regenerative-type switches.

**621.383:535.376:621.375.9** 3884

**Lumistors: Amplifiers of the Future**—C. F. Spitzer. (*Electronic Equipm. Engng.*, vol. 7, pp. 34–38; February, 1959.) An electroluminescent cell and a photoconductor have been combined into a device which will operate as an amplifier with a power gain of 40 db. Applications are suggested.

**621.383.5:621.3.011.4** 3885

**Use of Surface-Barrier Photodiodes as Fast-Response Photocapacitors**—E. Ahlstrom, W. G. Matthei and W. W. Gärtner. (*Rev. Sci. Instr.*, vol. 30, pp. 586–590; July, 1959.) The capacitance of a surface-barrier photo-diode comprising a gold film on *n*-type Si is plotted as a function of light intensity for different values of bias voltage and series resistance. An analysis to be published shows that the overall time constant may be reduced to millimicroseconds and further. Applications to photodetection using the parametric-amplifier principle are noted.

**621.385.029.6** 3886

**Paraxial Formulation of the Equations of Electrostatic Space-Charge Flow**—P. T. Kirstein. (*J. Appl. Phys.*, vol. 30, pp. 967–975; July, 1959.) Presents detailed analysis for beams from a space-charged-limited cathode in the form of a cone. The agreement between the paraxial theory and the exact theory for particular beams is investigated.

**621.385.029.6** 3887

**Improving Microwave Tube Efficiency**—D. Walsh. (*Electronics*, vol. 32, pp. 70–73; July 17, 1959.) Electron beams of that elliptical crosssection required by some microwave tubes are produced by passing a beam of circular crosssection through two successive magnetic lenses.

**621.385.029.6** 3888

**Some Characteristics of a Magnetically Focused Electron Beam**—G. R. Brewer. (*J. Appl. Phys.*, vol. 30, pp. 1022–1038; July, 1959.) Describes an experimental study of the detailed behaviour of a solid cylindrical electron beam focused by a uniform magnetic field. A simple model of the beam is used to explain certain of the observed characteristics.

**621.385.029.6** 3889

**Propagation of Electromagnetic Waves in Retarding Systems with a Helix and a Dielectric**—B. M. Bulgakov and V. P. Shestopalov. (*Zh. Tekh. Fiz.*, vol. 28, pp. 188–201; January, 1958.) Mathematical analysis for an electron beam in a helix located in a dialectric medium. Possible modifications in the design of this structure are discussed.

**621.385.029.6:621.372.413** 3890

**General Treatment of Klystron Resonant Cavities**—K. Fujisawa. (IRE Trans. on Antennas and Propagation, vol. MTT-6, pp. 344–358; October, 1958. Abstract, Proc. IRE, vol. 47, p. 112; January, 1959.)

**621.385.032.213.13** 3891

**Preconversion of Oxide Cathodes**—G. A. Haas and J. T. Jensen, Jr. (*Rev. Sci. Instr.*, vol. 30, pp. 562–565; July, 1959.) Reduction in the contamination of thermionic tube components and improved cathode emission characteristics are obtained if the oxide cathodes are preconverted in a separate envelope and then transferred to the final tube as the alkaline earth hydroxide.

**621.385.032.213.13** 3892

**Dissociation of Solid SrO by Impact of Slow Electrons**—G. E. Moore. (*J. Appl. Phys.*, vol. 30, pp. 1086–1100; July, 1959.) Positively and negatively charged dissociation products were identified using a mass spectrometer method.

**621.385.032.213.6** 3893

**High-Current-Density Thermionic Emitters: A Survey**—A. H. W. Beck. (*Proc. IEE* (London), Part B, vol. 106, pp. 372–388; July, 1959. Discussion, pp. 389–390.) "The steps leading to the development of modern emitters are described and the characteristics and operation of such emitters are discussed."

**621.385.032.269.1** 3894

**Theory of a Space-Charge-Limited-Crossed-Field Gun**—R. H. Bartram and M. C. Pease. (*Sylvania Tech.*, vol. 11, pp. 59–65; April, 1958.) A theoretical model for a single-trajectory electron beam is derived and applied to the design of a "ramp" gun. The advantages of this gun in improving the efficiency and tuning range of the backward-wave magnetron oscillator are discussed.

**621.385.1** 3895

**A Comparative Study of Cylindrical, Elliptical and Prismatic Forms of Electronic Tubes**—A. I. Vishnievsky, S. Sampath, and C. S. Upadhyay. (*J. Indian Inst. Sci.*, Section B, vol. 41, pp. 1–6; January, 1959.) An earlier study (3531 of October) is extended to cover the elliptical form. For the same electrostatic capacitance and for approximately the same space-charge-limited current, the prismatic form has the best "design parameter" but the elliptical form is structurally more stable.

**621.386.1** 3896

**Microphonic Effects in Electron Tubes**—D. Hoogmoed. (*Electronic Applic.*, vol. 19, pp. 25–44; March, 1959.) The causes, consequences and prevention of microphonic effects are discussed.

## MISCELLANEOUS

**061.4:621.37/.39** 3897

**National Radio Show**—(*Wireless World*, vol. 65, pp. 371–384; September, 1959.) A stand-by-stand report of the exhibition held in London, August 26–September 5, 1959.

**061.4:621.37/.39** 3898

**The German Radio Show**—(*Wireless World*, vol. 65, pp. 403–407; September, 1959.) A survey of the exhibition held in Frankfurt, August, 1959.

**621.37/.39(47)** 3899

**Soviet Equipment Design**—J. M. Carroll. (*Electronics*, vol. 32, pp. 37–39; July 24, 1959.) A review of current techniques and practice in industrial and domestic equipment.

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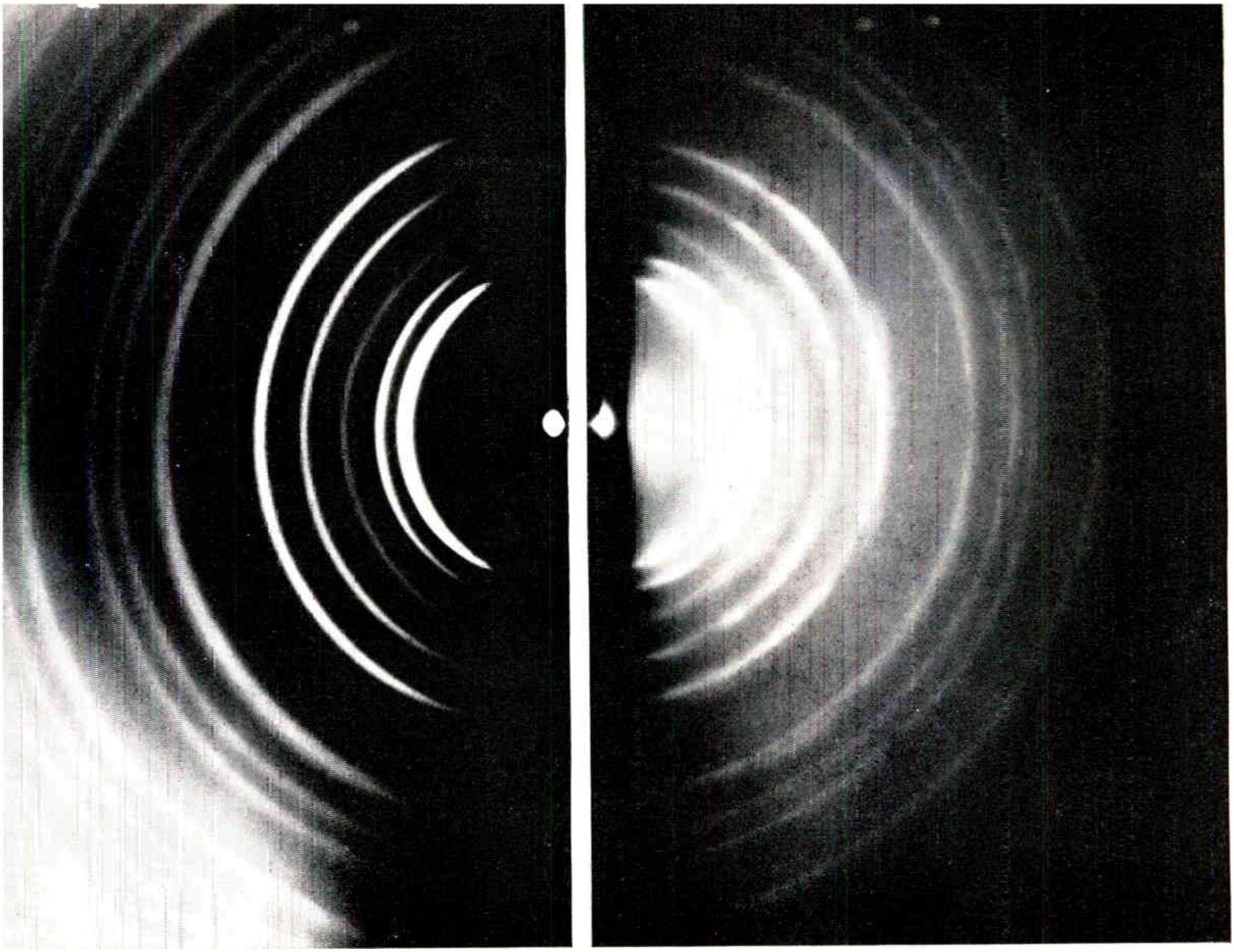

*Report from IBM* *Yorktown Research Center, New York*

## MAGNETIC EXPLORATION ALONG THE CRYSTAL AXIS

How does the orientation of crystallites within a thin metallic film relate to its magnetic properties? This is the question under study by a group of scientists at Zurich, Switzerland—one of the laboratories coordinated from the IBM Yorktown Research Center.

Electron-diffraction permits the investigation of the crystal structure of thin magnetic films prepared by evaporation in vacuum. In particular the orientation of the numerous small crystals in a polycrystalline film can be detected. The uniform distribution of density along the rings in the left-hand picture results from a random distribution of crystal axes, whereas the arcing of the rings at the right indicates a preferred orientation, known as fiber texture. Alignment of the axes of the individual crystallites contributes to the film's magnetic anisotropy—the variation of magnetic energy with different directions of magnetization.

Techniques for producing predictable anisotropy in thin films and for measuring magneto-crystalline relationships are among the goals of the present work. Thorough understanding of all factors influencing the magnetic anisotropy is mandatory for the development of optimal operation of magnetic thin film logic and memory devices. Mastery of anisotropic films may thus offer a promising route to greater capabilities in tomorrow's computers.

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IRE Professional Groups are only open to those who are already members of the IRE. Copies of Professional Group Transactions are available to non-members at three times the cost-price to group members.

**The Institute of Radio Engineers**
**1 East 79th Street, New York 21, N.Y.**

---

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## *Professional Group On Communications Systems*

The field of communications systems is as old as radio itself. For three decades after Marconi first spanned the Atlantic by radio in 1901 radio researchers devoted practically all their efforts to developing and perfecting new systems for utilizing electromagnetic waves for communication purposes.

Gradually, however, this new found knowledge opened the doors to other applications in industrial, military, scientific, and medical fields. Under the stimulus of wartime research these newer applications multiplied and expanded at a tremendous rate so that at the end of World War II the complexion of the radio engineering field had altered drastically.

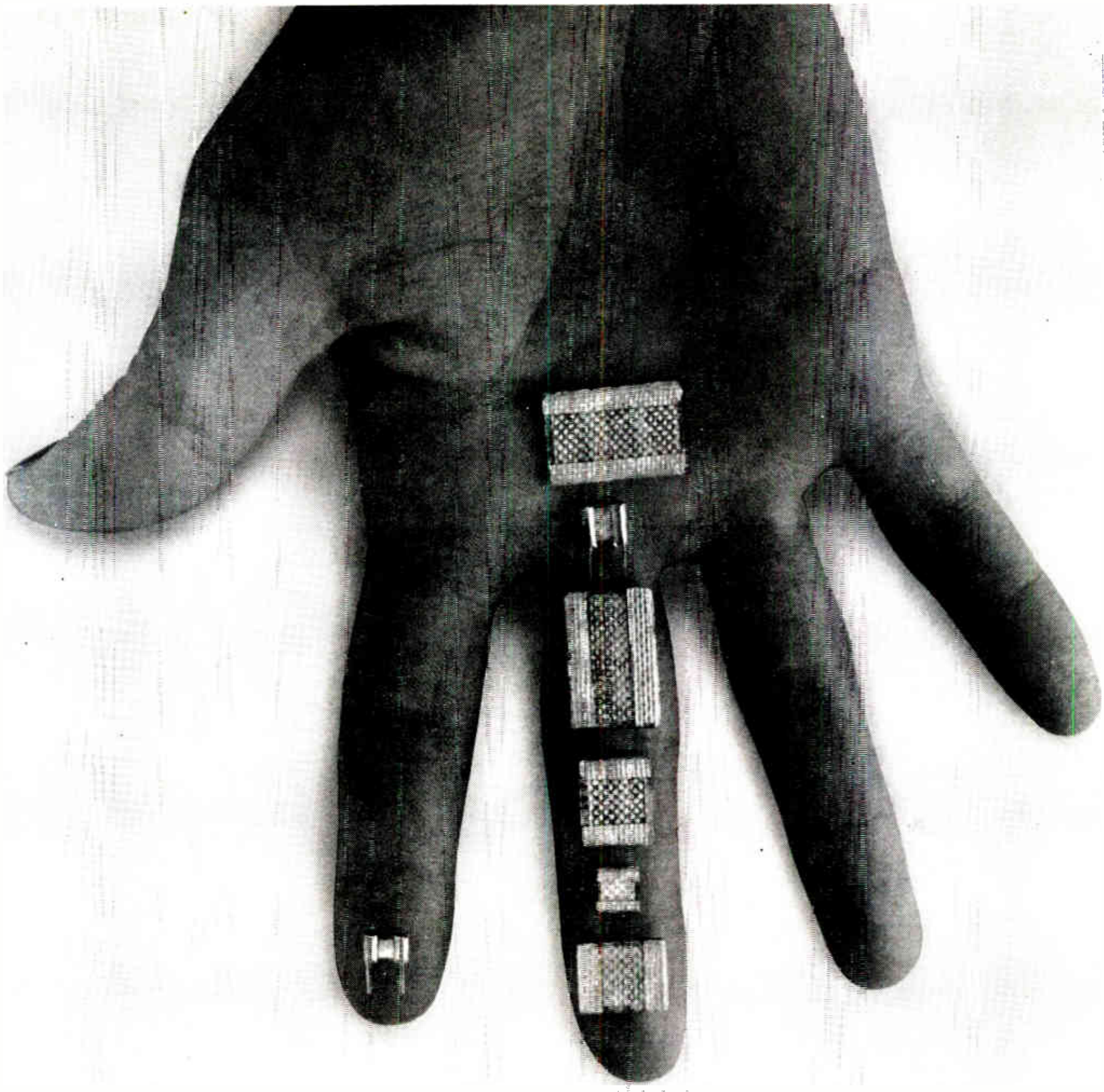
What had once been a fairly small, homogeneous group with common technical interests had now become a large body of engineers and scientists working in at least a score of separate and distinct specialized fields. Communications engineers found it increasingly difficult to find the specialized technical information they urgently needed since the sources for such information now had to serve many other fields as well.

On April 8, 1952, the IRE formed the Professional Group on Communications Systems. The response was almost instantaneous as communications engineers all over the U. S., and in other countries as well realized that for the first time an organization had been formed just to serve their particular technical needs.

As membership increased, the Group began publishing its own TRANSACTIONS, which is issued free to all members. This year alone, Group members received 300 pages of valuable technical papers. The Group also has become very active in sponsoring meetings in various parts of the country throughout the year. The value of these activities is attested to by the fact that some 3000 engineers have joined the Group and have found this affiliation indispensable to their professional well being.

*W. R. G. Baker*

**Chairman, Professional Groups Committee**



# NEW Corning wafer capacitors run from 1 to 10,000 uuf

Uuf for uuf the smallest, most stable capacitors you can get for printed circuits and high reliability components

Never has so much capacitance been crammed into so little space with so much ruggedness and reliability.

The smallest gives from 1 to 560 uuf while resting in a space only 0.00204 cubic inch in volume.

The largest runs from 4301 to 10,000 uuf and takes up only 0.02106 cubic inch.

*You sacrifice nothing for size.* The flat shape gives you more options in mounting, e.g., slot or flat mounting in printed circuits.

When you need leads we can provide those too, in the W-5 and W-4 sizes as WL-5 and WL-4.

These capacitors are rugged and reliable. The dielectric and conductor layers are fused at high temperatures and need no encasement. You'd almost have to smash one completely to stop its operation. Meets or exceeds the performance requirements of MIL-C-11272A.

For complete specs write for a new 4-page bulletin to Corning Glass Works, Dept. 542, Bradford, Pa.

| Capacitor | Capacitance (uuf) | Volume (approx.) |
|---|---|---|
| W-5 | 1 to 560 | 0.00204 in.$^3$ |
| W-4 | 561 to 1000 | 0.00327 |
| W-3 | 1001 to 2700 | 0.00702 |
| W-2 | 2701 to 4300 | 0.01951 |
| W-1 | 4301 to 10,000 | 0.02106 |

W-5, W-4 also available with leads as WL-5, WL-4

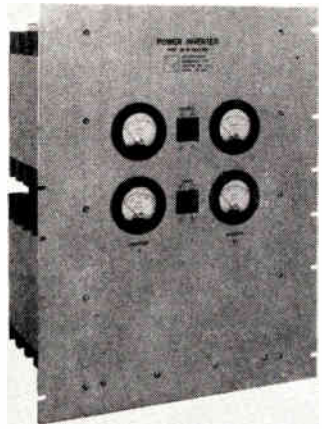
**CORNING ELECTRONIC COMPONENTS**

## NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

*(Continued from page 108A)*

### DC-AC Transistorized Inverter

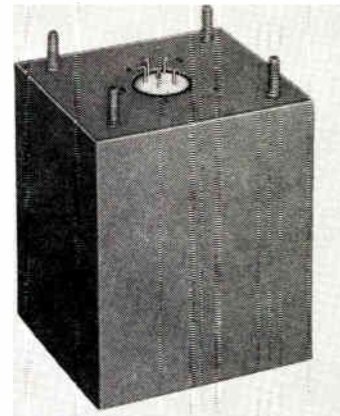


A new 2 kw dc-ac inverter has been added to **Electrodynamic Instrument Corporation's**, 2508 Tangley Rd., Houston 5, Texas, PI Series of transistorized power supplies. The unit will supply a 2 kva output or two 1 kva outputs of 120 volts, 60 or 400 cps, single phase, from an 11 to 14 vdc or 22 to 32 vdc source. Frequency stability of ±.01% and exceptional reliability make these inverters suitable replacements for rotary-type inverters in microwave, telemetry and automatic control installations. Efficiency at full load is about 85%. Solid-state circuit design throughout eliminates the need for standby power or warm-up time. The standard rack panel unit measures 24½×19×12".

### Frequency Calibrator

Rapid and accurate calibration of FM/FM telemetering systems is provided with the Model 520 series Frequency Calibrators manufactured by **Fenske, Fedrick & Miller, Inc.,** 12820 Panama St., Los Angeles 66, Calif. Features are accuracy, ease of operation, external metering provisions and elimination of the necessity for highly trained personnel. Calibration time is reduced to approximately 30 seconds per channel. Provisions are also made for crystal outputs for discriminator alignments.

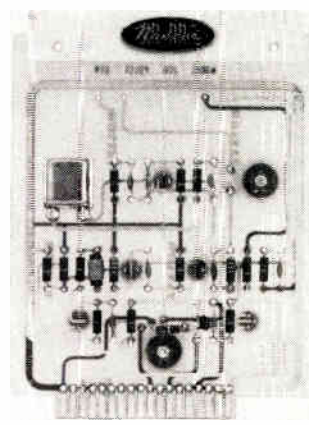
### Phase Splitting Transformer



A practical means for operating 3 phase devices where only single phase is available is provided by phase splitting transformers manufactured by **United Transformer Corp.,** 150 Varick St., New York 13, N. Y. The P-4674 unit, illustrated, provides 115 volts, 400 cps 3 phase to a 90 va gyro power supply. Input is 115 volts, 400 cps single phase. This unit is 2¾×3×3½" and weighs 3¼ pounds; meets MIL-T-27A requirement to Grade 4, Class S, Life X.

### Pulse Generator

The all transistor Model 300X Pulse Generator, developed by **Navigation Computer Corp.,** 1621 Snyder Ave., Philadelphia 45, Pa., provides accurately timed clock pulses at crystal controlled frequencies.



A standardized 2.5 volt pulse (Vk) of both polarities is generated by a crystal controlled oscillator. The output stage is transformer-coupled and has a constant voltage characteristic which maintains an undeteriorated pulse when loaded between 0 and 100 ma output current.

The Model 300X is fabricated on a 5"×6" glass-epoxy printed circuit card,

*(Continued on page 118A)*

*Announcing...*

# SILICON RECTIFIERS

*from*

# DELCO RADIO

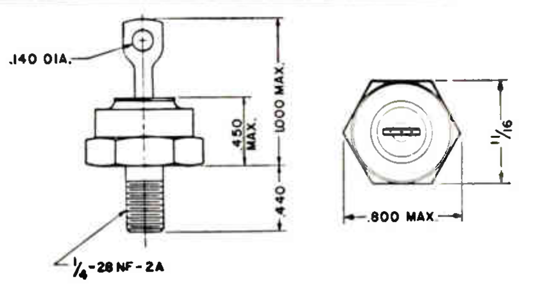
**High Quality**

**High Performance**

**Extreme Reliability**

From the leading manufacturer of power transistors, new Silicon Power Rectifiers to meet your most exacting requirements. Even under conditions of extreme temperatures, humidity and mechanical shock, these diffused junction rectifiers continue to function at maximum capacity! Thoroughly dependable, completely reliable—new Delco Rectifiers are an important addition to Delco Radio's high quality semiconductor line.

**Conservatively rated at 40 and 22 amperes for continuous duty up to case temperatures of 150°C.**




| TYPE | AVG. DC CURRENT | PIV | NORMAL MAX. TEMP. | MAX. FORWARD DROP | MAX. REVERSE CURRENT |
|---|---|---|---|---|---|
| 1N1191A | 22A | 50V | 150°C | 1.2V at 60 amps. | 5.0 MA |
| 1N1192A | 22A | 100V | 150°C | 1.2V at 60 amps. | 5.0 MA |
| 1N1193A | 22A | 150V | 150°C | 1.2V at 60 amps. | 5.0 MA |
| 1N1194A | 22A | 200V | 150°C | 1.2V at 60 amps. | 5.0 MA |
| 1N1183A | 40A | 50V | 150°C | 1.1V at 100 amps. | 5.0 MA |
| 1N1184A | 40A | 100V | 150°C | 1.1V at 100 amps. | 5.0 MA |
| 1N1185A | 40A | 150V | 150°C | 1.1V at 100 amps. | 5.0 MA |
| 1N1186A | 40A | 200V | 150°C | 1.1V at 100 amps. | 5.0 MA at 150° C case temperature and rated PIV |

For full information and applications assistance, contact your Delco Radio representative.

Newark, New Jersey
1180 Raymond Boulevard
Tel: Mitchell 2-6165

Chicago, Illinois
5750 West 51st Street
Tel: Portsmouth 7-3500

Santa Monica, California
726 Santa Monica Boulevard
Tel: Exbrook 3-1465

Division of General Motors • Kokomo, Indiana

**DELCO RADIO**

**EXCLUSIVE!**

# MOLDED* Contact Combinations on OHMITE® Relays

## "Molded Module"* Contact Springs

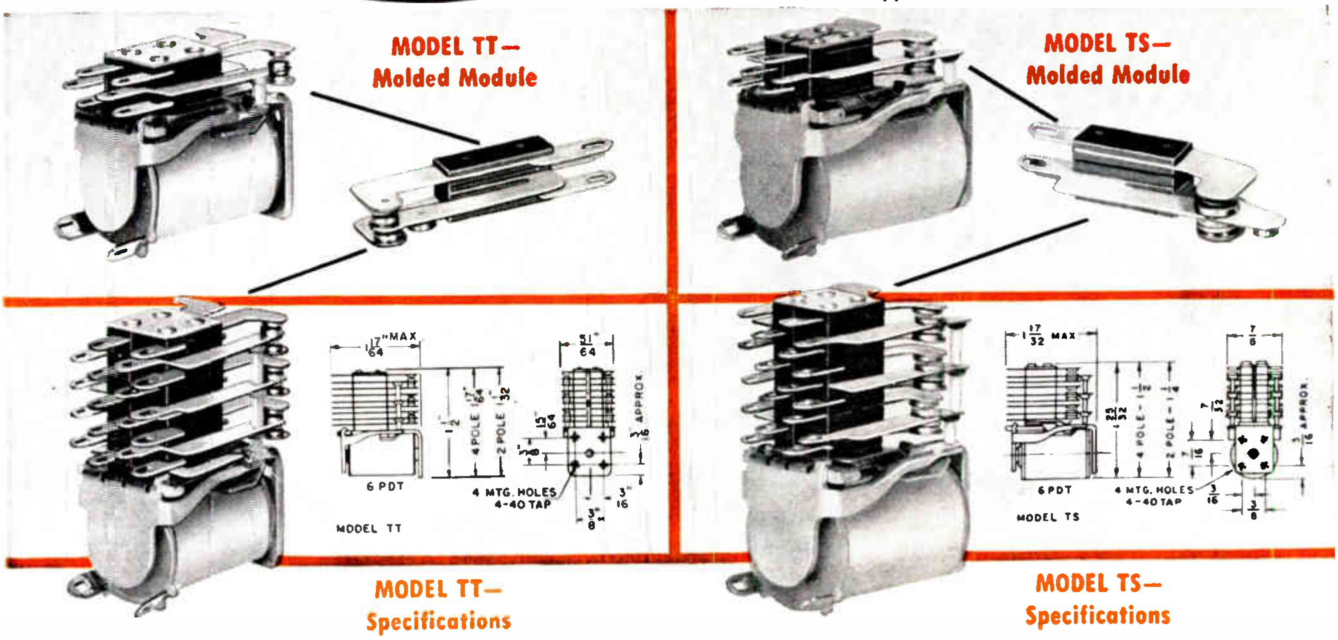
Ohmite Models TT and TS Relays meet the operational requirements of MIL-R-5757C and MIL-R-6106C, respectively, and will be found ideal for aircraft or industrial uses, particularly those involving ambient temperatures as high as 125°C. Both relays are lightweight, yet rugged.

Paramount among the design innovations is their revolutionary "Molded Module" contact spring construction. The "module" is a standard, single-pole, double-throw spring combination molded into a compact assembly. As many as six modules can be incorporated into a relay to provide a maximum six-pole, double-throw combination. With the springs rigidly held in a matrix of tough plastic, alignment of the springs is assured. More accurate alignment of all the subcombinations (modules) on the relay is possible, and adjustment of the individual contact springs is easier and more permanent. Diall Phthallate, the molding material, can withstand temperatures to 400°F.

## Exceptional sensitivity for small size

A contributing factor to the remarkable sensitivity of Ohmite Models TT and TS Relays is the design of the armature retaining guard to minimize undesirable heel gap. A wide variety of hermetically sealed enclosures is available.

*Patent applied for




## MODEL TT— Specifications

COIL WATTAGE: Rated nominally at .150 watt per pole at an ambient temperature of 20°C.

COIL OPERATING VOLTAGE RANGE: To 115 VDC.

CONTACT RATINGS: Up to 5 amperes at 115 volts AC or 32 volts DC noninductive, with standard contact material, palladium. Other materials can be supplied.

CONTACT COMBINATIONS: Standard combinations are DPDT, 4PDT, and 6PDT (maximum). Others can be furnished.

WEIGHT: Approximately 2 ounces for 4PDT relay.

## MODEL TS— Specifications

COIL WATTAGE: Rated nominally at .250 watt per pole at an ambient temperature of 20°C.

COIL OPERATING VOLTAGE RANGE: To 115 VDC.

CONTACT RATINGS: Up to 10 amperes at 115 volts AC or 32 volts DC noninductive with standard contact material, silver-cadmium oxide. Other materials can be supplied.

CONTACT COMBINATIONS: Standard combinations are DPDT, 4PDT, and 6PDT (maximum). Others can be furnished.

WEIGHT: Approximately 3 ounces for 4PDT relay.

Be Right with OHMITE® Quality Components

Write for Bulletin 160

**OHMITE MANUFACTURING COMPANY**
3617 Howard Street, Skokie, Illinois

RHEOSTATS RESISTORS RELAYS
TAP SWITCHES TANTALUM CAPACITORS DIODES
R.F. CHOKES VARIABLE TRANSFORMERS

## NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

*(Continued from page 114A)*

1/16″ thick, and is adapted for use with an 18 pin printed circuit receptacle.

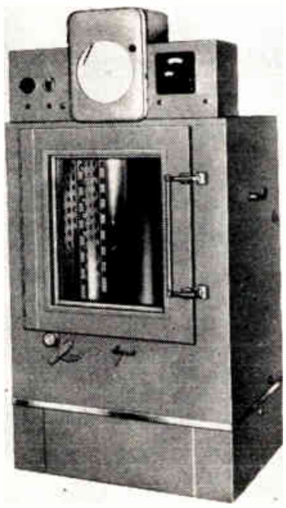
It is accurate to 0.01% of crystal frequency and will operate from 0°F to 135°F.

Available models are the 300X–1, 100 kc; 300X–2, 200 kc; and 300X–3, 300 kc.

Other frequencies are available by special request.

### Hot-Cold Test Chamber

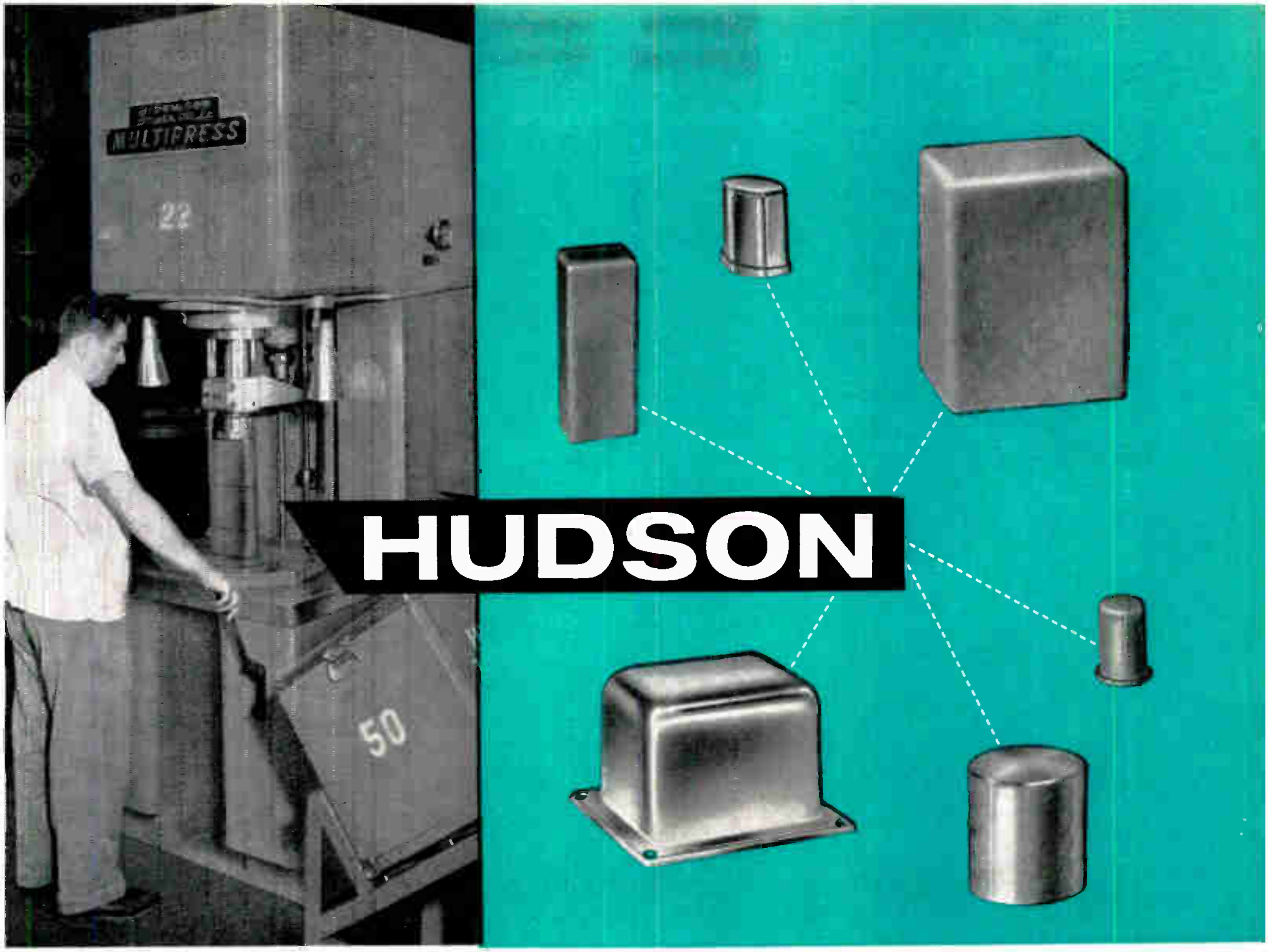
Designed for thermal shock and other controlled temperature testing and conditioning processes involving electronic parts, these chambers manufactured by **Electric Hotpack Co., Inc.,** Dept. 691, Cottman Ave., at Melrose St., Philadelphia 34, Pa., have temperature ranges from −65°F to 540°F.



Maximum temperature uniformity and even $CO_2$ dispersal is achieved by a built-in air circulation system. Controls include separate thermostats for operation above and below ambient temperatures. Automatic overtemperature controllers are independently circuited to prevent thermal damage to expensive loads in event of main control failure. Temperature chart recorder provides 24 hour record of chamber temperatures.

Cabinet is available in enamelled or heavy gauge stainless steel, and is supplied ready for immediate connection to $CO_2$ supply. Interior is polished stainless steel. All units are equipped to accommodate through wall connections for test articles. Automatic hot-cold cycles may be supplied if desired.

*(Continued on page 122A)*

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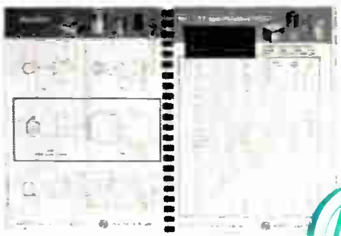
*DESIGNERS!*

For precision quality at commercial prices, consult the new HUDSON catalog. Call or write for this cost and time-saving handbook, today!



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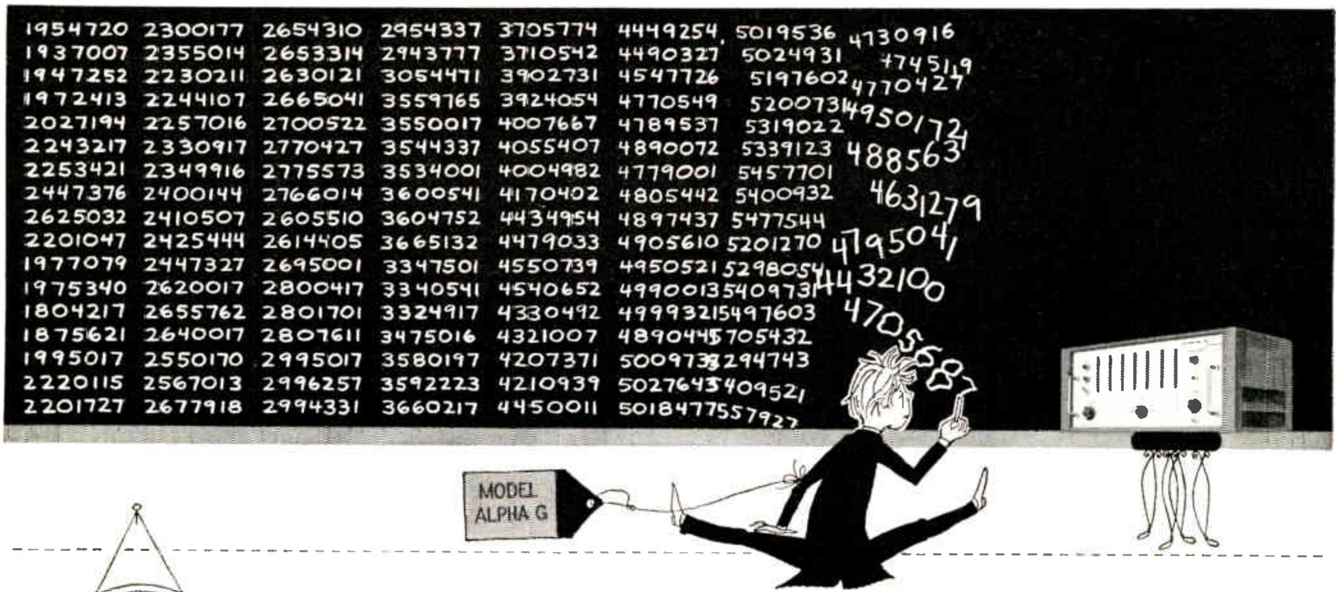
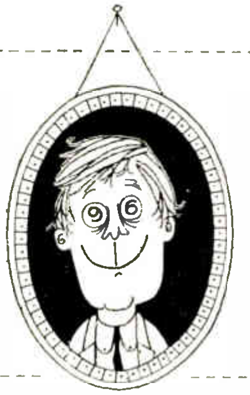
*3 MODERN PLANTS TO SERVE YOU*

# This data converter is no longer available

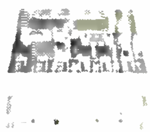


Alfonso Gotlentz, winner of the 1958 Data Conversion Competition, chalked up 16,792 Beckman counter readings in a record time of 7 hrs. 23 min. Unfortunately, Alfonso developed digitized eyeballs, a common occupational disability of mammalian data converters. Undismayed by the untimely end of his conversion career, he speedily procured electroluminescent contact lenses; now performs as a two-digit in-line display.

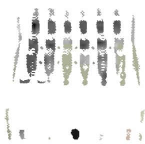
## replacing Alfonso, these more clever converters . . .

To put Beckman counter readings on punched IBM cards, you can get



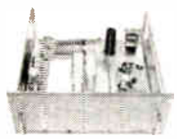
Model 3110 (for serial punch) or Model 3100 (for parallel punch)

To make a strip chart record of changing counter readings, you may procure



Model 3120, a digital-to-analog converter with resistance ratio output

To make a punched paper tape of counter readings, ask for



Model 3101 (drives a tape punch)

To print counter readings much faster than Alfonso, try

Model 1452, a digital recorder that prints 7, 8 or 10 digits

**Beckman®** T23

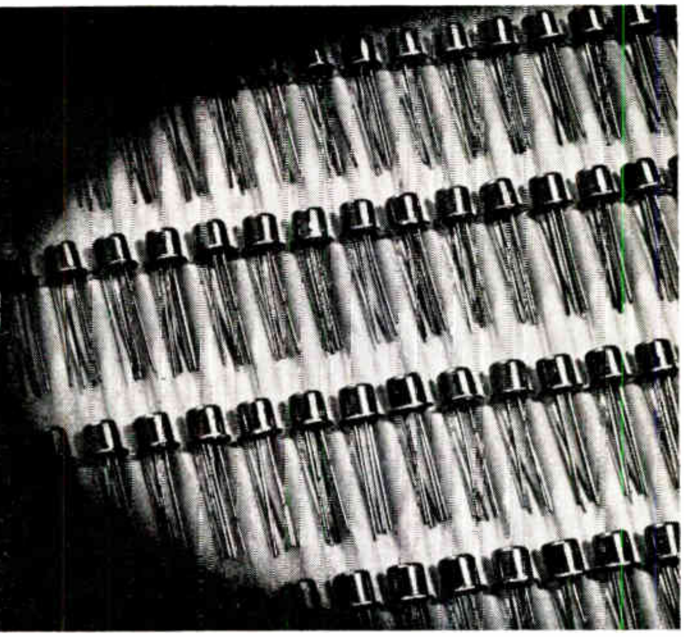
*Berkeley Division*

*2200 Wright Avenue, Richmond 3, California*

*a division of Beckman Instruments, Inc.*

Write for detailed technical bulletins

# for applications to 1000 mc the 2N700



# MOTOROLA MESA TRANSISTOR

## major price reductions make many VHF/UHF applications practical

### 2N700 FEATURES

| | |
|---|---|
| $f_{osc}$ (max) | 1000 mc |
| PG (neut.) | 14 db @ 200 mc |

- **High Temperature Operation.** All units baked-out under high vacuum at 200°C and stabilized at 100°C for 168 hours. Each lot must pass life tests of 1000 hours at 100°C. Units are rated for operation at 100°C.
- **High Efficiency.** A highly efficient oscillator, some points on the 2N700 efficiency-frequency curve are:

| Frequency | Efficiency |
|---|---|
| 40 mc | 80% |
| 100 mc | 62% |
| 200 mc | 44% |
| 400 mc | 20% |

- **Uniformity.** The Motorola Mesas are unquestionably the most uniform transistors available. Instead of the usual "selection process," closely controlled diffusion, etching and evaporative techniques enable Motorola to produce the Mesas to exact specifications. Such uniformity enables the engineer to tighten circuit tolerances, provide improved performance and simplify circuit design. It eliminates concern for variations in such factors as breakdown voltage, current handling capacity, frequency parameters, switching characteristics and saturation resistance.
- **Reliability.** 5,000 hour data on units tested at 100°C show the Motorola Mesa to be the most reliable transistor yet available.
- **Economy.** As the result of major price reductions, the 2N700 is an economical unit for VHF and UHF applications. In addition, fewer units are required on an overall circuit basis because of excellent performance characteristics.
- **Availability.** Engineering quantities are in stock at all 22 Motorola Semiconductor distributors. Production quantities shipped immediately from Phoenix.

**Communications Equipment** — Because of its small size, the Motorola 2N700 is ideal for low current, compact, highly reliable communications equipment.

**IF Strips in Radar Gear** — Offering greater gain per stage in its frequency range than any transistor available, the Motorola 2N700 is ideal for radar IF strips in the 60 mc range.

**Parametric Amplifier Pump** — The 2N700 makes an excellent source of pump power at the frequencies used.

**Precision Oscillators** — With stability in the order of $10^{-7}$ to $10^{-8}$, the 2N700 is ideal for use in precision oscillators for single sideband and other communication equipment. It also has low phase shift and high loop gain. The 2N700 offers the uniformity and stability important for compact, lightweight precision equipment and instruments.

**Oscilloscope Amplifiers** — Ideal for instrument probes such as those used to provide preamplification for high speed, high frequency amplifiers.

**Fixed IF Strips** — Because of its extreme uniformity in all operating characteristics, the 2N700 could be designed into fixed-tuned IF strips, using toroid coils . . . greatly reducing IF strip size and eliminating large tunable elements and alignment problems.

**Telemetering** — 2N700 operating characteristics are ideal for telemetering applications in the 200 mc band. Its ruggedness (withstands 20,000g's) suggests application in telemetering transmitters fixed to high speed rotating equipment.

**FOR COMPLETE SPECIFICATIONS AND DESIGN CONSIDERATIONS** on the 2N700 and the 2N695 (world's fastest switching transistor) contact your nearest Motorola Semiconductor regional office.

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**MOTOROLA SEMICONDUCTORS**

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4545 West Augusta Blvd
Chicago, Illinois

MOTOROLA, INC., 5005 E. McDOWELL, PHOENIX, ARIZONA

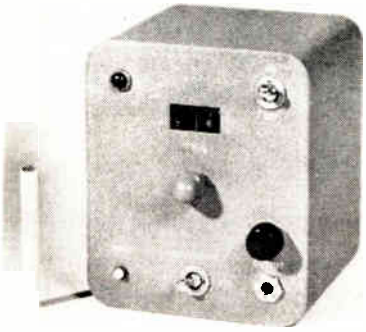
## NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

*(Continued from page 118A)*

### New Vibration Instrument

An accelerometer sensitivity standardizer called the Dia-A-Gain converts all accelerometer sensitivites to 1 Volt/g, allowing direct reading of acceleration on any VTVM. The Dial-A-Gain includes a cathode follower input and a precision amplifier with a continuously variable gain control dial, calibrated directly in accelerometer sensitivities.



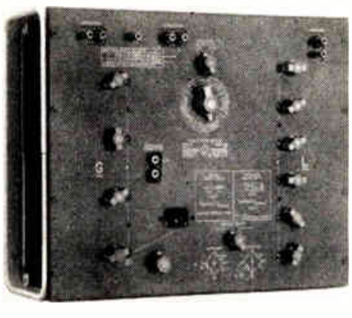
Dialing the sensitivity of your accelerometer automatically adjusts the output to 1 Volt/g allowing direct reading of acceleration on any volt meter.

Dial-A-Gain eliminates external cathode followers normally used, and is available with single or multiple inputs.

For complete specifications, write **Unholtz-Dickie Corp.,** 2994 Whitney Ave., Hamden 17, Conn.

### Inductance Bridge

A high-resolution (six-figure) inductance bridge (Type 1632-A) with a basic direct-reading accuracy of 0.1%, designed for the precise measurement of either the series or the parallel components of two-terminal grounded inductors, at audio frequencies, over a wide range of inductance from millimicrohenries to 1111 henries, has been announced by **the General Radio Co.,** West Concord, Mass.



Its high accuracy (two inductors of nearly the same nominal value can be compared to 10 parts in a million) and sensi-

*(Continued on page 124A)*

## NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 122A)

tivity (minimum indication—0.001 microhenry) make it suitable for standardization measurements. A novel in-line digital readout features for both inductance and conductance (with automatic positioning of the decimal point) and the absence of a sliding balance also makes possible rapid precision measurements.

The instrument uses the owen circuit, in which inductance is measured in terms of capacitance and resistance; the capacitors and resistors used are accurate to better than 0.05%. Four decades of low-loss polystyrene capacitors and a variable air capacitor (200 $\mu\mu f$–1.111 $\mu f$) serve to provide conductance balance.

An outstanding feature is a panel-engraved bridge schematic, complete with balance equations and voltage limits, which eliminates the need to consult an instruction book.

At frequencies up to 1 kc, maximum accuracy is possible; however, the instrument is usable to at least 10 kc, with some reduction in accuracy.

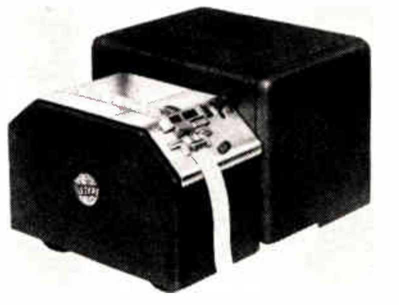
When used in conjunction with standard inductors (G-R Type 1482) in the laboratory, the instrument affords accurate inductance standardization.

Available in an aluminum cabinet and with a crackle finish dress panel, or for rack mounting. Size of the panel is 19"×15¾"; over-all depth is 9⅞".

Price of the Inductance Bridge (Type 1632-A) is $875.00 net, f.o.b., West Concord, Mass. This instrument may be seen at NEREM, Boston, Nov. 17–19.

### Miniaturized Tape Reader

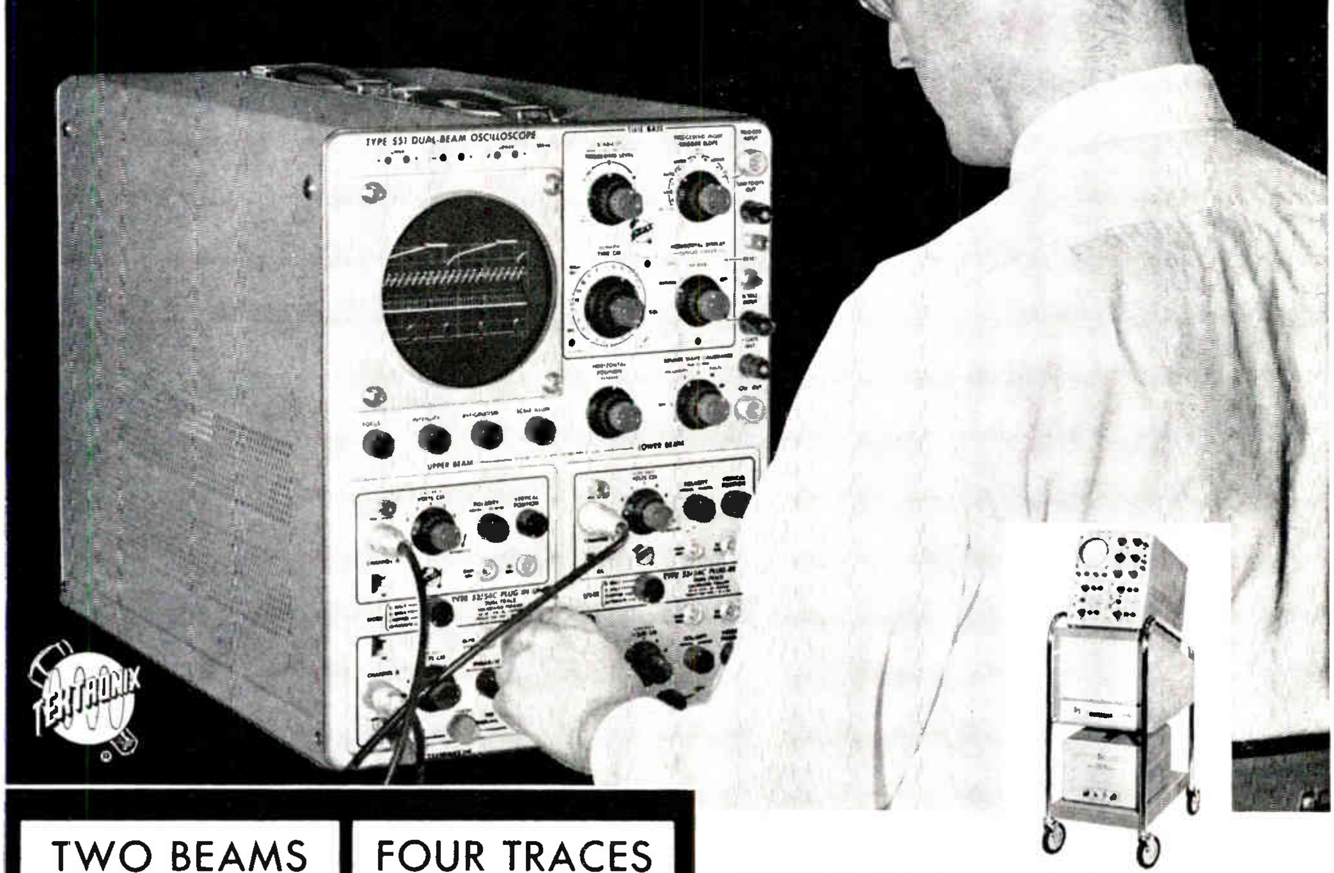
The development of a punched-tape reader set—including transmitter-distributor, motor, base and cover—that is some 40% smaller in size and weight than previous models, has been announced by **Teletype Corp.**, Dept. SP-8, 4100 Fullerton Ave., Chicago 39, Ill.

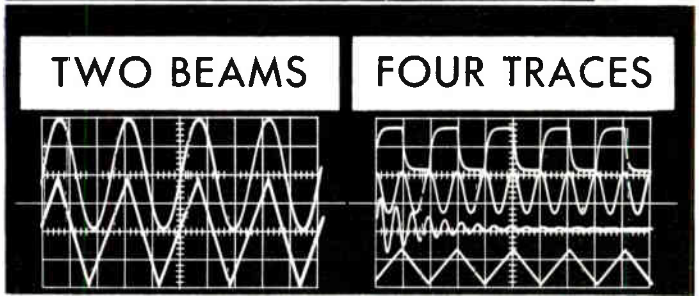


Called the Model 28 Miniaturized LXD set, the reader measures 5⅞" in height, 7½" in depth and features facilities for sequential (serial) output, hundred-word-per-minute transmission and reduced power requirements. Optimal contacts are available for multi-wire output.

(Continued on page 128A)

# FOUR-WAVEFORM DISPLAYS






## TYPE 551 DC-to-25 MC

*Special Features*

**WIDE-BAND VERTICAL AMPLIFIERS**
Main-unit risetimes—12 mμsec.
Passbands and risetimes with Type K (53/54K) units—dc-to-25 mc, 0.014 μsec.

**SIGNAL-HANDLING VERSATILITY**
All Tektronix A to Z Plug-In Preamplifiers can be used in both channels.

**0.2 μsec DELAY NETWORKS**

**WIDE SWEEP RANGE**
0.02 μsec/cm to 12 sec/cm.

**SINGLE SWEEPS**
Lockout-reset circuitry.

**COMPLETE TRIGGERING**
Fully-automatic or amplitude-level selection with preset or manual stability control.

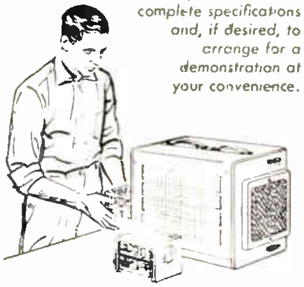
**10-kv ACCELERATING POTENTIAL**
Brighter display for fast sweeps and low repetition rates.

When the job requires it, you can double up and display four different waveforms at once with this dual-beam oscilloscope. Type 53/54C and/or Type C-A Dual-Trace Plug-In Units in both channels make possible the four-trace display.

Less spectacular but more frequent uses of this versatile fast-rise oscilloscope include waveform comparison measurements on a dual-beam display in the dc-to-25 mc range, and all the usual and unusual applications of a high-performance laboratory oscilloscope.

**PRICE**
without plug-in units . . . . . . . . . **$1800**
**Type 500/53A**
Scope-Mobile . . . . . . . . . . **$110**
**Type K** Fast-Rise
Plug-In Preamplifiers, each . . . . **$135**
**Type C-A** Dual-Trace
Plug-In Preamplifiers, each . . . . **$250**
*(f.o.b. factory)*

*Please call your Tektronix Field Engineer or Representative for complete specifications and, if desired, to arrange for a demonstration at your convenience.*



**ENGINEERS**—interested in furthering the advancement of the oscilloscope? We have openings for men with creative ability in circuit and instrument design, cathode-ray tube design, and semiconductor research. Please write Richard Ropiequet, V. P., Eng.


# Tektronix, Inc.

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# Your best combination of

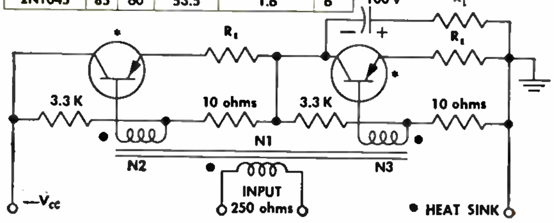
# $I_{CBO}$-$R_{CS}$-V- PLUS HIGH BETA

# ...TI germanium power transistors!

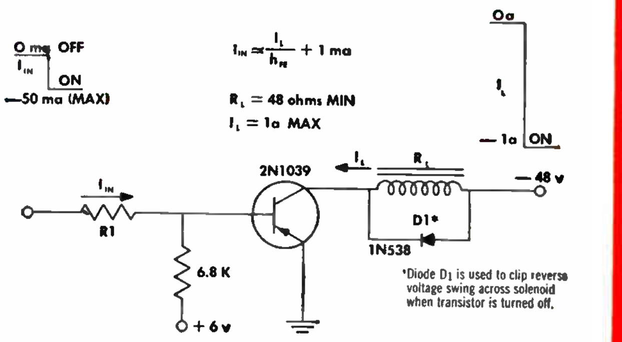
### TYPICAL AUDIO AMPLIFIER 10 WATTS OUTPUT

| TRANSISTOR | $V_{cc}$ volts | $R_L$ ohms | Efficiency % | Distortion % at $P_o$=10w | $R_e$ ohms |
|---|---|---|---|---|---|
| 2N1042 | 35 | 10 | 58 | 2.7 | 1 |
| 2N1043 | 55 | 25 | 57 | 1.8 | 2.5 |
| 2N1044 | 70 | 40 | 56 | 1.6 | 4 |
| 2N1045 | 85 | 60 | 53.5 | 1.6 | 6 |

Transformer: $N_1$:$N_2$:$N_3$ = 1:1:1 To Minimize Cross-Over Distortion the Coils Should be Bifilar Wound.




### TYPICAL SOLENOID RELAY DRIVER




*Diode D1 is used to clip reverse voltage swing across solenoid when transistor is turned off.

## 20-w power transistors:

switching circuits • relay drivers • audio and pulse amplifiers


ACTUAL SIZE

**TI 2N1042** series alloy-junction transistors **guarantee** 20 w dissipation at 25°C with voltage ratings of —40, —60, —80, and —100 v. You get guaranteed 20-to-60 beta spread at —3 amps and low 0.16 ohm saturation resistance at the —3 amp maximum collector rating.

## 1.25-w power transistors:

medium speed switching circuits • relay drivers • low-power audio and pulse amplifiers


ACTUAL SIZE

**TI 2N1038** series alloy-junction transistors **guarantee** 1.25 w dissipation in moving free air at 25°C with voltage ratings of —40, —60, —80, and —100 v. **Guaranteed** 20-to-60 beta spread at —1 amp and low 0.2 ohm saturation resistance assure reliable performance.

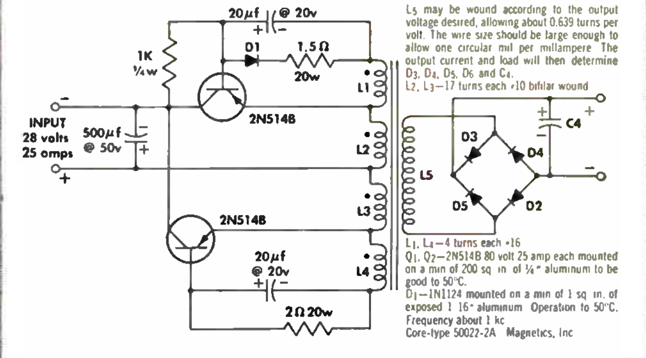
### TI GERMANIUM POWER TRANSISTOR CHARACTERISTICS AT 25°C

| Type | Dissipation at 25°C Watts | Max Collector Voltage Volts | Max Collector Current Amps | $h_{FE}$ min | $h_{FE}$ max | Collector Reverse Current $I_{CO}$ max | Typical Saturation Resistance $R_{CS}$ Ohms |
|---|---|---|---|---|---|---|---|
| 2N456 | 50 | —40 | —5 | 10 @ —5a | 50 | —2ma @ —40v | 0.048 |
| 2N457 | 50 | —60 | —5 | 10 @ —5a | 50 | —2ma @ —60v | 0.048 |
| 2N458 | 50 | —80 | —5 | 10 @ —5a | 50 | —2ma @ —80v | 0.048 |
| 2N511 | 80 | —40 | —10 | 10 @ —10a | 30 | —2ma @ —20v | 0.025 |
| 2N511A | 80 | —60 | —10 | 10 @ —10a | 30 | —2ma @ —30v | 0.025 |
| 2N511B | 80 | —80 | —10 | 10 @ —10a | 30 | —2ma @ —40v | 0.025 |
| 2N512 | 80 | —40 | —15 | 10 @ —15a | 30 | —2ma @ —20v | 0.025 |
| 2N512A | 80 | —60 | —15 | 10 @ —15a | 30 | —2ma @ —30v | 0.025 |
| 2N512B | 80 | —80 | —15 | 10 @ —15a | 30 | —2ma @ —40v | 0.025 |
| 2N513 | 80 | —40 | —20 | 10 @ —20a | 30 | —2ma @ —20v | 0.025 |
| 2N513A | 80 | —60 | —20 | 10 @ —20a | 30 | —2ma @ —30v | 0.025 |
| 2N513B | 80 | —80 | —20 | 10 @ —20a | 30 | —2ma @ —40v | 0.025 |
| 2N514 | 80 | —40 | —25 | 10 @ —25a | 30 | —2ma @ —20v | 0.025 |
| 2N514A | 80 | —60 | —25 | 10 @ —25a | 30 | —2ma @ —30v | 0.025 |
| 2N514B | 80 | —80 | —25 | 10 @ —25a | 30 | —2ma @ —40v | 0.025 |
| 2N1021 | 50 | —100 | —5 | 10 @ —5a | 30 | —2ma @ —100v | 0.08 |
| 2N1022 | 50 | —120 | —5 | 10 @ —5a | 30 | —2ma @ —120v | 0.08 |
| 2N1038 | 1.25 | —40 | —1 | 20 @ —1a | 60 | —125µa @ —20v | 0.2 |
| 2N1039 | 1.25 | —60 | —1 | 20 @ —1a | 60 | —125µa @ —30v | 0.2 |
| 2N1040 | 1.25 | —80 | —1 | 20 @ —1a | 60 | —125µa @ —40v | 0.2 |
| 2N1041 | 1.25 | —100 | —1 | 20 @ —1a | 60 | —125µa @ —50v | 0.2 |
| 2N1042 | 20 | —40 | —3 | 20 @ —3a | 60 | —125µa @ —20v | 0.16 |
| 2N1043 | 20 | —60 | —3 | 20 @ —3a | 60 | —125µa @ —30v | 0.16 |
| 2N1044 | 20 | —80 | —3 | 20 @ —3a | 60 | —125µa @ —40v | 0.16 |
| 2N1045 | 20 | —100 | —3 | 20 @ —3a | 60 | —125µa @ —50v | 0.16 |
| 2N1046 | 35 | —80 | —3 | 20 @ —3a | 160 | —1ma @ —40v | 0.9 |

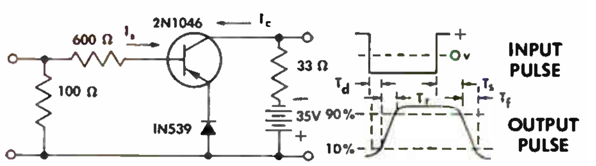
germanium and silicon transistors
silicon diodes and rectifiers
tan-TI-cap solid tantalum capacitors
precision carbon film resistors
sensistor silicon resistors

TEXAS

DC-TO-DC POWER CONVERTER 630-WATT OUTPUT AT 90% EFFICIENCY




TYPICAL SWITCHING CHARACTERISTICS




TYPICAL SWITCHING TIMES

| | | |
|---|---|---|
| $T_d$ | Delay Time | 0.3 μsec |
| $T_r$ | Rise Time | 0.7 μsec |
| $T_s$ | Storage Time | 1.2 μsec |
| $T_f$ | Fall Time | 0.5 μsec |

TEST CURRENTS

$I_{B1}$ (Turn-on Current) = — 30mA

$I_{B2}$ (Turn-off Current) = + 30ma

$I_C$ (Collector Current) = — 1A

ACTUAL SIZE


## 10 to 25-amp switchers:

high current switching applications

**TI 2N511** series alloy-junction transistors **guarantee** collector currents of **—10, —15, —20, and —25 amps** in —40, —60 and —80 v ratings. All units provide low 0.025 ohm saturation resistance and typical switching times at 25°C of 12.5 μsecs ($t_{on}$) and 8.0 μsecs ($t_{off}$).

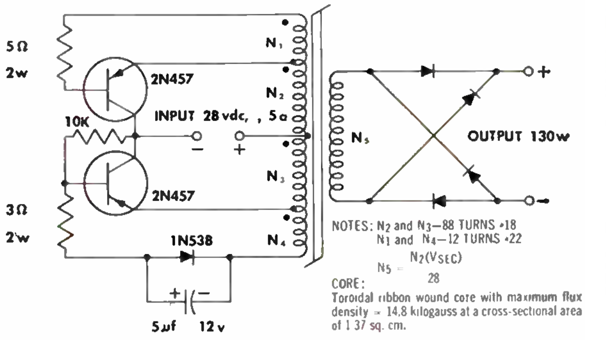
ACTUAL SIZE


## high power/high frequency switchers:

computer core drivers • deflection circuits • light weight converter applications

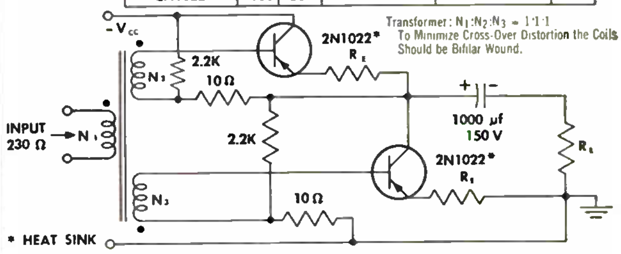
**TI 2N1046** alloy diffused transistors combine high power, high frequency and high voltage performance in a single package. **Guaranteed** 35-w dissipation, collector breakdown voltage to —80 v, and low 0.75 ohm saturation resistance with **12 mc** typical alpha cutoff insure reliable operating characteristics.

TYPICAL DC TO DC POWER CONVERTER




TYPICAL 20 WATT AMPLIFIER POWER GAIN = 23 db

| TRANSISTOR | $V_{CC}$ V | $R_L$ Ω | EFFICIENCY | DISTORTION 20 WATTS | $R_E$ Ω |
|---|---|---|---|---|---|
| 2N1021 | -80 | 30 | 66% | 2% | 3 |
| 2N1022 | -100 | 50 | 66% | 2% | 5 |




ACTUAL SIZE


## high beta power amplifiers:

audio amplifiers • current switchers • power converters

**TI 2N456** series alloy-junction transistors with **guaranteed** 50-w dissipation, **—40, —60, and —80** $BV_{CBO}$ ratings and less than 0.048 ohm saturation resistance provide optimum performance characteristics.

ACTUAL SIZE


## high voltage power converters:

audio • servo • power applications

**TI 2N1021 and 2N1022** alloy-junction transistors **guarantee** maximum operating voltages of **—100 v and —120 v** respectively, low 0.08 ohm saturation resistance, and typical betas of 60 at —1 amp, 23 at —5 amps. You get **guaranteed** collector reserve current of —2 ma maximum at full rated voltage.

Check the specifications at left for the unit most suited to your particular requirements.

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Write on your company letterhead *to your nearest TI sales office* describing your application for specific details on TI products.

## NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 124A)

Models may be had to read 5- or 6-level chadless or fully perforated tape.

The new set is proposed for a wide range of tape reading applications including on-line data transmission over existing communications facilities and off-line control of tape-operated factory or office machines.

Components of the Model 28 Miniaturized LXD set, such as the transmitter-distributor portion, are available separately (without motor, base or cover) for integration with systems equipment.

A new 4-page applications brochure is available upon request.

### Anechoic Chamber

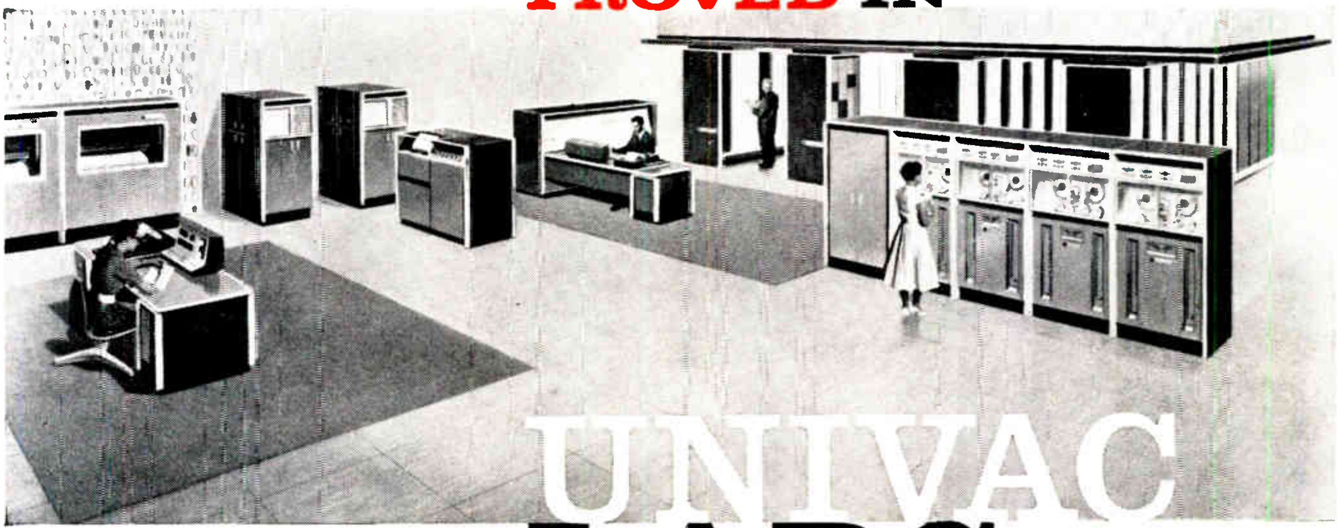
The microwave anechoic chamber shown in the attached photograph embodies advanced design construction. The chamber, designed and constructed by **Emerson & Cuming, Inc.**, Canton, Mass., is about 120′ long, 45′ wide and 25′ high. In contrast with the more conventional darkroom, in which the diffracting edges of transverse baffles lie in planes normal to the long axis of the room, the baffle edges are here parallel to the longitudinal center line. The absorber is Eccosorb FR 340 on the walls, ceiling and floor, with −40 db Eccosorb CV-9 at each end in a vertical cylindrical arrangement. The frequency range is 900 mc through 50 kmc

Two major electrical advantages accrue from the longitudinal baffle concept First, baffle edge diffraction effects are minimized since the edges are aparallel to the axial field components which are relatively small in most instances. Unless a conventional transversely baffled room is excessively large in cross section, several of the baffle edges are invariably illuminated by parallel fields comparable in amplitude to those illuminating the target area. Recent theoretical and experimental work indicates that, under typical chamber illumination conditions, the very existence of baffle edges parallel to radiation fields imposes a severe limitation upon the "darkness" of a darkroom. The quality of the absorbing material covering these edges is theoretically of little consequence.

(Continued on page 130A)

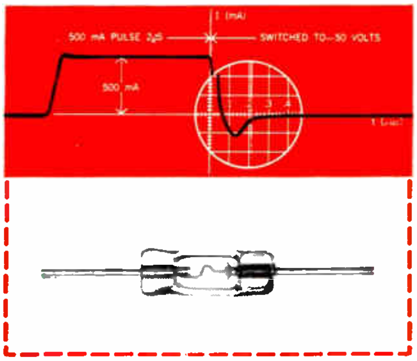
**DEVELOPED BY SPERRY SEMICONDUCTOR . . .**

# PERFORMANCE PROVED IN



# UNIVAC LARC

SOLID
STATE
COMPUTER




## HIGH-CURRENT FAST-SWITCHING SILICON DIODES

Ultra-high speed computing, 25 to 200 times faster than other existing computers, is an accomplished fact in Remington Rand's UNIVAC LARC—the most sophisticated of the new "second-generation" computers. Key to its unparalleled speed and reliability are the thousands of Sperry high-current fast-switching diodes built into its critical memory driving circuits.

Selected from Sperry's unique high-current silicon types, these were the only diodes in the industry able to meet the severe performance requirements of the LARC circuitry. Many Sperry computer diodes, such as the 1N690 and 1N691, are finding wide acceptance by the industry in more than a dozen other high speed computer prototypes.

For the most advanced semiconductor devices in your computer applications—

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## NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

*(Continued from page 128A)*

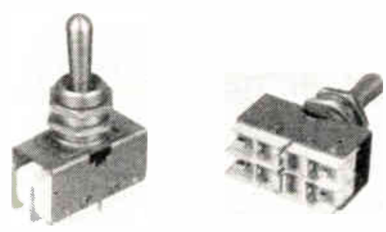
The longitudinal-baffle design significantly minimizes these limitations by making the baffle edges parallel to the weak axial field components.

Secondly, the residual and unavoidable reflections from longitudinal baffles impose no limitation on the distance between transmitter and target. A uniformly "quiet" volume, having dimensions subject to design control, surrounds the long axis of the chamber and extends to within a few feet of either end. In a transversely baffled room, an axially short quiet volume exists close to one end, and very elaborate baffling is required to permit a range of transmitter-to-target distances. Additional elaboration of shape and number of transverse baffles is necessary if the room must be used for transmission in either direction, and still further design complications result if the room must be used for both reflectivity and pattern work. In sharp contrast, the much simpler longitudinal-baffle chamber is equally good for transmission in either direction and it is inherently satisfactory for both reflectivity measurement and pattern recording.

The effectiveness of the new design can be readily appreciated by examining the specular reflection paths of rays originating on or near the long axis of the room. In the Canton, Massachusetts, chamber, no energy reflected specularly from walls, ceiling or floor returns to a central 6-foot diameter cylinder except after suffering three reflections from microwave absorbing material. Only a very few "second-bounce" rays traverse an 8-foot cylinder. Testing of the chamber shows the 6-foot diameter cylinder to exhibit −40 db reflection characteristics down to about 1 kmc and −50 db performance from kmc upward. Complete testing will pinpoint reflectivity versus frequency and a plot will be available.

### Multi-Circuit Toggle Switch

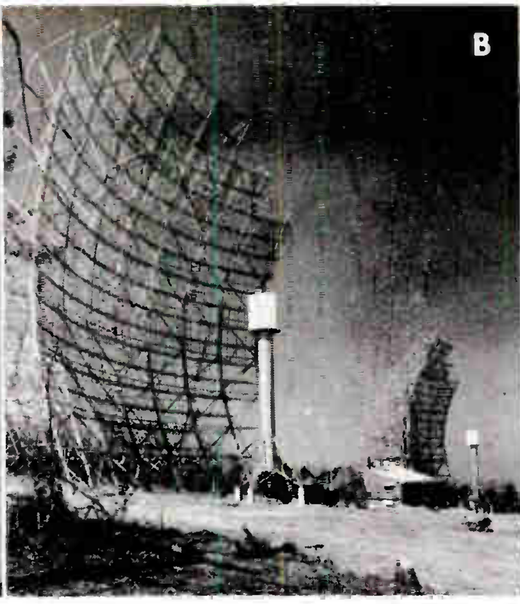
**Electrosnap Corp.,** 4218 W. Lake St., Chicago 24, Ill., manufacturer of precision switches, has developed a toggle switch, Model A3-77, containing four poles, yet occupying less than one cubic inch of space below the panel.



The switch is designed for aircraft and military use as well as for compact control panels on electrical and electronic equipment. All exposed metal parts are either

*(Continued on page 132A)*


A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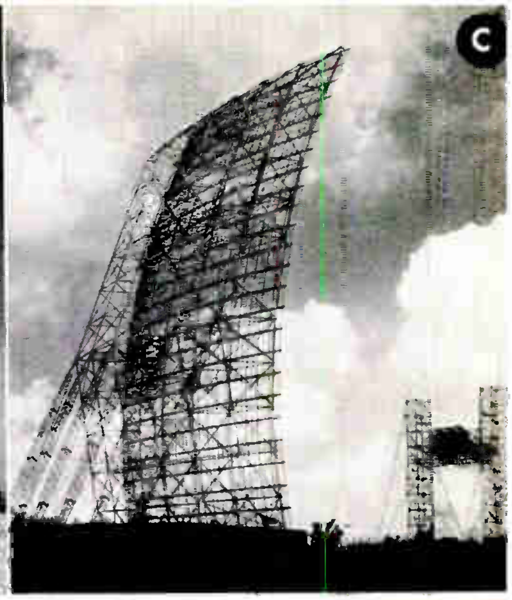
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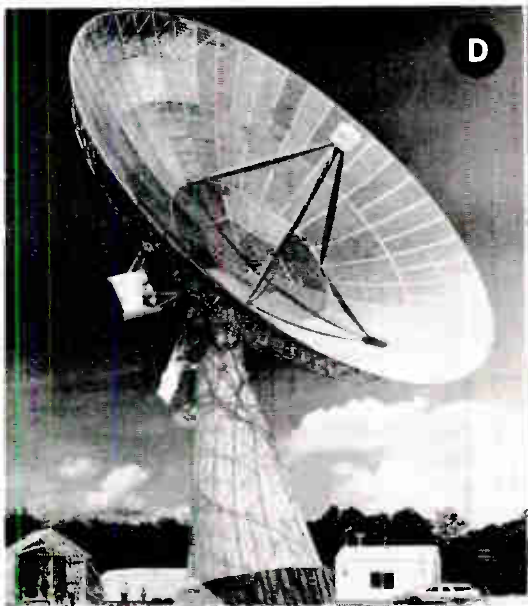
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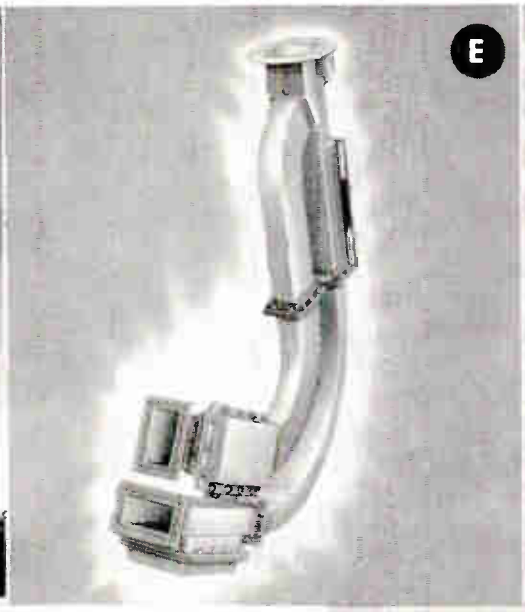
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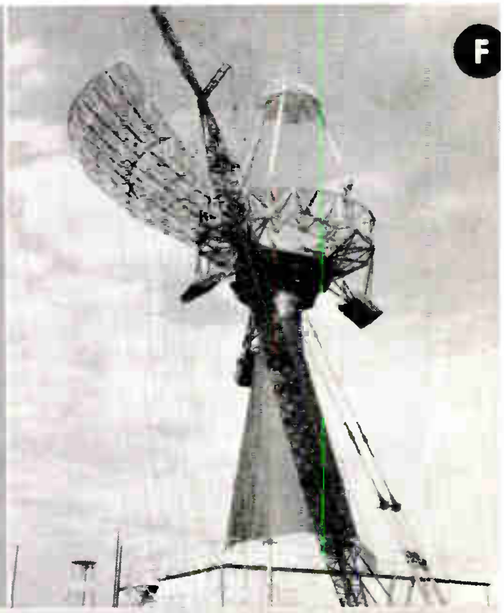

F

# NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(*Continued from page 130A*)

stainless steel or are treated for corrosion resistance. The operating force required to move the bat handle is set above the point where vibration or accidental jarring will actuate the switches. A detent action gives a positive "feel" to the movement of the bat handle from one side to the other.

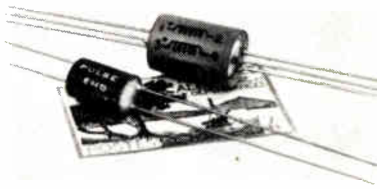
The bat handle of the switch is maintained in one of three positions with the center position off. Each pole of the switch element is rated at 6 amperes, 125/250 volts ac, 30 volts dc, resistive and 3 amperes, 30 volts dc, inductive. Weight is approximately 1 oz.

For further details, write to Electro-snap.

## Sub-Miniature Pulse Transformer

Production of a new sub-miniature pulse transformer featuring clamped ferrite core construction has begun at **Pulse Engineering, Inc.**, 560 Robert Ave., Santa Clara, Calif.

Known as the Micro-Stat®, the new magnetic component uses a high permeability core in the typical CI configuration developed by Pulse Engineering for its ferrite core transformers.



Use of core-gapped construction instead of the conventional toroid and cup core provides improved voltage breakdown and insulation resistance, according to company engineers.

This unique design also features faster reset and less $B_r$, higher power capabilities, lower losses, and increased total flux swing capability.

The units are constructed on an armite form for precise winding geometry to control leakage inductance and distributed capacity. Each Micro-Stat has a polished gap which represents ½ mil of effective gap.

Micro-Stats are available for immediate delivery in either epoxy construction or in hermetically-sealed metal casings. The epoxy model is 0.41" long with a diameter of 0.30". The metal casing is 0.57" long with a diameter of 0.41".

All applicable military specifications are met by the Micro-Stat. At present, it is available in over 50 designs.

For complete details, please write to the firm.

(*Continued on page 134A*)

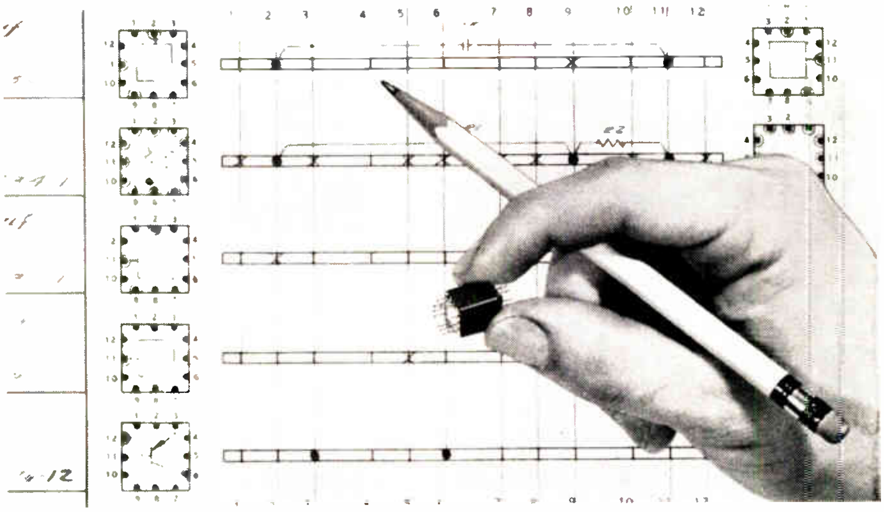
*Status Report on RCA Micromodules—*
*dramatic new devices for high-density parts packaging*

# How soon will you see your electronic products in Micromodule form?

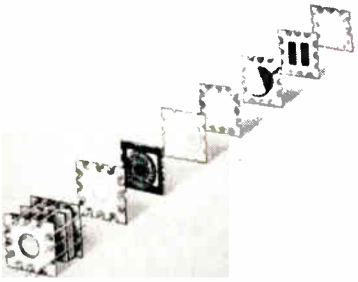
The excitement over Micromodules is still mounting! We haven't seen such enthusiasm and activity since the early days of transistors. Scores of electronic equipment designers and manufacturers are asking: "How soon can I see my product in Micromodule form?" Our answer: *Right Now!* We'll take your circuit, breadboard, or black box, evaluate it and convert it to module form. In fact, you will find that end-equipment in Micromodule form is probably only *one design cycle away!*

### Special Presentation Now Ready!

RCA Field Engineers are prepared to show you a presentation that will clearly explain the potentialities and the current working realities of Micromodules for application in military computers, digital devices for missiles and satellites, airborne or portable communication equipment, or submarine electronics. Many designers who have seen this presentation were so impressed with the possibilities of extreme miniaturization and increased reliability of Micromodules that they have immediately placed orders to begin micromodularization of their equipment. Call your RCA Field Representative today and he will set up a presentation for you at your convenience.



RCA Micromodules, todays' most exciting, most practical answer to high-density parts packaging, make possible equipment with modular parts densities to 600,000 per cubic foot. Result: important space savings over existing miniature equipment and an amazing increase in the number of *circuit functions* per cubic foot. Increased reliability through redundancy, room for more circuits to improve accuracy, precision, control and sensitivity are other significant advantages offered to designers.



Micromodules, developed through the joint efforts of RCA and other leading component manufacturers, in cooperation with the U.S. Army Signal Corps, are units in which several microelements are combined to perform specific functions such as amplifier, oscillator, or divider. The microelements are tiny ceramic wafers .310 inches square and 1/100th inch thick, on which conducting, semiconducting, and insulating materials are fused to provide the electrical characteristics of basic electronic components such as resistors, capacitors, and transistors. The microelements are interconnected and encapsulated to form Micromodules.

**RCA FIELD OFFICES**

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**Northeast:** 64 "A" St., Needham Heights 94, Mass. HIllcrest 4-7200
**East Central:** 714 New Center Bldg., Detroit 2, Mich. TRinity 5-5600
**Central:** Suite 1154, Merchandise Mart Plaza Chicago, Ill., WHitehall 4-2900
**West:** 6355 E. Washington Blvd. Los Angeles, Calif., RAymond 3-8361
**Gov't:** 224 N. Wilkinson St., Dayton, Ohio BAldwin 6-2366
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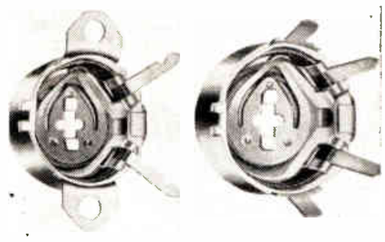
**NEWS**
**New Products**

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

*(Continued from page 132A)*

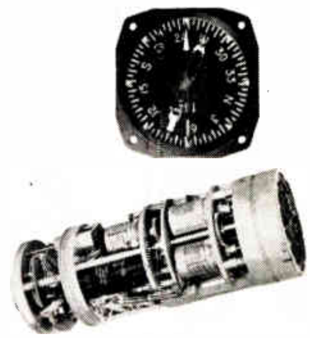
### Preset Wirewound Variable Resistors

A new line of $\frac{3}{4}''$ diameter lower cost miniature preset wirewound $\frac{1}{2}$–5000 ohms resistance range variable resistors has been developed by **Chicago Telephone Supply Corp.**, Elkhart, Ind.



Positive contact with the resistance winding at every point of rotation is insured by special alloy spring contactor. Continuous contact between contactor, rotor and cover is provided by 3 embossed dimples on the contactor. Dimensional stability under high humidity conditions is achieved by using fine grade winding strip material with low moisture absorption. This avoids the hazard of winding turns loosening or shorting after humidity exposure. Controls are designed for sensitivity, hum balance, bias adjust and other applications requiring a highly reliable preset wirewound control at lower cost. Rotational torque is 2 to 8 oz./in., stop torque 12 in./lbs. minimum and angle of rotation 240° ±5° without fixed resistor stop. Type 110 is available with straight or snap-in mounting tabs and terminals for printed circuits and Type 112 with flange type cover for eyelet or rivet mounting. Moveable contactor is connected electrically to the cover in both types.

### Computing Navigation Indicator



**John Oster Manufacturing Co., Avionic Div.**, 1 Main St., Racine, Wis., has developed a new computing indicator combining the functions of the ID-250/ARN Course Indicator, the ID-307/ARN Azimuth Indicator and the ID-310/ARN Range Indi-

*(Continued on page 138A)*

# 31 reasons why Transistorized GUARANTEED

## LAMBDA LT TRANSISTORIZED POWER SUPPLIES

IMMEDIATE DELIVERY FROM STOCK


Every Lambda Transistorized Power Supply is guaranteed to perform within applicable specifications and is further warranted to be free from defects in material and workmanship for a period of five full years. This plus the excellent experience of present users is your assurance of getting the finest in power supply service when you specify Lambda.

**Voltage Bands** ......0-8, 8-16, 16-24, 24-32 VDC

**Line Regulation** ......Better than 0.15 per cent or 20 millivolts (whichever is greater). For input variations from 105-125 VAC.

**Load Regulation** .....Better than 0.15 per cent or 20 millivolts (whichever is greater). For load variations from 0 to full load.

**AC Input** ...........105-125 VAC, 50-400 CPS

**Electrical Overload Protection** ..........Magnetic circuit breaker, front panel mounted. Unit cannot be injured by short circuit or overload.

**Thermal Overload Protection** ..........Thermostat, manual reset, rear of chassis. Thermal overload indicator light, front panel.

**Size** ...............3½" H x 19" W x 14⅜" D.

## CONVECTION COOLED

*No internal blowers – No moving parts*

0-32 VDC • 0-1 AMP • 0-2 AMP

- **Ambient 50° C at full rating.**
- **High efficiency radiator heat sinks.**
- Silicon rectifier.
- 50-400 cycles input.
- Special, high-purity foil, long-life electrolytics.

- **Compact. Only 3½" panel height.**
- **Short-circuit proof.**
- Protected by magnetic circuit breakers.
- Hermetically-sealed transformer. Designed to MIL-T27A.

- **All transistor. No tubes.**
- **Fast transient response.**
- Excess ambient thermal protection.
- Excellent regulation. Low output impedance. Low ripple.
- Remote sensing and DC vernier.

- Model LT 1095 **$285**
- Model LT 1095M (metered) **$315**
- Model LT 2095 **$365**
- Model LT 2095M (metered) **$395**

### SEND FOR COMPLETE DATA

Write for information and specifications on Lambda's full line of transistor-regulated and tube-regulated power supplies.

λ LAMBDA ELECTRONICS CORP.
11-11 131 STREET • COLLEGE POINT 56, N. Y. • INDEPENDENCE 1-8500

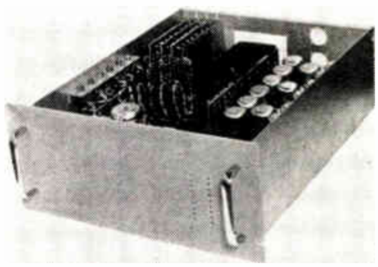
These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

*(Continued from page 134A)*

cator into a single extremely compact unit. Type 9814-02 eliminates 2 indicators from the instrument panel and weighs 50% less and has 60% less volume than the 3 units it replaces. Overall length is $9\frac{1}{4}''$, diameter $3\frac{1}{8}''$ and weight $4\frac{1}{2}$ lbs. Maximum. The unit contains 14 major components consisting of 3 ac servo motors, 4 resolvers, 1 control transformer, 1 torque receiver, 4 potentiometers and 1 servo amplifier. The entire mechanical portion is hermetically sealed. One of the unit's computers determines aircraft distance from a Tacan beacon and another computer, aircraft bearing with respect to beacon. For the pilot's convenience, the single indicator face presents compass information on a rotating compass card, distance information on a 3 digit counter and relative Tacan bearing information on a double-bar pointer. An auxiliary single bar pointer is provided for use with other navigational systems. Designed for use with Tacan Receiver-Transmitter Units such as ARN21 in connection with an MA-1 Compass System.

## DC Signal Sources

The first commercially available dc signal sources for digital programming have been introduced by **Consolidated Avionics Corp.**, 800 Shames Dr., Westbury, L. I., N. Y., a subsidiary of Consolidated Diesel Electric Corporation, company spokesmen report.



Typical uses, according to the manufacturer, include data systems, automatic checkout equipment and precision testing applications, both in the laboratory and on the production line.

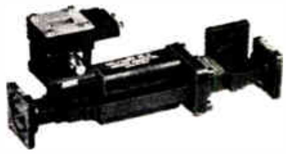
Output voltages are determined by the digital code, in the form of external contact closures, applied to the programming input terminals. Standard units are for three binary-coded decimal digits; other codes are available. The three digits may be fed serially or simultaneously. External contacts must remain closed three milliseconds in order to register. Units also incorporate a clock closure circuit for timed programs.

Output voltage stability is 0.05 per cent under any combination of the following

*(Continued on page 140A)*

New parametric amplifiers for 4 to 14 db improvement in receivers operating within the 100-1500 mc range.

New ruggedized magnetrons for increased reliability of air-borne systems.



New ferrite duplexers, isolators and circulators for advanced systems.

New computer diodes with recovery times lower than 4 mμ secs.

New Varactor diodes that reduce receiver noise to as low as 1 db.

New duplexer tubes that guarantee crystal protection up to 1000 hours and at elevated temperatures.

New solid-state limiters that protect receivers without external bias.

# PROGRESS AT MICROWAVE

## *has a unique 12-month pattern . . .*

This pattern of progress at Microwave Associates during the past 12 months reveals a unique combination of solid state and microwave competence. It shows a new-development pace unmatched by any other single source in the microwave field. It promises that your own microwave system planning can benefit from close cooperation with our skilled team of physicists, metallurgists and engineers. Let's move ahead *faster . . . together!*

For data and prices on any of these new products . . . or for engineering cooperation in developing systems components for your specialized needs, write or call:

MICROWAVE ASSOCIATES, INC.

BURLINGTON, MASS. BRowning 2-3000

# IMPULSE

## A DIGEST OF NEW DEVELOPMENTS IN ELECTRONICS AND AUTOMATION

PUBLISHED BY ROME CABLE CORPORATION, ROME, N. Y.

*PIONEERS IN INSTRUMENTATION CABLE ENGINEERING*

**BEHIND THE NEUTRON CURTAIN.** It may be that the Russians are planning to create an immense neutron cloud cover by setting off a series of high-altitude (300 miles and up) atom and hydrogen bomb blasts. Such a cloud cover would act as a sort of shield against atomic warheads, heating atomic missiles that travel at speeds of 15,000 mph and causing the uranium 235 or plutonium to melt. The atomic engines of planes would also be destroyed in this way. The destructive clouds would probably move in well-defined paths, the Russians theorize, and could also be used to destroy life aboard manned satellites.

**WANTED:** *By the Air Force:* a non-radiating range-measuring device capable of ranging 20,000 to 30,000 feet ahead of aircraft flying at 500-1000 feet absolute altitude. *By the Navy:* some sort of electronic device that can detect atomic submarines at long distance. Problems that must be overcome: subs are quiet, don't surface, are fast. Some consider atomic subs to be the greatest menace of World War III. The jackpot could run to billions of dollars for the electronics company that solves the detection problem. *By the Air Force:* a means of identifying overstressed materials before failure occurs, to solve the problem of detecting impending failure in rotor blades and components.

**FRIENDLY CHALLENGE.** Perhaps the competition between the U. S. and the U. S. S. R. in the field of technology could be diverted to accommodate a new "race" in which the consequences for the loser are less ominous. This thought came to us with the announcement of the recent development in the U. S. of an electronic chess-playing computer, the third and most sophisticated of its kind yet developed, that is capable of giving a "fairly good player" a battle. The Russians, too, have developed a machine of equal merit, so . . . our machine will play your machine, Ivan—just name the date.

**CHECK LIST FOR SPECIAL CABLE.** As an aid to the engineer who has to design and use special electronic cables, we've printed the following check list which summarizes the desired requirements. Copies of this check list as a Cable Procurement Information Form will be sent at your request if you write to IMPULSE, c/o Rome Cable Corp., Dept. 1212, Rome, N. Y. When writing, ask for Bulletin RCD-400, a summary of special instrumentation cables available from Rome.

**Number of conductors . . . conductor's size and stranding . . . desired insulation . . . shielding . . . outer covering . . . desired cable construction . . . maximum and minimum O.D. . . . upper operating-temperature limit . . . lower operating-temperature limit . . . bending radius desired . . . type of duty . . . electrical characteristics . . . special requirements . . . desired shipping lengths . . . specifications.**

**CABLEMAN'S CORNER.** An important phase in multi-conductor cable manufacture is the manner and equipment used to "cable," or "twist," the various components together. The end use of the cable becomes an important factor in the assembly of a cable. Where flexibility is important, the length of lay, direction of lay, and the internal components all play important roles. Where connector fittings are employed, the sequential arrangement of the components may be important. Because of differing machine capabilities, even the selection of the specific piece of equipment for assembling your cable becomes important. To obtain the best results, consult a cable specialist—a man familiar with all the aspects of cable manufacture—your Rome Cable salesman.

These news items represent a digest of information found in many of the publications and periodicals of the electronics industry or related industries. They appear in brief here for easy and concentrated reading. Further information on each can be found in the original source material. Sources will be forwarded on request.

## NEWS New Products

**These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.**

*(Continued from page 138A)*

conditions; no load to full load, ±10% variation in line voltage and/or ±10°C temperature change. Recovery time for a 20 per cent load change is 100 microseconds. Voltage is adjustable with an accuracy of ±0.1%. Output voltage ripple is under 0.05%.

Units are packaged for mounting in standard 19-inch relay racks. They require $8\frac{3}{4}''$ of rack space and are 23" deep.

Two models are offered. Model 1101 provides voltages from one to 999 volts in one-volt steps. Output current capacity is 100 milliamperes from one to 100 volts; 10 ma from 101 to 999 volts. Model 1102 provides voltages from 0.1 to 50 in 0.1-volt steps. Its current capacity is 15 amperes at all voltages.

### Core Design Data

G-L precision-made, tape wound cores can now be obtained in two new core materials to precise limits and these materials and limits are illustrated and described in a new, 8-page, two color, illustrated catalog recently issued by **G-L Electronics,** 2921 Admiral Wilson Blvd., Camden 5, N. J. Data is included on SUPER HYMU "80" and SILICON Steel cores as well as on "O" ORTHONIK, "H" HYMU "80" and "B" HYMU "80" core materials. Core design data is included, as well as new case sizes. Bulletin TB-105 has diagrams, charts and tables which show the new test limits to precise ranges, constant-current flux-reset data and standard core sizes, and information on G-L matched cores, protective boxes and vibration and shock protection is supplied together with details on how to order.

"M" SUPER HYMU "80" is described as a vacuum melted material similar, chemically, to HYMU "80", but highly refined and carefully processed to produce initial permeability and dynamic core loss considerably beyond the possibilities of "B" HYMU "80" material; "S" SILICON Steel as a grain oriented, 3% silicon, 97% iron alloy which has a rectangular hysteresis loop.

For a free copy of Bulletin TB-105, write to the firm.

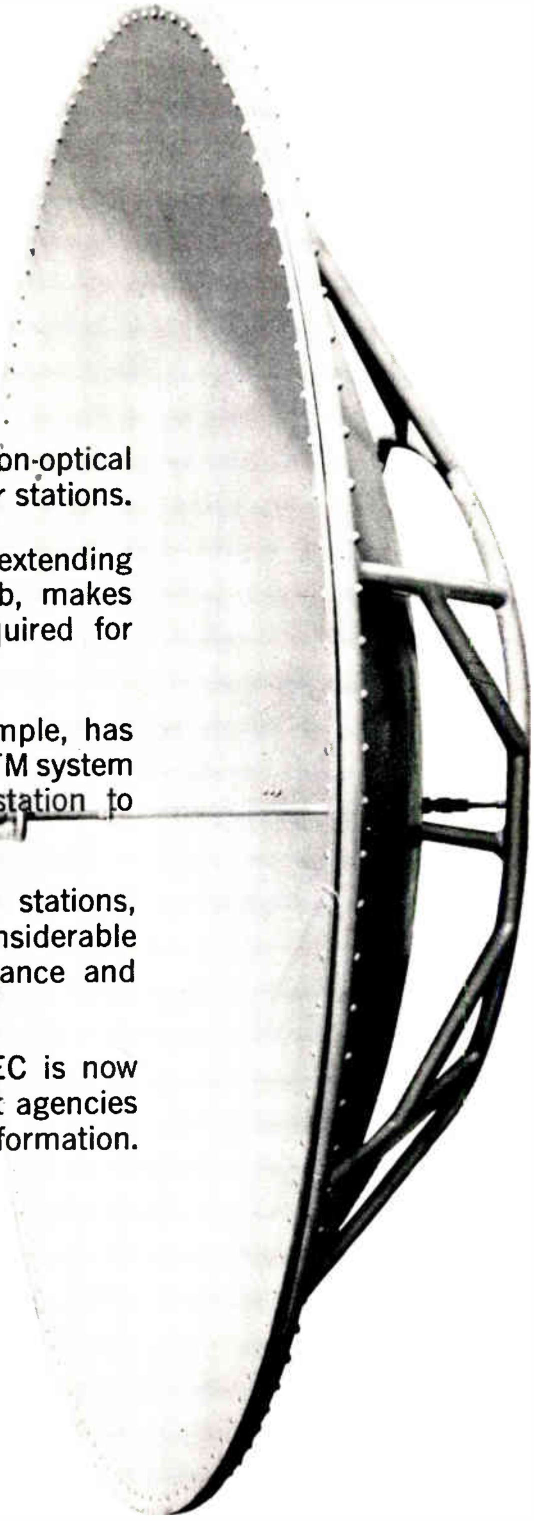
### Spectrum Analyzer

**The Federal Scientific Corp.,** 615 W. 131st St., New York 27, N. Y., announces a line of real-time Simoramic (tradename) spectrum analyzers. The analyzer synthesizes the equivalent of thousands of band-pass filters located side by side in the frequency domain through the use of a single delay line in a well-controlled closed loop. The frequency location, impulsive response, and gain of all the synthesized filters are determined by the same network elements within the closed loop, making for excellent reliability and stability. The

*(Continued on page 142A)*

# New from Japan . . .

## Important advance in short-haul, multi-channel communications



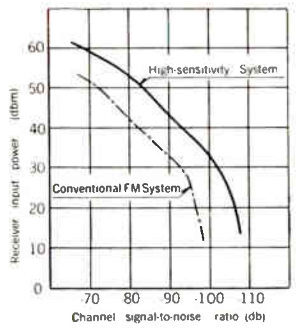
Microwave 60-channel voice transmission over a non-optical path up to 300 MILES is now possible without repeater stations.

NEC's High Sensitivity Reception System, by extending threshold level and improving S/N ratio 10 to 13 db, makes this hop with only 1/20 of the power output required for conventional systems.

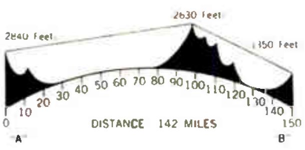
A 100 W transmitter in the 1,800-mc band, for example, has a scatter path of 100—150 MILES. A conventional FM system requires 2 KW output and at least one repeater station to connect the same distance over a non-optical path.

By eliminating high-power amplifiers and repeater stations, the High Sensitivity Reception System results in considerable reduction in initial investment. Savings in maintenance and power consumption are estimated at 40% or more.

Extensive propagation tests have been made, and NEC is now prepared to supply commercial users and government agencies anywhere in the world. Please write for detailed information.




CURVE compares receiver performance of High Sensitivity Reception System to conventional FM




PROFILE shows how a 100 W transmitter operating at 1,920 mc connects a non-optical distance of 142 MILES in one hop. Average receiver input level is 75 dbm

**Nippon Electric Company Ltd.**
Tokyo, Japan
Electronics / Communications Systems

## NEWS New Products

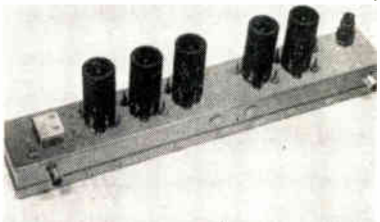
**These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.**

*(Continued from page 140A)*

outputs of the individual synthesized filters are presented sequentially for either human observation or computer consumption.

The Model 4A analyzer covers the frequency band 1 cps to 200 cps with approximately 1 cps resolution. In conjunction with attachment FC4A the 200 cps frequency coverage range of the instrument may be positioned anywhere in the 1 cps to 10 kc frequency range.

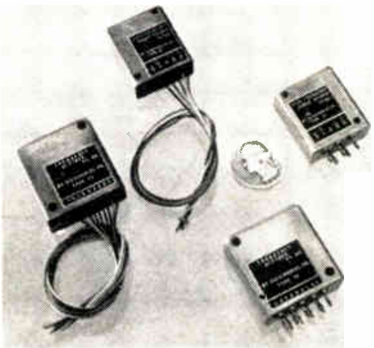
### IF Amplifier



**LEL, Inc.**, 380 Oak St., Copiague, L. I., N. Y., has introduced a new addition to their IF amplifier line which extends the range of their standard cataloged units to 200 mc. The IF 39 has a gain of 120 db, 3 mc bandwidth, 200 mc center frequency, detector output, and provision for gain control. A matched input noise figure of 6.5 db is standard; lower noise figure input circuitry can be supplied if required. For further information contact the firm.

### Transistorized Flip Flops

**MF Electronics Co.**, 122 E. 25th St., New York 10, N. Y., announces a new line of packaged transistorized Flip Flops and Binary Dividers.

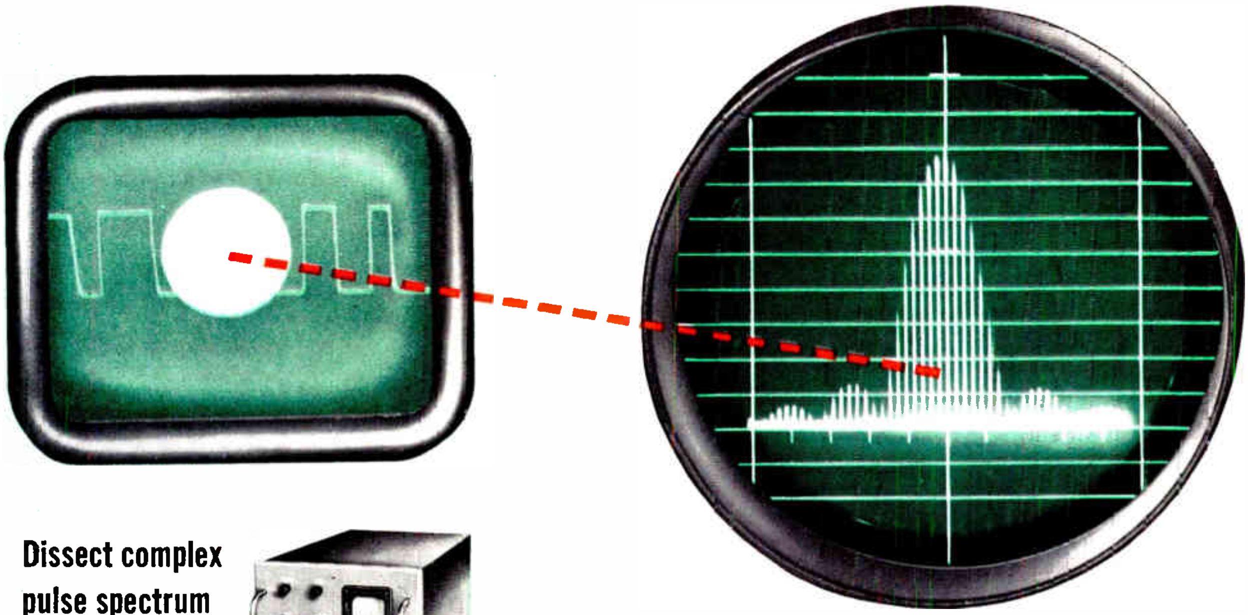


Designated our Types 24 through 27, these units are designed for high reliability operations and are available in speeds up to 1.2 mc. They are epoxy resin filled and can be furnished with either soft wire inline leads or solder hook terminals. The soft wire units are ideal for assembling on a printed wiring board, while the solder

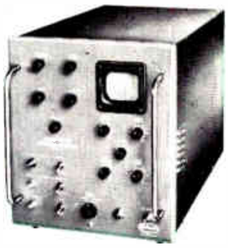
*(Continued on page 146A)*

# VISUAL MICROWAVE ANALYSIS—10 to 44,000 mc

## COMPLEX SPECTRUM DECODING



Dissect complex pulse spectrum visually by means of Polarad Model SD-1



## MULTI-PULSE SPECTRUM SELECTOR

Used with any Polarad analyzer, this Model SD-1 Spectrum Selector permits complete analysis of any complex pulse modulated microwave signals. The unit decodes and isolates any segment of a complex pulse train and permits corresponding spectrum analysis of that segment.

Model SD-1 Spectrum Selector displays pulse groups up to 180 microseconds duration (Model SD-1X: 350 microseconds).

**Applications:**

Design and operation of radar, telemetry equipment, IFF systems and beacons.

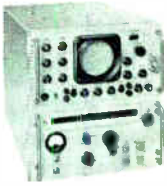
Analyze complex spectrum visually using any of Polarad's wide band

## MICROWAVE ANALYZERS

**Model TSA Spectrum Analyzer** — 25 kc resolution, 400 kc to 25 mc dispersion. 5 sensitive plug-in tuning units.

**Model TSA-S Combination Synchroscope-Spectrum Analyzer** — Displays pulse waveform or frequency spectrum. 5 kc to 5 mc adjustable bandwidth, 400 kc to 25 mc dispersion. 5 sensitive plug-in tuning units.

**Model TSA-W Wide Dispersion Spectrum Analyzer** — 100 kc to 70 mc dispersion. 7 kc and 50 kc resolution. Logarithmic amplitude display. 5 sensitive plug-in tuning units.



**Model SA-84 Multi-band Spectrum Analyzer** — 10 to 40,880 mc in a single unit. 25 kc resolution, 400 kc to 25 mc dispersion. Simple band switch, slide-rule dial. Military approved.

FREE LIFETIME SERVICE ON ALL POLARAD INSTRUMENTS

Ask your nearest Polarad representative (in the Yellow Pages) for a copy of "Handbook of Spectrum Analyzer Techniques" and "Notes on Microwave Measurements"

**POLARAD ELECTRONICS CORPORATION**

43-20 34th Street, Long Island City 1, N. Y.

Representatives in principal cities

MAIL THIS CARD

**POLARAD ELECTRONICS CORPORATION:**

POLARAD

Please send me information and specifications on:

- ☐ Model SD-1 Multi-Pulse Spectrum Selector
- ☐ Microwave Spectrum Analyzers
- ☐ Model B Microwave Code Generator (see reverse side of this page)

My application is: ______

Name ______

Title ______ Dept. ______

Company ______

Address ______

City ______ Zone ______ State ______

ED IRE WEN MJ

# COMPLETE FACILITIES–CODED MICROWAVE SIGNALS 950 to 10,750 mc

**APPLICATIONS:**

**One integrated instrument:**

**Provides** a complete system for simulating and testing missile and telemetry systems, IFF and radar, microwave beacons, direction finding and navigational equipment and microwave relay links.

**Performs** general purpose signal generator and oscilloscope measurements, multi-pulse testing and analysis.

## SET FREQUENCY

Frequency range 950 to 10,750 mc is covered by four interchangeable microwave oscillator units, all stored in the instrument. Each has UNI-DIAL control, precision power monitor circuit to maintain 1 milliwatt power output reference level, and non-contacting short-type chokes to assure long life.

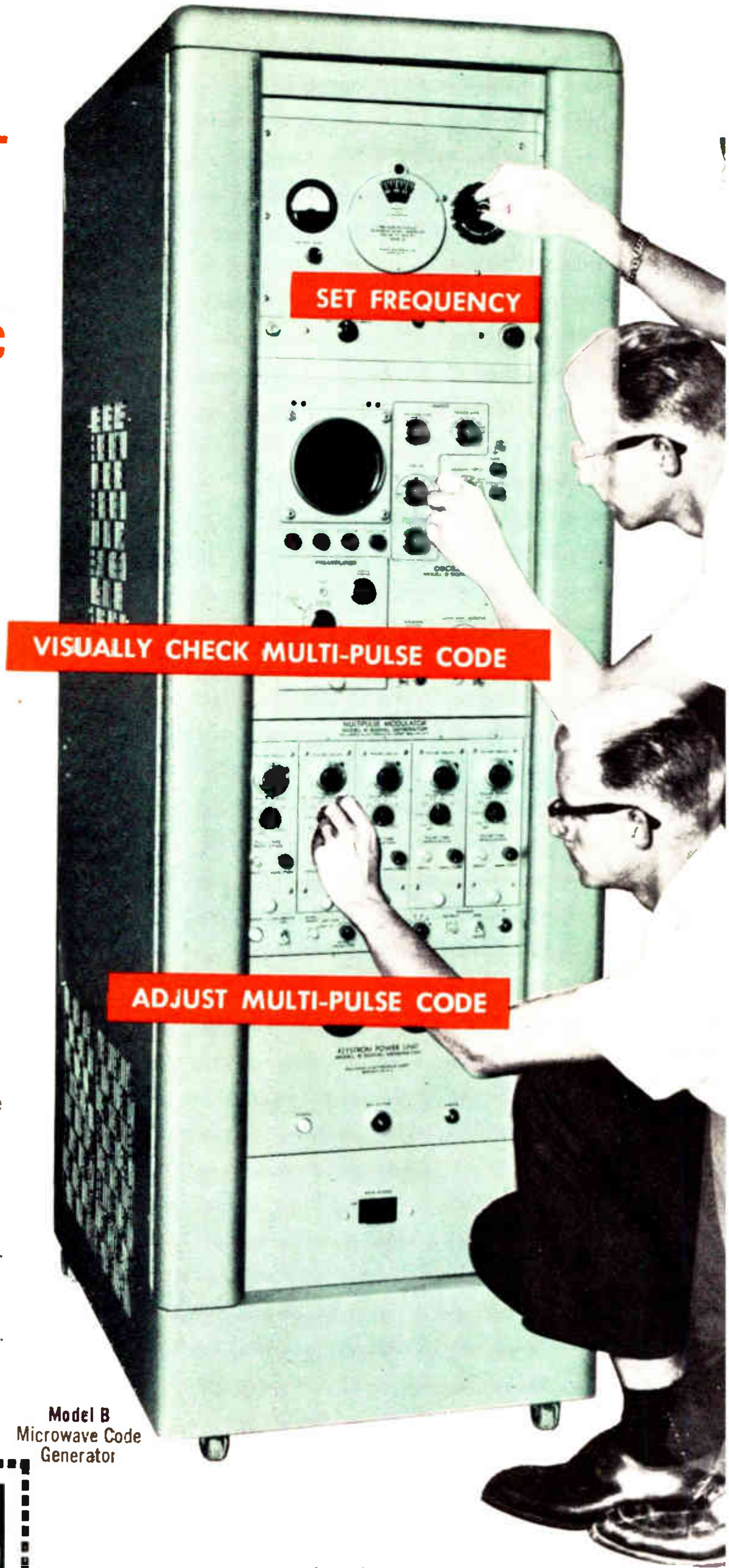
## VISUALLY CHECK MULTI-PULSE CODE

Calibration of r-f pulse width, delay and group repetition rate is simplified by ability to view pulse train on a precision oscilloscope with a built-in wide band r-f detector.

## ADJUST MULTI-PULSE CODE

Code modulation is achieved with five independently adjustable pulse channels providing: **pulse repetition rate** variable, 10-10,000 pps; **width** variable 0.2 to 2 microseconds; **delay** variable 0-300 microseconds. **Pulse rise and decay**, 0.1 microsecond.

**NO ADJUSTMENT NECESSARY** on self-contained power supplies. Klystron power unit adjusts to proper voltage automatically for each interchangeable tuning unit. Built-in AC regulator. Equipped with an electronically regulated low-voltage DC supply.




Model B Microwave Code Generator

Postage Will be Paid by Addressee

No Postage Stamp Necessary If Mailed in the United States

**BUSINESS REPLY CARD**
First Class Permit No. 18, Long Island City 1, N.Y.

**POLARAD ELECTRONICS CORP**
**43-20 34th St., Long Island City 1, N.Y.**

POLARAD

**MAIL THIS CARD** for detailed specifications. Ask your nearest Polarad representative (in the Yellow Pages) for a copy of "Notes on Microwave Measurements"

FREE LIFETIME SERVICE ON ALL POLARAD INSTRUMENTS

**POLARAD ELECTRONICS CORPORATION**
43-20 34th Street, Long Island City 1, N. Y.
Representatives in principal cities


for voltage stabilizing... rectifying...controlling...

# THERE'S A RAYTHEON GAS DIODE TO MATCH YOUR TOUGHEST POWER-SUPPLY 'SPEC'

## VOLTAGE REGULATOR TUBES

| Type | Base | D.C. Operating Voltage | Current Range | Regulation |
|---|---|---|---|---|
| OA2WA<br>CK6626/OA2WA<br>CK6073, OA2 | Miniature | 150 v. | 5 — 30 ma. | 2 v. |
| OB2WA<br>CK6627/OB2WA<br>CK6074, OB2 | Miniature | 108 v. | 5 — 30 ma. | 1 v. |
| OC2 | Miniature | 75 v. | 5 — 30 ma. | 3 v. |
| CK5787 | Subminiature | 98 v. | 5 — 25 ma. | 3 v. |
| CK5787WA | Subminiature | 98 v. | 5 — 25 ma. | 1.5 v. |
| CK6542 | Subminiature | 148 v. | 5 — 25 ma. | 2 v. |
| **Corona Voltage Regulators** | | | | |
| CK1038 | Subminiature | 885 — 915 v. | 5 — 55 μa. | 15 v. max. |
| CK5962 | Miniature | 700 v. | 2 — 55 μa. | 15 v. max. |
| CK6437 | Subminiature | 700 v. | 5 — 125 μa. | 15 v. max. |
| CK6438 | Subminiature | 1200 v. | 5 — 125 μa. | 20 v. max. |

## VOLTAGE REFERENCE TUBES

| Type | Base | D.C. Operating Voltage | Current Range | Regulation | Voltage Jump Max. |
|---|---|---|---|---|---|
| CK5651 | Miniature | 85 v. | 1.5 — 3.5 ma. | 1.5 v. | 0.1 v. |
| CK5651WA | Miniature | 85 v. | 1.5 — 3.5 ma. | 1.5 v. | 0.005 v. |
| CK5783 | Subminiature | 85 v. | 1.5 — 3.5 ma. | 3.0 v. | 0.1 v. |
| CK5783WA | Subminiature | 85 v. | 1.5 — 3.5 ma. | 2.4 v. | 0.005 v. |
| CK6213 | Subminiature | 130 v. | 1.0 — 2.5 ma. | 1.0 v. | — |

## COLD CATHODE RECTIFIER TUBES

| Type | Construction | Base | Max. Peak Inverse Voltage | Peak Plate Current | Max. D.C. Output Current |
|---|---|---|---|---|---|
| OZ4A/1003 | Double Diode | Octal | 880 v. | 330 ma. | 110 ma. |
| CK1005 | Double Diode | Octal | 450 v. | 210 ma. | 70 ma. |
| CK1006 | Double Diode | 4-Pin. | 1600 v. | 600 ma. | 200 ma. |
| CK1007 | Double Diode | Octal | 1200 v. | 510 ma. | 85 ma |
| CK5517 | Diode | Miniature | 2800 v. | 100 ma. | 12 ma. |
| CK6174 | Diode | Miniature | 2800 v. | 30 ma. | 3 ma. |
| CK6659 | Diode | Subminiature | 2800 v. | 40 ma. | 8 ma. |
| CK6763 | Diode | Miniature | 2800 v. | 100 ma. | 12 ma. |

Detailed technical data bulletins on any of these types are yours for the asking. Better yet, ask to have a Raytheon sales engineer drop in for a firsthand appraisal of your application and prototype needs — no obligation, of course. Write directly to Dept. 2528.

*Small order and prototype quantities available directly from your local Raytheon electronics parts distributors.*

**Want to Receive Our Technical Data Regularly?** We'll be happy to keep you informed of latest technical developments, new products, design tips, etc. An application for addition to our new Technical Information Mailing List is yours for the asking. Write on your company letterhead directly to: W. J. Davis, Dept. 2528, at division address listed.

RAYTHEON

Industrial Tube Subdivision

**INDUSTRIAL COMPONENTS DIVISION**

49 Chapel Street, Newton 58, Massachusetts

**RELIABLE MINIATURE AND SUBMINIATURE TUBES • HARD-GLASS POWER TUBES • GAS TUBES • CATHODE RAY TUBES • STORAGE TUBES**

**LOS ANGELES,** NOrmandy 5-4221 • **SAN FRANCISCO,** Fireside 1-7711 • **CHICAGO,** NAtional 5-4000 • **KANSAS CITY,** PLaza 3-5330
**CLEVELAND,** WInton 1-7716 • **BALTIMORE,** SOuthfield 1-1237 • **ORLANDO, FLA.,** GArden 3-1553 • **NEW YORK,** PLaza 3-3900 • **BOSTON,** BIgelow 4-7500
**GOVERNMENT SALES: BOSTON,** BIgelow 4-7500 • **WASHINGTON, D. C.,** MEtropolitan 8-5205 • **DAYTON,** BAldwin 3-8128

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

*(Continued from page 142A)*

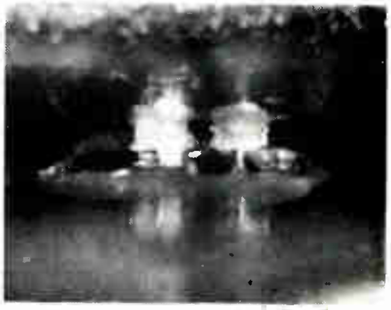
hook terminal units may be wired from point to point.

All units operate up to 60°C and are designed to meet the requirements of MIL-T-21038, Grade 5, Class Q, Life Expectancy X, with respect to materials, workmanship and general design features.

## 4,000-MC Esaki-Diode Oscillator

One of the most interesting semiconductor devices to come along in recent years is the Esaki or tunnel diode. High frequency response, low noise figure, ability to operate from near absolute zero to several hundred degrees centigrade and remarkable resistance to radiation damage are some of its features.

**International Business Machines Corp.,** 590 Madison Ave., New York 22, N. Y., has done considerable experimental and theoretical work in investigating the Esaki diode or tunnel diode as a possible computer component. One result of this research effort is reported in an article by R. F. Rutz in the October issue of the IBM Journal of Research and Development.



Greatly magnified view of the "heart" of the Esaki-diode oscillator. At left is the germanium resistor. At right is the highly etched Esaki diode. Its narrowest dimension is about 0.001 inch.

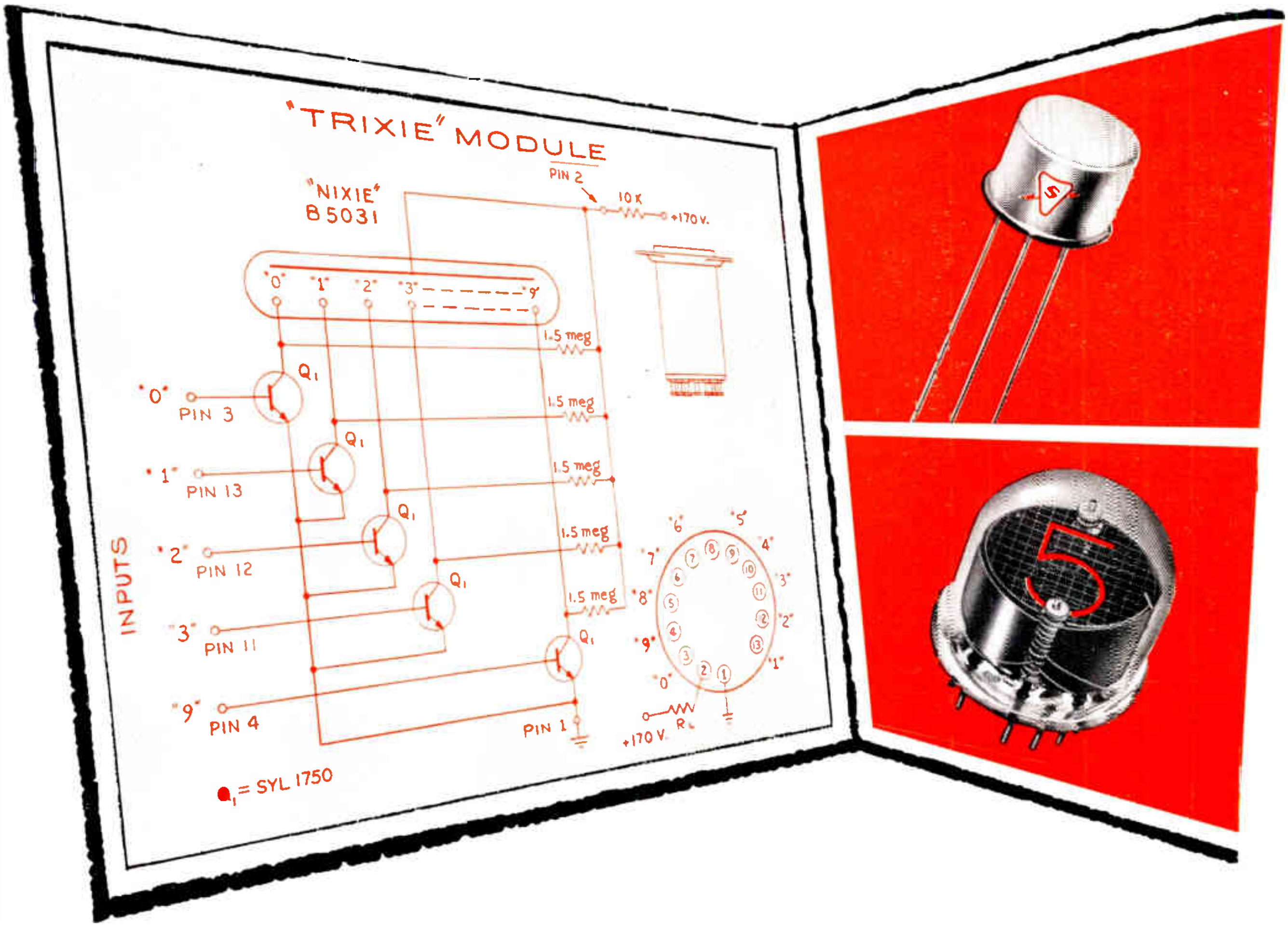
Two significant factors in this development* should be noted. First, an experimental oscillator has been fabricated from germanium with a fundamental frequency of oscillation of 3,010 mc. (A more recent model, however, has a fundamental frequency of oscillation of 4,020 mc.) These are believed to be the highest frequencies of oscillation for Esaki-diode oscillators yet reported. The high-frequency limit of the oscillator design is not known. Second, the design approach is non-conventional in that no cavities are used as tuned elements. Instead, the design is one using "lumped parameter" components, (inductance, capacitance and resistance).

Complete technical details on the design of the oscillator are given in the article.

A second article by P. J. Price and J. M. Radcliffe, in the same issue, reports on investigation of the fundamental theory of "Esaki Tunneling."

* This work was supported by the Department of Defense.

*(Continued on page 148A)*




## ...NEW LOW-COST

# Transistorized Readout

**"Trixie", new computer readout circuit design, utilizes Sylvania's new NPN transistor, Syl 1750, and the Nixie® indicator tube**

Now, designers can meet direct readout requirements for computers, instrumentation and data display with new economy and efficiency. Sylvania, pioneer manufacturer of NPN transistors, has developed new parameters in the Syl 1750 to meet the need for a low voltage input driving circuit for the Nixie indicator tube.

"Trixie" (Transistors + Nixie tube) comprises ten Sylvania NPN medium voltage switching transistors, Syl 1750, in a common emitter configuration. Each transistor drives one of the tube's ten cathodes. The result is the lowest power visual readout available. It can be designed in plug-in module form around a standard Nixie tube socket with terminals provided for electrical connections. A typical module, especially adaptable for direct panel mounting, has an over-all length of two inches and a nominal one-inch diameter.

The new Syl 1750, specially designed for "Trixie," is a 40 v (minimum) NPN germanium alloy junction transistor. Its low cost is a product of Sylvania's production know-how in NPN transistor manufacture and long experience in NPN design. Syl 1750 meets the reliability and performance criteria of other Sylvania switching transistors and matches their high-quality standards. It is encased in a JEDEC TO-5 package with the Sylvania welded hermetic seal for full protection against humidity and other environmental conditions.

Call your Sylvania representative now for full details of the new low-cost transistorized readout components.

"Trixie" & "Nixie" are trade marks owned by Burroughs Corporation.

**SYLVANIA** GENERAL SYSTEM

Subsidiary of
**GENERAL TELEPHONE & ELECTRONICS**

Sylvania Semiconductor Division
100 Sylvan Rd., Woburn. Mass.

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

*(Continued from page 146A)*

## Ewen Knight Has New Plant

More than three hundred attended official dedication ceremonies, on Tuesday, of the **Ewen Knight Corporation**'s new installation at Cerel-Perini's East Natic, Industrial Park, East Natick, Mass.

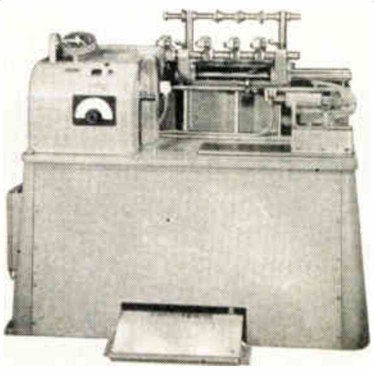
Following the presentation, guests were taken on a guided tour of the new facilities and were shown the technical equipment being produced at the laboratory, both for government and private industry. The very sensitive (low internal noise) receivers and radiometers are used to receive signals from other planets, the sun, moon and stars. These signals give indications as to the nature of other planets, their surrounding atmosphere and distance and motion of the celestial body in relation to the earth.

Open House guests were shown the firm's process for producing synthetic rubies which are used in their latest low noise receiving equipment.

Various groups also viewed Maser Systems, all types of ferrite devices, low-internal noise receiver systems and other advanced projects being developed at the new laboratory.

## Multiple Transformer and Bobbin Winder

A new multiple transformer/bobbin winder which eliminates gear changes and permits rapid change-over from one wire gauge to another is now available from **Geo. Stevens Mfg. Co., Inc.**, Pulaski Road at Peterson, Chicago 46, Ill.



*(Continued on page 150A)*

# CUT

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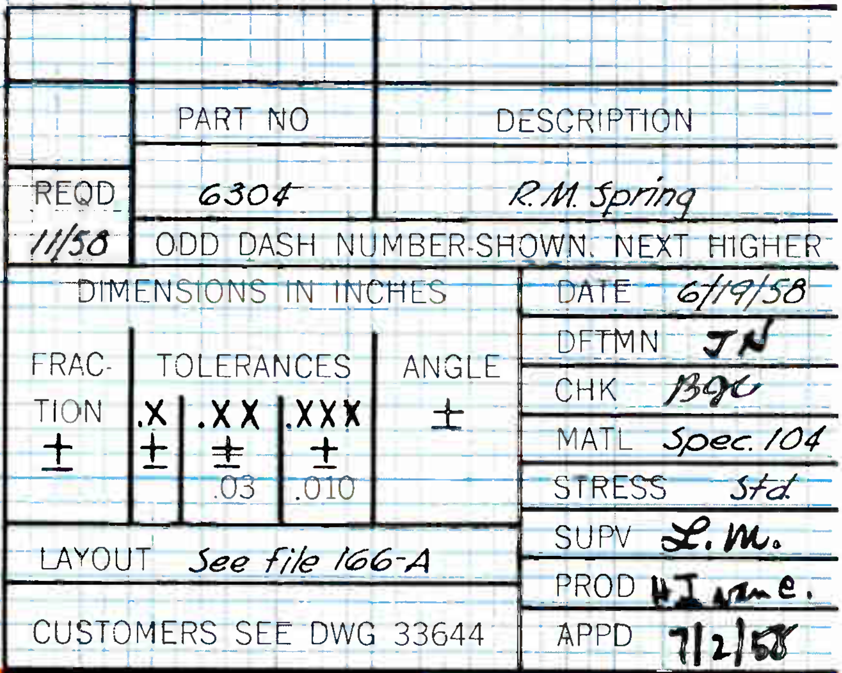


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Vertical lines are identically placed on every sheet and provide uniform guides for vertical layout.

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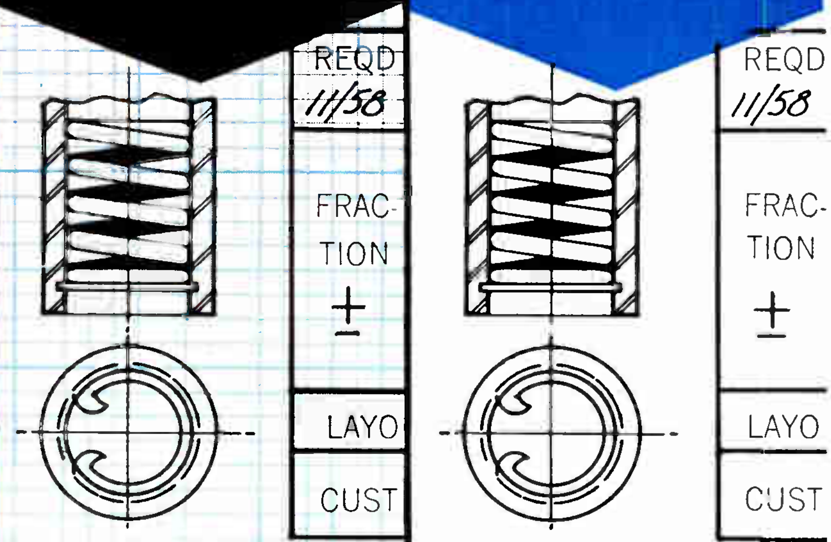


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## NEWS New Products

**These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.**

*(Continued from page 148A)*

Model 500-AM winds power, audio and similar types of heavy duty transformer coils and all types of heavy duty field coils and bobbins. Complete transformers may be wound without removing mandrels from machine. Dial is calibrated in wire sizes from 10 to 31 AWG, permitting instant selection of correct winding pitch. Machine also handles wire finer than 31. Maximum coil OD is 16", maximum winding stroke 9", maximum loading distance for multiple winding 24" and winding range from 5 through 100 turns-per-inch on calibrated dial and up to 450 turns-per-inch uncalibrated. Winding width is instantly adjusted by moving slider on claibrated scale to desired winding width. Machine is furnished with instant re-set automatic counter, magnetic brake, instant spiral/rapid traverse, motor and heavy duty tailstock. Winding speeds are up to 380 RPM. Machine is also available as Model 500, without automatic counter and without magnetic brake but with heavy duty positive locking tailstock and dial counter.

### Infrared Standard

The ISL 403 Black Body with the ISL 100 Temperature Controller represents an accurately adjustable standard of radiant energy which checks and calibrates other infrared sources and measuring instruments.

Designed to emit black body radiation over the temperature range of 500°K to 1000°K, the stability of its operation is such that the radiation source temperature is maintained within ±1°K despite wide changes in ambient temperature, line voltage variations, transients and tube aging.

The ISL 403 is maintained at the selected temperature by a combination of vacuum-tube amplifier and thyratron circuitry in a power-proportioning temperature controller of high performance.

Write today for ISL Bulletin #2 and more complete specifications to: **Infrared Standards Laboratory,** 10555 Magnolia Ave., Riverside, Calif.

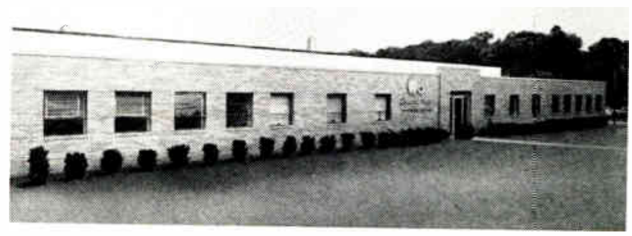
*(Continued on page 154A)*

## NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

*(Continued from page 150A)*

## Dynamic Gear Opens New $250,000 Plant in Amityville, N. Y.



**Dynamic Gear Co.,** which began operations in 1948 in a barn in Brooklyn, opened a new $250,000 plant in Amityville, N. Y. last month. The firm's president William A. Wiegand was formerly employed by W. L. Maxson Corp. This was during the period when Maxson was one of a limited number of firms which produced precision gears. Nine months before leaving Maxson, Wiegand formed his own firm and handled it on week-end and part time basis. His original investment at this point was $2,000.

One of Wiegand's innovations was to design a standard line of precision miniature gears available from stock. An engineer who needed a precision gear of this type formerly had to draw the specifications, request a bid and on acceptance wait for delivery. Dynamic's stock gears could be sold at 1/15 of the custom price. His delivery time was four or five days. The original line of off-the-shelf items was 40 types, the present line is over 12,000.

Many private firms are currently using Dynamic's gears, but his big customers are firms doing business with the military. Here they are used in 3 different missiles, and inertial guidance systems in two new submarines.

Typical of the firm's diverse line of products is a miniature 15 speed transmission.

The 15 precisely controlled speeds range from 3.3 RPM to 7812 RPM is electronically controlled by the use of magnetic clutches with desired speeds obtained by dialing. No manual shifting of gears is necessary.

Case dimensions of this transmission, excluding power source and control panel, measures $4\frac{1}{4}''$ in width, $7\frac{1}{4}''$ in length and is $3\frac{5}{8}''$ high. Torque developed at the various speeds range from 50 to over 100 oz./in. The magnetic clutches are rugged construction and designed to offer years of satisfactory operation.

All gears and shafts used in the transmission are part of the Dynaco line and constructed of either #303 stainless steel or 24 ST aluminum which, in addition to the housing, offer resistance to corrosion.

The input motor is reversible and will deliver the above speeds and respective torque in either direction. The motor speed is self-governed and maintained at 8,500 RPM. Units operate on 115 volts, 60 or 400 cps current.

Typical applications of Dynamic Gear's 15-speed transmission, presently in the prototype stage, are for recording instruments such as oscillographs and other recording devices requiring constant and precise speeds. It can also be used as a laboratory device for testing servo packages.

*(Continued on page 156A)*

for your voice communications

# STROMBERG-CARLSON TELEPHONE HANDSETS

## MODELS FOR MANY INDUSTRIAL APPLICATIONS

**No. 26: short, lightweight, sturdy.** Comes with capsule-type receiver and transmitter.

**No. 27:** high-gain version of No. 26 handset.

**No. 28: "push-to-talk" handset.** Rocker bar switch; various spring combinations.

**No. 29:** high-gain version of No. 28 handset.

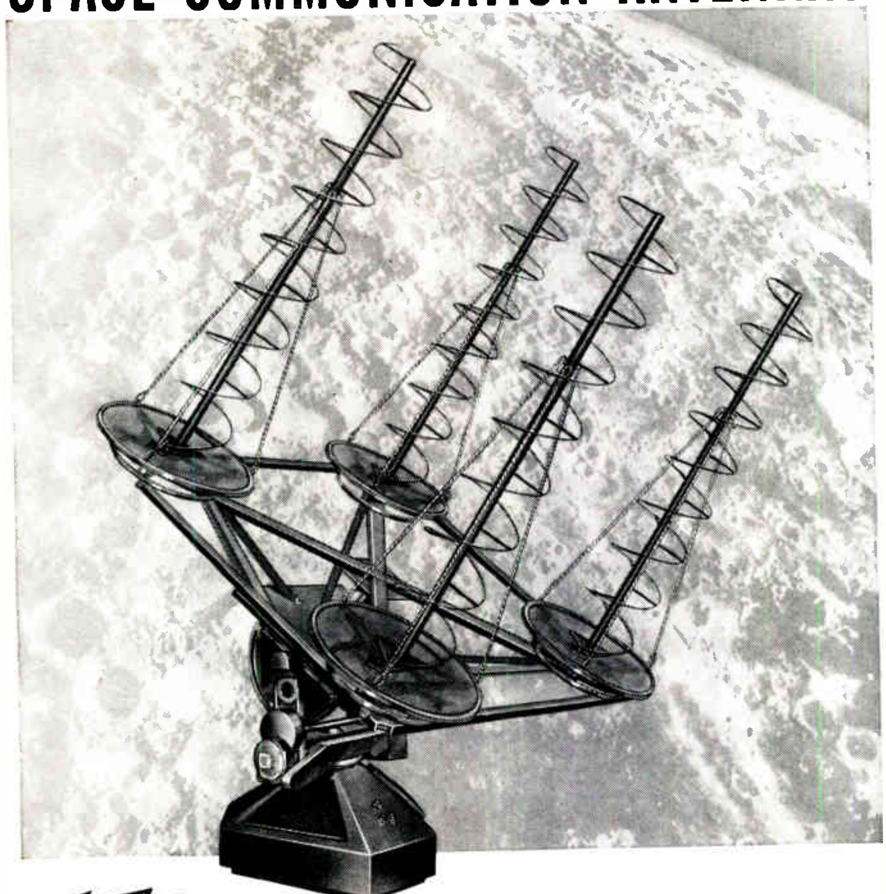
**Typical applications:** mobile radio • intercom systems • carrier and microwave • aircraft and railroad.

**Modern handset cradle** for mobile or panel use fits any Stromberg-Carlson handset.

Send for Bulletins T-5005 and T-5013. Write to Telecommunication Industrial Sales, 115 Carlson Road, Rochester 3, New York.

STROMBERG-CARLSON
A DIVISION OF GENERAL DYNAMICS

# SPACE COMMUNICATION ANTENNAS



ANDREW

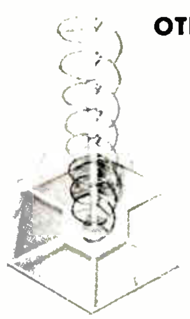
## Quad-Helix antenna

### tracks long and medium-range missiles

Telemetry circuits between missile (or satellite) and ground station are reliably maintained with the ANDREW Quad-Helix Array. This system offers low VSWR, high gain, and easy control.

Gain is 17.5 db at 265 mc, 14.5 db at 215 mc. VSWR is less than 2.0:1 across this range. Polarization is right hand circular; impedance 50 ohms. Counterbalanced rotator provides 180° elevation and 720° azimuth tracking at speeds from 0° to 30° per second.

Optional remote control unit regulates speed and direction.



### OTHER ANDREW GROUND-AIR ANTENNAS

**TRI-HELIX ANTENNA**

880-990 MC 17.5 DB GAIN TYPE 81068

**HELIX ANTENNAS**

| FREQUENCY | GAIN | TYPE NUMBER |
|---|---|---|
| 108-132 mc | 12 db | H 19110 A-1 |
| 215-265 mc | 10.5 db | H 50140 A |
| 215-265 mc | 13 db | H 19110 A-2 |
| 260-320 mc | 13 db | H 19110 A-3 |
| 320-400 mc | 13 db | H 19110 A-4 |
| 400-500 mc | 12 db | H 19110 A-5 |

**DISCONE ANTENNAS**

| FREQUENCY | TYPE NUMBER |
|---|---|
| 25-50 mc | 50154 |
| 50-108 mc | 51150 |
| 108-215 mc | 19050-1 |
| 215-420 mc | 19050-2 |
| 420-1000 mc | 19050-3 |

For full information on these and other ANDREW ground-air antennas, write today for Bulletin 8456

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## NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

*(Continued from page 154A)*

### Telemetering Oscillator

A new millivolt transistorized oscillator that reduces bulk and weight, lowers power demands, and eliminates a source of error, was announced by the **Hoover Electronics Co.**, Timonium, Md.


The new oscillator, developed by Hoover's engineering staff, makes it possible and advantageous, for the first time, to feed the output of low level transducers (such as thermocouples, strain gauges, accelerometers) directly into the Hoover subcarrier oscillator without dc amplification.

The new millivolt oscillator also has several characteristics which set it apart from earlier developments in the field, including dc common mode rejection and floating input terminals. The dc common mode rejection is conservatively rated at $10^7$ within $\pm 20$ volts of ground.

This permits the oscillator to be used with bridge circuits for measuring the voltage between two points in the bridge, without the oscillator's being affected by a voltage from one point to ground.

The floating input terminals eliminate problems which often result from a common ground among several components.

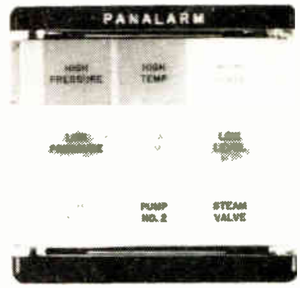
The subcarrier oscillator contains an internal voltage regulator. Its power requirement is +26 volts. The distortion of the output signal is limited to less than 1% by a bandpass filter which also prevents interference with adjacent channels.

The unit is produced to IRIG specifications of frequencies and deviations for channels 5 through 18 and A through E.

### New Rep For Polyphase

**Polyphase Instrument Co.**, E. Fourth St., Bridgeport, Montgomery Co., Pa., is pleased to announce the appointment of the J. S. Kempf Company, 10304 Praire Ave., Inglewood 2, California, as West Coast Sales Representative for the sales of its pulse and specialty transformers, electrical wave filters, and associated magnetic electronic components.

### Solid State Annunciator




A new economical, solid state, miniature lo-drain, expandable, annunciator providing information and control of industrial process systems has been developed by **Panellit, Inc.**, 7401 No. Hamlin Ave., Skokie, Ill. The "Panastat" annunciator has longer life and greatly decreased maintenance because there are no moving parts. All operational functions are performed by highly derated solid state elements. Low energy control circuits (a tiny fraction of 1500 millijoules) and negligible inductance (considerably below 0.001 Henry) provide intrinsic safety. Ignition in hazardous atmospheres is impossible because no arc can be sustained. All Class I, Division II requirements are exceeded; there are no make or break contacts. The annunciator operates on standard ac or dc line voltages; no transformer power supply is required. Operation is not affected by normal line variations or surges. Continuous duty is maintained at $\pm 20\%$ nominal voltage. Lamps are interchangeable with existing annunciators. Models of this system can be expanded easily due to interchangeable plug-in units. Momentary field contact operation of 0.5 milliseconds is sufficient to lock-in the system and avoid alarm loss. The miniature annunciator can be supplied to fit a 5″×5″, 6″×6″ standard pneumatic or electronic instrument case or any standard annunciator cabinet.

### Millimicrosecond Current Generators Catalog

Single catalog bulletin describes Model 3000A (2 channels) and Model 3010A (4 channels) which provide fast rise time, high power, current pulse outputs. Modular plug-in construction allows versatility of performance and application. For a copy contact **Electro-Pulse, Inc.**, 11861 Teale St., Culver City, Calif.

### Precision Potentiometer Catalog

**Electromath Corp.**, 115 Pleasant Ave., Roosevelt, L. I., N. Y., has 8 new catalog sheets describing their line of precision potentiometers. These include illustrations and specifications on single-turn trimmers, dual 10-turn, continuous single-turn, dual 3-turn, miniature single-turn, high temperature single-turn, high stability 3-turn, and high resolution 10-turn types.

*(Continued on page 180A)*

# SENSITIVE RESEARCH

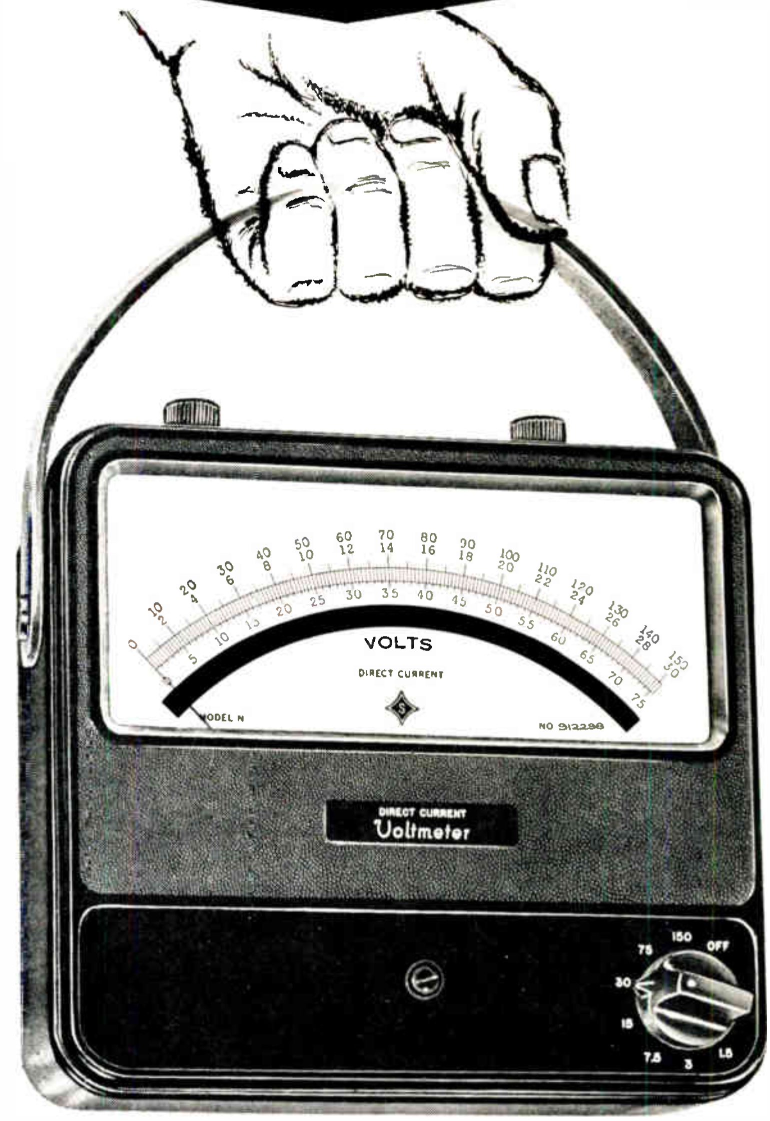
# THE *New* MODEL "N"

**A new series of AC and DC portable electrical indicating instruments — *that can also be panel mounted.***

## A *New* HIGH in accuracy, resolution, and stability.

## A *New* LOW in cost.

In short, the SRIC Model "N" series probably has just the instrument for which you've been looking **HIGH** and **LOW**. The Model "N" is a true "secondary standard" because it is engineered and manufactured by "standards people."




Model "N"

**The *New* Model "N"** is a stable, rugged, versatile field or laboratory instrument that is *spectacular* because in every way it offers a little bit "more" than any other instrument in its class. It is available in standard range combinations or in quantities with special ranges and/or special scale markings.

***The New Model "N" conforms to ASA specs. C 39.1-1951 for .5% class instruments. All SRIC instruments are calibrated against primary standards that have National Bureau of Standards Certificates of Accuracy and are unconditionally guaranteed for a period of one year.***

### GENERAL SPECIFICATIONS:

**Accuracy:** .5% of full scale.

**Scale:** Hand-drawn and mirrored.

**Scale length:** 6".

**Resolution:** 100 to 150 division.

**Ranges:** DC from 50 ua. to 50 A. and 20 mv. to 1000 v. full scale. AC from 10 ma. to 10 A. and 7.5 v. to 750 v. full scale.

**Availability:** 1 to 8 ranges completely switch-controlled and self contained.

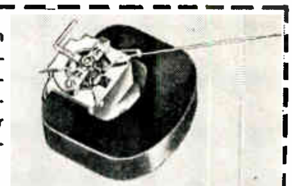
**Construction:** DC — double pivoted permanent magnet type. AC — moving iron vane for RMS measurements and germanium rectifier type for average reading measurements.

**Shielding:** Magnetic and electrostatic.

**Pivots and Jewels:** High carbon steel pivots and shock mounted sapphire jewels. (Diamond pivots available on special order).

**Case:** Black moulded bakelite with leather carrying handle. Size 7½" x 6¾" x 3½". Internal lighting avail.

The movement construction shown features a large size U-shaped magnet with an inherently high torque-to-weight ratio, stability and sensitivity — and not the common center core magnet usually found in instruments in its price range.



AC INSTRUMENTS UTILIZE A FAST-ACTING, RUGGED, MOVING IRON-VANE MOVEMENT.

Symbol of Quality

# SENSITIVE RESEARCH INSTRUMENT CORPORATION

NEW ROCHELLE, N. Y. ELECTRICAL INSTRUMENTS OF PRECISION SINCE 1927

# Positions Open

The following positions of interest to IRE members have been reported as open. Apply in writing, addressing reply to company mentioned or to Box No. ....

**The Institute reserves the right to refuse any announcement without giving a reason for the refusal.**

Proceedings of the IRE
1 East 79th St., New York 21, N.Y.

## ENGINEER

Unusual opportunity for creative engineer to perform challenging, diversified work with Long Island quality instrument mfg.-leader millimicrosecond techniques. Excellent salary and room for rapid growth in active, congenial and expanding company. Requirements: 5 years development experience in pulse, transistor and high frequency circuits. Must be capable of assuming product responsibility. Apply Lumatron Electronics, Inc., 68 Urban Ave., Westbury, N. Y. Tel. EDgewood 4-3100.

## PROFESSOR AND ASSOCIATE PROFESSOR

Professor and Associate Professor of Electrical Engineering—to teach graduate and undergraduate subjects to participate in developing research program in a southern university. Good location in an industrial region. Competitive salaries for various levels of education and experience. Box 2003.

## TEACHING—RESEARCH

The new Electrical Engineering Dept. at the University of Rochester is seeking to expand its staff, and has openings on its faculty for qualified electrical engineers and scientists interested in positions combining teaching and research responsibilities. Salary scales are fully competitive with other leading institutions, and are designed to interest people of the highest competence. Write, including resume, to Daniel W. Healy, Jr., Head, Dept. of Electrical Engineering, University of Rochester, Rochester 20, N. Y.

## ELECTRONICS ENGINEER

Our company is setting up a new industrial electronic group and may have just the position you are seeking. We would like to engage a man capable in the application of electronic measuring and control systems to industrial processes. Prefer he be familiar with electrical laboratory test equipment and current in knowledge of available instrumentation. Knowledge of pulse techniques and transistor circuitry background would be very helpful. Reply immediately giving education, experience, age and salary expected. Box 2004.

## TEACHING—ELECTRICAL—ENGINEERING

Additions to electrical engineering faculty desired by engineering school of midwestern university at all professorial ranks. To conduct research and teach both graduate and undergraduate classes. Research interests of considerable importance. Send resume of education and experience to Box 2005.

## CHIEF MICROWAVE ENGINEER

If you can assume the electrical design and test functions responsibilities for an outstanding company devoted exclusively to the manufacture of microwave components, (such as mixer-duplexers and antenna assemblies), this is the opportunity

*(Continued on page 160A)*


General Motors pledges
AC QUESTMANSHIP

## Positions Open

*(Continued from page 158A)*

you have been searching for. Your ability will be the only factor in establishing the scope of your authority; your income will be commensurate. We offer liberal benefits, a substantial future and professional freedom and growth. Send complete resume in confidence to Personnel Dept., Budd-Stanley Co., Inc., 43-01 22nd St., Long Island City 1, N.Y.

### ELECTRICAL ENGINEER

Evaluate instrument systems, establish calibration and operation procedures. Procurement, acceptance testing and shakedown of new instruments required in wind tunnel testing of models and propulsion systems of rockets and missiles. Establish preventive maintenance procedures, monitor data quality and improve instrumentation. Send resume and salary requirements to Technical Employment, ARO, Inc., Tullahoma, Tenn.

### TEACHING POSITION

Excellent teaching opportunity will be available beginning Feb.-Sept. 1960. Advanced degree required. Attractive full year contract available. Salary range for 9 months is $5,000 to $7,000. Location is in the midwest at a medium-size private university. Complete resume to Box 2006.

### INSTRUMENT OR ELECTRONIC ENGINEERS

Electronic or electrical engineer or physicist with instrumentation experience to do research and development work on the design, construction and evaluation of instrumentation for sampling and analysis of atmospheric air pollutants. Responsibilities for projects from design to prototype models. Salaries $5,500 to $8,200. Another, salary $10,130, in design and development of radiation measuring devices to direct program involving identification and measurement of radionuclides in environmental samples. Good prospects for growth and advancement. Federal Civil Service benefits and requirements. Apply U.S. Public Health Services, Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio.

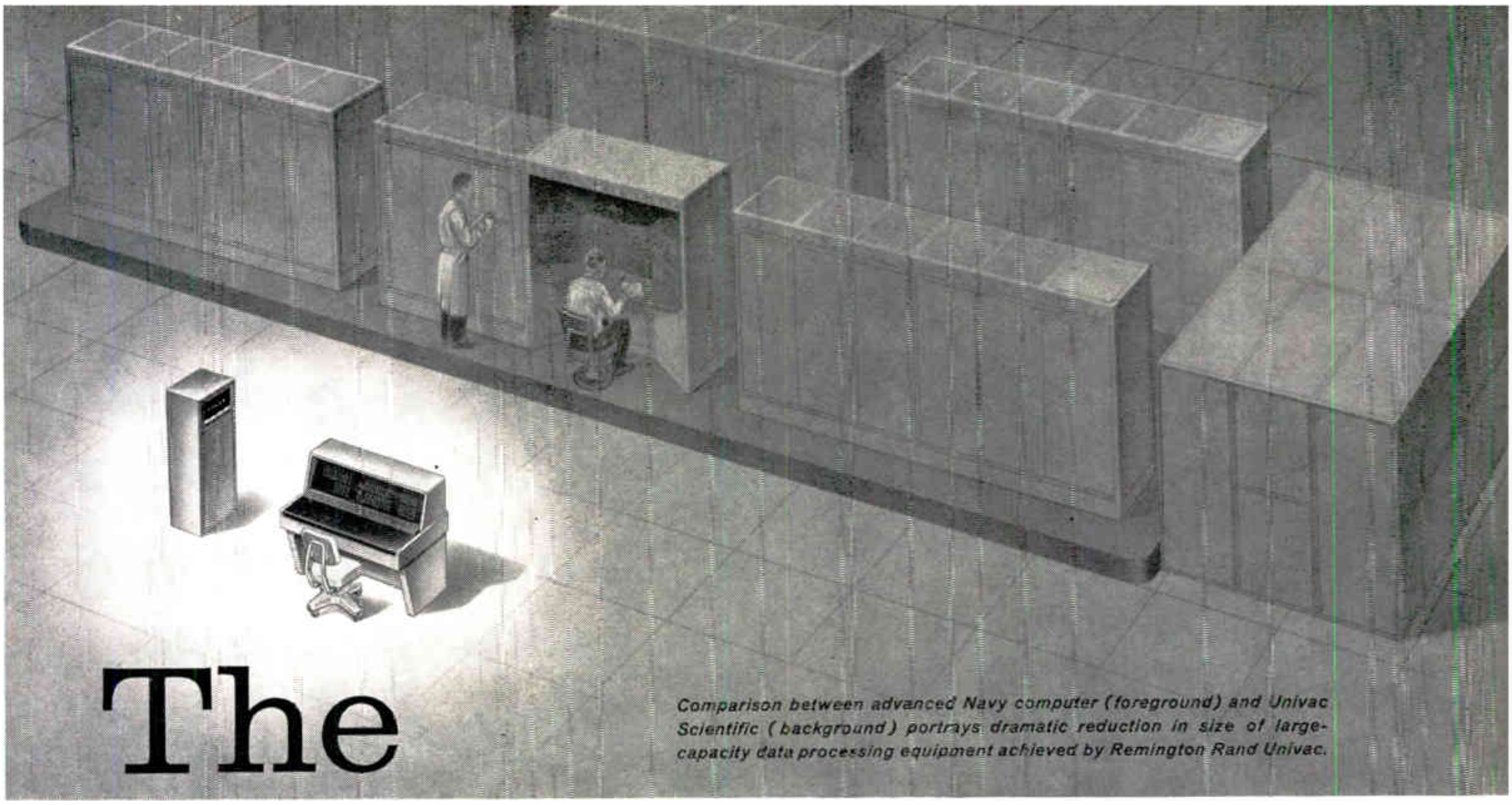
### ENGINEERS

The Pratt & Whitney Aircraft Division of United Aircraft Corp., East Hartford, Conn. has openings for graduate engineers in the areas of Propulsion Systems Performance Analysis, Heat Transfer Research, Ultra High Temperature Materials, Dynamics, Vibrations, Structures Research, Experimental Testing, Technical Report Writing and Propulsion System Control Engineering. Many of these openings are in our advanced Development Groups where we are presently conducting studies in solid and liquid propellants, ion propulsion, arc jet, plasma jet, and other advanced forms of propulsion. Openings are available at both the Conn. and Florida Facilities. For more information, contact Mr. Henry M. Heldmann, Employment Office.

### PROFESSORS

Rank of Assistant Professor or Associate Professor, depending on qualifications. Salary $5,500 to $8,500 for session, 10 months nominal, 9 months actual. Start February or September 1960. Duties will include offering graduate courses and helping to develop research facilities. Opportunities for curriculum experimentation. Various sources of additional income available. Substantial allowance for relocation. Exceptionally good retirement plan. Fully accredited Electrical Engineering Dept. in medium sized university (700 undergraduate stu-

*(Continued on page 164A)*



*Comparison between advanced Navy computer (foreground) and Univac Scientific (background) portrays dramatic reduction in size of large-capacity data processing equipment achieved by Remington Rand Univac.*

# The case of the shrinking computer

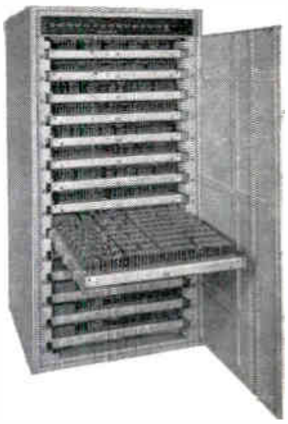
**Remington Rand Univac compresses large-capacity performance into small package**

In an advanced computer developed for the U.S. Navy, Remington Rand Univac dramatically reduced the size of large-scale data processing equipment. With a 32,786-word memory, the capacity of this miniaturized computer almost equals that of earlier vacuum tube systems of 10 times its size.

This compact, completely transistorized system has a cycle time of eight micro-seconds, and is linked with seven input-output registers, each of which may operate simultaneously and independently of computer programs.

Remington Rand Univac has openings on projects associated with advanced equipment such as the computer described above. These positions offer you the opportunity to advance your career development while at the same time participating in rapid advances in the state of the art.

If you are thinking of changing positions, or would consider a change, be sure to investigate the openings described below.



Central computer of the advanced Navy system shown at top of page illustrates compact size and ease of maintenance provided by building block construction. Containing 4,100 packages, the cabinet occupies only 37 cubic feet of space. Roll-out drawers permit easy and rapid access to component packages.

**Opportunities for Electronic Engineers, Physicists and Mathematicians**

COMPUTER APPLICATIONS ANALYSTS—Engineering, Mathematics, or Physics degree with experience in the use of large scale digital computers in real-time control systems, with emphasis on timing and control studies, data handling methods, and compiler development.

MILITARY SYSTEMS ANALYSTS—Engineering, Mathematics, or Physics degree with experience in weapons and missile guidance systems involving digital control, digital conversion, radar and communications information processing and display and output equipment.

BUSINESS SYSTEMS ANALYSTS—College degree with experience in business applications and programmings of digital data processing equipment as applied to production control, and maintenance logistics.

TRANSISTOR CIRCUIT DESIGNERS—Electrical Engineering degree with experience in transistorized pulse circuitry.

ENGINEER WRITERS—Engineering or Science degree with experience in the preparation of maintenance and operational manuals for electronic equipment.

QUALITY CONTROL ENGINEERS—Electrical Engineering degree with experience in reliability, statistical methods, and test procedures for electronic equipment.

CONTRACT REPRESENTATIVES—Engineering or Science degree with experience in government electronic R & D contracts.

SERVO-ENGINEERS—Electrical Engineering degree with experience in servo-amplifiers, servo-mechanisms and airborne electronics.

COMMUNICATIONS ENGINEERS—Electrical Engineering degree with experience in HF transmission, network theory and antenna design.

Send resume of education and experience to R. K. PATTERSON—Dept. D-1

**Remington Rand Univac**

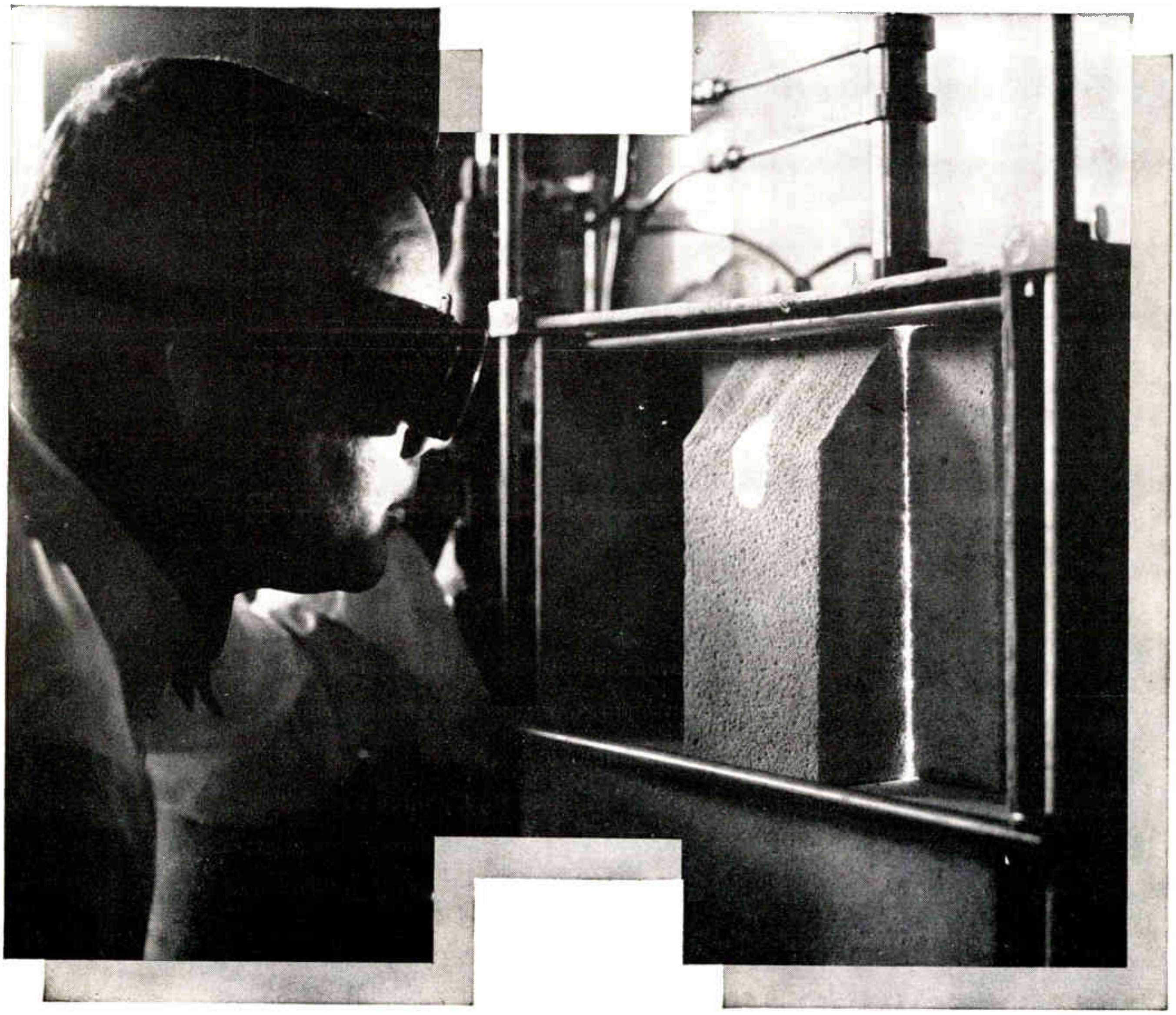
DIVISION OF SPERRY RAND CORPORATION
2750 West Seventh Street, St. Paul 16, Minnesota

*All inquiries regarding openings at our other laboratories should be addressed to:*

F. E. NAGLE—Dept. D-1
REMINGTON RAND UNIVAC
1900 West Allegheny, Philadelphia 29, Penn.

R. F. MARTIN—Dept. D-1
REMINGTON RAND UNIVAC
Wilson Avenue, South Norwalk, Conn.

# alchemy in the 20th



**Development** *of new and highly reliable direct display storage and microwave tubes is being carried on at the Electron Tube Division, Hughes Products.*

# century

**In medieval times,** alchemists spent lifetimes trying to transform the commonplace into the precious without success. Today, in the Hughes Research Laboratories, scientists and engineers using advanced methods and equipment, are synthesizing many new and precious materials to be used in solid state research.

The photograph, for example, shows a Hughes Research Laboratories scientist observing the growth of an yttrium aluminum garnet crystal using the flame fusion method. This work, as well as other crystal growth techniques, is part of a major Hughes materials research and supply program for the synthesis of ruby, sapphire, spinel, ferrite, garnet and related oxide single crystals. These materials provide atomic circuit elements which are the key to quantum electronics.

As solid state research at the Hughes Research Laboratories continues to expand and intensify, a supply of new and tailor-made materials in the form of high-quality single crystals is essential. Effective utilization and improvement of existing and new crystal growth methods requires extensive knowledge of their range of applicability, crystal growth mechanisms and the relationships between growth parameters and perfection of the resulting materials.

Materials research is contributing significantly to existing ferrimagnetic, paramagnetic and absorption spectroscopic studies...and is opening new areas of investigation by providing materials not previously available as large single crystals.

Other Hughes activities cover practically every part of the electronics spectrum...providing stimulating outlets for creatively-oriented engineers. These include: Space Vehicles, Nuclear Electronics, Ballistic Missiles, Advanced Data Handling and Display Systems, Infrared Devices, Three-Dimensional Radar...and many others.

The variety and advanced nature of Hughes projects provides an ideal environment for the scientist or engineer who wishes to increase his professional stature.

**Feedback** *in the form of performance data and suggestions for modifications to advanced Hughes Systems is provided by Hughes Field Engineers.*

*Newly instituted programs at Hughes have created immediate openings for engineers experienced in the following areas:*

| | |
|---|---|
| Electroluminescence | Field Engineering |
| Infra-red | Equipment Engineering |
| Plasma Physics | Commercial Sales |
| Digital Computers | Microwave & Storage Tubes |
| Systems Design & Analysis | Communications Systems |
| Circuit Design & Evaluation | Micro Electronics |

*Write in confidence to Mr. D. E. Eikner*
*Hughes General Offices, Bldg. 6-E12, Culver City, Calif.*

*The West's leader in advanced ELECTRONICS*

**HUGHES**



HUGHES AIRCRAFT COMPANY

Culver City, El Segundo, Fullerton, Newport Beach, Malibu and Los Angeles, California; Tucson, Arizona

## Positions Open

(Continued from page 160A)

dents in engineering) located in a very pleasant uncrowded city of 350,000. Address resume to Dean Otto Zmeskal, College of Engineering, University of Toledo, Toledo 6, Ohio.

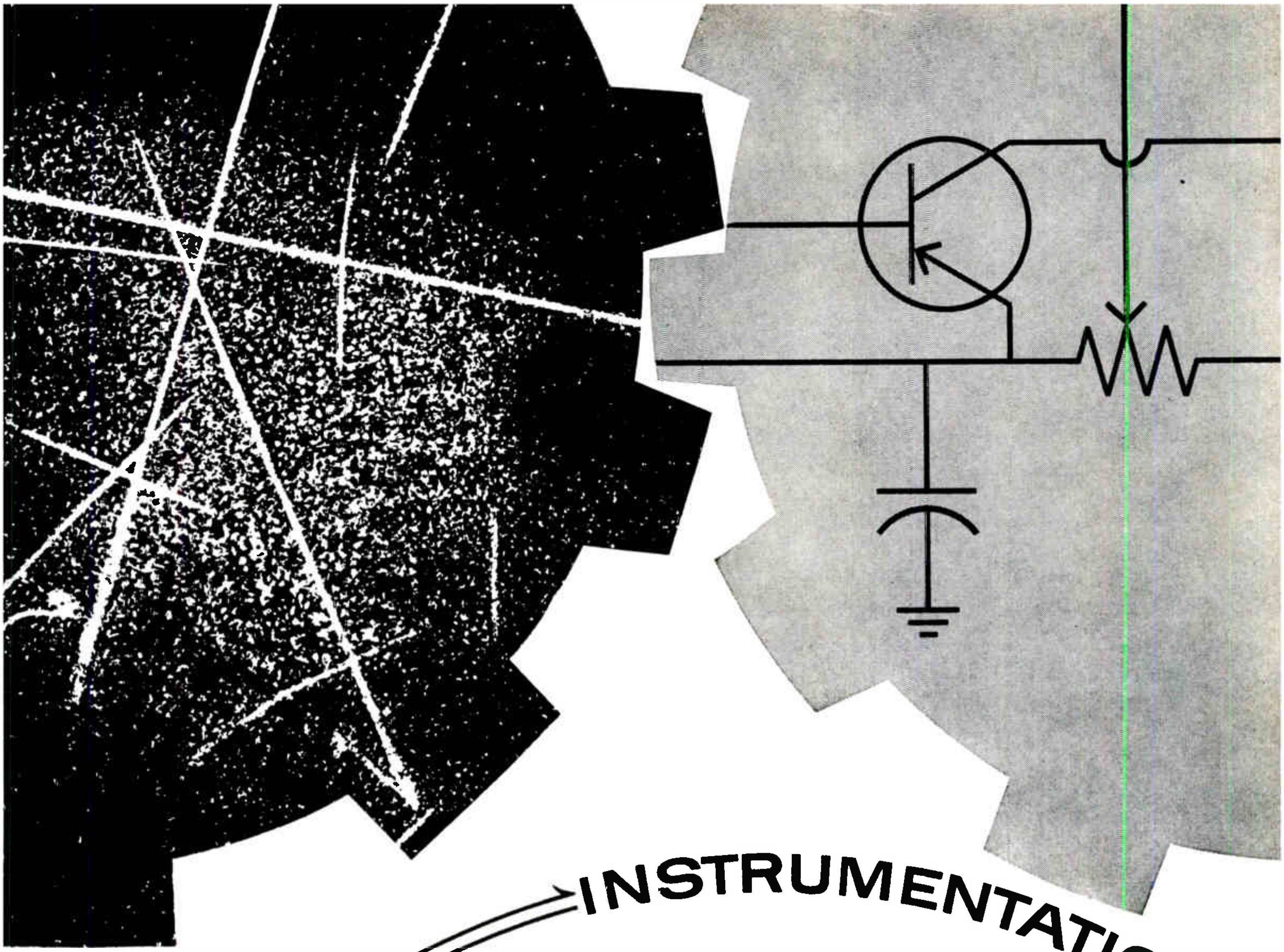
### INSTRUCTOR OR ASSISTANT PROFESSORS

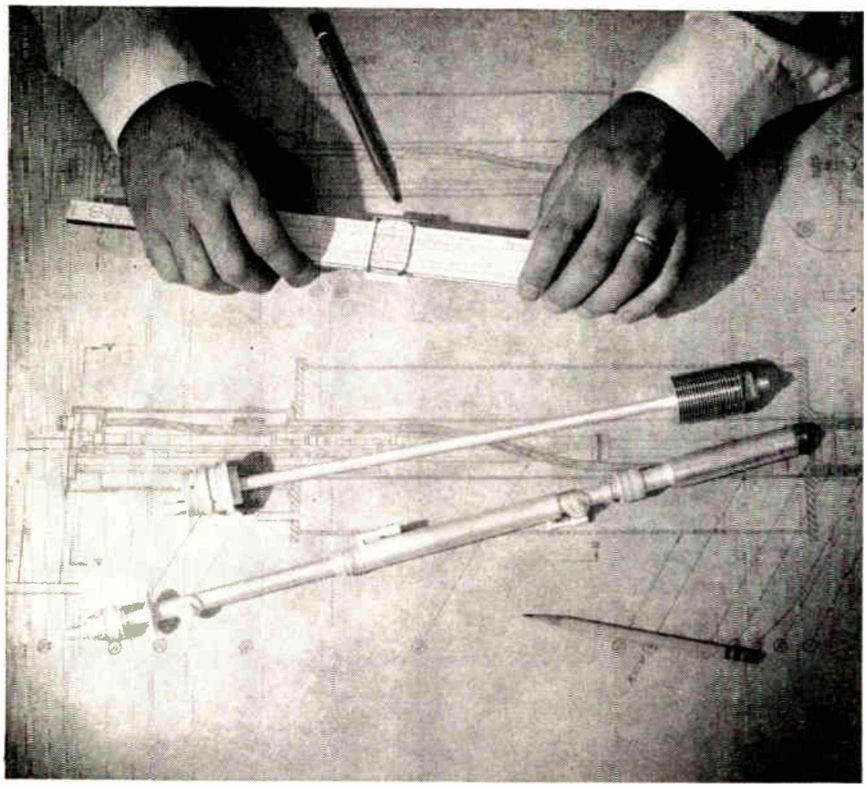
Retirement of a staff member creates a vacancy in Electrical Technology Dept. for February 1960. Teaching area is mainly in electronics at the technician level. Minimum requirements are BEE. or BS. in E.E. and 2 years of industrial experience. Starting salary $5,000 to $7,000. Opportunity for an additional $2,000 through evening and summer teaching. Excellent pension system and other fringe benefits. Write to Prof. J. De France, Dept. of Elec. Tech., New York City Community College, 300 Pearl St., Brooklyn 1, New York.

### SCIENCE AND ENGINEERING

Opportunities at Robert College, Istanbul, Turkey for qualified men in engineering, mathematics, physics and chemistry interested in combining teaching and the development of limited research and consulting activities with the opportunity to live and travel in a vital part of the world: Strengthening staff, modernizing undergraduate engineering curricula, beginning graduate programs in engineering, developing undergraduate and later graduate programs in sciences, constructing new science and engineering building to prepare engineers for the industrial and techno-

(Continued on page 168A)





# Senior Level Positions in Fast Growing Microwave Research and Engineering Programs

*Project Level Responsibility*

A 100 watt CW, C-Band ceramic traveling wave tube has recently been developed by Eimac. It is just one of the steps Eimac is taking in the field of electron devices to take advantage of microwave frequencies. In TWT's, reflex and amplifier klystrons, Eimac is, and will continue to be, the leader in advancing the state of the art. Career opportunities are now available for outstanding engineers with BS, MS, and PhD degrees with a company specializing in electron tubes.

1 Research Engineers and Scientists to conduct theoretical and experimental research in microwave measurements, microwave tube problems, plasma physics and circuit design.

2 Microwave Engineers to test and evaluate tube performance and design of VHF and UHF circuits with respect to klystrons, negative grid tubes and traveling wave tubes.

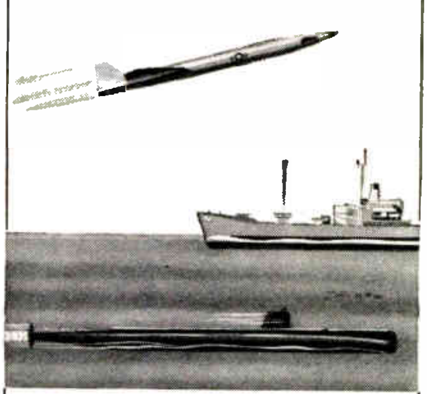
3 Project Engineers to assume responsibility for existing and newly-approved projects in high power klystrons... including design and testing of electronic guns, cavities and related tube components.

Salaries offered are excellent and, naturally, Eitel-McCullough will pay relocation expenses to the company's facilities in Salt Lake City, Utah and San Carlos, California. All replies will be honored with the strictest confidence. Please write: C. F. Giesler, Dept. P, Eitel-McCullough, Inc., San Carlos, California.

Eimac

**EITEL-McCULLOUGH, INC.**
SAN CARLOS, CALIFORNIA

**ELECTRONICS: Over, on and under...**



## Electronic and Electromechanical

## SYSTEMS ENGINEERS

Openings are waiting for you at Autonetics
in
Systems Research and Development
on
Integrated Systems involving the following equipments:

**Radars**

**Inertial Guidance**

**Digital Computers**

**Flight Control Equipment**

Opportunities have never been better in the history of Autonetics for the engineer with sound technical competence in the above fields.

Advanced degrees preferred, with four to ten years' broad experience in the above or related fields.

Send your resume to:
Mr. B. D. Benning
Manager, Employment Services
Dept. G-123
9150 East Imperial Highway
Downey, California

**Autonetics**
A Division of North American Aviation, Inc.

## Positions Open

*(Continued from page 164A)*

logical development of Turkey and the Middle East. Address inquiries to Dean Howard P. Hall of the College of Engineering, Robert College, Bebek P.O. 8, Istanbul, Turkey, with copy to Near East College Assoc., 40 Worth St., Rm. 521, New York 13, N.Y.

### DEVELOPMENT ENGINEER

Development Engineer to head a small development group in the field of small electronic components. Degree, or its equivalent, and experience in this field required. Write Philadelphia Plant Employment, International Resistance Co., 401 North Broad St., Philadelphia 8, Pa.

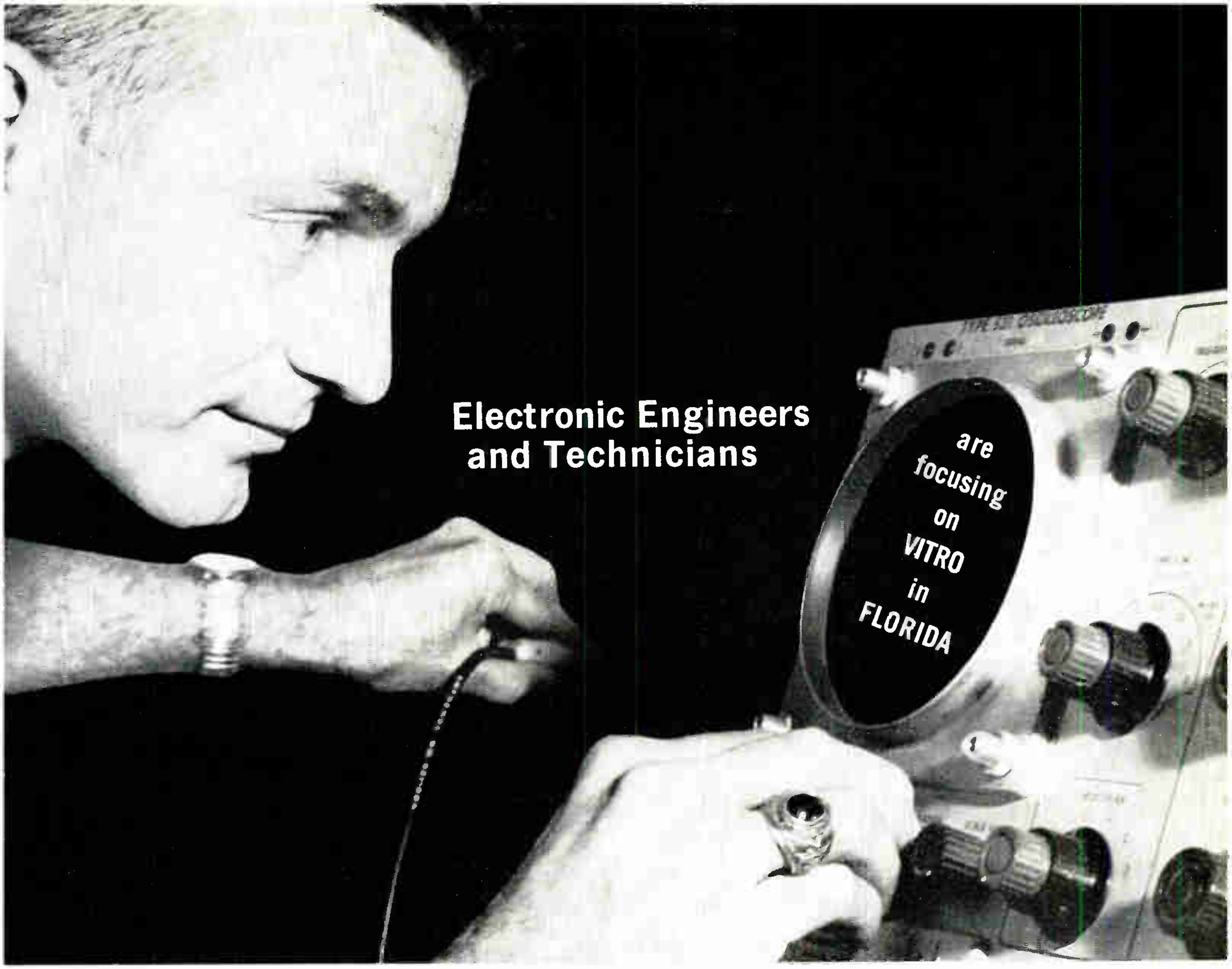
### STAFF IN ELECTRICAL ENGINEERING

Attractive positions combining teaching (graduate and undergraduate) and research are available. Appointment at any level from Assist. Professor up, depending on qualifications. A person with interests in electrical energy conversion and modern electrical machines is especially sought, but openings in other fields are available. Applicants must have Ph.D. or equivalent evidence of research potential. Write Chairman, Div. of Engineering, Brown University, Providence 12, R. I.

### TECHNICAL SALES ENGINEER

Knowledge of Government operations and experience in microwave tube field desired. Retired service personnel would be considered. Good position in growing company. Please call or write American Radio Company, Inc., 445 Park Ave., New York 22, N.Y. PL-3-5046.

*(Continued on page 170A)*




Vitro Laboratories' Florida Operation, Vitro Weapons Services, is rapidly expanding its professional staff to meet new contractual and technical requirements.

For the last nine years, Vitro has assisted the Air Research and Development Command in planning, developing, installing and operating the test ranges and facilities of the Air Proving Ground Center, Eglin Air Force Base, Florida. Current projects include test of the *Bomarc*, *Quail*, *Hound Dog* and *Genie* missile systems, as well as investigations in the fields of frequency diversity, electronic countermeasures, vertical launching, high altitude research and drone development.

Now we are accelerating our activities to operate the nation's newest missile range, the Eglin Gulf Test Range, which extends some 450 miles from Eglin to Key West, Florida. This new responsibility in part explains our dynamic growth, but more particularly, it creates outstanding supervisory and staff openings for:

**Electronic Engineers** – with degree(s) in E.E., plus experience in Automatic Tracking Radar, Electronic Instrumentation, Phase Comparison Space Positioning Systems, Data Recording and Conversion, Telemetry or Missile Range Instrumentation. These are senior level positions, particularly challenging to the man with field engineering and design experience in tracking type radar systems.

**Radar Technicians** – with training and experience in MSQ-1, MSQ-1A, FPS-16, Nike, M-33, MPS-9, SCR-584, CPS-6, FPS-3 and FPS-20 equipments.

**Electronic Technicians** – with a solid background in electronics and several years experience in Telemetry, Data Converters, Oscillograph Recorders or Range Electronic Instrumentation.

To focus your future on a career with Vitro in Florida, please submit a brief resume of your experience in confidence to Mr. D. D. Cox, *Director of Personnel*, Vitro Weapons Services, 119 East Main Street, Fort Walton Beach, Florida, Dept. P-1. All replies will be answered immediately, and interviews will be arranged.

**Vitro LABORATORIES**
Division of Vitro Corporation of America

VITRO WEAPONS SERVICES
EGLIN AIR FORCE BASE, FLORIDA

Other laboratories at West Orange, N. J., and Silver Spring, Md.

# ELECTRONIC ENGINEERS

**The expanding activities of the Armour Research Foundation, an independent research organization, requires the services of several additional experienced engineers to work on its many diversified research programs. As a member of our staff you will enjoy the friendly atmosphere and cooperation which exists plus the exceptional opportunity for creative research coupled with excellent facilities, working conditions and stimulating staff associations. In many cases you are able to work on ideas of your own choosing through our internally sponsored research activities.**

**Applicants should possess several years of experience in one or more of the following areas:**

**Communication and Radar Systems Analysis**
**Microwave Field Theory**
**Radio-Radar Interference**

**Salaries are offered to suit your individual experience and educational background. Benefits include liberal insurance and retirement programs, a vacation policy which provides up to four weeks vacation per year, tuition free graduate study and a generous relocation allowance.**

**If you are interested in this challenging opportunity to advance professionally, please send a resume of your qualifications to:**

A. J. Paneral
ARMOUR RESEARCH FOUNDATION
of Illinois Institute of Technology
10 West 35th St. Chicago 16, Ill.

# growth at granger associates

creates extraordinary opportunities now at all levels as techniques specialists and project managers in the development and manufacture of advanced r-f systems...including traveling wave tube applications, transistor circuits, transmitter and receiver techniques, microwave components, distributed amplifiers, and antennas for airborne and ground-based systems. Vital projects...a blue ribbon staff...and an expanding employee-owned company...add up to unlimited potential For details inquire direct to Dr. J. V. N. Granger at granger associates 974 commercial street / palo alto, california

Granger Associates

## Positions Open

(Continued from page 168A)

### PRODUCTION FOREMAN

Production Foreman—Electronic Transformer: 5 years (+) experience in coil winding business. Familiar with general machine shop equipment and vacuum potting techniques. New company. Excellent opportunity. Sunny San Diego. Apply Atlas Transformer Co., 1839 Moore St., San Diego 1, Calif.

### ASSOCIATE PROFESSOR

Electrical Engineering faculty being expanded in rapidly growing department, graduating first class in 1960. Current positions available to rank of Associate Professor and to 9 months salary of $6,000, depending upon education and experience. Background emphasis preferably upon electronics and advanced circuit theory. Opportunity for research and other industrial programs in the area. Send full background to Chairman, Electrical Engineering, University of Bridgeport, Conn.

## Positions Wanted

### By Armed Forces Veterans

In order to give a reasonably equal opportunity to all applicants and to avoid overcrowding of the corresponding column, the following rules have been adopted.

The IRE publishes free of charge notices of positions wanted by IRE members who are now in the Service or have received an honorable discharge. Such notices should not have more than five lines. They may be inserted only after a lapse of one month or more following a previous insertion and the maximum number of insertions is three per year. The IRE necessarily reserves the right to decline any announcement without assignment of reason.

Address replies to box number indicated, c/o IRE, 1 East 79th St., New York 21, N.Y.

### DIGITAL SYSTEMS ENGINEER

BEE.; Tau Beta Pi, Eta Kappa Nu; graduate work in digital techniques. 6 years broad experience, logical design, systems integration, transistorized circuit design, systems evaluation. Married, 2 children. Desires position in Japan or other opportunity of unusual interest. Box 2031 W.

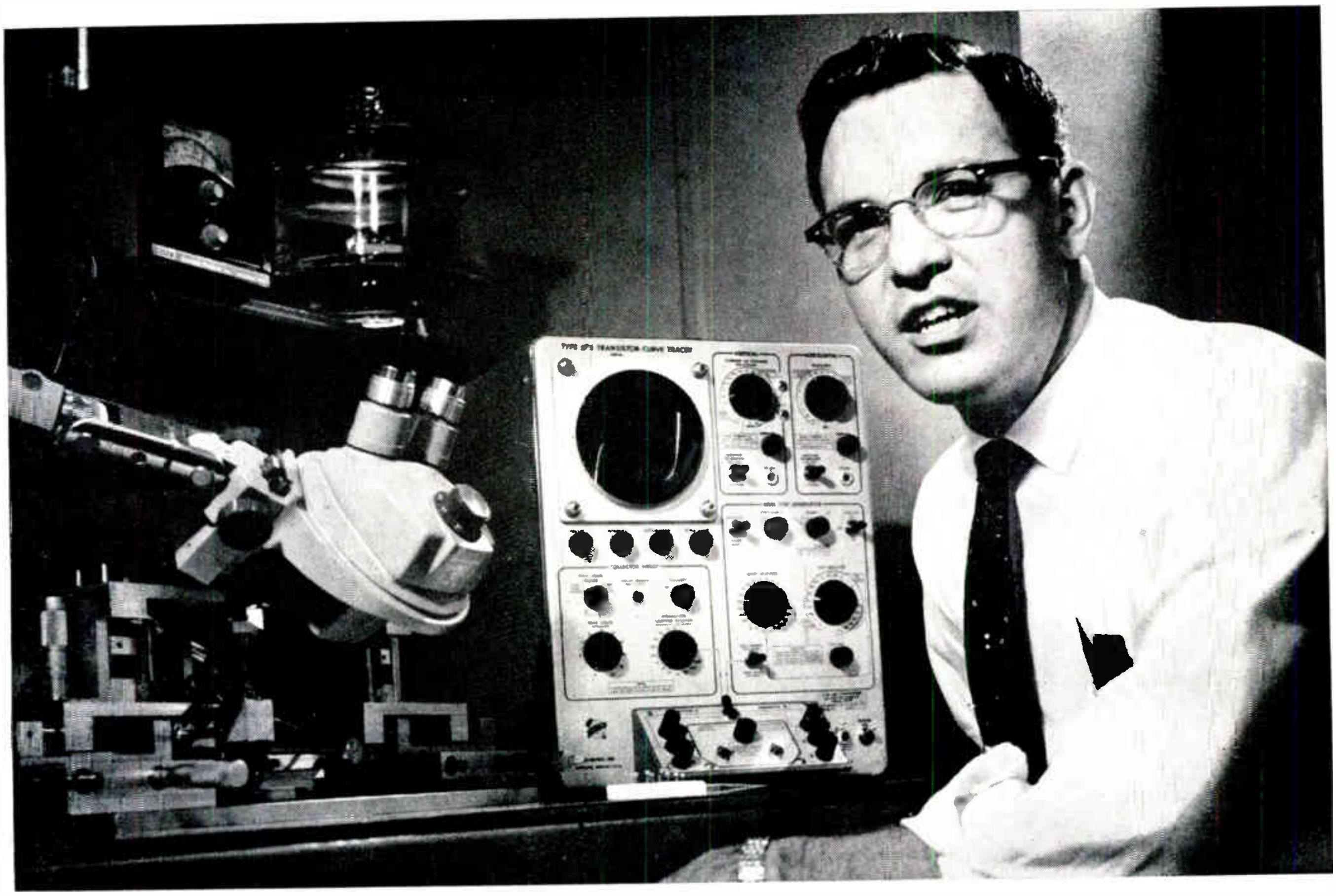
### ELECTRICAL ENGINEER

Age 23. BEE, Georgia Tech, September 1957. 1/Lt. U.S. Army Ordnance Corps, 1½ years as project coordinator at White Sands. Desires position in missile instrumentation or allied field with management opportunities. Location south-east or southwest. Box 2032 W.

### ELECTRONIC TECHNICIAN

Signals Officer 15½ years service in HF communication work. Age 37. Associate Brit. IRE. Associate Member IRE (USA). Graduate H.R.T.

(Continued on page 174A)



T. R. Selig, B.S. Physics 1954, St. Norbert College. Joined G-E Physics Training Program June 1954. Went from Advanced Technical Course to 4 rotating assignments. U. S. Navy 2 years. Returned to G-E Semiconductors in Advance Process Group. Has worked on power transistors, multi-layer switches and the new tunnel diode (100 times faster than a transistor). Studying for M.S. in Physics. Married; 2 children.

# Tom Selig takes time off from the tunnel diode . . .

## *to tell you about General Electric's Semiconductor Products Dept.*

"In the General Electric Company, each department must stand on its own two feet. It's like working for a small company, but with the depth of talent and technical backup you find only in a large organization.

"G-E Semiconductors has an expert in almost any subject you may be working on. They are found within your own group, in the Advanced Semiconductor Laboratory, and at the Research and Engineering Laboratories in Schenectady. Each is a recognized authority in his field and all are available for consultation at any time. You have only to pick up the phone.

"My present assignment, the tunnel diode, calls for work with electrical, chemical and physical phenomena. This is typical of semiconductor development and leads to a broad background in several areas, strengthened by the educational opportunities at G.E. There are about 30 engineering courses taught here at General Electric, besides tuition refund for advanced study at Syracuse University."

●

Unusual opportunities now open for chemical, electrical, mechanical and metallurgical engineers, physicists and physical chemists (B.S. through Ph.D.) at all levels of experience. U. S. citizenship not required. Semiconductor experience desirable but not essential. Write in strict confidence to Mr. M. D. Chilcote, Division J4.

**GENERAL ELECTRIC**

Semiconductor Products Dept., Electronics Park, Syracuse, N. Y.

# Put Yourself in this "Growth" Picture!

**grow faster with a growing company . . .**

utilize advanced facilities available

for research, development

and manufacturing projects of the highest technical nature

. . . where your work and talents are recognized

as extremely vital . . . enjoy year-round living

and recreation in the pleasant Southwestern climate

To date, almost 14,000 people at Texas Instruments are in this "Growth" picture. In addition, they are enjoying many other benefits from TI's enlightened personnel policy — company-sponsored profit sharing plan*, periodic advancement and salary reviews, educational assistance, insurance, and retirement programs.

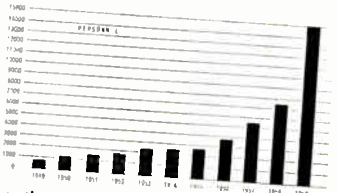
TI offers a stimulating challenge in research, development and manufacture in geosciences, military and industrial instruments and systems, semiconductors and other electronic components. To keep its position as a leader in these fields, and to stay ahead of the ever-increasing demands of Space Age technology, more new permanent positions have been created for qualified Engineers.

Come grow with us . . . work and live in an environment of professional, social and recreational freedom. Write to your area of interest on the right.

***Which, in 1958, was 15% of base salary!**

*you'll grow faster with a growing company!*

**TEXAS INSTRUMENTS**
**INCORPORATED**
**DALLAS 9, TEXAS**

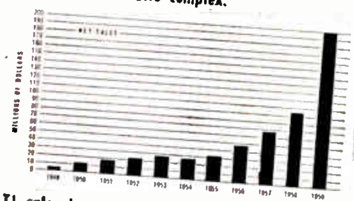


Over the post decade, TI personnel increased over 15-fold from 800 to almost 14,000. Will be 15,000 by end of 1959.

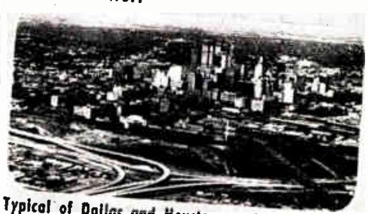
Semiconductor-Components plant . . . world's largest semiconductor manufacturing facility. Construction underway will more than double its size.

Typical of all TI plants and offices, the Apparatus division assembly area is well-lighted and air-conditioned.

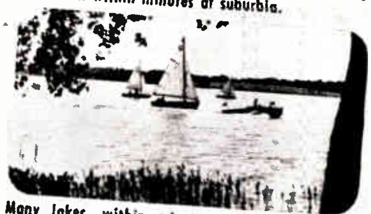
TI Central Research Laboratory's new building, located adjacent to the Semiconductor-Components plant at the 300-acre complex.



TI sales have grown over 20-fold over the past ten years . . . from under $5,000,000 to $200,-000,000 for 1959.



Typical of Dallas and Houston: modern buildings and facilities, new multi-lane freeways that bring downtown within minutes of suburbia.



Many lakes, within minutes of Dallas, provide excellent recreation. Houston is "next door" to Galveston, nationally known seaside resort.

# specific career opportunities now open at Texas Instruments

## SEMICONDUCTOR-COMPONENTS DIVISION

**DEVICE DEVELOPMENT**—Develop new semiconductor devices; conduct experimental and theoretical studies on the effects of nuclear radiation on semiconductor materials and devices; evaluate experiments in the analysis of gases and electro-chemistry; conduct physical measurements on semiconductor surfaces; determine the effects of chemical reaction on semiconductor surfaces; studies in device stability, reliability and characterization; materials research and development including crystal growth and crystallography.
**CIRCUIT DEVELOPMENT**—Transistor circuit design and application; design automatic and semi-automatic test equipment.
**MECHANIZATION**—Design and develop high speed automatic machinery.
*Please write to* C. A. Besio, Dept. 1004, P. O. Box 312, Dallas, Texas

## APPARATUS DIVISION

**MANUFACTURING ENGINEER**—To perform the planning and coordination of the manufacture of electro-mechanical/electronic systems and components on an assigned project basis; to determine action to be taken; follow-up and report successful operation of the course of action selected. BS in EE, ME or IE, with minimum 3 years experience in manufacturing processes, tooling, scheduling, and costs.
**QUALITY CONTROL ENGINEER**—To establish and maintain standards of quality and inspection methods for all raw materials, work in process and finished products. BS in EE, ME or IE with minimum 3 years experience in working to customer requirements, procedures, quality reports plus prevention and detection of defects in electro-mechanical apparatus.
**SENIOR MICROWAVE ENGINEER**—To perform applied research and development in the field of microwave and high-powered transmitter equipment including ASR transmitter and automatic performance monitoring. MS in Physics or EE with minimum 5 years experience in the field of microwave and high-powered transmitting equipment.
**SENIOR ELECTRONIC ENGINEER**—To conduct engineering analysis of techniques that will be incorporated into various product lines. Electronic design experience associated with the missile field involving circuit (transistor), computers, telemetry, and guidance systems design essential. MS in EE, ME or Physics with minimum 7 years experience in field of missile electronic design and systems planning and analysis.
**CIRCUIT DESIGN ENGINEER**—With strong instrumentation background with emphasis on circuit design. Experience in application of transistor circuits to instrumentation highly desirable although not essential. BS or MS in EE or Physics with minimum 5 years experience.
**RESEARCH ANALYST**—To perform industrial marketing research in the field of military and industrial electronics; requires analytical ability with imagination to foresee variables and recognize limitations and data; ability to present ideas clearly in verbal and written form. Must also be able to interpret and point out use and conclusion of statistical studies to division management. BS in ME, EE or MBA or MA in Economics.
**SENIOR GUIDANCE ENGINEER**—To design microwave antennas and circuit components; supervise engineering personnel in design and development of complete missile antenna and microwave systems; contribute original advancements in missile microwave and antenna concepts for proposals and system development. BS in EE or Physics with minimum of 5 years experience in stripline microwave design. Also thoroughly familiar with radiation and propagation theory.
**MATHEMATICAL STATISTICIAN**—To specialize in the study of noise applications; to perform systems analysis of sonar and radar product lines; to provide consulting service to other technical personnel. MS or PhD in Mathematics with minimum of 6 years experience in applied analysis of advanced mathematics.
**MATHEMATICIAN**—To specialize in transform calculus as applied to servo mechanisms and network analysis and continued fraction work; provide consulting services to other technical personnel. MS or PhD in Mathematics with minimum of 6 years experience in applied analysis of advanced mathematics.
*Please write to* John Pinkston, Professional Placement, Dept. 1004, 6000 Lemmon Avenue, Dallas 9, Texas

## GEOSCIENCES AND INSTRUMENTATION DIVISION

**MECHANICAL DESIGN ENGINEERS**—BS or MS in ME to design small electro-mechanical mechanisms.
**ELECTRICAL DESIGN ENGINEERS**—BS in EE or Physics to design and construct supervisory control systems of electro-mechanical and electronic design; transistor test equipment, requiring heavy experience on electronic circuit design, preferably with transistors; digital computers with experience in detailed logical design.
**MANUFACTURING ENGINEER**—BS in ME or IE with experience in production, planning, production control, methods and tooling in the electronics industry.
**SALES ENGINEER**—BS in EE, Physics or ME with sales experience in electro-mechanical instruments.
*Please write to* Dave Turner, Dept. 1004, 3609 Buffalo Speedway, Houston, Texas

## CENTRAL RESEARCH LABORATORY

**HEAD—PHYSICS SECTION**—4 to 5 years experience in semiconductor physics and proven ability to direct a variety of technical projects. Responsible for directing work on the measurement and understanding of electrical, thermal, magnetic, optical, and transport properties of semiconductors. Educational requirement is PhD in Physics.
**HEAD—DEVICE SECTION**—4 to 5 years experience in semiconductors plus experience in group leadership and proven ability to supervise a variety of technical projects. Will be responsible for directing work on design, fabrication and evaluation of new solid state devices. Educational requirement is MS or PhD in either Physics or EE.
**SOLID STATE THEORIST**—Responsible for the understanding and interpretation of the physical properties of semiconductors and other solid state materials. Educational requirements: PhD in Physics with concentration in quantum mechanics. Solid state experience desirable but not necessary.
**DEVICE THEORIST**—Responsible for the design of new solid state devices and interpretation of their characteristics in terms of physical and fabrication parameters. Educational requirement is PhD in Physics or EE, or MS with 2 to 3 years experience in solid state device theory.
**SEMICONDUCTOR TECHNOLOGY**—Responsible for the design and interpretation of experiments on the technology of semiconductors, including impurity diffusion and alloying. Educational requirement is PhD in Physical Chemistry or Metallurgy. Experience requirement: 3 to 4 years experience in semiconductor technology.
**THEORETICAL PHYSICIST**—2 to 3 years experience in electron or nuclear magnetic resonance with interest and background to perform theoretical analysis of EMR and NMR to develop possible new types of magnetometers or to make significant improvement in present types. Sufficient experimental background and interest to assist in translating theoretical results into experimental projects.
**PHYSICISTS**—Either MS or PhD with 1 year minimum experience in the fields of superconductivity and low temperature physics. Should be acquainted with conventional techniques of transferring and handling liquid helium and designing circuits and instrumentation for studies in this area.
*Please write to* A. E. Prescott, Dept. 1004, P. O. Box 1079, Dallas, Texas

# An Invitation To Join ORO...Pioneer In Operations Research

Operations Research is a young science, earning recognition rapidly as a significant aid to decision-making. It employs the services of mathematicians, physicists, economists, engineers, political scientists, psychologists, and others working on teams to synthesize all phases of a problem.

At ORO, a civilian and non-governmental organization, you will become one of a team assigned to vital military problems in the area of tactics, strategy, logistics, weapons systems analysis and communications.

No other Operations Research organization has the broad experience of ORO. Founded in 1948 by Dr. Ellis A. Johnson, pioneer of U. S. Opsearch, ORO's research findings have influenced decision-making on the highest military levels.

ORO's professional atmosphere encourages those with initiative and imagination to broaden their scientific capabilities. For example, staff members are taught to "program" their own material for the Univac computer so that they can use its services at any time they so desire.

ORO starting salaries are competitive with those of industry and other private research organizations. Promotions are based solely on merit. The "fringe" benefits offered are ahead of those given by many companies.

The cultural and historical features which attract visitors to Washington, D. C. are but a short drive from the pleasant Bethesda suburb in which ORO is located. Attractive homes and apartments are within walking distance and readily available in all price ranges. Schools are excellent.

**For further information write:**
**Professional Appointments**

**OPERATIONS RESEARCH OFFICE**

**ORO The Johns Hopkins University**

6935 ARLINGTON ROAD
BETHESDA 14, MARYLAND

## Positions Wanted

## By Armed Forces Veterans

*(Continued from page 170A)*

Institute, Los Angeles. Desires suitable position, willing to undergo preparatory training if necessary. Non-U.S. citizen, at present residing outside USA. Location—any part of the world, preferably U.S. or possessions. Box 2033 W

### EDITOR—PUBLICATIONS MANAGER

B.S. in physics, 10 years technical writing experience including 4 years as supervisor; 3 years teaching radio and television repair, laboratory and theory; holder of 1st class radiotelephone license; excellent mathematician; expert typist and stenographer. Desires position as editor of electronics periodical or as supervisor in publications section of manufacturer of electronic equipment. New York City area preferred. Box 2034 W.

### TECHNICAL REPRESENTATIVE

Assistant to Technical Director in Europe desires position of broad responsibility in Europe. University training in eng. and administration; 10 years comm. and mil. elec. Member IRE; FCC 1st. Age 40. Married. Box 2035 W.

### ELECTRONIC ENGINEER

Completing Ph.D. in E.E. this fall at large midwestern university. 6 years broad experience in ECM, communication, and control systems. Strong background in applied mathematics. Former Fulbright scholar. Desires long term position in continental Europe. Age 29, married, U.S. citizen, languages. Box 2039 W.

*(Continued on page 178A)*

# INERTIAL PLATFORM ENGINEER

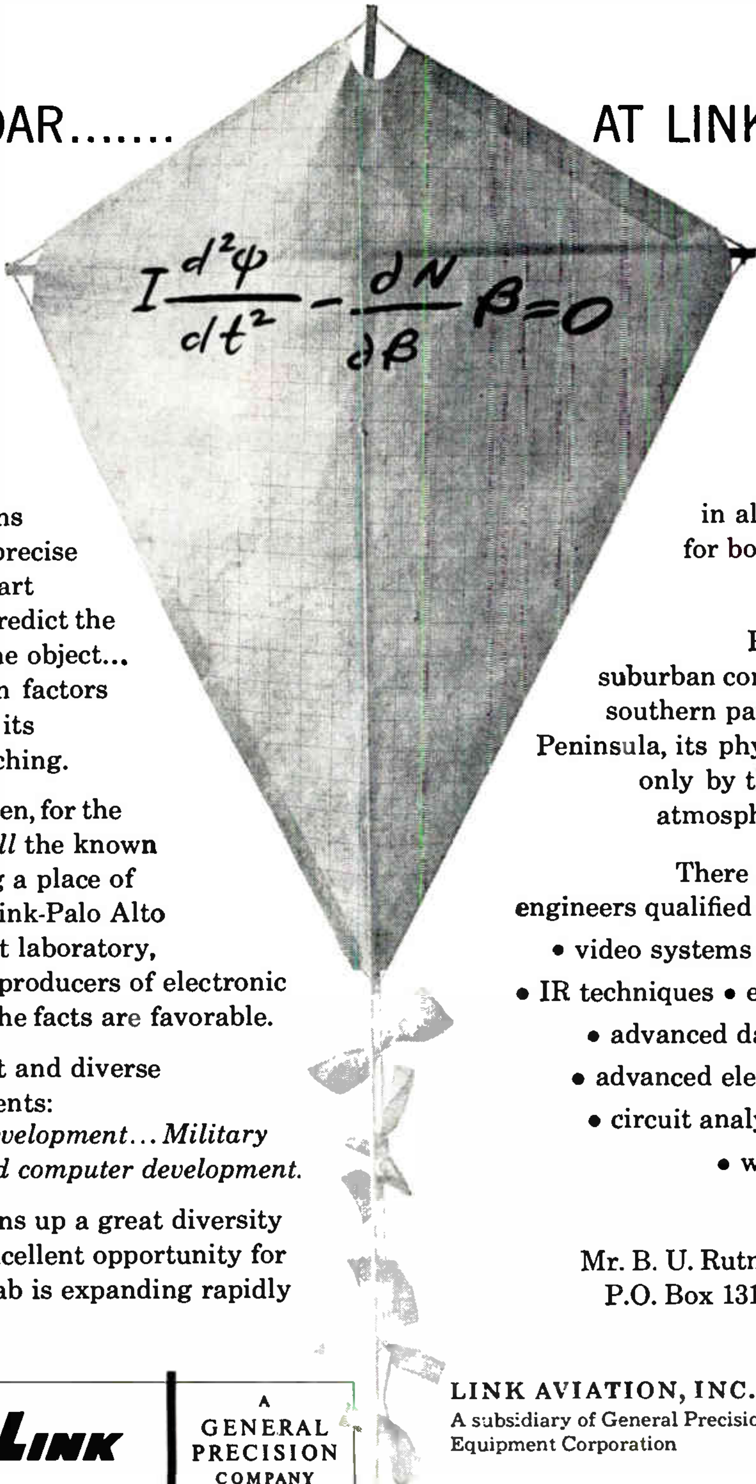
To be responsible for inertial navigator platform subsystems development. 2-3 years experience desired in inertial electronics and platform development.

To arrange interview call collect, Niagara Falls BUtler 5-7851, or send resume to:

***Supervisor Engineering Employment***

**BELL AIRCRAFT CORP.**
**BUFFALO 5, NEW YORK**

# CAREERS SOAR....... AT LINK-PALO ALTO




An engineer soon learns that in order to make precise projections, he must start with precise facts. To predict the reactions of an airborne object... even a kite...all known factors must be considered in its construction and launching.

How important it is, then, for the engineer to consider *all* the known factors when choosing a place of employment. At the Link-Palo Alto electronic development laboratory, (pioneers and leading producers of electronic flight simulators) *all* the facts are favorable.

Link has three distinct and diverse development departments: *Industrial products development... Military electronics... Advanced computer development.*

This arrangement opens up a great diversity of assignments and excellent opportunity for advancement, as the lab is expanding rapidly in all areas of development for both our commercial and military customers.

Palo Alto is a charming, suburban community located on the southern part of the San Francisco Peninsula, its physical climate matched only by the benign professional atmosphere at the Laboratory.

There are many openings for engineers qualified in the following fields:

- video systems
- electronic packaging
- IR techniques
- engineering psychology
- advanced data processing systems
- advanced electro-mechanical design
- circuit analysis
- computer design
- weapon system analysis

Move up! Write to
Mr. B. U. Rutman, Link Aviation, Inc.
P.O. Box 1318, Palo Alto, California

LINK | A GENERAL PRECISION COMPANY

**LINK AVIATION, INC.**
A subsidiary of General Precision Equipment Corporation

*Lockheed Missiles and Space Division*

*invites your inquiry into these*

# UNUSUAL RESEARCH AND DEVELOPMENT OPPORTUNITIES

Important career positions are available at Lockheed Missiles and Space Division at its new facilities on the beautiful San Francisco Peninsula – one of the choicest living areas in the nation. Headquarters for the Division are at Sunnyvale, California, with Research and Development Facilities located in the Stanford Industrial Park in nearby Palo Alto.

The Division is widely diversified – having complete capability in more than 40 areas of science and technology, from concept to operation. Areas of work include: metallurgy; sonics; reconnaissance; computer design and development; propulsion and exotic fuels; space physics; hydrodynamics; the flight sciences; space medicine; manned space vehicles; telemetry; electronics; applied mathematics; operations research and analysis; space communications; reentry; design; and test, both environmental and flight.

Equipment and facilities are completely modern and include one of the largest computer centers in the world.

The Division is systems manager for several major, long-range projects and its research and development programs reach far into the future. It is a rewarding future with a company that has an outstanding record of leadership and progress.

Unusual opportunities exist for experienced engineers and scientists to contribute to the solution of new problems in the areas listed on the next page. If you are experienced in these areas, or have background in related fields, we invite your inquiry. Please write: Research and Development Staff, Dept. L-33, 962 West El Camino Real, Sunnyvale, California. U.S. citizenship required.



## Positions Wanted

## By Armed Forces Veterans


*(Continued from page 174A)*


### ELECTRONIC ENGINEER

BSEE, 1956 from Louisiana Tech. Professional Engineer, La.; FCC license; 3 years in radio equipment research and development. Desires diversified work involving planning and circuit work. Age 25; married; USAF officer; January 1960. Box 2044 W.

### INSTRUMENTATION

Group Leader: instrument development for product improvement; development of unique applications of sound, light and electronics to measurement of various process parameters; and development of automatic equipment. 13 years experience; BS, Eng. Physics, MS, Electrical Engineering. Box 2045 W.

### ENGINEER

Ph.D., June 1960. 5 years industrial experience, several semesters experience teaching lecture courses at the senior EE level. Interested in teaching and research at progressive EE dept. Prefer western U.S. Box 2049 W.

### SYSTEM ENGINEER

3 years engineering experience in digital and analog system development. 2 years technician experience in switching. 4 years USAF Nuclear Weapons. Interested in system engineering especially hybrid systems for control and data processing. Tau Beta Pi, Eta Kappa Nu. Available on completion of M.E.E. requirements, June 1960. Age 28, married, 2 children. Box 2050 W.

### SENIOR ENGINEER—CHIEF

Age 43; broad electronic experience with vacuum tube and transistor circuitry, analog computers, gyro systems, power supplies, miniaturization and printed circuitry. Senior Member IRE. Tau Beta Pi, Eta Kappa Nu. Will relocate for an outstanding opportunity. Box 2051 W.

### ENGINEERING TEACHER

BS. and MS. in E.E. 2 years industrial research, 2 years applicable military, and 4 years full-time teaching on the faculty of a major east coast university. Desires position of permanent with good family living conditions. Summer income opportunity desirable. Available June 1960. Box 2052 W.

### ELECTRICAL ENGINEER

BS. in physics, graduate work in E.E.; 7½ years experience in electronics of which 3½ years is in commercial data processing. Have published articles and hold patents in electronics. Desires overseas position. Box 1053 W.

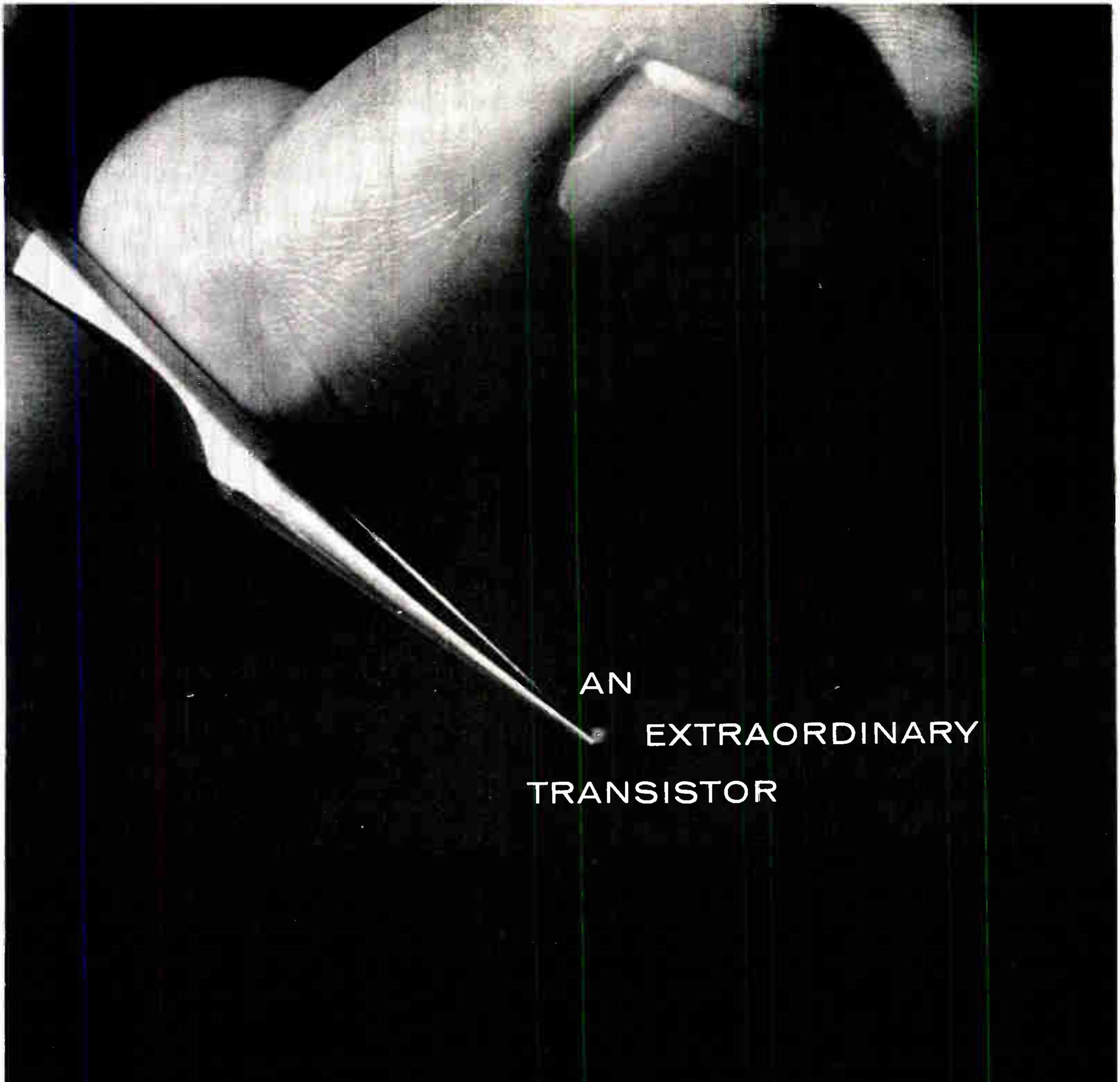
### ENGINEER

BSEE., extensive antenna and R.F. experience, design and project supervision. Broad background includes sales and engineering management, contract negotiations. Desires position as General Manager of antenna company, or participant in ownership management of antenna consulting firm or small growing company. Box 2054 W.

### COMPONENTS ENGINEER

E.E. degree. 10 years solid experience in electromechanical components—development, evaluation, application and standardization. Desires a challenging, responsible position in a supervisory capacity. New York, Long Island area preferred. Box 2055 W.


*(Continued on page 180A)*




This tiny silicon chip does something no other transistor can do. It achieves the speed of the fastest germanium plus having the superior temperature characteristics and reliability inherent to silicon. It is the Fairchild 2N706.

This extraordinary transistor was introduced to industry in August of 1959. Within two months, many thousands of units had been shipped and the 2N706 was being designed into highest performance computer circuits. No "blue sky" project, the 2N706 is applicable and extremely advantageous to all types of high speed computer logic.

The 2N706 is also extraordinary as a success story in people—solid-state physicists, physical chemists, metallurgists, electrical engineers, mechanical engineers and industrial engineers. Free flow of ideas and enthusiasm produced an accumulation of advanced semiconductor technologies at an unprecedented rate. From the beginning, only two years ago, the 2N706 was the goal. En route, these technologies resulted in the production of eight other silicon transistors. These devices have clearly established Fairchild as the leader in advanced semiconductor development.

Step by step, the Fairchild program was planned and held in focus by a top management team of advanced degree scientists. And now, this same program is being zeroed in on new targets, among them Esaki diodes and integrated solid-state circuitry. If yours is a relevant background and you like the way we work, why not drop us a line? We would like to hear from you.

FAIRCHILD
SEMICONDUCTOR CORPORATION

545 WHISMAN ROAD / MOUNTAIN VIEW, CALIFORNIA / YORKSHIRE 8-8161

## Positions Wanted

### By Armed Forces Veterans

(*Continued from page 178A*)

#### ELECTRONIC FIELD ENGINEER

Graduate engineer, BSEE., several years experience, age 32, fair health, seeking position as electronic engineer—sales engineer, field engineer, coordinator customers' technical requirements either commercial or military customers, or supervisor equipment installation and installation checkout. Preparation with company training course desirable. Box 2056 W.

#### ENGINEERING MANAGER—TECHNICAL REPRESENTATIVE

Retiring Navy Captain. Engineering Duty Officer. Senior Member IRE. Desires to locate in Southern California. Graduated Naval Academy 1926. 3 years sea duty. 12 years civilian electronics engineer. Returned to active duty 1941; 9 years technical administrator in Naval laboratories; 4 years comptroller in Naval Shipyard with collateral duty as project officer for electronic data processing; available late spring 1960. Box 2057 W.

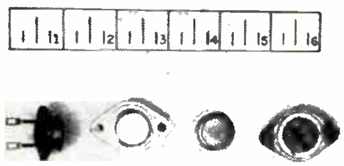
## NEWS New Products

**These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.**

(*Continued from page 156A*)

### Military-Type Transistor

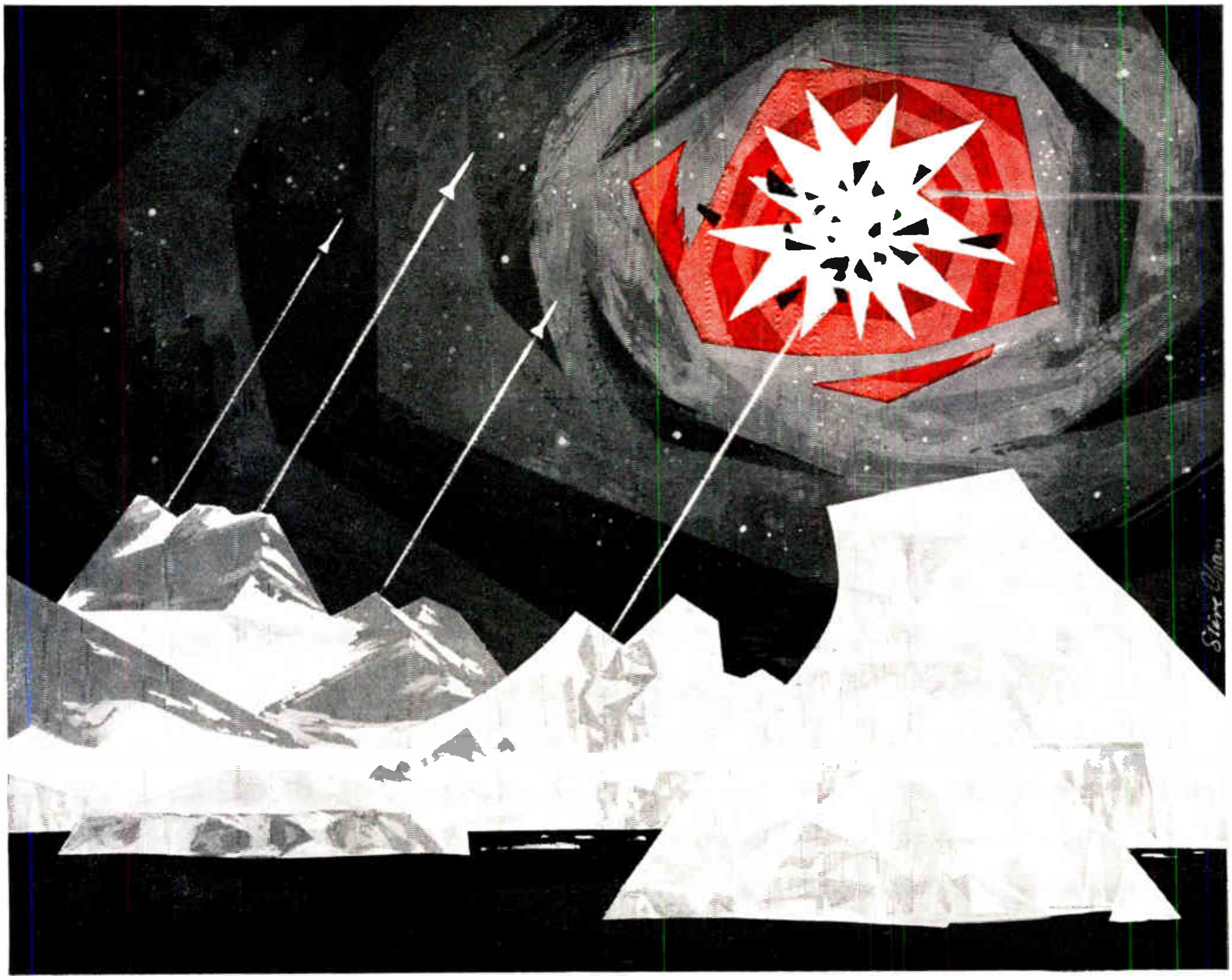
Military-type 2N120, a high current, high-power switching transistor is now in production by **Bendix Aviation Corp.,** Semiconductor Products, Long Branch, N. J.



The 2N1120 has been designed to meet the specification MIL-T-19500/68 (SigC). Its maximum collector current rating of 10 Adc makes it particularly appropriate for high current switching applications, while a collector-emitter voltage rating of 70 Vdc suits it equally well to high voltage applications. The 2N1120 will readily dissipate 45 watts at a 25°C mounting base temperature. Subjected to the environmental testing required by the specification, this transistor has the high reliability demanded in military applications.

For further information, contact Marketing Department.

(*Continued on page 184A*)



## WITH ONLY MINUTES TO ACT

If America should be attacked . . . from bases around the world Strategic Air Command bombers, tankers and surface-to-surface missiles will rise to action. Minutes only will be available.

To integrate and control this assault requires accessibility and handling of a staggering volume of data. In the missile era, present methods of gathering and processing data will be inadequate. SAC is automating the system.

As systems manager, International Electric Corporation is developing and will turn over to SAC a world-wide electronic combat control system, an integrated complex of electronic subsystems. The system, employing digital techniques and equipment, will transmit, process and display information on a global basis . . . with only seconds involved.

Engineers whose interests lie in systems engineering, data processing and communications will find in this long-term project exceptional opportunity to exercise creative competence and individual initiative. For details of engineering assignments write B. J. Crawford, Director of Technical Staffing.

**INTERNATIONAL ELECTRIC CORPORATION**

*An Associate of International Telephone and Telegraph Corporation*

Route 17 & Garden State Parkway, Paramus, New Jersey

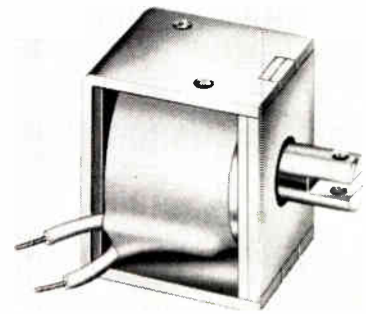
ITT

## NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

*(Continued from page 180)*

### AC or DC Solenoid



**Guardian Electric Mfg. Co.,** 1621 West Walnut St., Chicago 12, Illinois, has developed a new (No. 28) Midget Solenoid, available ac or dc, intermittent or continuous duty, which the company claims will be of interest to design engineers, because of its size, power and versatility. This solenoid has tapered plug and plunger for greater power. Plunger strokes from $\frac{1}{16}''$ to $\frac{1}{2}''$ with a lift of over 41 ounces. Overall dimensions: $1\frac{1}{4}'' \times 1'' \times 1\frac{3}{16}''$. Weight: approximately $3\frac{1}{2}$ ounces. For further information write to Guardian.

*(Continued on page 186A)*

## NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

*(Continued from page 184A)*

### Rotary Switch Bulletin

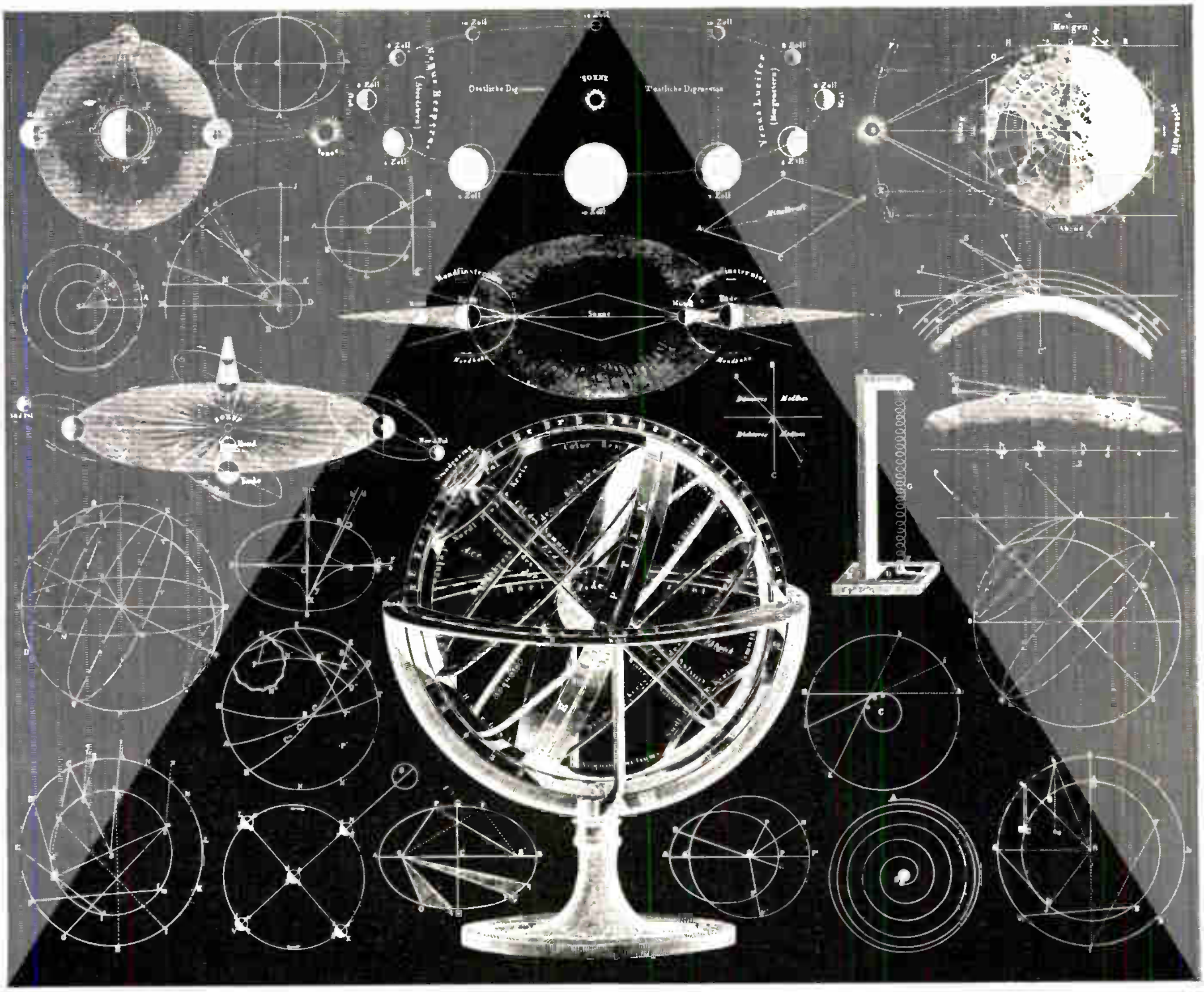
A bulletin on the new High Precision Rotary Switch WP-2 recently brought out by **Waters Manufacturing, Inc.,** Wayland, Mass., is now available. Illustrations are actual size. Electrical, mechanical and environmental specifications including a dimensional schematic are also given.

### Ground Support Equipment Catalog

Ground support equipment systems, components and capabilities for aircraft and missiles are described in a new four-page brochure which is available from **Lear, Inc., Contracts Div.,** P.O. Box 688, Grand Rapids 2, Mich.

Lear, which has had 29 years of experience in the aerospace industry, carries on continuous research into the design and manufacture of ground handling actuation components and systems. The basic building blocks described in the brochure are available for use as either components in themselves or as groupings for complex systems.

*(Continued on page 216A)*



# *Guided tour of the solar system*

The new NASA Thor-boosted research rocket, DELTA, now being constructed by Douglas, will set up big signposts for further space explorations. Combining elements already proved in space projects with an advanced radio-inertial guidance system developed by the Bell Telephone Laboratories of Western Electric Company, DELTA will have the versatility and accuracy for a wide variety of satellite, lunar and solar missions. Douglas insistence on reliability will be riding with these 90 foot, three-stage rockets on every shoot. At Douglas we are seeking qualified engineers to join us on this and other equally stimulating projects. Some of our requirements are listed in our column on the facing page.

Maxwell Hunter, Asst. Chief Engineer—Space Systems, goes over a proposed lunar trajectory with Arthur E. Raymond, Senior Engineering Vice President of **DOUGLAS**

MISSILE SYSTEMS ■ SPACE SYSTEMS ■ MILITARY AIRCRAFT ■ JETLINERS ■ CARGO TRANSPORTS ■ AIRCOMB ■ GROUND-HANDLING EQUIPMENT

## Membership

The following transfers and admissions have been approved and are now effective:

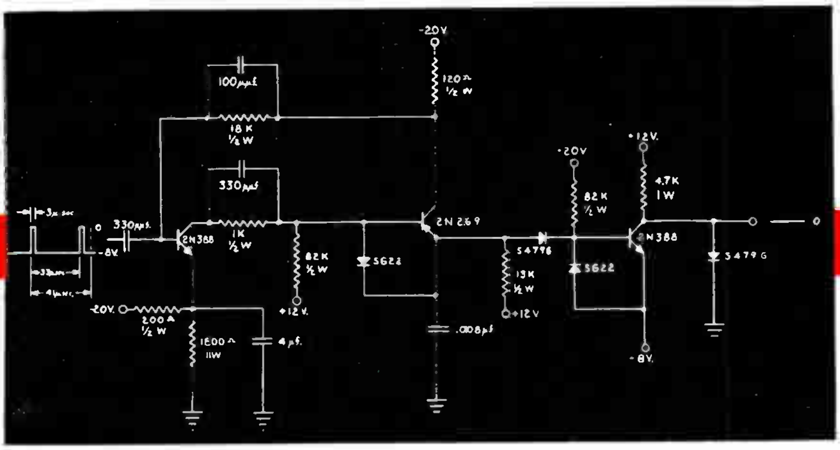
### Transfer to Senior Member

Andrews, E. G., Nashua, N. H.
Barron, J. I. Charlotte, N. C.
Bartram, J. F., Severna Park, Md.
Bennett, W. E., San Diego, Calif.
Berliner, J., Rome, N. Y.
Birge, W. A. Winter Park, Fla.
Blacker, H. L., Belleville, Ont., Canada
Bobber, R. J., Orlando, Fla.
Bracco, D. J., Bayside, L. I., N. Y.
Brugliera, F. J., Niles, Ill.
Byam, L. A., Jr., New York, N. Y.
Carlson, R. A., Richfield, Minn.
Dumey, A. I., Roslyn Heights, L. I., N. Y.
Frese, R. E., Fort Huachuca, Ariz.
French, C., Yonkers, N. Y.
Good, L. H., Riverton, N. J.
Gordon, R. R., Holliston, Mass.
Haag, E. J., Los Angeles, Calif.
Heines, J. M. H., Westmount, Montreal, Que., Canada
Henning, R. E., Clearwater, Fla.
Herring, R. A., Jr., University, Miss.
Herron, R. G., Albuquerque, N. M.
Honig, W. M., Brooklyn, N. Y.
Ikerd, H. M., La Jolla, Calif.
Kuss, P. W., West Englewood, N. J.
Lathrop, P. A., Levittown, Pa.
Lesman, E., New York, N. Y.
Mandel, M., Pacoima, Calif.
Martin, R. E., Tucson, Ariz.
Maybell, J. L., Dayton, Ohio
Myers, G. H., South Orange, N. J.
November, F. D., Great Neck, L. I., N. Y.
Nylander, R. F., Saratoga, Calif.
Ogg, F. C., Jr., Baltimore, Md.
Phillips, G. D., St. Joseph, Mich.
Plehaty, S. L., Stamford, Conn.
Powers, E. W., Lanham, Md.
Rehm, W. L., Shrewsbury, N. J.
Riddle, F. M., Pasadena, Calif.
Robinson, R. A., New Westminster, B. C., Canada
Rodatus, E. J., Rochester, N. Y.
Romanelli, P. A., Utica, N. Y.
Schlager, K. J., Wauwatosa, Wis.

### Admission to Senior Member

Andrews, M. C., Poughkeepsie, N. Y.
Beam, R. L., Little Neck, L. I., N. Y.
Cotter, J. J., Lynn, Mass.
Crawford, A. E., Hythe, Southampton, England
DiGirolamo, J., VM., Orange, N. Y.
Driver, D. L., Jr., Los Angeles, Calif.
Elser, F. J., Van Nuys, Calif.
Fine, C. R., New York, N. Y.
Fisher, L. H., Forest Hills, L. I., N. Y.
Generales, C. D. J., Jr., New York, N. Y.
Gertz, N., Providence, R. I.
Godfrey, R. M., Smallfield, Horley, Surrey, England
Grondin, G. F., Van Nuys, Calif.
Gunter, R. C., Jr., Charlton, Mass.
Hessinger, P. S., West Caldwell, N. J.
Hiser, H. W., Coral Gables, Fla.
Hogge, S. F., Washington, D. C.
Hope, H. R., Hermosa Beach, Calif.
House, R. W., State College, Pa.
Jarleton, P., Paris, Seine, France
Karolus, A., Zollikon-Zurich, Switzerland
Krohn, P. L., Easton, Pa.
Laning, C. B., Plainfield, N. J.
Lawson, J. S., Jr., Belmont, Mass.
Leichtman, D. K., Tonawanda, N. Y.

*(Continued on page 192A)*




**ELECTRONIC ENGINEERS . . . PHYSICISTS . . . CHEMISTS:**

# NATIONAL OFFERS CHALLENGING OPPORTUNITIES IN YOUR FIELD

The National Cash Register Company—a leader in the application of automation to business machines—has organized its Research and Development Division to provide ideal working environments for technically trained men and women of the highest calibre. Projects in progress are of an exciting, stimulating nature . . . for instance, considerable work is being done on Encapsulation and thin film memory and switching components. Your training and experience may qualify *you* for a position in one of these areas:

### DATA PROCESSING RESEARCH AND DEVELOPMENT

- Computer Theory
- Computer Component Development
- Machine Organization Studies
- High-Speed Non-Mechanical Printing and Multi-Copy Methods
- Direct Character Recognition
- Systems Design

### ELECTRONIC ENGINEERING DEVELOPMENT

- High-Speed Switching Circuit Techniques
- Random Access Memory Systems
- Circuit and Logical Design
- Advanced Storage Concepts Utilizing Electron Beams
- Microminiaturization of Components and Circuitry

### SOLID STATE PHYSICS

- Electrodeposited Magnetic Films
- Vacuum Deposited Thin Magnetic Films
- Ferrites and Ferromagnetics
- Electroluminescence-Photoconductor Investigations
- Advanced Magnetic Tape Studies

### CHEMISTRY

- Plastics and Polymers
- Encapsulation *(A process for producing microscopic capsules containing liquids or reactive solids)*
- Photochromic Materials *(Studies of National-developed compounds which are photosensitive to specific wave lengths of light, for application to memory, printing and photocopy devices)*
- Magnetic Coatings

**NATIONAL'S NEW RESEARCH AND DEVELOPMENT** Center is located in Dayton, Ohio, one of the midwest's most progressive cities. There are also attractive positions available at our Electronics Division in Hawthorne, California.

**FOR COMPLETE INFORMATION,** simply send your resume to Mr. T. F. Wade, Technical Placement, F-2A, The National Cash Register Company, Dayton 9, Ohio. All correspondence will be kept strictly confidential.

**THE NATIONAL CASH REGISTER COMPANY, Dayton 9, Ohio**

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**ADVANCED RECONNAISSANCE** system developments at **Melpar** provide unusual opportunities for the technical advancement of participating professional personnel. Technological challenge in an area vital to our national defense assures our engineers and scientists that their contributions will have lasting significance. **Melpar's** reconnaissance systems engineering department has achieved national recognition for its outstanding accomplishments in the fields of acquisition, processing, and interpretation of intelligence. Techniques resulting from our deep probes into advanced aspects of electronics, optics, and physics are being quickly translated into operational equipment for the armed forces.

***Positions in the following areas offer particular challenge at this time:***

| | |
|---|---|
| Reconnaissance Systems | Detection & Identification Systems |
| Airborne Equipment | Antenna & Radiation Systems |
| Ground Data Handling Equipment | Physical Sciences Laboratory |
| Simulation & Training Systems | Applied Physics Laboratory |
| Communication & Navigation Systems | Production Engineering |
| Ground Support Equipment | Quality Control |

**Melpar's** remarkable growth continues to create attractive opportunities for the exceptional engineer and scientist.
Your own intellectual dimensions govern remuneration and assignments.

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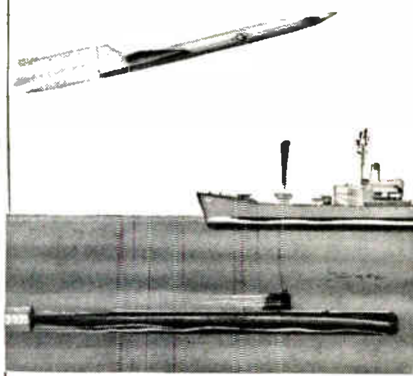
*In Historic Fairfax County*
*10 miles from Washington, D. C.*

**ELECTRONICS: Over, on and under . . .**



## DIGITAL COMPUTER ENGINEERS

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Autonetics now offers you advanced opportunities in the design, research, development, test and checkout, manufacture, and field service of digital computers. Apply your experience to:

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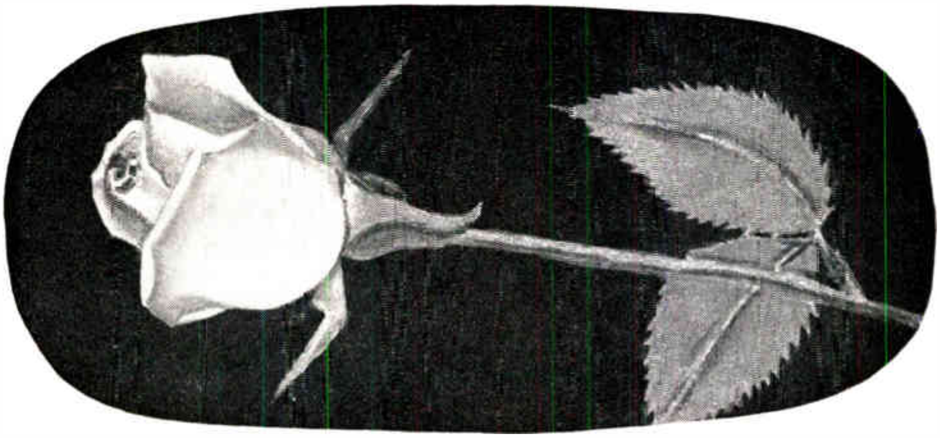
**Flight Control Systems**
**Automatic Checkout Centrals**
**Armament Control Systems**

BSEE or better is preferred, along with several years experience in either systems or components associated with digital computers in circuits, memories, input-output equipment, logic design, analysis, or programing.

Send your resume to:
Mr. B. D. Benning,
Manager, Employment Services
Dept. G-122
9150 East Imperial Highway
Downey, California

**Autonetics**
A Division of North American Aviation, Inc.



*At Bendix York, we have a number of immediate openings for Electronic Engineers and Physicists.*

*There are many worthwhile advantages awaiting the Professional Engineer who chooses to advance his career with us at Bendix York.*

# *A white rose . . .*

The white rose is a symbol at Bendix York . . . a symbol with two meanings. Both of vital importance to *your* future.

First, the white rose is the official flower of York, Pennsylvania. It is a symbol of the good life in our dynamic community, located in the heart of the scenic Pennsylvania Dutch region. It is a wholesome, happy area with excellent schools, delightful recreational opportunities and many cultural advantages. Here—away from high-pressure, high-cost, big-city living—you will enjoy the fuller, more rewarding life that you want for yourself and for your family.

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We would like to have the opportunity to tell you more about Bendix York. We invite you to contact us—by dropping us a post card, by giving us a call or, if you will, by sending us a brief resume. Address Professional Employment: Dept. P

Bendix AVIATION CORPORATION **YORK DIVISION** York, Pennsylvania
Phone: York 47-1951

## Membership

(Continued from page 188A)

Marti, E., Orlando, Fla.
McCumber, W. H., Griffiss AFB, N. Y.
McDaniel, J. L., Decatur, Ala.
Meachem, J. R., Lake Worth, Fla.
Miyake, Y., Yokohoma, Japan
Olson, C. L., Orange, Calif.
Owens, T. E., Jr., Dallas, Tex.
Procter, E. N., Ojai, Calif.
Renskers, J. O., Lombard, Ill.
Ristic, D., Belleville, Ont., Canada
Seeling, T. V., Milwaukee, Wis.
Yoder, J. R., Westport, Conn.

### Transfer to Member

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Akerberg, E. D., Mountain View, Calif.
Allard, G. A., Phoenix, Ariz.
Arbuckle, R. D., Indianapolis, Ind.
Bearinger, V. W., Hopkins, Minn.
Benningfield, L. M., Columbia, Mo.
Berger, J. E., Fullerton, Calif.
Blatchford, D., Woodland Hills, Calif.
Bliss, R. W., Champaign, Ill.
Bradley, R. W., Lincoln Park, Mich.
Brodd, W. D., Wappingers Falls, N. Y.
Brown, F. W., Boulder, Colo.
Burgh, A. J., Bellevue, Wash.
Burjoice, R. A., Ashtabula, Ohio
Chisholm, R. M., Kingston, Ont., Canada
Clerke, B. C., Ontario, Canada
Coleman, G. A., Hartford, Conn.
Coombs, C. C., Jr., Dayton, Ohio
Corrado, V. M., Albertson, L. I., N. Y.
Dalton, R. C., Prairie Village, Kan.
Davidson, R. C., Riverton, N. J.
Dundatscheck, E. P., Poughkeepsie, N. Y.
Eckmann, L. G., Berkeley, Ill.
Emerson, M. R., Rolling Hills, Calif.
Femiano, D. J., Washington, D. C.
Fremming, H. O., Elmwood Park, Ill.
Gillin, G. F., Commack, L. I., N. Y.
Giordano, S., Port Jefferson Sta., L. I., N. Y.
Gordon, J. M., Evansville, Ind.
Hager, R. E., Pittsburgh, Pa.
Hill, C. M., Los Altos, Calif.
Hinde, J. E., Albuquerque, N. M.
Holman, F. S., Seattle, Wash.
Horn, V. M., New York, N. Y.
Hovda, R. E., Buena Park, Calif.
Ikeda, T., White Plains, N. Y.
Intagliata, S. J., Windsor, Conn.
Isaacson, A. M., Jr., Fanwood, N. J.
Jacobs, E., Oreland, Pa.
Jarvis, W. E., Palo Alto, Calif.
Jaycox, R. L., Cedar Rapids, Iowa
Johannes, V. I., New York, N. Y.
Johnson, D. E., Brentwood, L. I., N. Y.
Joline, E. S., Huntington Station, L. I., N. Y.
Jones, D. F., San Jose, Calif.
Jones, R. H., Eastview, Ottawa, Ont., Canada
Klein, E. A., San Jose, Calif.
Kling, N., St. Louis, Mo.
Kostyshyn, B., Apalachin, N. Y.
Krackhardt, E. M., Syracuse, N. Y.
Kreer, J. B., Morgantown, W. Va.

(Continued on page 191A)

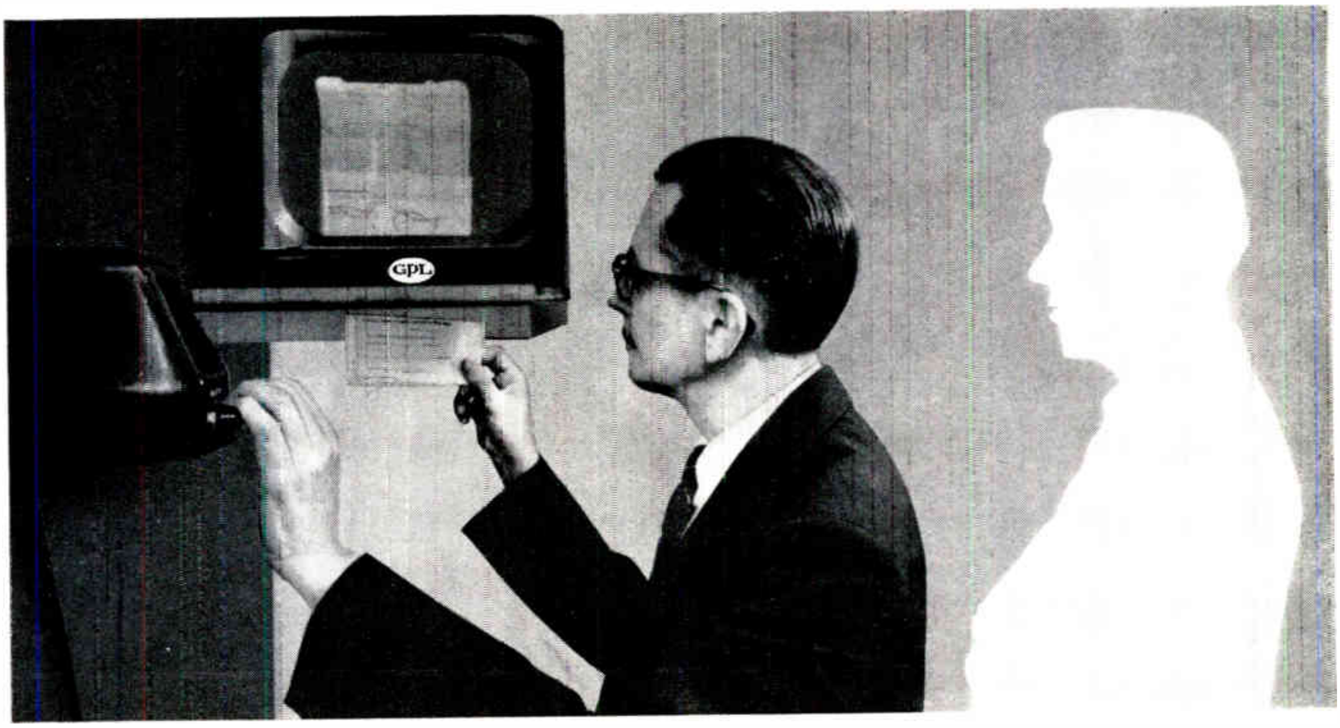
## Membership

(Continued from page 192A)

Krieger, R. W. Whippany, N. J.
Kucera, F. M., St. Paul, Minn.
Kundrotas, A. P., Chicago, Ill.
Kurihara, Y., Tokyo, Japan
Lancaster, W. W., Philadelphia, Pa.
Lazier, W. A., North Adams, Mass.
Lee, F. M., Washington, D. C.
Lees, J. W., Needham, Mass.
Leone, W. C., Palos Verdes Estates, Calif.
Lefebvre, R. A., Quebec, Canada
Leidigh, W. J., San Carlos, Calif.
Libaw, W. H., Los Angeles, Calif.
Lind, R. P., Seattle, Wash.
Ludwig, J. T., St. Paul, Minn.
Luedde, W. J., Brentwood, Mo.
Markowitz, S., Los Angeles, Calif.
Martinez, H. M., San Mateo, Calif.
Mason, F. G., Weston, Conn.
Massoglia, F. P., San Francisco, Calif.
McCord, H. L., San Pedro, Calif.
McCoy, D. R., Liverpool, N. Y.
Meader, G. S., Jr., Arlington, Va.
Miller, V. F., Portland, Ore.
Mohsen, A., Newark, N. J.
Murdock, W. G., Lindenwold, N. Y.
Murphy, A. T., Wichita, Kan.
Nelson, V. R., Sioux Falls, S. D.
Nikirk, H. S., Mt. Airy, Md.
Noone, J. R., Cocoa Beach, Fla.
O'Hearn, W. F., Jr., Cleveland, Ohio
Oliveros, C. G., Jr., Wright-Patterson AFB, Ohio

(Continued on page 196A)

# You are here...




## ... speeding the flow of business data

At a teller's window elsewhere in this bank, a savings withdrawal has been requested. With previous systems, there was a considerable delay while tellers checked individual files to verify signatures and balances. Now they turn to you. Now, from a central file, you can transmit any of the thousands of bank records to tellers at any branch in seconds. You are here in the form of a GPL closed-circuit television system. You are the GPL Engineer.

This is just one example of how the GPL Engineer is converting his enthusiastic and well-rewarded imagination into significant fact on many of today's most interesting and most difficult problems.

**Closed Circuit Television** In addition to the example cited above, there are other projects requiring the design of special military, industrial and institutional systems. These include problems in high resolution (1,000 lines) cameras and receivers, transistorized camera equipment, environment-proof cameras for missile and rocket viewing, low light level pickup, large screen projection equipment, airborne and space pickup and transmission systems.

A great deal is expected of the GPL Engineer by a top management of engineers who have created a completely engineer-oriented atmosphere—from an unsurpassed physical environment, including the most modern equipment and facilities situated on 69 acres of suburban woodland—to a unique professional atmosphere of encouragement and mutual respect. Following are some of the current employment opportunities:

**TV Engineers.** 2-10 years' experience in the design of TV cameras, monitors, or related equipment. Transistor circuitry experience desirable.

**CRT Display Engineers.** 2-10 years' experience in the design of CRT display or related circuitry.

*Engineers and physicists are invited to call ROgers 9-5000 (collect), write or submit résumé in complete confidence to:*

William R. Schell

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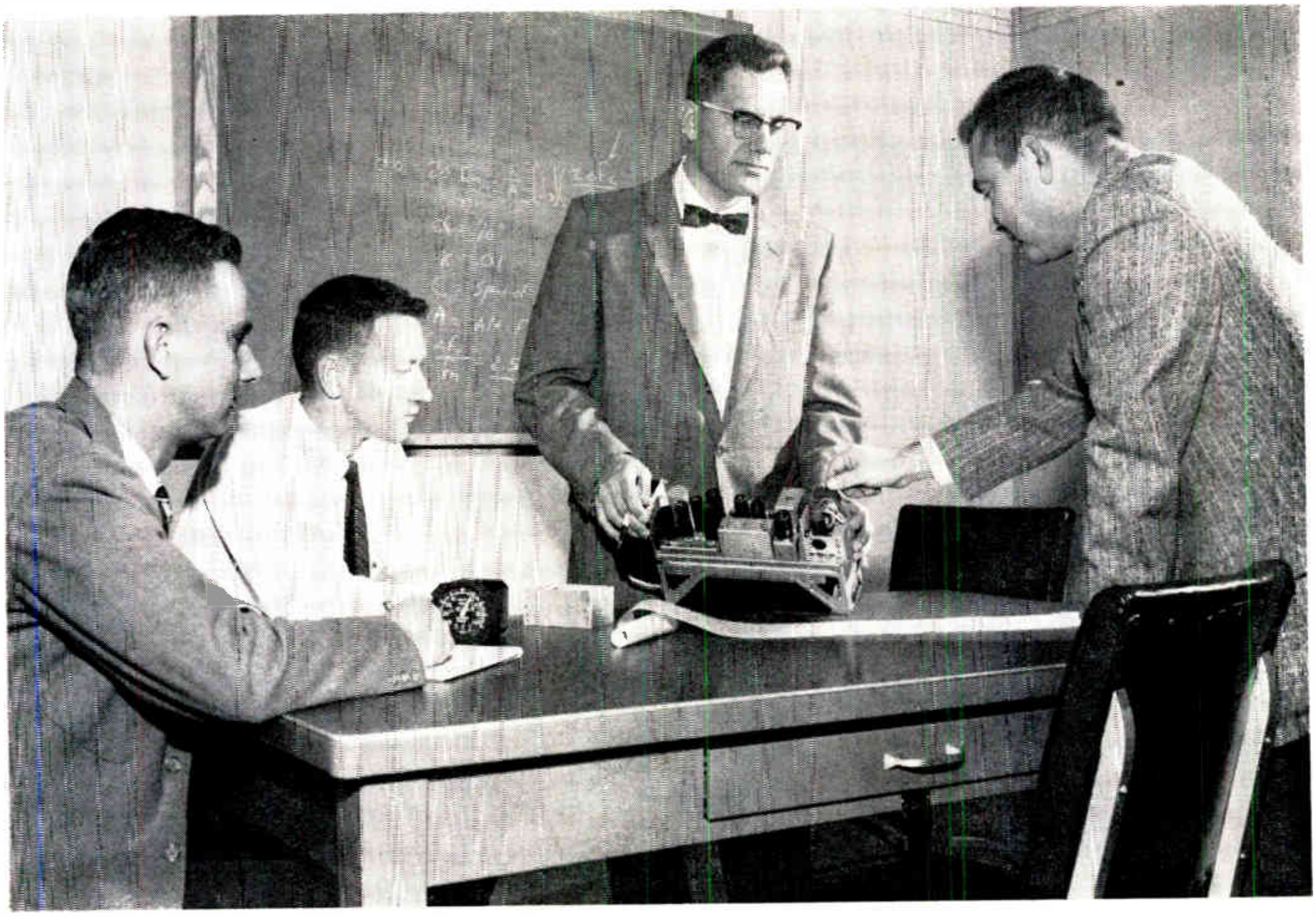
## Membership

*(Continued from page 194A)*

Page, E. R., Syracuse, N. Y.
Pappas, M. J., Dayton, Ohio
Paris, A. A., Collingswood, N. J.
Paul, A. J., Jr., Wappingers Falls, N. Y.
Pearson, R. E., Seattle, Wash.
Pitt, G. E., Torrance, Calif.
Pizzicara, D. J., Plainview, L. I., N. Y.
Pizzuti, A. D., Pomona, Calif.
Pranke, J. A., Rome, N. Y.
Pulliam, S. B., Silver Springs, Md.
Raffel, J. I., Lexington, Mass.
Raub, R. D., Indianapolis, Ind.
Reineke, R. C., Albuquerque, N. M.
Richardson, R. J., Yonkers, N. Y.
Rinaudo, R. F., San Mateo, Calif.
Roenitz, R. K., Roselle, Ill.
Rogers, C. L., Jr., Deerfield, Ohio
Rogers, J. H., Jr., Menlo Park, Calif.
Russell, C. R., Stanmore, Middlesex, England
Rymer, R. H., Atlanta, Ga.
Sabto-Agami, J. C., New York, N. Y.
Schafersman, R. L., Whippany, N. J.
Scharff, J. H., Albuquerque, N. M.
Schmid, L. H., San Pedro, Calif.
Schwalm, C. M., Dallas, Tex.
Schwartz, E. C., Buffalo, N. Y.
Schwartz, R., Brooklyn, N. Y.
Shapiro, H., New Rochelle, N. Y.
Shapiro, H., Anaheim, Calif.
Shechet, M. L., San Diego, Calif.
Sherman, R. G., Ludlowville, N. Y.
Shinners, S. M., Brooklyn, N. Y.
Silvern, L. C., Los Angeles, Calif.
Slade, C. B., Bolton, Mass.

*(Continued on page 198A)*



# *Collins "engineering team" approach gives you individual expression and recognition*

Ideas — new ideas — are the foundation of any business' growth and success.

Collins Radio Company has achieved leadership in the electronics field by creating a working system that stimulates ideas from engineers. Three factors are basic to this system: 1) The opportunity to expand imagination and develop ideas. 2) Group ideation and the help of other talented engineers. 3) Complete recognition of each engineer's own ideas.

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**Collins in Burbank**
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Thomson, M. E., Phoenix, Ariz.
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Clayton, R. H., Horseheads, N. Y.
Coates, J. R. Dunedin, Fla

*(Continued on page 200A)*

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(*Continued from page 198A*)

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Edwards, A. J., Washington, D. C.
Eichman, M. E., Lombard, Ill.

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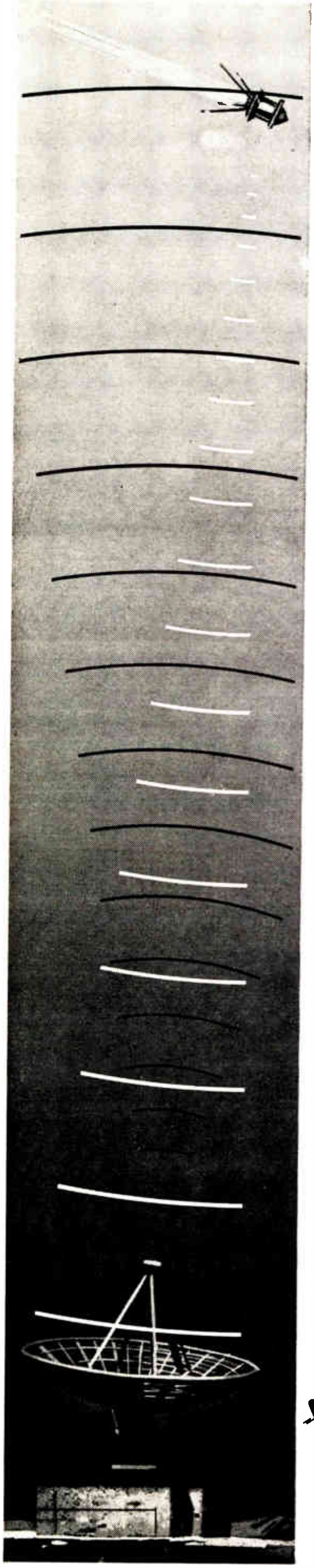

Advanced System Engineers

# Programs to Extend Detection and Direction-Finding Systems Capabilities by Several Orders of Magnitude

Sylvania's Waltham Laboratories is accelerating its systems engineering efforts on a widening technological front. The scope of these programs afford advanced system engineers opportunity to direct their individual efforts toward major state-of-the-art advances in synthesis, design and analysis of sophisticated detection and direction finding systems:

Typical problems toward whose solution you can focus your skills are:

- *Determine the optimum illumination functions for phase quantized antenna arrays.*
- *Calculate the allowable tolerances in a signal processing channel to achieve desired MTI cancellation ratios.*
- *Analyze the performance of matched filter radars in the presence of a dispersive medium such as the ionosphere.*
- *Determine optimum system configurations from a cost-effectiveness and reliability viewpoint.*

If you are systems-oriented and possess a degree in engineering, physics, or mathematics plus previous experience in antenna analysis, statistical communication theory, electromagnetic propagation and operations analysis, you are invited to inquire about a position at Sylvania.

**Please write to J. B. Fenno, Dept. 18-G**

Waltham Laboratories
SYLVANIA ELECTRONIC SYSTEMS
*a division of*
SYLVANIA
Subsidiary of
GENERAL TELEPHONE & ELECTRONICS
100 First Avenue
Waltham 54, Massachusetts

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(Continued on page 206A)

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We offer you an opportunity to do non-routine research and use your initiative and creative ability.

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# Will tomorrow be a challenge ...or a bore?

If you feel that your present job is not fully tapping your potential, here are 4 new career opportunities for Electronics Engineers that have every bit of the challenge you may be looking for . . .

1 *Site Systems Reliability Engineer:* This position calls for a seasoned engineer capable of integrating and directing on-site reliability assurance activities necessary to secure customer acceptance of the detection system. Unusual combination of technical ability, relations and communications (written and spoken) is required. Desirable experience includes approximately ten years in design and field installation of transmitters on electronic systems with ability in both electronic and mechanical fields. Ability to motivate technicians for optimum performance is necessary. Salary structure is equal to the challenge.

2 *Radar Equipment Systems Specialist:* This position calls for a creative engineer capable of conceiving and directing the design of long-range radar systems. Desirable experience includes around ten years in at least one of the following: radar systems design, antenna systems, R.F. components, radar receiver systems or radar data processing systems. Salary structure is equal to the challenge.

3 *Advanced Systems Engineer:* This position calls for a creative engineer capable of defining future defense and space detection problems as well as the ability to conceive and establish the feasibility of optimum systems solutions to these problems—making use of the most advanced techniques and understanding. He must recognize the need for and coordinate the development of new techniques and the exploration of new phenomena in the area of detection systems. Background desired: Bachelor degree plus a combination of advanced training and several years experience in both the theoretical and practical aspects of detection systems engineering. A desire to work in the conceptual phase of system design with the analytical ability required to evaluate and demonstrate the effectiveness of proposed systems.

4 *Advanced Radar Systems Analysis and Development Engineer:* Engineers are needed who are able to visualize and define future defense and space problems—conceive advanced radar systems to solve them. An advanced degree and/or strong background in system analysis and design is essential. Assignments open include: analyze and define requirements for advance detection systems and determine broader parameters for such systems, establish their feasibility; analyze long range missile detection systems and specify optimum configuration on the basis of utility, performance, cost and delivery.

228-9

All of these openings are on General Electric missile and satellite detection projects and will be filled with engineers having the capability and desire to make creative contributions.

*Write in confidence to T. M. George, Supervisor—Personnel Administration*

**Missile Detection Systems Section**

**HEAVY MILITARY ELECTRONICS DEPARTMENT**

**GENERAL ELECTRIC**

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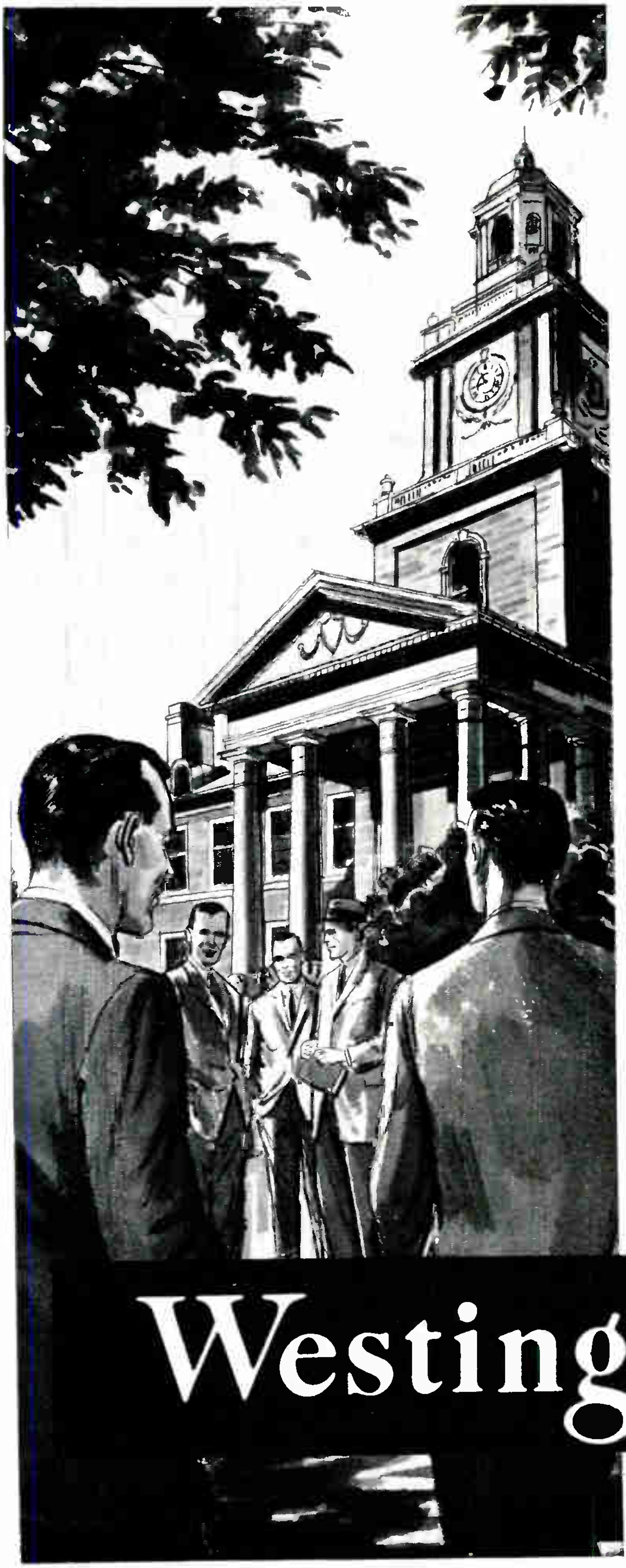

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Current Career Openings for Electrical Engineers, Mechanical Engineers and Physicists include:

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Hoover, J. C., St. Petersburg, Fla.
Hornecker, C. W., Rosemead, Calif.
Horst, R. L., St. Paul, Minn.
Horwitz, L. P., Briarcliff Manor, N. Y.
Huard, G. P., Baltimore, Md.
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Hundley, J. C., Jr., Owego, N. Y.
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Ilias, D., Paris, France
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Johnson, R. E., Middletown, Ohio
Jordan, A. K., Bala-Cynwyd, Pa.
Joyce, F. J., Los Angeles, Calif.
Junker, S. L., Murray Hill, N. J.
Kaempf, U., Mountain View, Calif.

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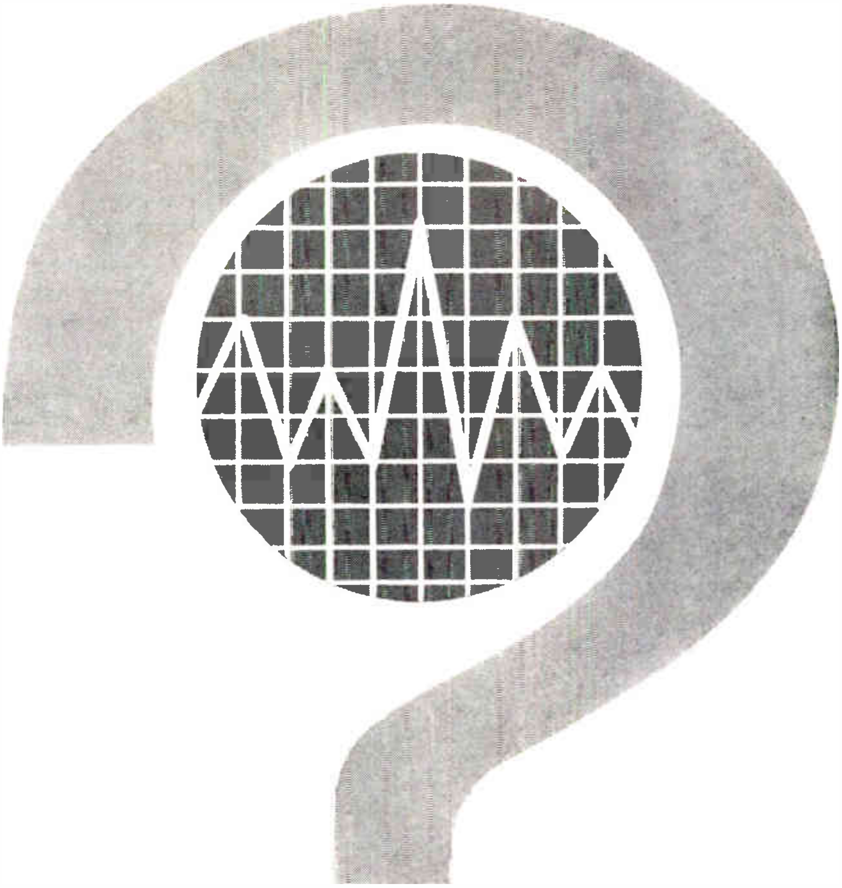

# WHAT ATTRACTS TOP ENGINEERS TO STROMBERG-CARLSON

In the opinion of our technical people, Stromberg-Carlson's philosophy of fine engineering has had a lot to do with the record growth of its engineering and scientific manpower in the last 5 years — an increase of 583%.

And corollary to this, the company's established reputation for quality engineering, design, production ("there is nothing finer than a Stromberg-Carlson") is a decisive factor in the award of major contract responsibilities in such diversified and advanced areas as:

- **nuclear instrumentation for Enrico Fermi Atomic Power Plant**
- **new applications of solid state technology, including the Euclid Modular concept in data handling systems**
- **sonar detection systems and other ASW projects**
- **a large scale, electronic passive reconnaissance system (for which Stromberg-Carlson is both Prime Contractor and Systems Manager)**
- **a revolutionary development in telecommunications for military field service (its all-transistorized electronic switching system operates without moving parts)**

If you take pride in fine engineering, and have professional capacities in any of the areas listed, why not look into the opportunities here. Please address resumes, including salary requirements, to Robert L. Ford.

Positions are available for design and development engineers at intermediate to senior levels to work in fields involving navigation control systems, electronic countermeasures, anti-submarine warfare systems, communication systems and telecommunications. The following type of experience is required:

**CIRCUIT ENGINEERING.** Logic circuits, control circuits, switching, storage, detector, display.

**TRANSMISSION ENGINEERING.** Electro-magnetic propagation, antennas, wire propagation, wave guides.

**COMMUNICATIONS ENGINEERING.** Voice studies, data studies, coding and modulation, security and reliability.

**TEST ENGINEERING.** Factory electronic test, field service and automatic test equipment design.

**TECHNICAL PUBLICATIONS.** Instruction book, proposal, military and commercial handbook writers with electronic backgrounds.

**PHYSICISTS.** Backgrounds in solid state, electron physics, and acoustics with heavy emphasis on mathematics.

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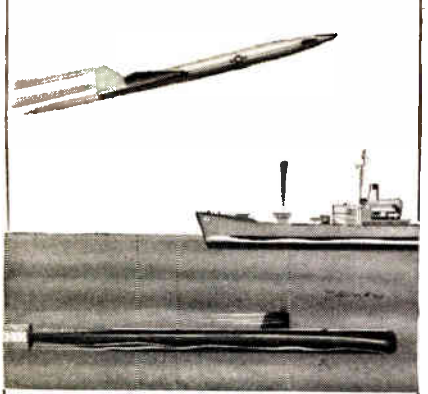

## Membership

(*Continued from page 206A*)

Kahanic, F. P., Arlington Heights, Ill.
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Kaminski, A., Glen Head, N. Y.
Kang, K. J., Lexington, Mass.
Kantor, P. M., Massapequa, N. Y.
Kaye, S., El Monte, Calif.
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Kent, R. L., Winchester, Mass.
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King, C. M., Needham, Mass.
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King, L. S., Bradford, Pa.
King, R. C., Jackson, Mich.
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Lonnquist, C. W., Brooklyn, N. Y.
Luscombe, J. P., West Hyattsville, Md.

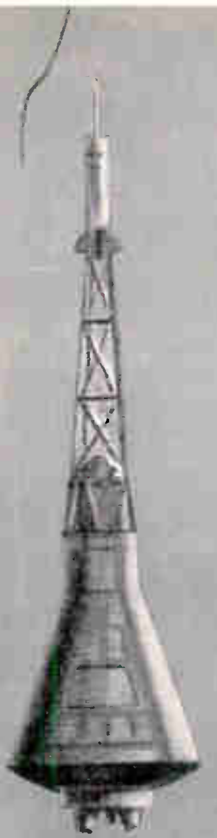
(*Continued on page 210A*)

# "ANTICIPATION ENGINEERING"

"Anticipation Engineering" is not a new science at McDonnell Aircraft. It's a built-in concept that has created a long lineage of aviation "firsts" during the company's dynamic 20-year history.

It was this anticipation that led to initial work on the first U. S. manned Space Capsule a full year before the competition was announced. Designed to carry a human astronaut beyond the atmosphere into orbital space flight, the Capsule is an integral part of N.A.S.A.'s Project Mercury.

All facets of McDonnell engineering and research are projected years into the future. Exploration of the scientific uses of space vehicles and satellites is just one of many such areas of study.



McDONNELL AIRCRAFT

## ELECTRONIC ENGINEERS

**SYSTEMS:**

Openings available for Department Managers, Group Leaders and Senior Electronic Engineers with a minimum of five years experience.

- Flight Control Systems
- Communications Systems
- Navigational Systems
- Infra-red Systems
- Guidance Systems
- Radar Systems

Senior Systems Engineers are needed for:

**ADVANCED PROJECTS DEPARTMENT**

Creative engineers are needed with experience and interest in the areas of:

- Establishment of Overall Approach
- Definition of System Requirements
- Definition of Optimum Equipment
- Overall System Integration

**CIRCUIT AND PRODUCT DESIGN:**

Electronic Engineers are needed for assignments in the design and development of:

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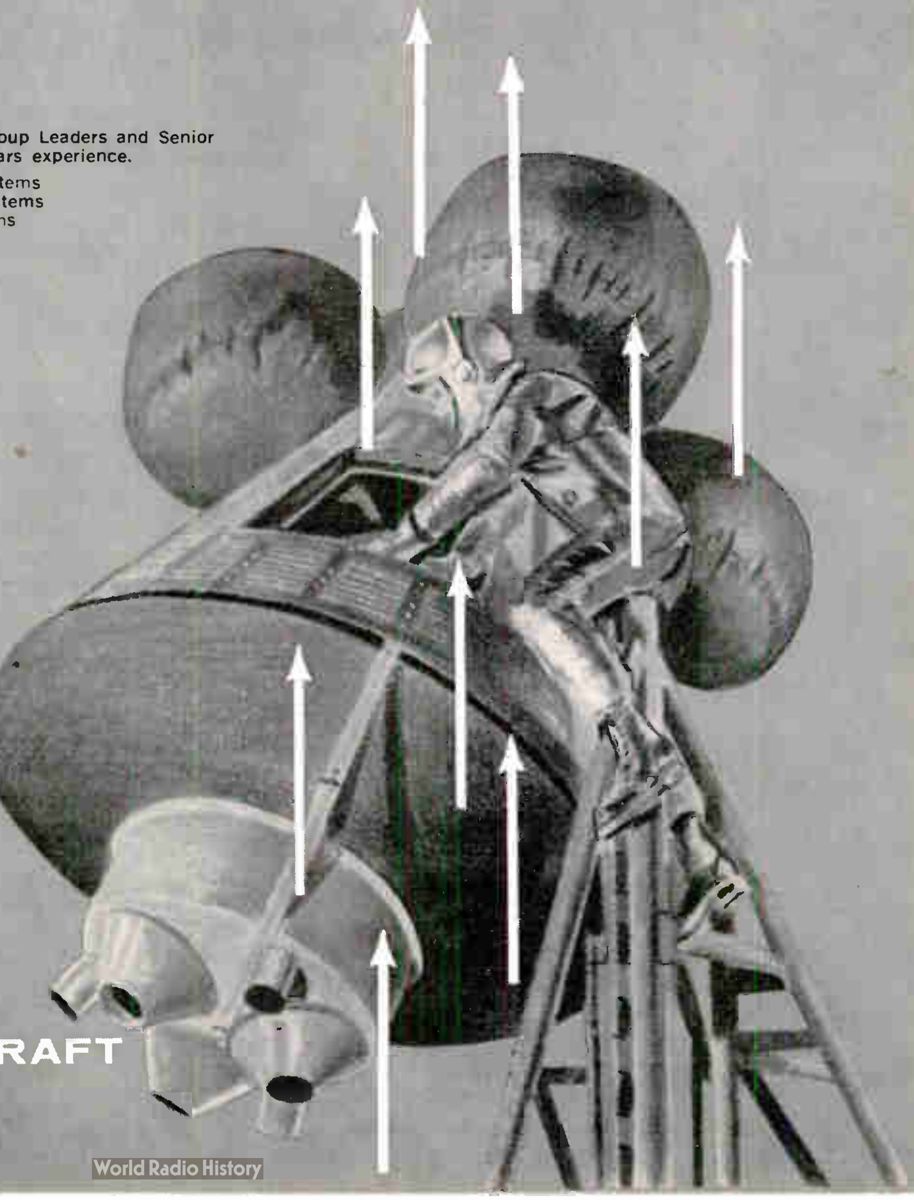
- Airborne Digital Computers
- Airborne Radar
- Controls Instrumentation
- Electronic Producibility
- Antennas
- Beacons
- Auto-pilots
- Analog Computers
- Checkout Equipment

**CONTACT:**

**RAYMOND KALETTA**

Supervisor Engineering Employment



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Masich, A. M., Jr., Winston-Salem, N. C.
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Rich, S. F., Hawthorne, Calif.
Richardson, J. D., Johnson City, N. Y.
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Ring, R. B. Utica, N. Y.
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Shelor, G. M., Winston-Salem, N. C.
Shiff, M. B., Auburn, Ala.
Silver, J., Los Altos, Calif.
Simms, R. L., Jr., Hanover, N. J.
Skaar, I. G., St. Paul, Minn.
Slack, E. G., Asbury Park, N. J.
Sliwa, R. A., Nutley, N. J.
Smaller, P., Portola Valley, Calif.

*(Continued on page 212A)*

## and this is the way the range is run:

# OPERATION

On the Atlantic Missile Range, operation is precise execution. Here thousands of engineers and scientists, scores of corporations, and dozens of government and military agencies work together, in concert, to achieve significant advances in rocketry and astronautical exploration.

As prime contractor to the Air Force for operation of the Range, Pan American has for the last six years provided range planning, supply, maintenance, data collection and ground support engineering services – from test conception to critique – for this team and all its projects.

Throughout this period, the key to our strong capability has been the operational talent of the creative engineers and scientists comprising our technical management staff. At present, new technical investigations and responsibilities create unique opportunities for similarly talented individuals, particularly those experienced in electronics, quality control and facilities engineering.

If you are one such man, we invite you to investigate these openings by addressing Mr. J. B. Appledorn, *Director of Technical Employment*, Pan American World Airways, Inc., Patrick Air Force Base, Florida, Dept. C-12.

GUIDED MISSILES RANGE DIVISION · PATRICK AIR FORCE BASE, FLORIDA

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*(Continued from page 210A)*

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Staluppi, J. P., Fairview, N. J.
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Steward, W. H., Rochester, N. Y.
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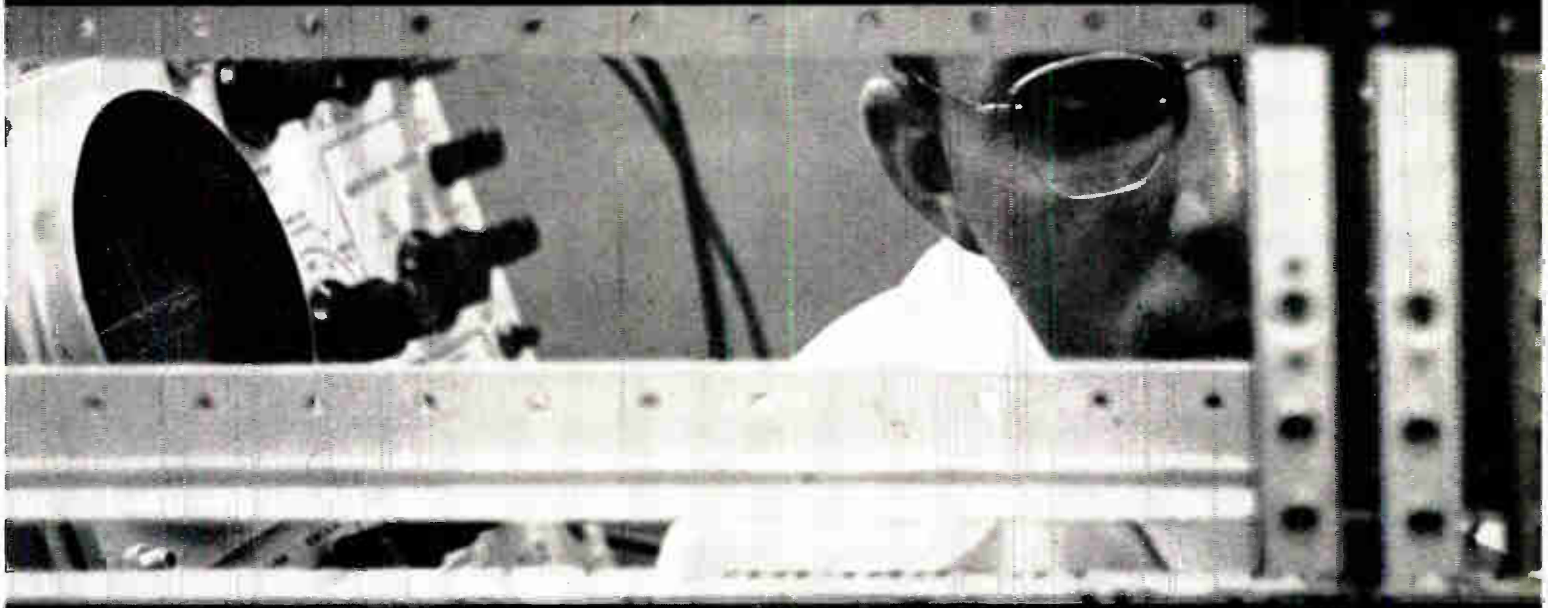
Whalen, J. E., Seattle, Wash.
White, C. D., Jr., Hyattsville, Md.

*(Continued on page 211A)*

*If your career interests are in electronics and missile sciences*



*and you possess creative foresight*

*you will logically investigate Martin Orlando*

Many engineers and scientists who make continuing appraisals of their futures are investigating new professional engineering positions with the Orlando, Florida, Division of The Martin Company. Our unusual growth record has opened many ground-floor opportunities for creative engineers who can manage and staff ambitious new programs.

Because Martin Orlando has prime responsibility for 5 major weapon systems, you are offered many channels for growth. Engineers find professional development is faster in the creative climate of Martin Orlando's new $20 million plant.

To help you make a realistic evaluation of what your part can be in the engineering success story at Martin Orlando, send for the free bulletin which gives you facts you need to reach a rewarding conclusion. Use the handy coupon.

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(Continued from page 212A)

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Declercq, V. J., Jr., Warren, Mich.
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Dolan, H. C., Asbury Park, N. J.
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Rebaudengo, S., Milano, Italy
Ronen, J., Haifa, Israel

(Continued on page 216A)

## Membership

*(Continued from page 214A)*

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Winn, R., Las Vegas, Nev.
Yaselli, P., Caracas, Venezuela

## NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

*(Continued from page 186A)*

### Power Monitor Diode

A new power monitor diode, manufactured by **Microwave Associates, Inc.,** Burlington, Mass., the MA-437 (1N2771) provides an accurate and inexpensive method of monitoring power output of RF generating devices in the 140 mc to 750 mc range. It is especially suited for communications and TV transmitters, and may be coupled directly to a microammeter for an accurate indication of transmitter RF power.

The MA-437 is a point-contact silicon diode with a cartridge construction identical to the 1N23 series and conforms to MIL-E-1 requirements.

Rectified current through the diode is monitored in a standard holder at three frequencies: 140, 375, and 750 mc, at input power levels of −2.8, 0, and 3.6 dbm. Within this power range, power monitoring error is less than 1 db over the given frequency range. At each specific test frequency, the power error is less than 0.5 db.

Using the MA-437 in a relatively simple circuit arrangement enables considerable manufacturing economies when compared to the use of bolometer bridges or other accurate monitoring standards.

Output is coupled directly to a dc microammeter, which can be calibrated directly in units of RF power. All diodes of this type number used in accordance with the specifications, in well-designed holders, obey a law of detection which is reproducible for any MA-437 (1N2771) diode selected at random from production samplings.

***RESEARCH SCIENTISTS and ENGINEERS with MS, PhD or ScD***

# The Academic Approach to Research

### *...can it be transplanted to an industrial laboratory?*

YES...in its environment of free inquiry and in scholarly consideration of the work of qualified colleagues.

This attainment is the experience of members of the Scientific Research Staff at Republic Aviation. Here, the initiation of original research is encouraged and generous support is provided to demonstrate the validity of theoretical concepts.

A preference exists for theoretical and experimental studies related to the many and varied disciplines of aeronautics and astronautics. These cover a wide spectrum of scientific research in its most active and interesting aspects.

At the same time, more emphasis is placed upon bringing new theories into the realm of feasible engineering than would normally be found at an academic institution.

**THE PRACTICAL RESULTS OF THIS POLICY**

The fruitfulness of the research environment at Republic is evidenced by the advancements and developments continually resulting. One well-known example is the current research and development of the Plasma Pinch Engine (for interplanetary travel) conceived by members of the Scientific Research Staff. Other wide-ranging research programs concern such subjects as the theory of lifting fans, new sophisticated methods of structural analysis, advanced electronic systems and techniques, space mechanics and nuclear physics, among others.

**SCIENTISTS AND ENGINEERS ARE INVITED TO JOIN OUR STAFF AS NEW RESEARCH CENTER NEARS COMPLETION**

Early in 1960, a new Research Center, including 7 modern laboratories, will be completed to support Republic's expanding effort in research and advanced development. Existing areas of investigation are being enhanced and new ones will be initiated.

If your interests coincide with the work of such a group and you feel you can contribute to progress in any of the physical and engineering sciences related to aeronautics and astronautics — Republic would like to talk with you. Salaries are high, commensurate with talent and expert knowledge.

**IMMEDIATE OPPORTUNITIES EXIST FOR SCIENTISTS WITH APPROPRIATE RESEARCH EXPERIENCE AND ADVANCED DEGREES IN:**

- Navigation and Guidance Systems
- Communications Systems
- Radiation and Propagation (RF, IR, UV)
- Solid State and Thermionic Devices
- Information Theory
- Radio Astronomy

*Write in confidence directly to:*
Dr. Theodore Theodorsen
Director of Scientific Research

**REPUBLIC AVIATION**
Farmingdale, Long Island, New York

## Advertising Index



## DISPLAY ADVERTISERS



*(Continued on page 220A)*

# PROFESSIONAL CONSULTING SERVICES

## Advertising rates

Professional Consulting Service Cards.

| | |
|---|---|
| 1 insertion | $ 15.00 |
| 12 insertions | $120.00 |

50% discount to IRE members on 3 or more consecutive insertions.

In IRE DIRECTORY $15.00 flat rate.
1 inch only, no cuts or display type.

New rate effective January 1960
1 insertion $25.00
12 insertions $180.00
50% discount to IRE members on 3 or more consecutive insertions.
In IRE DIRECTORY $25.00 flat rate

Advertising restricted to professional engineering and consulting services by individuals only. No product may be offered for sale, and firm names may not be mentioned in cards.

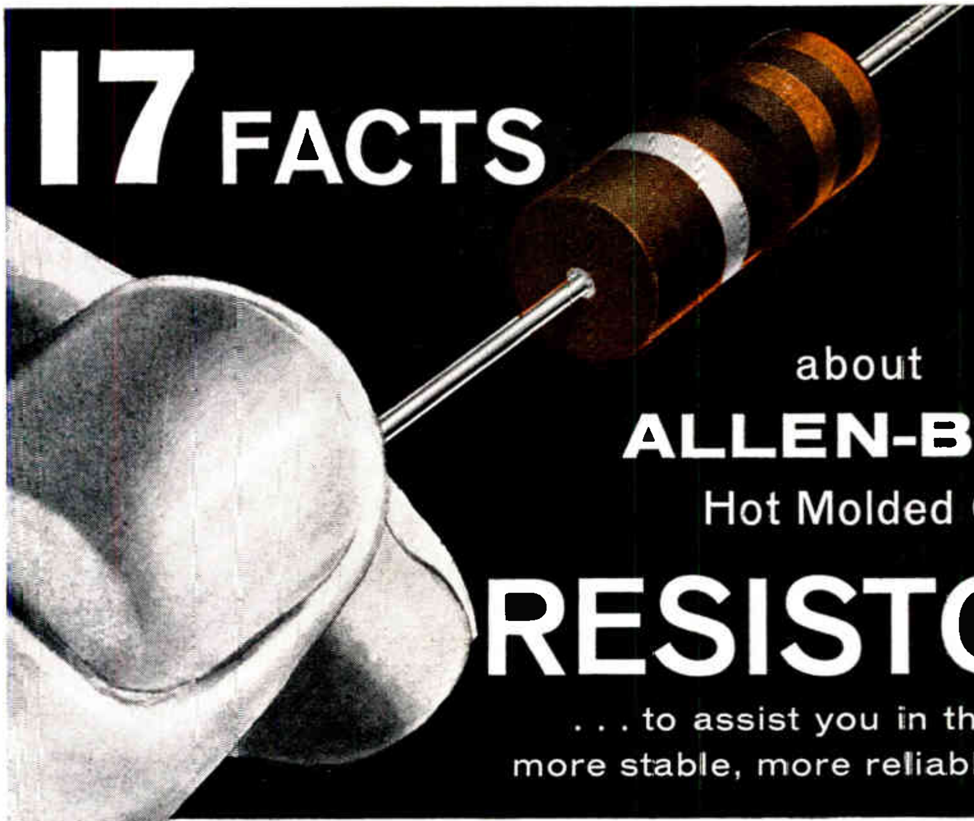


## Advertising Index

(Continued from page 218A)



(Continued on page 222A)



# 17 FACTS

about

## ALLEN-BRADLEY

Hot Molded Composition

# RESISTORS

. . . to assist you in the design of more stable, more reliable circuits

Circuit reliability is determined by the quality of the components and the understanding with which they are applied. A-B hot molded resistors are universally recognized for their quality and reliability. Here are 17 facts that will assist you with your design and development work.

**1** Resistance changes due to humidity are temporary, but Allen-Bradley resistors can be returned to their original value by proper conditioning or "loading."

**2** Resistance changes due to increase in moisture content are always positive.

**3** Resistance change due to humidity varies with the resistance value and is less in the lower values.

**4** Resistance change which has occurred due to humidity may be returned to the original value by conditioning the resistor at 100°C for 48 hours.

**5** Resistors operating at 1/10 rated wattage load are hardly—if at all—affected by humidity.

**6** Hermetically sealed resistors do not change because of humidity.

**7** Resistance change due to "load life" is permanent and ultimately negative.

**8** Resistance change due to "load life" can be minimized—on the order of 1% to 2% in many thousands of hours of service by derating the resistor approximately 50%.

**9** This same result can be attained by limiting the maximum operating surface temperature of the resistor under load to 100°C.

**10** Resistance change due to soldering is positive; but if the resistor is dry, it will return to its original value in a matter of hours.

**11** The temperature characteristic of the Allen-Bradley resistor is positive above and below room temperatures between +10°C and +80°C ambient.

**12** The temperature characteristic of the Allen-Bradley resistor is negligible from +10°C to +80°C ambient.

**13** The voltage characteristic of the Allen-Bradley resistor is negative. It is less at elevated temperatures than at room ambient (+10°C to +80°C).

**14** The voltage characteristic is less in low-value resistors than in high-value units—it is linear.

**15** The voltage characteristic and the temperature characteristic tend to cancel one another in an Allen-Bradley resistor under average operating conditions where both voltage and temperature are present.

**16** The "heat sink" to which a resistor is connected affects its rating. Resistors operated in parallel should be derated unless an adequate "heat sink" is provided.

**17** The quality and reliability of Allen-Bradley resistors are exactly the same regardless of the "tolerances" for which the resistor is listed.

Allen-Bradley Co., 114 W. Greenfield Ave., Milwaukee 4, Wis. • In Canada: Allen-Bradley Canada Ltd., Galt, Ont.

**ALLEN-BRADLEY**

*Quality*
Electronic Components

## Advertising Index

(Continued from page 220A)



(Continued on page 221A)

*The*

# *Avco Everett Research Laboratory*

*announces*

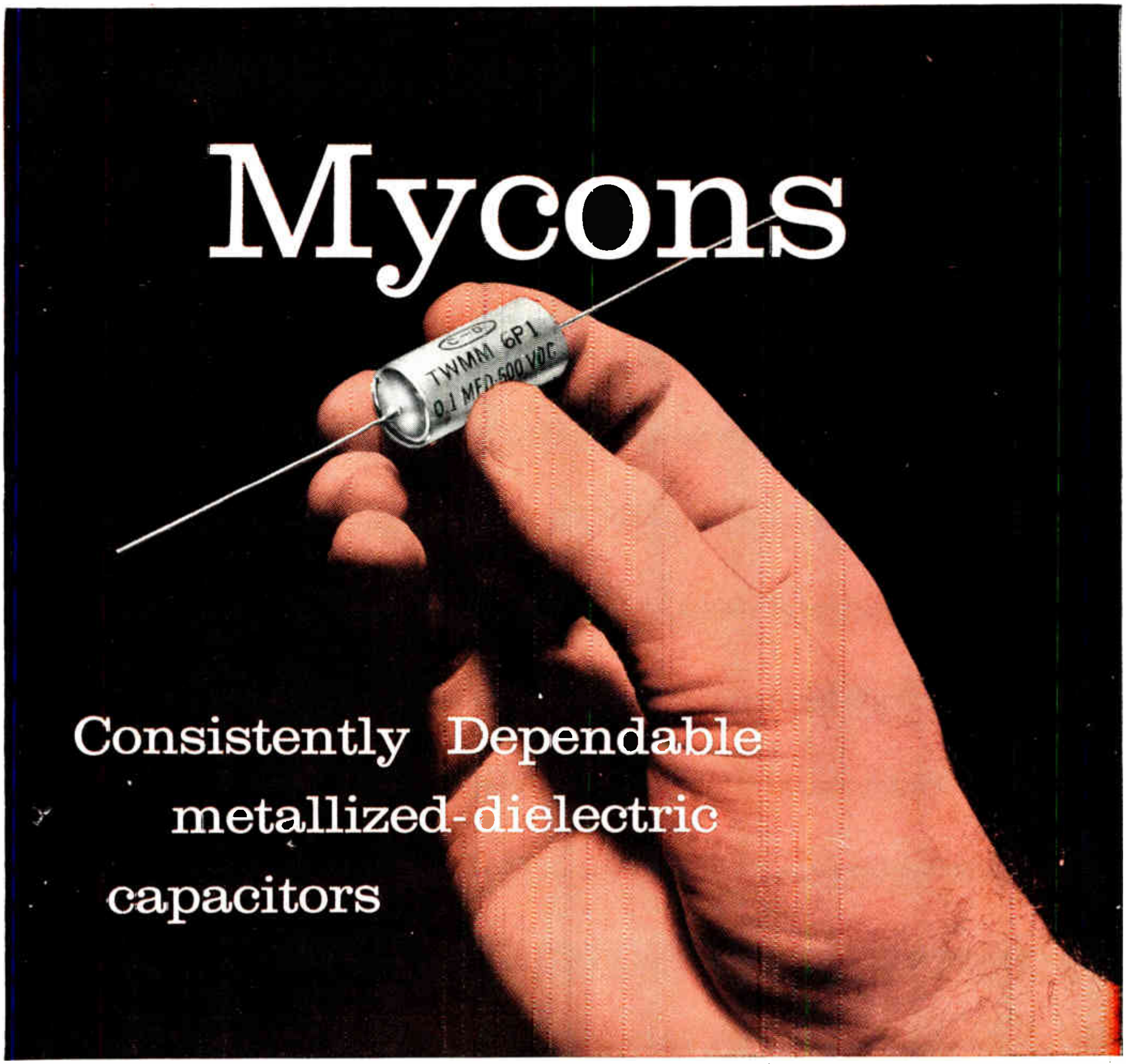
it is expanding its activities
to explore and bring to engineering
fruition electric propulsion for space
vehicles, generation of electricity
for both ground station and space
application through MHD, and satellite
and space vehicle design.

IF THIS OPPORTUNITY
INTERESTS YOU, WRITE:

DR. ARTHUR KANTROWITZ, DIRECTOR
AVCO EVERETT RESEARCH LABORATORY
2385 REVERE BEACH PARKWAY
EVERETT, MASSACHUSETTS

## Advertising Index

(Continued from page 222A)




**New Metallized Mylar* (Type TWMM) and Mylar-Paper (Type MTWK) Capacitors by Cornell-Dubilier.**

Whether you specify miniature metallized capacitors for military or industrial electronic equipment—for critical power-supply filter circuits or bypass applications—Cornell-Dubilier's new MYCON metallized capacitors assure top performance and dependability. Backed by over 47 years of capacitor engineering and manufacturing leadership, MYCONs combine better high-temperature operation and better insulation resistance with low dissipation factor and fault count. Available in a wide choice of mounting styles, MYCONs meet the requirements of applicable military specifications. For complete specifications, write for Engineering Bulletins 190 and 185 to Cornell-Dubilier Electric Corporation, South Plainfield, New Jersey.

*Du Pont Reg. T.M.

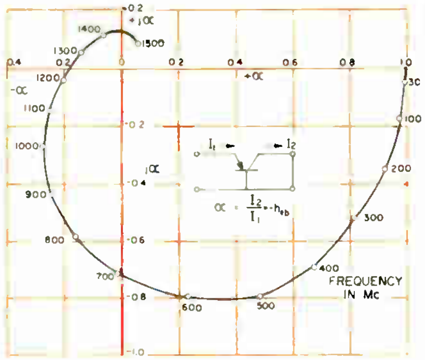
**MYCONS**

TYPE TWMM—
Metallized Mylar*
TYPE MTWK—
Metallized Mylar and Paper Film

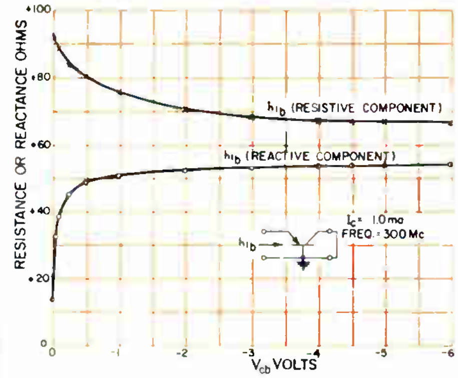
*Specifications and Features*

- Ratings from .01 mfd. to 12.0 mfd. Voltages of 200, 400, or 600 volts DC Working.
- Wide useful temperature characteristics within range of —55 C to +125°C.
- Hermetically sealed in miniature tubular metal cases with metal-to-metal end-seals.
- Wire lead or solder lug terminals.
- Various bracket-mounting or Threaded-neck mounting styles.

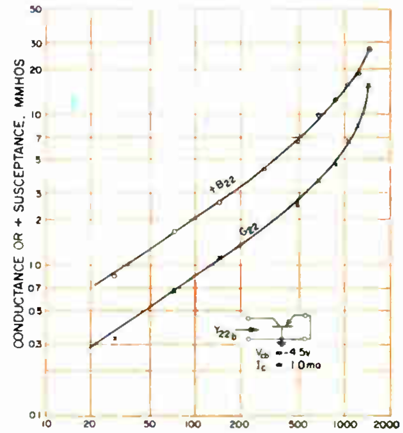
*Consistently Dependable*
**CORNELL-DUBILIER**
**CAPACITORS**



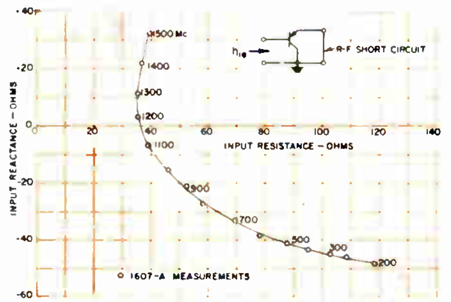

Plot of $\alpha$, or $-h_{fb}$, versus frequency.




Variation of transistor parameters as a function of collector voltage.




Plot of short-circuit output admittance as a function of frequency




Plot of input reactance versus input resistance

## ...Some of the

## made with this instrument

### Type 1607-A Transfer Function and Immittance Bridge

**Frequency Range:** 25 to 1500 Mc.
**Biasing Provisions:** Built-in for use with external d-c sources.
Maximum current, 250 ma; maximum voltage, 400 volts.

**Price: $1665**

| FUNCTION | RANGE | ACCURACY |
|---|---|---|
| Voltage and current ratios (R) | 0-30 | $2.5\left(1+\sqrt{R}\right)\% + 0.025$ |
| Transimpedance ($Z_{21}$) | 0-1500 ohms | $2.5\left(1+\sqrt{\frac{Z_{21}}{50}}\right)\% + 1.25$ ohms |
| Transadmittance ($Y_{21}$) | 0-600 mmhos | $2.5\left(1+\sqrt{\frac{Y_{21}}{20}}\right)\% + 0.5$ mmho |
| Impedance ($Z_{11}$) | 0-1000 ohms | $2.0\left(1+\sqrt{\frac{Z_{11}}{50}}\right)\% + 1.0$ ohm |
| Admittance ($Y_{11}$) | 0-400 mmhos | $2.0\left(1+\sqrt{\frac{Y_{11}}{20}}\right)\% + 0.4$ mmho |

★ Measures $h_{fb}$, $h_{fe}$, $h_{rb}$, $h_{ib}$, $h_{ie}$, $h_{ob}$, $h_{oe}$ of transistors directly, *plus* any desired short-circuit or open-circuit input, output, or transfer function of either active or passive networks.

★ Operates with very low r-f levels on unknown — an essential for accurate measurements of transistors and nonlinear devices.

★ The bridge is completely passive — stability of calibration dependent only on permanent physical dimensions.

*write for complete information*

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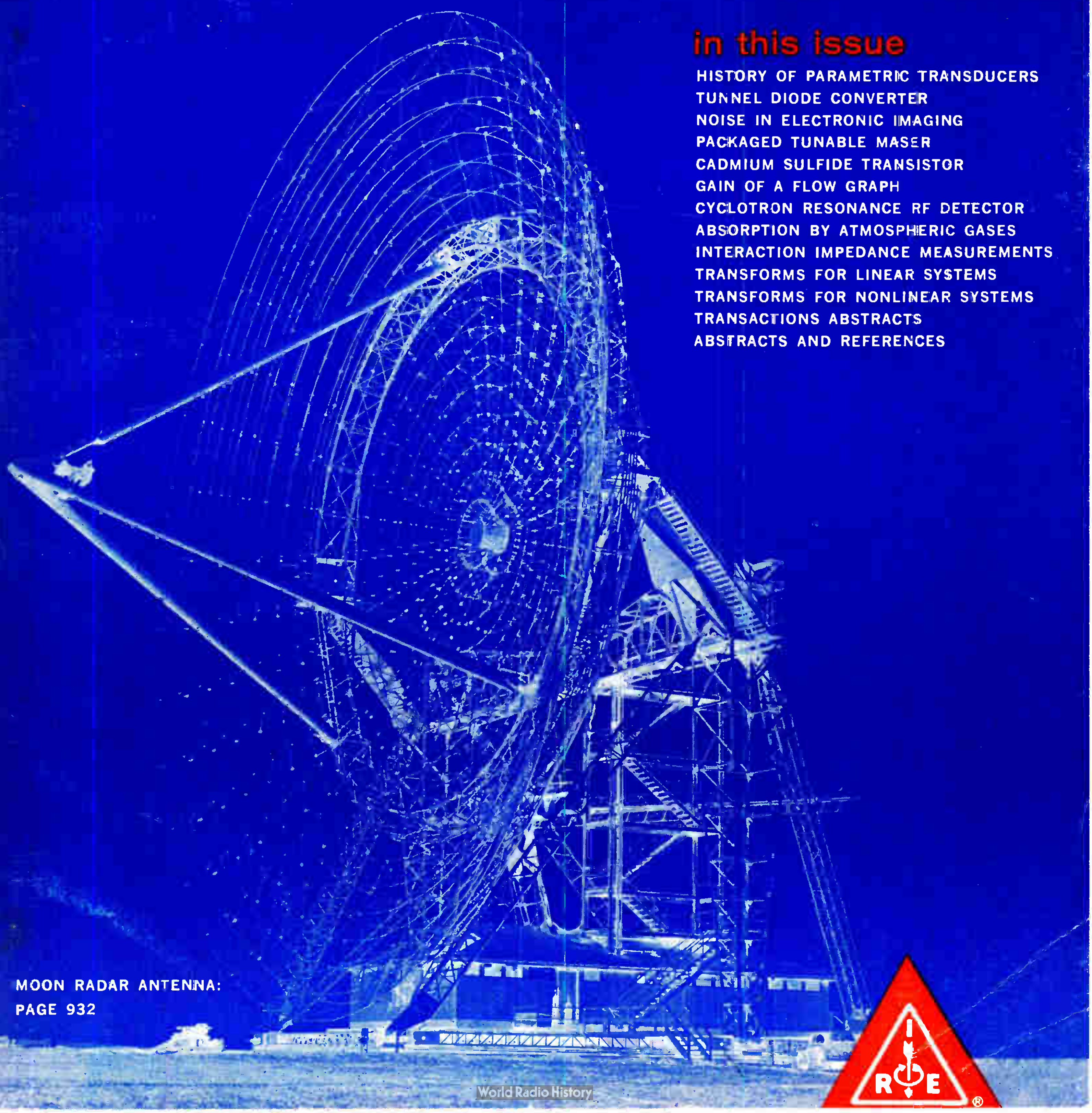
may 1960

the institute of radio engineers

# Proceedings of the IRE

## in this issue





MOON RADAR ANTENNA: PAGE 932

# For Your Special Applications

The bulk of UTC production is on special units designed to specific customers' needs. Illustrated below are some typical units and some unusual units as manufactured for special applications. We would be pleased to advise and quote to your special requirements.

## FILTERS

All types for frequencies from .1 cycle to 400 MC.

400 ~ telemetering, 3 db at ± 7.5%, 40 db at 230 and 700 ~, 5/8 x 1 1/4 x 2"

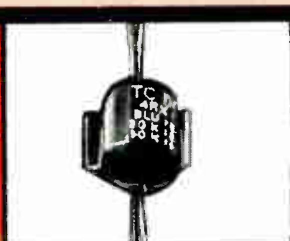
15 ~ BP filter, 20 db at 30 ~, 45 db at 100 ~, phase angle at CF less than 3° from —40 to + 100° C.

LP filter within 1 db to 49 KC, stable to .1 db from 0 to 85° C., 45 db at 55 KC.

LP filter less than .1 db 0 to 2.5 KC, 50 db beyond 3 KC.

## HIGH Q COILS

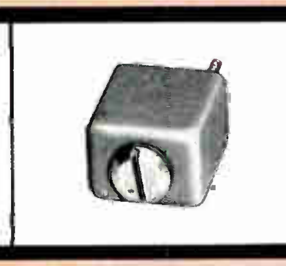
Toroid, laminated, and cup structures from .1 cycle to 400 MC.



Tuned DO-T servo amplifier transformer, 400 ~ .5% distortion.

Toroid for printed circuit, Q of 90 at 15 KC.

Dual toroid, Q of 75 at 10 KC, and Q of 120 at 5 KC.



HVC tapped variable inductor for 3 KC oscillator.

## SPECIALTIES

Saturable reactors, reference transformers, magnetic amplifiers, combined units.

RF saturable inductor for sweep from 17 MC to 21 MC.

Voltage reference transformer .05% accuracy.

Multi-control magnetic amplifier for airborne servo.

Input, output, two tuned interstages, peaking network, and BP filter, all in one case.

## PULSE TRANSFORMERS

From miniature blocking oscillator to 10 megawatt.

Wound core unit .01 microsecond rise time.

Pulse current tansformer 100 Amp.

Pulse output to magnatron, bifilar filament.

Precise wave shape pulse output, 2500 V. 3 Amps.

## POWER COMPONENTS

Standard and high temperature . . . hermetic, molded, and encapsulated.

Multi-winding 140 VA, 6 KC power transformer 1 1/4 x 1 1/4 x 1"

200° C. power transformer, 400 ~, 150 VA.

400 ~ scope transformer, 20 KV output.

60 ~ current limiting filament transformer, Sec. 25 Mmfd., 30 KV hipot.

# UNITED TRANSFORMER CORPORATION

150 Varick Street, New York 13, N. Y. • EXPORT DIVISION: 13 E. 40th St., New York 16, N. Y., CABLES: "ARLAB"

PACIFIC MFG. DIVISION, 4008 W. Jefferson Blvd., Los Angeles, Cal.

VOLUME 48, NUMBER 5

**May, 1960**

*published monthly by The Institute of Radio Engineers, Inc.*

# Proceedings of the IRE®

*contents*



**COVER**

The advent of more powerful and sensitive radars has led to novel proposals for studying the surface of the moon by radar, as reported in the Correspondence section of this issue. Shown on the cover is a 142-foot steerable parabolic antenna, the second largest in the world, located in Fraserburgh, Scotland. Built and operated by Stanford Research Institute under contract with the Rome Air Development Center, this antenna was used in the moon radar experiments reported on page 932.

MAY

*published monthly by The Institute of Radio Engineers, Inc.*

# Proceedings of the IRE®

*continued*



MAY



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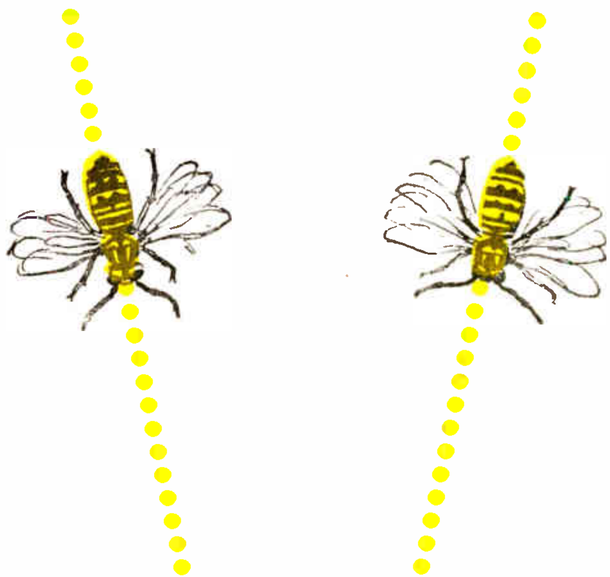
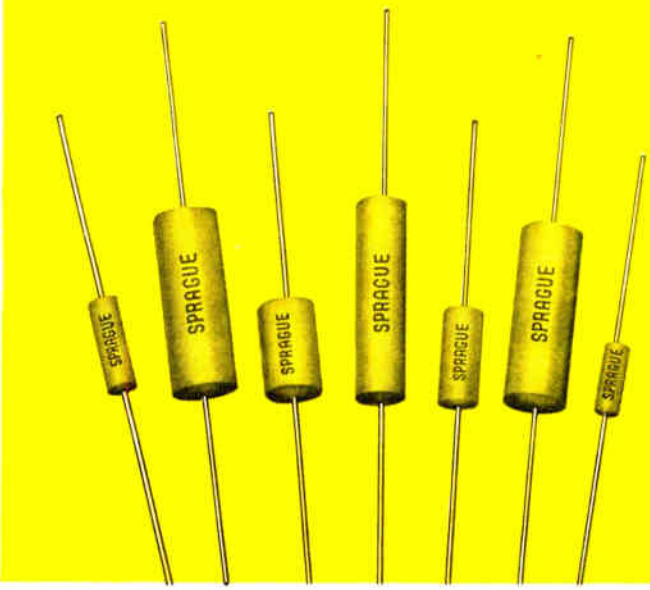
Thirty days advance notice is required for change of address. Price per copy: members of the Institute of Radio Engineers, one additional copy $1.25; non-members $2.25. Yearly subscription price: to members $9.00, one additional subscription $13.50; to non-members in United States, Canada, and U. S. Possessions $18.00; to non-members in foreign countries $19.00. Second-class postage paid at Menasha, Wisconsin under the act of March 3, 1879. Acceptance for mailing at a special rate of postage is provided for in the act of February 28, 1925, embodied in Paragraph 4, Section 412, P. L. and R., authorized October 26, 1927. Printed in U.S.A. 

## MOST RELIABLE "WRAP-AND-ENDFILL" FILM CAPACITORS—



*Reliability in a "wrap-and-endfill" at last!* . . . Sprague Yellow-Jacket Filmite "E" Capacitors. The design of these small, lightweight film capacitors is based on the most extensive life test data for polyester film dielectrics available at the present time. These capacitors will withstand a 250 hour accelerated life test of 150% of the 85 C rated voltage impressed or the equivalent derated 125 C voltage. *Not more than 1 failure is permitted in 25 samples tested.*

The "extended-foil" capacitor sections are fully protected against moisture by an outer wrap of yellow polyester-film tape. Only ultra-thin, specially selected foil and polyester film are used. The end seals are of a plastic resin which has been formulated to bond with the film wrap and the tinned leads so as to provide a secure seal.

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# YELLOW-JACKET® CAPACITORS

## for military and industrial electronics

Because of their outstanding resistance to humidity, vibration, and shock, Type 158P Yellow-Jacket Capacitors are ideal for many military, computer, industrial control, and similar applications. They are particularly well-suited for potting or encapsulating in electronic sub-assemblies, filters, etc.

*For complete engineering data on Military-Grade Yellow-Jacket Film* Capacitors (Type 158P) write for Engineering Bulletin 2301. Data on Sprague's Commercial and Entertainment Grade Yellow-Jacket Capacitors (Types 148P and 149P) is given in Bulletin 2063A. Both bulletins are available from Technical Literature Section, Sprague Electric Company, 235 Marshall Street, North Adams, Massachusetts.

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**In this article, Robert L. Sleven of our Department of Applied Electronics discusses a branch type *directional* filter and some surprising results of a study program.**

# Directional Filters

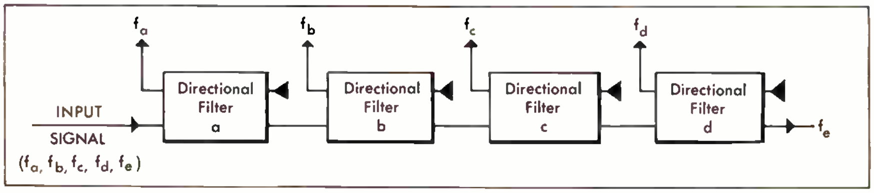


Figure 1. Directional Filter Multiplexer

The problem of "peeling off" the frequency components of an input signal as shown in Figure 1 is inherent in many countermeasures systems. While other types of filters have been used in the past, a rather unconventional filter appeared to offer several advantages. This filter (Figure 2) is a branch-type *directional* filter and its performance has recently been studied at AIL. The study program revealed the surprising result that many of the advantages of directional filters can be obtained if *one* and *only one* resonator is included in each branch.

The directional filter is a four-port network whose ideal responses are:

Port 1—Unity SWR
Port 1 to Port 2—
Band-Pass Response
Port 1 to Port 3—
Infinite Isolation
Port 1 to Port 4—
Band-Reject Response

A network with the above performance is well-suited for multiplexing systems as can be seen from the block diagram shown in Figure 1. Signals at the resonant frequency of each directional filter will appear at the correct ports without any branching loss and the effect of one directional filter upon the other is negligible. This is not true with conventional branching filters.

The symmetry of the branch line directional filter is utilized to simplify the analysis of the four-port network by reducing it to an equivalent two-port. The overall network can be described as the product of three ABCD matrices. One of these matrices is for the filter network in each branch of the directional filter and the other two matrices are for lengths of transmission line corresponding to the spacing of the branches along the main transmission lines. In order to obtain theoretically the response stated above for each of the directional filter ports, certain conditions must be imposed on each of the matrices. High directivity (isolation of Port 3 from Port 1) is obtained when each branch of the directional filter is identical and the spacing of the branches is $(2n + 1)\lambda/4$ on one manifold and

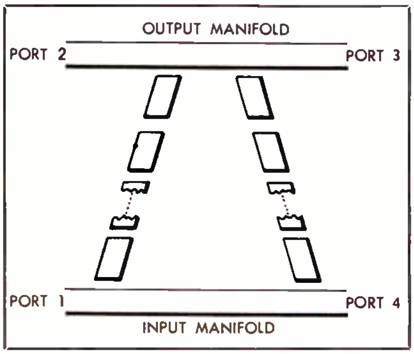


Figure 2. Branch Line Directional Filter

$(2n + 3)\lambda/4$ on the other manifold. To obtain the desired response at Ports 1, 2 and 4, conditions are imposed on the filter network which cannot be satisfied when each branch contains multiresonator filters. The filter network, in order to satisfy all conditions, must have identical driving point and transfer functions. This requirement can only be fulfilled when each branch of the directional filter contains one resonator. This result is significant because in the past it had been felt that as greater selectivity was required, more resonators would be used in each branch of the directional filter.

After having proved that ideal directional filter characteristics were not theoretically obtainable with multiresonator branches, the study continued until a suitable compromise in the response at each of the ports, was found, for the multiresonator case. The discrepancies between desired and obtainable directional filter performance differ depending upon the number of resonant elements in each branch. With an even number of dissipationless resonators in each branch, the power at resonance divides between Ports 2 and 4 and finite SWR exists at Port 1. With an odd number of resonant elements in each branch, the desired directional filter performance is obtained at resonance: that is, all power out Port 2. Except for the one resonator case, however, all directional filters with an odd number of resonators in each branch exhibit high SWR's at points in the passband.

The effect of dissipation on the directional filters performance is to mask some of the undesired characteristics and to magnify others. The passband SWR's are diminished in the presence of loss and the power out Port 4, which should be zero at resonance, becomes significant when dissipation is present.

The conclusions drawn from the directional filter study program were: (1) the ideal directional filter response listed above is theoretically obtainable when each branch consists of only one resonator and (2) when the selectivity of multiresonator filters is required, proper selection of filter decrements and coefficients of coupling will result in a directional filter response that is adequate for many purposes. The theoretical conclusions of the branch line directional filter program were verified experimentally by AIL.

*A complete bound set of our fourth series of articles is available on request. Write to Harold Hechtman at AIL for your set.*

Airborne Instruments Laboratory

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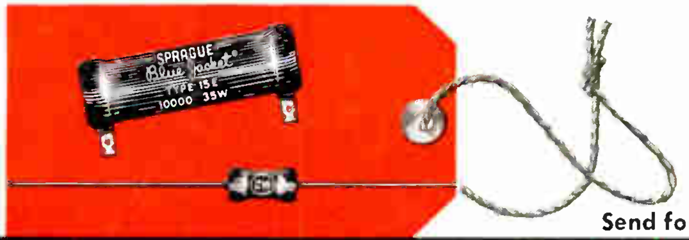


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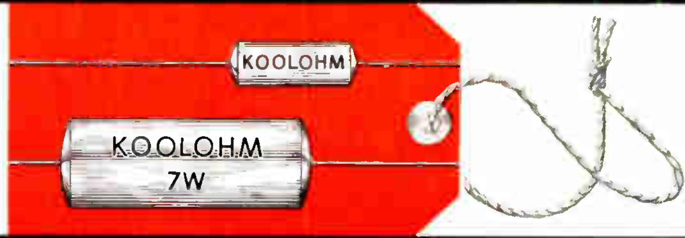


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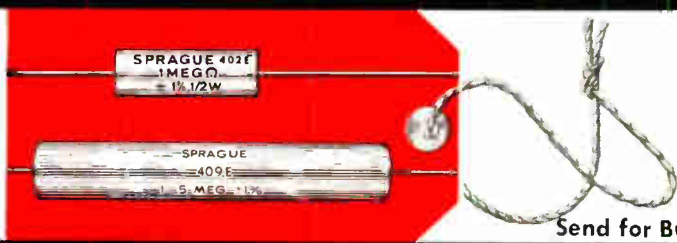


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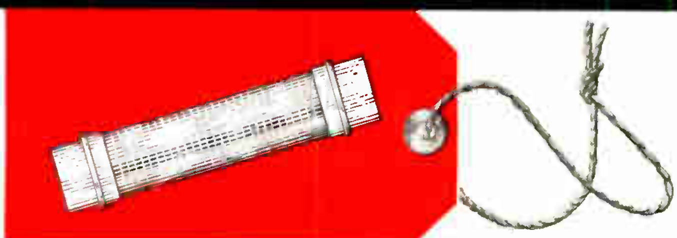

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HAROLD S. BLACK, LAMME MEDALIST


# A MAN WINS A MEDAL...AND STRENGTHENS A PHILOSOPHY

The search for the "hitherto unattainable" sometimes ends in strange places.

For years Bell Laboratories engineer Harold S. Black pondered a problem: how to rid amplifiers of the distortion which unhappily accumulated as signal-transmission paths were made longer and amplifiers were added. There had been many approaches but all had failed to provide a practical answer.

Then one day in 1927 the answer came—not in a research laboratory, but as he traveled to work on the Lackawanna Ferry. On a newspaper, Mr. Black jotted down those first exciting calculations.

Years later, his *negative feedback principle* had revolutionized the art of signal amplification. It is a principal reason why telephone and TV networks can now blanket the country, the transoceanic cable is a reality, and military radar and missile-control systems are models of precision.

For this pioneer achievement, and for numerous other contributions to communications since then (some 60 U. S. patents are already credited to him), Mr. Black received the 1957 Lamme Medal from the American Institute of Electrical Engineers. He demonstrated that the seemingly "unattainable" often *can* be achieved, and thus strengthened a philosophy that is shared by all true researchers.

He is one of many Bell Telephone Laboratories scientists and engineers who have felt the challenge of telephony and have risen to it, ranging deeply into science and technology. Numerous medals and awards have thus been won. Two of these have been Nobel Prizes, a distinction without equal in any other industrial concern.

Much remains to be done. To create the communication systems of the future, we must probe deeper still for new knowledge of Nature's laws. We must continue to develop new techniques in switching, transmission and instrumentation for every kind of information-bearing signal. As never before, communications offer an inspiring challenge to creative men.

**BELL TELEPHONE LABORATORIES**

WORLD CENTER OF COMMUNICATIONS RESEARCH AND DEVELOPMENT

## Meetings with Exhibits

● As a service both to Members and the industry, we will endeavor to record in this column each month those meetings of IRE, its sections and professional groups which include exhibits.

Δ

*May 23-25, 1960*
**1960 National Telemetering Conference,** Miramar Hotel, Santa Monica, Calif.
*Exhibits:* Mr. William Van Dyke, Douglas Aircraft Co., Inc., El Segundo, Calif.

*May 24-26, 1960*
**Seventh Regional Technical Conference & Trade Show,** Olympic Hotel, Seattle, Wash.
*Exhibits:* Mr. Rush Drake, 1806 Bush Place, Seattle 44, Wash.

*May 24-26, 1960*
**Armed Forces Communications & Electronics Association Convention and Exhibit,** Sheraton-Park Hotel, Washington, D.C.
*Exhibits:* Mr. William C. Copp, 72 West 45th St., New York 36, N.Y.

*June 20-21, 1960*
**Chicago Spring Conference on Broadcast and Television Receivers,** Graemere Hotel, Chicago, Ill.
*Exhibits:* Mr. Stanley Hopper, Zenith Radio Corp., 6001 W. Dickens Ave., Chicago 39, Ill.

*June 27-29, 1960*
**National Convention on Military Electronics,** Sheraton-Park Hotel, Washington, D.C.
*Exhibits:* Mr. L. David Whitelock, BuShips, Electronics Div., Dept. of Navy, Washington, D.C.

*August 1-3, 1960*
**Fourth Global Communications Symposium,** Hotel Statler, Washington, D.C.
*Exhibits:* Mr. Robert O. Brady, Office of the Chief Signal Officer, U. S. Army Signal Corps, Washington, D.C.

*August 23-26, 1960*
**WESCON, Western Electronic Show and Convention.** Ambassador Hotel & Memorial Sports Arena, Los Angeles, Calif.
*Exhibits:* Mr. Don Larson, WESCON, 1435 LaCienega Blvd., Los Angeles, Calif.

*September 19-21, 1960*
**National Symposium on Space Electronics & Telemetry,** Shoreham Hotel, Washington, D.C.
*Exhibits:* Mr. Leon King, Jansky and Bailey, 1339 Wisconsin Ave., N.W., Washington, D.C.

*October 3-5, 1960*
**Sixth National Communications Symposium,** Hotel Utica & Utica Municipal Auditorium, Utica, N.Y.
*Exhibits:* Mr. R. E. Bischoff, 19 Westminster Road, Utica, N.Y.

*(Continued on page 10A)*

# A Complete, Automatic Noise Figure Test Set

NEW!

**KAY**

## —*Auto-Node**—

**AUTOMATIC NOISE FIGURE TESTS AND GAIN OR LOSS MEASUREMENTS AT UHF, VHF AND MICROWAVE FREQUENCIES**


Cat. Number 790

- **Optimum Noise Figure Adjustments**
- **Precision Noise Figure Read Out**
- **Noise Figure Measurements using other type External Noise Generators**
- **Precision Measurements of Gain or Loss in components and systems at Microwave, UHF and VHF Frequencies**
- **No Errors Associated with Temperature-Limited-Diodes, Meter Readings, Transit Time**

### SPECIFICATIONS

**as an automatic noise-figure measuring set:**

**Useful Frequency Range of Noise Generator:** 2-2000 mc.

**Maximum VSWR Variation during test:** 2 parts per 1000.

**Noise Figure Accuracy Including Read Out Error:**

$\pm$ 0.1 db $\pm \dfrac{\text{Noise Figure}}{20}$ (db) (depends mainly on noise figure calibration of post amplifier).

**Nominal Output Impedance of Noise Generator:** 50 ohms (N-type connector).

**Noise Figure Range:** 0-18 db.

**Input Center Frequency:** 30, 60 or 70 megacycles (others available on special request).

**Input Impedance:** 70 ohms nominal.

**Maximum Noise Figure of Measuring System:** 3.5 db (matched) 2 db (mismatched).

**Accuracy of System** when making other type measurements including Microwave, UHF, and VHF Gain or Loss: ±0.2 db.

**Power Requirements:** 117V, 60 cps.

**Dimensions:** 9¾" × 19½" × 13"

**Weight:** 55 lbs. (approx.)

**Price:** $1,995.00, f.o.b. factory.

*Kay Auto-Node* is a complete, highly flexible, Automatic Noise Figure Test Set designed to obtain simplified, noise figure meter displays for making optimum noise figure adjustments and provide precision noise figure read-out, noise figure measurements using other type external noise generators as well as precision measurements of Gain or Loss in components and systems at microwave, UHF and VHF frequencies.

*Kay Auto-Node* Automatic Noise Figure Test Set features a small, probe size, temperature modulated resistor as a noise generator having the following additional characteristics.

- Sine wave temperature-modulation at a 10 cps rate with temperature excursions between 300° and 400° K
- Extremely small VSWR variations during modulation (less than 2 parts in 1000)
- Useful frequency range of noise generator from 2 to 2000 mc.

*KAY Auto-Node's* high-gain, low-noise post amplifier has excellent noise figure stability, better than 3.5 db (matched) and the gain is sufficient to raise the input noise to a value of 10 volts after final detection. The bandwidth is 2 megacycles and the unit is supplied with one of three center frequencies—30, 60 or 70 mc.

*Kay Auto-Node's* precision step attenuator and expanded output meter allows for measurements to within 0.2 db accuracy when making Gain or Loss measurements. Bridge detection and selective AGC, allows noise figure up to 18 db to be made with small temperature modulation in the noise source.

**OTHER KAY NOISE GENERATORS**

| Instrument & Cat. No. | Frequency Range (mc) | Noise Figure Range (db) | Output Impedance (ohms) | Price f.o.b. factory |
|---|---|---|---|---|
| *Mega-Node** 240-B | 5-220 | 0-16 at 50 ohms<br>0-23.8 at 300 ohms | unbal. 50, 75, 150, 300, etc<br>bal. 100, 150, 300, 600, etc | $365.00 |
| *Mega-Node* 403-A | 3-500 | 0-19 | unbalanced 50 | $365.00 |
| *Mega-Node* 3000 | 1-1000 | 0-20 | unbalanced 50 | $790.00 |
| *Rada-Node*® 600-A | 5-400 | 0-23.8 depending on impedance | unbalanced as specified | $1495.00 |
| | 10-1000 | 0-20 | unbal. nom. 50 | $1965.00 |
| | 1120-26 500 | 15.28 or 15.8 | waveguide | † |
| *Microwave Mega-Nodes** | 1120-26.500 | 15.28 or 15.8 | waveguide | $175.00 to $595.00 |
| *Therma-Node* | 2-1000 | ±0.1 | unbalanced 50 | $495.00 |

† Price varies with Microwave Mega-Node used as accessory.

* Ideally suited for noise figure measurement in radar communication.

*Pat. Pending

Write for New Kay Catalog

**KAY ELECTRIC COMPANY**

Dept. I-5, 14 Maple Avenue, Pine Brook, New Jersey — CApital 6-4000

## Meetings with Exhibits

(Continued from page 8A)

*October 10-12, 1960*

**National Electronics Conference,** Hotel Sherman, Chicago, Ill.

*Exhibits:* National Electronics Conference, Inc., 228 North La Salle St., Chicago 1, Ill.

*October 24-26, 1960*

**East Coast Aeronautical & Navigational Electronics Conference,** Lord Baltimore Hotel & 7th Regiment Armory, Baltimore, Md.

*Exhibits:* Mr. R. L. Pigeon, Westinghouse Electric Corp., Air Arm Div., P.O. Box 746, Baltimore, Md.

*October 26-28, 1960*

**Fifth Annual Conference on Non-Linear Magnetics and Magnetic Amplifiers,** Bellevue-Stratford Hotel, Philadelphia, Pa.

*Exhibits:* J. L. Whitlock Associates, 6044 Ninth St., North, Arlington 5, Va.

*Oct. 31-Nov. 2, 1960*

**13th Annual Conference on Electrical Techniques in Medicine & Biology,** Sheraton-Park Hotel, Washington, D.C.

*Exhibits:* Mr. Lewis Winner, 152 West 42nd St., New York 36, N.Y.

*November 15-16, 1960*

**Mid-America Electronics Convention (MAECON),** Hotel Muehlebach, Kansas City, Mo.

*Exhibits:* Mr. Gustav Vasen, H. A. Roes Co., 2106 Cherry, Kansas City 8, Mo.

*November 15-17, 1960*

**Northeast Electronics Research & Engineering Meeting (NEREM),** Boston Commonwealth Armory, Boston, Mass.

*Exhibits:* Miss Shirley Whitcher, IRE Boston Office, 73 Tremont St., Boston, Mass.

*December 1-2, 1960*

**PGVC Annual Meeting,** Sheraton Hotel, Philadelphia, Pa.

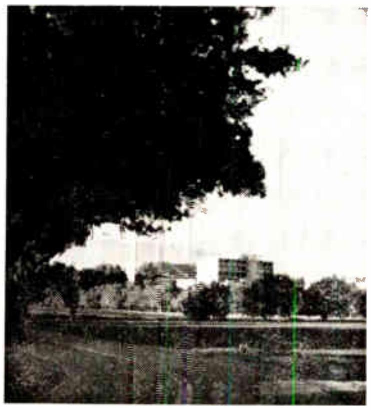
*Exhibits:* Mr. E. B. Dunn, Atlantic Refining Co., 260 S. Broad St., Philadelphia 1, Pa.

*December 11-14, 1960*

**Eastern Joint Computer Conference,** Hotel New Yorker, New York, N.Y.

*Exhibits:* J. L. Whitlock Associates, 6044 Ninth St., North, Arlington 5, Va.

Note on Professional Group Meetings: Some of the Professional Groups conduct meetings at which there are exhibits. Working committeemen on these groups are asked to send advance data to this column for publicity information. You may address these notices to the Advertising Department and of course listings are free to IRE Professional Groups.



# At The Ramo-Wooldridge Laboratories... integrated programs of research & development of electronic systems and components.

The new Ramo-Wooldridge Laboratories in Canoga Park provide an environment for creative work in an academic setting. Here, scientists and engineers seek solutions to the technological problems of today. The Ramo-Wooldridge research and development philosophy places major emphasis on the imaginative contributions of the members of the technical staff. ■ There are outstanding opportunities for scientists and engineers. *Write* Dr. Richard C. Potter, Head, Technical Staff Development, Department 22-E.

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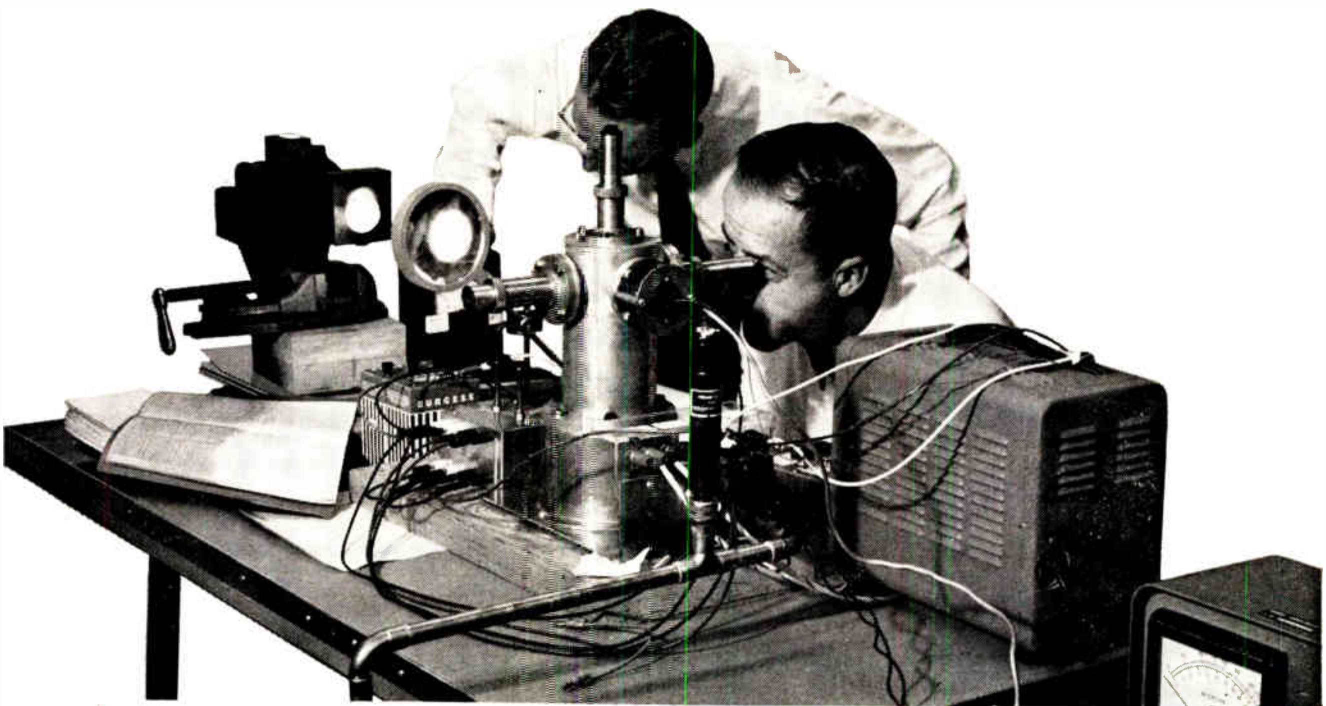
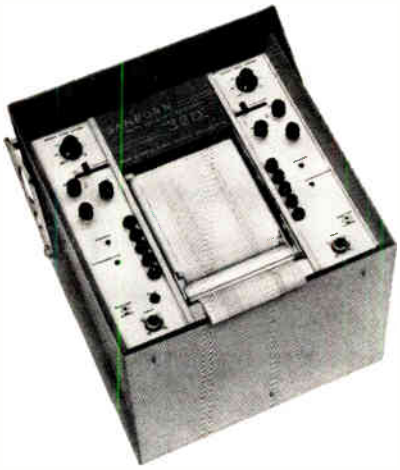


An electron device permits scientists to study the behavior of charged dust particles held in suspension.

# keep an accurate graphic record

OF RESEARCH, DESIGN, TEST DATA

## two channels



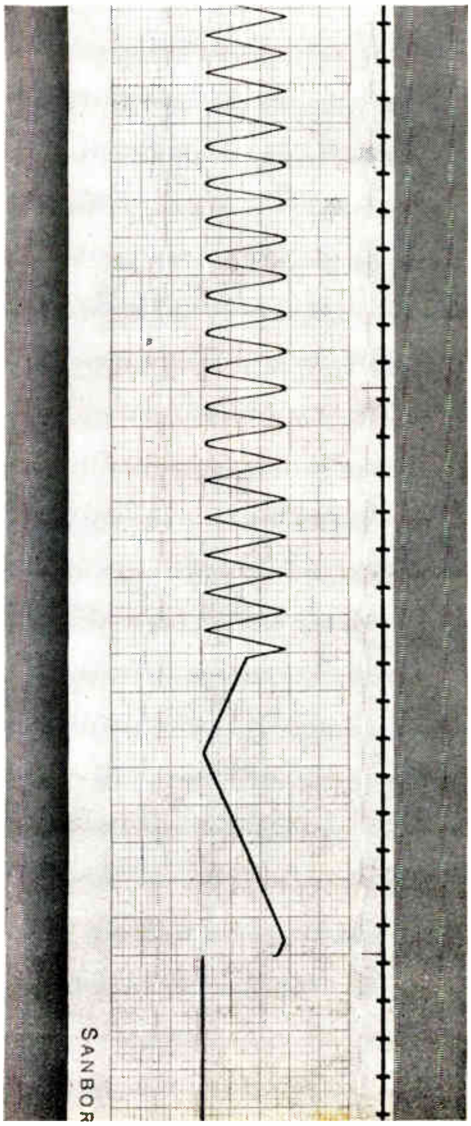
**For General Purpose DC Recording — Model 320**

For recording *two variables* simultaneously, the Model 320 provides a versatile, transistorized amplifier for each input signal. The rugged 2-channel recorder assembly has heated stylus recording on two *50 mm wide* rectangular coordinate channels, 4 pushbutton chart speeds, and 6 inches of visible chart. The Recorder can be placed vertically, horizontally or at a 20° angle.

MODEL 320 SPECIFICATIONS

Sensitivity: 0.5, 1, 2, 5, 10, 20 mv/mm and v/cm
Frequency Response: 3 db down at 125 cps, 10 mm peak-to-peak
Common Mode Voltage: ±500 volts max.
Common Mode Rejection: 140 db min. DC
Calibration: 10 mv internal ±1%
Output Connectors for each channel accept external monitoring 'scope or meter
**Price: $1495**

# NEW SANBORN PORTABLE DIRECT WRITING RECORDERS FOR IN-PLANT, LABORATORY OR FIELD RECORDING




Two models of this 21 lb. brief case size recorder are available — Model 301 for AC strain gage recording, Model 299 for general purpose DC recording. Both provide immediately visible, inkless traces by heated stylus on 40 division rectangular coordinate charts . . . frequency response to 100 cps . . . 5 and 50 mm/sec chart speeds . . . approx. 4 inches of record visible in top panel window.

## single channel

MODEL 301 SPECIFICATIONS

The amplifier section of the Model 301 is an all-transistorized carrier type with phase sensitive demodulator. The power supply and internal oscillator circuits are also transistorized.
Sensitivity: 10 uv rms/div (from transducer)
Attenuator Ratios: 2, 5, 10, 20, 50, 100, 200
Carrier Frequency: 2400 cps internal
Transducer Impedance: 100 ohms min.
Calibration: 40 uv/volt of excitation
Output Connector: for external monitoring 'scope or meter
**Price: $750**

MODEL 299 SPECIFICATIONS

Combines the dependability of transistors with the high input impedance of vacuum tubes for reliable broad-band DC recording.
Sensitivity: 10, 20, 50, 100, 200, 500 mv/div and 1, 2, 5 and 10 v/div
Input Resistance: 5 megohms balanced each side to ground
Common Mode Voltage: ±2.5 volts max. at 10 mv/div sensitivity increasing to ±500 volts max. at other sensitivities
Common Mode Rejection: 50:1 most sensitive range
Calibration: 0.2 volt internal ±1%
Output Connector: for external monitoring 'scope or meter
**Price: Model 299 (with zero suppression) $700**
**Model 299A (without zero suppression) $650**

All prices are F.O.B. Waltham, Mass., within continental U.S.A. and are subject to change without notice.

*Contact your Sanborn Sales-Engineering representative for complete information, or write the main office in Waltham. Sales-Engineering representatives are located in principal cities throughout the United States, Canada and foreign countries.*

**SANBORN COMPANY**
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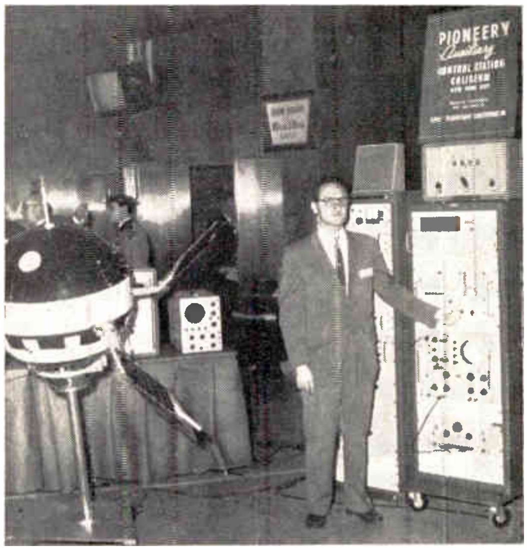
175 Wyman Street, Waltham 54, Mass.

# 1960 INTERNATIONAL IRE CONVENTION

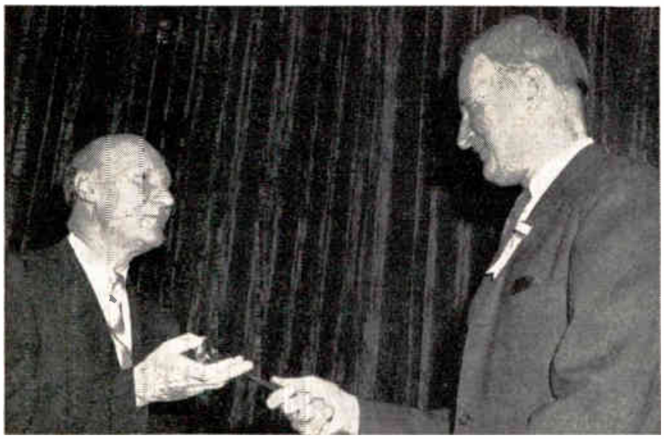
**Record 69,760 Attendance**

Engineers at the opening of the IRE Convention in the Colliseum gather around the Pioneer V auxiliary control station which was designed, assembled and operated by Space Technology Laboratories, Inc. Contact was made with Pioneer V a few moments after this picture was taken.



Dr. George Mueller, Vice President of Space Technology Labs., Inc., about to initiate a command signal from the control station in the lobby of the Coliseum. The command was sent by transatlantic cable to the Jodrell Bank radio telescope in England, which relayed the command to Pioneer V, which at the moment was1, 448,000 miles from the earth. Pioneer V's response came back to the Coliseum by the same route. At the left is a full-scale model of Pioneer V.

One of the highlights of the technical program was a seminar on the 1959 International Radio Conference in Geneva. Participants were (*left to right*) Rosel H. Hyde, FCC Commissioner; Francis C. de Wolf, Chief, Telecommunications Division, Department of State; T. A. M. Craven, FCC Commissioner; Arther L. Lebel, Assistant Chief, Telecommunications Division, Department of State; and Edward W. Allen, Jr., Chief Engineer, FCC.

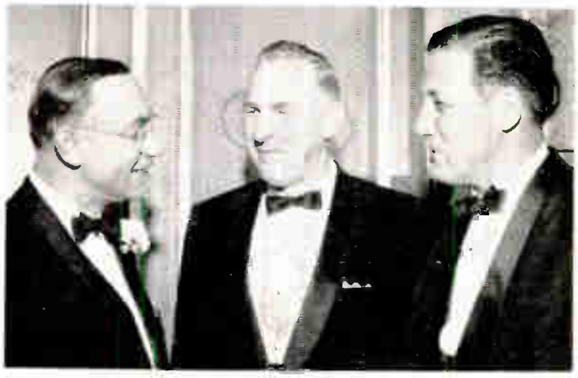


Retiring IRE President, Ernst Weber, hands the gavel of office to the incoming IRE President, R. L. McFarlan at the Annual Meeting held in the Grand Ballroom of the Waldorf-Astoria Hotel.

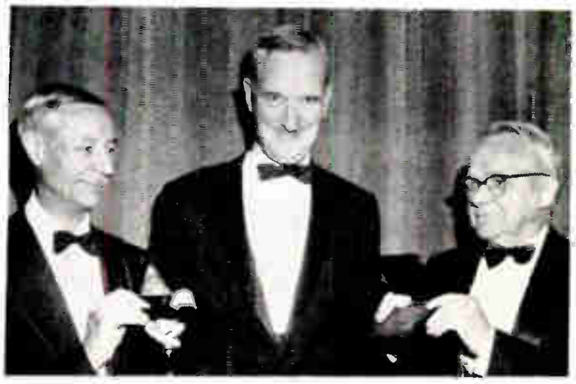
IRE Officers present at the Convention (seated, *left to right*): G. W. Bailey, Executive Secretary; Ferdinand Hamburger, Jr., Editor; John N. Dyer, Vice President; and L. V. Berkner, Director and Speaker at the Annual Meeting. Standing, *left to right*, are Ernst Weber, Junior Past President; R. L. McFarlan, President; and Haraden Pratt, Secretary.


A view of some of the exhibits at the Coliseum, topped by the theme of the Radio Engineering Show, "Where Tomorrow is Today." There were 856 exhibitors at the Show, with 25,000 items on display.

The speaker's table at the Annual IRE Banquet, held in the Grand Ballroom of the Waldorf-Astoria Hotel.



Eric Walker, President of Pennsylvania State University, spokesman for the new Fellows; H. I. Romnes, President of Western Electric, principal speaker; and B. M. Oliver, Vice President, Hewlett-Packard, Co., toastmaster, at the Annual Banquet.



(*Left*) IRE President R. L. McFarlan presents the Founder's Award to Haraden Pratt, left, and the Medal of Honor to Harry Nyquist, right, at the Annual Banquet.

(*Right*) President McFarlan presents the Morris Liebmann Memorial Prize to J. A. Rajchman, the Browder J. Thompson Memorial Prize to J. W. Gewartowski, and the Harry Diamond Memorial Award to K. A. Norton.

# IRE News and Radio Notes

## Current IRE Statistics

(As of March, 31, 1960)

Membership—80,274
Sections*—105
Subsections*—27
Professional Groups*—28
Professional Group Chapters—263
Student Branches†—187

* See this issue for a list.
† See October, 1959 issue for a list.

## Calendar of Coming Events and Authors' Deadlines*

1960

**Natl. Aeronautical Electronics Conf., Dayton-Biltmore and Miami Hotels, Dayton, Ohio, May 1–3.**

**URSI-IRE Spring Mtg., Sheraton Park Hotel and NBS, Washington, D. C., May 2–5.**

**Western Joint Computer Conf., San Francisco, Calif., May 2–6.**

Symp. on Graduate Programs in Bio-Medical Engrg., Univ. of Vermont, Burlington, May 5–6.

**PGMTT Natl. Symp., San Diego, Calif., May 9–11.**

**Electronic Components Conf., Hotel Washington, Washington, D. C., May 10–12.**

**Natl. Telemetering Conf., Miramar Hotel, Santa Monica, Calif., May 23–25.**

**7th Reg. Tech. Conf. & Trade Show, Olympic Hotel, Seattle, Wash., May 24–26.**

**6th Radar Symp., Ann Arbor, Mich., June 1–3.**

Inst. on Recent Advances in Solid State Devices, Marquette Univ., Milwaukee, Wis., June 1–2.

10th Ann. Conv. of Soc. of Women Engrs., Benjamin Franklin Hotel, Seattle, Wash., June 9–11.

**Radio Frequency Interference Symp., Shoreham Hotel, Washington, D.C., June 13–14.**

**Chicago Spring Conf. on Broadcast and Television Receivers, Graemere Hotel, Chicago, Ill., June 20–21.**

**Conf. on Standards and Electronic Measurements, NBS Boulder Labs., Boulder, Colo., June 22–24.**

**Workshop on Solid State Electronics, Purdue Univ., Lafayette, Ind., June 23–24.**

**Natl. Conv. on Mil. Elec., Sheraton Park Hotel, Washington, D. C., June 27–29.**

**Cong. Intl. Federation of Automatic Control, Moscow, USSR, June 25–July 9.**

**Int'l Conf. on Electrical Engrg. Education, Sagamore Conf. Center, Syracuse Univ., Syracuse, N. Y., Jul.**

7th Ann. Symp. on Computers and Data Processing, Stanley Hotel, Estes Park, Colo., July 28–29.

* DL = Deadline for submitting abstracts.

(*Continued on page 18A*)

## Benelux Section to Conduct Data Transmission Symposium

The Benelux Section of the IRE has announced an International Symposium on Data Transmission, to be held at Delft, Netherlands, on September 19 and 20, 1960. The symposium will be concerned with the problems of transmitting and receiving information in digital form. Particular emphasis will be placed on the behavior of practical communication networks—including existing telephone systems, existing and planned military systems, and schemes of the future, such as those that use satellites. Appropriate topics include the choice of modulation, the application of coding, the demands of channel users, the design of new systems and the improvement of old, the behavior of links and networks under test, and the selection of models for further study. The aim will be to reduce the gap now existing between theory and practice.

The symposium will be conducted in English. Papers already promised indicate good representation of the work being carried on in the USA, as well as that conducted in Europe. The Symposium Committee consists of H. C. A. van Duuren, Chairman, B. B. Barrow, H. Rinia, and F. L. Stumpers. All correspondence regarding the symposium should be addressed to B. B. Barrow, Secretary, The Benelux Section of the IRE, Postbus 174, Den Haage, Nederland.

## First Army MARS Net Presents May Speakers

With the presentation of its May Speaker Schedule, the First U. S. Army MARS SSB Technical Net will recess its weekly series of technical talks and forum until September of this year. The Net meets on 4030 kc each Wednesday at 9:00 P.M. EDT. The schedule for May includes:

May 4 "Antenna Panel," W. Offutt, Engineering Manager; L. De Size, Group Leader and B. Woodward, Engineer—Airborne Instrument Labs, Inc., Melville, L. I., N. Y.

May 11 "Frequency Control," Dr. G. Winkler, Scientist USARDL, Fort Monmouth, N. J.

May 18 "Communication Electronic Needs of the Future," Dr. J. V. Harrington, Division Head, and Dr. B. Lax, M.I.T. Lincoln Lab., Lexington, Mass.

May 25 "Fundamentals of Oscillator Operation," R. W. Gunderson, Editor, Braille Technical Press, New York, N. Y.

## NBS Head Honored By Civil Service League

Allen V. Astin (SM'50–F'54), Director of the National Bureau of Standards, has been selected by the National Civil Service League as one of the top ten career employees in the Federal civil service for 1960. The Award was presented to Dr. Astin at a dinner in Washington, D. C., on March 15.

The League, a non-partisan citizens' organization for better government through better personnel, this year will give its sixth series of Career Service Awards to ten Federal employees chosen for competence, character and achievement.

Dr. Astin has been in government 27 years. A native of Salt Lake City, Utah, with degrees from the University of Utah, New York University, Lehigh and George Washington, he now lives in Bethesda, Md.

Joining the Bureau of Standards in 1932, he was active for eight years in research in the Heat and Power and Electricity Divisions, and during the next eight became successively Chief of the Optical Fuze Section and the Ordnance Development Division. He was promoted to Director of the Bureau in 1952.

Among his scientific contributions are the discovery and development of improved methods of measuring dielectric constants and power factors of dielectric materials; pioneering work in developing radio telemetering techniques and instruments, especially applied to meterological and cosmic ray problems; and contributions to the development and evaluation of proximity fuzes. His record of publications begins in 1929 and has continued productively. He has served on many committees and boards, such as the Defense Science Board, International Committee of Weights and Measures, and National Advisory Committee for Aero-

At a recent meeting of the national committee of the 13th Annual Conference on Electrical Techniques in Medicine and Biology, in the Sheraton Hotel, Philadelphia, Pa., where plans for the forthcoming Washington, D. C., conference (October 31, November 1–2) were made, *left to right:* A. L. Henley, secretary; Lewis Winner, public relations-exhibits; L. E. Flory, editorial board; A. Shapero, treasurer; G. N. Webb, program chairman and R. L. Bowman, conference chairman.

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| C | BL-243 | Tunable | 5400-5900 | 200 | UG699/U |
| C | BL-242 | Tunable | 5400-5900 | 400 | N |
| C | BLM-022 | Tunable | 5400-5900 | 500 | TNC |
| C | BLM-026 | Tunable | 5400-4900 | 500 | TNC |
| C | BLM-020 | Tunable | 5400-5900 | 700 | TNC |
| C | BL-245 | Tunable | 5400-5900 | 900 | TNC |
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## Calendar of Coming Events and Authors' Deadlines*

*(Continued from page 16A)*

4th Global Communications Symp., Hotel Statler, Washington, D. C., Aug. 1–3.

AIEE Pacific Gen. Mtg., El Cortez Hotel, San Diego, Calif., Aug. 9–12.

**WESCON, Los Angeles Mem. Sports Arena, Los Angeles, Calif., Aug. 23–26.**

URSI 13th Gen. Assembly, Univ. of London, London, Eng., Sept. 5–15.

**Joint Automatic Control Conf., M.I.T., Cambridge, Mass., Sept. 7–9.**

**Conf. on Communications, Roosevelt Hotel, Cedar Rapids, Iowa, Sept. 9–10.**

4th Ann. Joint Mil. Ind. Electronic Test Equip. Symp., Chicago, Ill., Sept. 14–15.

**Space Electronics and Telemetry Conv. and Symp., Shoreham Hotel, Washington, D.C., Sept. 19–22.**

**Industrial Elec. Symp., Manger Hotel, Cleveland, Ohio, Sept. 21–22,**

**Sixth Natl. Communications Symp., Hotel Utica and Utica Municipal Aud., Utica, N. Y., Oct. 3–5. (DL*: June 1, B. H. Baldridge, 25 Bolton Rd., New Hartford, N. Y.)**

**PGNF 7th Ann. Mtg, Gatlinburg, Tenn., Oct. 3–5.**

**Natl. Elec. Conf., Hotel Sherman, Chicago, Ill., Oct. 10–12. (DL*: May 1960 Prof. T. F. Jones, Jr., School of E.E., Purdue Univ., Lafayette, Ind.)**

**Engrg. Writing and speech Symp., Bismark Hotel, Chicago, Ill., Oct. 13–14.**

**Symp. on Space Navigation, Deshler-Hilton Hotel, Columbus, Ohio. Oct. 19–21, (DL*: July 15, J. D. Kraus, Ohio State Univ. Radio Observatory, Columbus.)**

East Coast Conf. on ANE, Lord Baltimore Hotel, Baltimore, Md., Oct. 24–26. (DL*: June 6, S. Hershfield, The Martin Co., Baltimore, Md.)

**5th Ann. Conf. on Nonlinear Magnetics and Magnetic Amplifiers, Bellevue-Stratford Hotel, Philadelphia, Pa.**

**Electron Devices Mtg., Hotel Shoreham, Washington, D. C., Oct. 27–29.**

**13th Ann. Conf. on Elec. Tech. in Med. and Bio., Sheraton Park Hotel, Washington, D. C., Oct. 31, Nov. 1–2.**

**Radio Fall Mtg., Hotel Syracuse, Syracuse, N. Y., Oct. 31, Nov. 1–2.**

6th Ann. Conf. on Magnetism and Magnetic Materials, New Yorker Hotel, N. Y., N. Y., Nov. 14–17.

**Mid-Amer. Elec. Conv., Hotel Muehlebach, Kansas City, Mo., Nov. 15–16. (DL*: June 15, J. Austin, Bendix Aviation Corp., 95 and Troost, Kansas City, Mo.)**

**PGPT Ann. Conf., Boston, Mass., Nov. 15–16. (DL*: June 1, C. W. Watt, Raytheon Co., Waltham, Mass.)**

**1960 NEREM (Northeast Electronics Res. & Engrg. Mtg.), Boston, Mass., Nov. 15–17.**

**PGVC Ann. Mtg., Sheraton Hotel, Philadelphia, Pa., Dec. 1–2, (DL*: July 15, W. G. Chaney, American Telephone and Telegraph Co., 195 Broadway, N. Y. 7, N. Y.)**

**Eastern Joint Computer Conf., New Yorker Hotel, New York, N.Y., Dec.**

* DL = Deadline for submitting abstract.

nautics. He has had a leading role in government science programs and the direction of national and international science activities. His awards include the Presidential Certificate of Merit and His Majesty's Medal for Service in the Cause of Freedom.

### National Science Foundation Establishes Advisory Panel

A temporary Advisory Panel on Radio Telescopes has been appointed by the National Science Foundation. The purpose of the Panel is to 1) study the present and predictable needs of radio astronomers with regard to improved instrumentation; 2) study existing and proposed instruments with regard to their capabilities and limitations and 3) advise the Foundation with regard to the desirability and feasibility of more powerful instruments. The members of the Panel are Dr. J. R. Pierce, Bell Telephone Laboratories, Chairman; Dr. R. N. Bracewell, Stanford University; Dr. P. E. Chenea, Purdue University; Dr. L. J. Chu, Massachusetts Institute of Technology; Dr. R. M. Emberson, Assoc. Universities, Inc.; Dr. W. E. Gordon, Cornell University; Dr. D. S. Heeschen, National Radio Ast. Obs.; Dr. R. Minkowski, Mt. Wilson and Palomar Obs.; Dr. G. W. Swenson, Jr., University of Illinois; J. H. Trexler, Naval Research Lab. Scientists and engineers wishing to bring their ideas to the attention of the panel are encouraged to communicate them (to the panel members or directly) to the Astronomy Program, National Science Foundation.

### Cornell University To Hold June Seminars

The annual Industrial Engineering Seminars are being presented for the seventh successive year at Cornell University during June 14–17, 1960. Seminars will be conducted in seven major areas. Of these, those of interest to radio and electronics engineers will be the seminars in Engineering Administration, Systems Simulation Using Digital Computers, Statistical Decision-Making: Theory and Applications, and in Statistical Reliability Analysis: Theory and Applications.

The seminar series on Engineering Administration has been planned for persons responsible for the administration of engineering and applied research activities. Topics to be discussed include a) communication problems in the technical organization, b) manpower planning and the growing shortage of engineers, c) the development of engineers as supervisors, d) creativity through group effort, e) directing engineering programs, f) engineering program planning, g) the management of technical services, and h) cost control of engineering projects.

The seminar group on Statistical Reliability Analysis: Theory and Application will provide a current survey of statistical theory and techniques on reliability analysis that are being developed to meet the growing demands for improved materials and component reliability. It is intended for those engineers and manufacturing executives whose responsibilities include predicting and implementing the economic balance of product quality against cost through environmental destruction tests, marginal checking and failure analysis. Among the topics to be discussed will be: a) statistical aspects of experimentation, b) statistical theory of reliability based on failure models such as the exponential, Weibull, gamma and extreme-value, c) techniques of analyzing failure data, d) the improvement of reliability through redundancy and maintenance, e) the design of life-testing experiments, f) selection and ranking problems, and g) unsolved problems in reliability.

The use of simulated experimentation in the analysis and design of complex systems is one of the most promising of the applications of high-speed digital computers. The series of seminar sessions on Systems Simulation Using Digital Computers will explore this expanding field and consider problems in constructing the program, in using a simulator and in analyzing results. The topics for discussion will include a) the experimental investigation of complex systems, b) equipment requirements for digital simulation, c) the logical representation of an operating system, d) the construction of a computer program to simulate a simple system, e) problems in the design of a simulation experiment, f) experimental determination of

In preparation for the 1960 IRE 7th Regional Conference, Dr. D. K. Reynolds, Technical Program Chairman (*far right*) explains to other IRE committee chairmen the three major fields which the conference attendants will study. The conference, to be held in Seattle on May 24–26, will feature studies of control systems, solid state electronics, and electromagnetics. The other IRE conference chairmen include (*left to right*) W. T. Harrold, Public Relations Chairman; Rush Drake, Electronics Exhibit Chairman; Dr. Frank S. Holman, Chairman; L. C. Perkins, Chairman of the Seattle Section; and Frank A. Little, Treasurer.

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Dr. Edgar A. Sack, Jr. (*center*), who received recognition by Eta Kappa Nu as the outstanding young electrical engineer of 1959, receives congratulations from HKN's President, Albrecht Naeter (*left*) and Dr. Ernst Weber, president of Brooklyn Polytechnic Institute, who delivered the major address of the evening.

optimum operating conditions, g) production control simulation and the comparison of decision rules, and h) manufacturing systems simulation.

The seminar on Statistical Decision-Making is designed for individuals who are engaged in research, experimentation, production, inspection, or acceptance sampling where attention is centered on problems of selecting or ranking processes, methods, or categories according to various criteria of "goodness." It will consist of integrated sessions in which new statistical procedures will be proposed for coping with such multi-decision problems. Among the topics to be discussed will be a) some statistical aspects of experimentation, b) multiple comparison procedures: why and how they are used, c) three-decision problems, d) selection and ranking problems (Bechhofer-Sobel approach), e) selection and ranking problems (Sommerville approach), f) selection and ranking problems (Gupta-Sobel approach), and g) implications of the approaches, directions of research, and new applications.

These seminars are sponsored by the Department of Industrial and Engineering Administration of the Sibley School of Mechanical Engineering, College of Engineering at Cornell. For further information address inquiries to: J. W. Gavett, Seminars Coordinator, Upson Hall, Cornell University, Ithaca, N. Y.

## PGPT Calls for Papers

The 4th Annual Conference of the PGPT will be held in Boston, Mass., on November 15-16, in conjunction with the 1960 Northeast Electronics Research and Engineering Meeting (NEREM). Papers for two sessions, to be grouped under the general headings of "Design Techniques That Insure a Better Product," and "Materials and the Product Today," are being solicited. Reports on new and original work in these fields are especially desired. Prospective authors should submit, before June 1, 1960, summaries of their papers, in triplicate, to C. W. Watt, Program Chairman, 4th Annual Conference PGPT, c/o Raytheon Company, Waltham 54, Mass.

## Marquette University To Sponsor Institute

An Institute sponsored by the Department of Electrical Engineering of Marquette University will be held on June 1 and 2, 1960. The title of the Institute is "Recent Advances in Solid State Devices." The program emphasizes High-Power Controlled Rectifiers, Application of the Silicon Controlled Rectifier, Parametric Amplification, Tunnel Diode and Applications, Direct Energy Conversion—Thermoelectric Devices, Direct Energy Conversion, Solid State Maser Amplifiers, Avalanche Devices and Solid State "Grown" Circuits. Persons highly specialized in their fields will present the program.

For further information write to Stanley Krupnik, Jr., Assistant Chairman of Electrical Engineering, Marquette University, Milwaukee 3, Wis.

## PGRFI Will Conduct 2nd Annual Symposium

The Professional Group on Radio Frequency Interference (PGRFI) will hold its 2nd Annual Symposium in Washington, D. C. at the Shoreham Hotel on June 13 and 14, 1960.

The program will include morning and afternoon sessions on both Monday, June 13 and Tuesday, June 14. The morning session on June 13 will deal with RFI prediction with various computer models, the afternoon program with measurement methods and system characteristics. A total of 10 papers will be presented. The second day will feature a round table discussion in the morning covering the present status of RFI and compatibility standards. In the afternoon, there will be a field trip to the NOL and FCC Laboratories. The ladies' program will include a daily hospitality room, a fashion show, an embassy tea, and a sight-seeing tour.

Advance registration is recommended; for further information please contact: E. F. Mischler, Chairman, Public Relations Committee, National Engineering Service, 1108 16th Street, N.W., Washington 6, D.C.

## Summer Workshop Announced

A day and a half tutorial program on solid-state electronics is to be presented at Purdue University on June 23 and 24, 1960 under the joint sponsorship of the IRE Professional Group on Education and the Electrical Engineering Division of ASEE. The program for the event was announced by Dr. John G. Truxal and Dr. J. H. Mulligan, Jr., respective Chairmen of the two organizations. Dr. Warren B. Boast, Iowa State University, is Chairman of the Program Committee for the Workshop. Other members are Dr. R. H. Mattson, Iowa State University; Dr. J. L. Moll, Stanford University; Dr. R. L. Pritchard, Texas Instruments, Inc., and Mr. G. R. Madland, Motorola Semiconductor Products Division.

Designed primarily for electrical engineering educators, but open to all interested parties, the Workshop will include nine papers arranged in three sessions as follows:

Thursday afternoon, June 23

"Characteristics of Electrons in Solids," *Dr. J. M. Shive, Bell Telephone Lab., Inc.*

"Semiconductors," *Dr. R. H. Mattson, Iowa State University.*

"Electrical Properties of Semiconductor Materials," *Dr. W. G. Dow, University of Michigan.*

Friday morning, June, 24

"Diodes," *Dr. M. O. Thurston, Ohio State University.*

"Transistors," *Dr. J. M. Early, Bell Telephone Lab., Inc.*

Friday afternoon, June 24

"Energy Conversion Devices," *Dr. S. J. Angello, Westinghouse Electric Corp.*

"Low Temperature Devices," *Dr. A. L. McWhorter, Lincoln Labs., M.I.T.*

"Other Solid State Devices," *Dr. J. L. Moll, Stanford University.*

Further details regarding program information may be obtained from Dr. Warren B. Boast, Iowa State University, Ames, Iowa; information regarding living accommodations for the meeting may be obtained from Dr. Thomas F. Jones, Purdue University, Lafayette, Ind.

The Workshop on Solid-State Electronics is but one of the events of the Electrical Engineering Division scheduled for the ASEE Annual Meeting at Purdue University. On Monday, June 20 there will be a session on "Learning Machines" under the chairmanship of Professor A. V. Eastman of the University of Washington. The following papers will be presented:

"The Automization of Socrates," *Dr. D. Cook, Purdue University.*

"Design Techniques of Automatic Teaching Machines," *Dr. H. A. Baldwin, University of Arizona.*

"Teaching Elementary Stress Analysis

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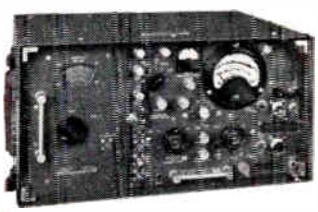

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The following issues of miscellaneous publications are available from the Institute of Radio Engineers, Inc., 1 East 79th Street, New York 21, New York, at the prices indicated below:

| Meetings | Publications | Price per Copy |
|---|---|---|
| Aeronautical and Navigational Electronics Conference | *Proceedings of the 5th Annual East Coast ANE Conference*, held October 27-28, 1958 in Baltimore, Md. | $5.00* |
| Electronic Components Symposium | *Proceedings of the 1957 Electronic Components Symposium*, held May 1-3, 1957 in Chicago, Ill. | 5.00 |
| Electronic Computer Conferences | *Proceedings of the Joint AIEE IRE ACM Eastern Conference*, held December 10-12, 1951 in Philadelphia, Pa. | 3.50 |
| | *Proceedings of the Joint AIEE IRE ACM Eastern Conference*, held December 8-10, 1954 in Philadelphia, Pa. | 3.00 |
| | *Proceedings of the Joint AIEE IRE ACM Eastern Conference*, held November 7-9, 1955 in Boston, Mass. | 3.00 |
| | *Proceedings of the Joint AIEE IRE ACM Eastern Conference*, held December 10-12, 1956 in New York, N. Y. | 3.00 |
| | *Proceedings of the Joint AIEE IRE ACM Eastern Conference*, held December 9-13, 1957 in Washington, D. C. | 3.00 |
| | *Proceedings of the Joint AIEE IRE ACM Eastern Conference*, held December 3-5, 1958 in Philadelphia, Pa. | 3.00 |
| | *Proceedings of the Joint AIEE IRE ACM Eastern Conference*, held December 1-3, 1959 in Boston, Mass. | 3.00 |
| | *Proceedings of the Joint AIEE IRE ACM Western Conference*. held March 1-3, 1955 in Los Angeles, Calif. | 3.00 |
| | *Proceedings of the Joint AIEE IRE ACM Western Conference*, held February 7-9, 1956 in San Francisco, Calif. | 3.00 |
| | *Proceedings of the Joint AIEE IRE ACM Western Conference*, held May 6-8, 1958 in Los Angeles, Calif. | 4.00 |
| | *Proceedings of the Joint AIEE IRE ACM Western Conference*, held March 3-5, 1959 in San Francisco, Calif. | 6.00 |
| Magnetic Amplifiers Conference | *Proceedings of the Conference on Magnetic Amplifiers*, held April 5-6, 1956 in Syracuse, N. Y. | 4.00 |
| Bio-Medical Electronics Bibliographies | *Bibliography on Medical Electronics*, June 1958<br>*Bibliography on Medical Electronics*, June 1959 (Supplement #1) | 2.50<br>2.50 |
| Military Electronics | *Proceedings of the 1st National Convention*, held June 17-19, 1957 in Washington, D. C. | 5.00† |
| | *Proceedings of the 2nd National Convention*, held June 16-18, 1958 in Washington, D. C. | 5.00† |
| | *Proceedings of the 3rd National Convention*, held June 29-July 1, 1959 in Washington, D. C. | 4.00 |
| Reliability and Quality Control in Electronics Symposia | *Proceedings of the 4th National Symposium*, held January 6-8, 1958 in Washington, D. C. | 5.00 |
| | *Proceedings of the 5th National Symposium*, held January 12-14, 1959 in Philadelphia, Pa. | 5.00 |
| | *Proceedings of the 6th National Symposium*, held January 11-13, 1960 in Washington, D. C. | 5.00 |
| Telemetering Conference and Symposia | *Proceedings of the 1953 National Conference*, held May 20-22, 1953 in Chicago, Ill. | 2.00 |
| | *Proceedings of the 1958 National Symposium*, held September 22-24, 1958 in Miami Beach, Fla. | 5.00 |
| | *Proceedings of the 1959 National Symposium*, held September 28-30, 1959 in San Francisco, Calif. | 5.00 |

* IRE Member Rate $3.50.
† IRE Member Rate $3.00.

by Machine," *Dr. A. F. Johnson and Dr. D. J. Mayhew, University of Utah.*

"MARI—A Simple Electrical Teaching Device," *Dr. M. Crosby and Dr. O. Lancaster, Pennsylvania State University.*

On Monday evening at 8:00 P.M. there will be a panel discussion on the theme "The Role of the Electrical Engineering Division in the Next Decade." Participants will be Dr. Warren B. Boast, Head, Electrical Engineering Department, Iowa State University; Dr. Richard K. Moore, Head, Electrical Engineering Department, University of New Mexico; and Dr. James H. Mulligan, Jr., Head, Electrical Engineering Department, New York University.

On Tuesday, June 21 at 2:00 P.M. there will be a session devoted to Probability and Statistics in Electrical Engineering under the direction of Dr. J. Stuart Johnson, Dean of Engineering, Wayne State University. The four papers scheduled for this meeting are:

"Mathematics Approach to Probability and Statistics Instruction for Electrical Engineers," *Dr. J. G. Brainerd, University of Pennsylvania.*

"Electrical Engineering Approach to Probability and Statistics Instruction for Electrical Engineers," *Dr. R. J. Schwarz, Columbia University.*

"Random Process Studies and Information Theory," *Dr. V. C. Rideout and Dr. A. Burr, University of Wisconsin.*

"Reliability of Electronic Equipment," *Dr. C. A. Krohn, Motorola, Inc.*

### Photography Seminar To Be Held at M.I.T.

The scientific and engineering uses of high-speed photographic measurement techniques will be the subject of a one week seminar at the Massachusetts Institute of Technology, starting Monday, August 15, 1960. The meetings will center at the Stroboscopic Light Laboratory where the theory and application of numerous methods will be discussed and studied.

It is planned that mornings will be devoted to theory and demonstrations and the afternoons to laboratory practice and experience.

Subjects to be covered include pulsed stroboscopic lighting, optical high-speed cameras, Kerr cells, Faraday shutters, image converters, and so forth. Specialists in high-speed photography have been invited to cover their subjects at the seminar, and there will be practical laboratory demonstrations of many types of high-speed photography equipment.

The high-speed motion picture and still cameras give space-time resolution for complicated mechanical motions. In some ways one can think of high-speed cameras as instruments for the mechanical engineer that correspond to the cathode-ray oscillograph for the electrical. One of the objects of the seminar is to give those who attend a real working knowledge of the various devices.

The program is under the direction of Professor Harold E. Edgerton of the Department of Electrical Engineering at M.I.T. For further information inquire from the Office of the Summer Session, Room, 7-103, M.I.T., Cambridge 39, Mass.

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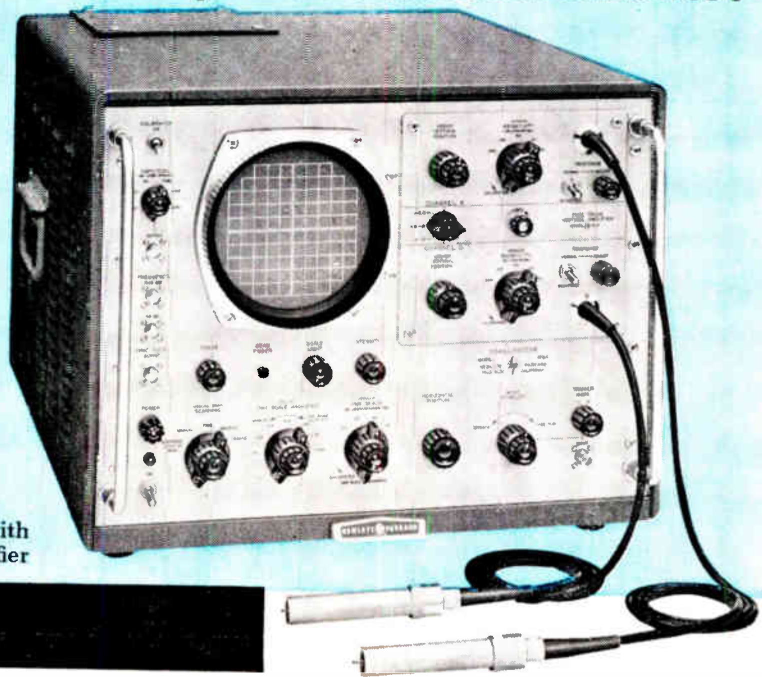

-hp- 185A Sampling Oscilloscope with
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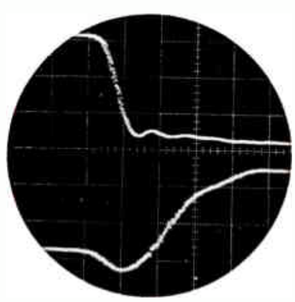
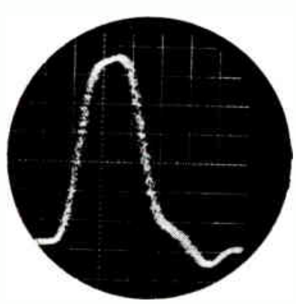


Bright, clear dual pulse presentation on *-hp-* 185A's big 5" scope face. Top trace shows pulse from mercury pulser applied to 2N1385 mesa transistor. Bottom trace shows responding turn-on of transistor. Dip in bottom trace at start of turn-on results from capacitance. Scope sweep speed is 1 mμsec/cm.



Brilliant, steady trace of a 2 millimicrosecond pulse on the 185A 5AQP cathode ray tube face.

6362

**IMPORTANT FEATURES:** Less than 0.7 mμsec rise time. 500 MC pass band; bright steady traces even at rep rates down to 50 cps. Sensitivity 10 mv/cm to 200 mv/cm; vernier increases sensitivity to 3 mv/cm. Sweep times 10 mμsec/cm to 100 mμsec/cm with expander to 0.1 mμsec. Front panel delayed sync pulse for triggering circuits under test. Dual channel input. 10 cm vertical display. High sensitivity, wide dynamic range. 100,000 ohm probe minimizes circuit disturbance. X-Y recorder output. Time-amplitude calibrators, beam finder, panel similar to conventional scopes. Built-in time and amplitude calibrators.

**FOR COMPLETE DETAILS** of this totally new, easy-to-use instrument, call your -hp- representative or write direct.

-hp- 185A 500 MC Oscilloscope, $2,000.00
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and development—are invited for presentation at the 1960 Northeast Electronics Research and Engineering Meeting (NEREM) which will be held on November 15, 16, 17, 1960, in the Commonwealth Armory and the Sheraton-Plaza Hotel, Boston, Mass.

This year's meeting will project a marked departure in technical program format, scope and size, as well as type and number of exhibits. The program will feature many invited state-of-the-art tutorial sessions, with related evening informal discussion periods.

All registrants will receive, free-of-additional charge, a copy of the NEREM Record, a printed 200-page conference report with 600–1000 word digests (supported by drawings and photographs) of every paper presented at the meeting. Illustrated profiles of every NEREM speaker will also be included in the Record.

A suggestive, but not inclusive, list of subject areas for NEREM 1960 is: Antennas; Circuit Theory; Components, Production Techniques and Reliability; Electronic Computers; Engineering Management; Feedback Control Systems; Information Theory and Processing; Biomedical Electronics; Microwave Devices—Theory and Techniques—Involving Ferrites, Masers, Parametric Amplifiers and Ionized Media; Military Electronics Including Inertial, Infrared and Data-Handling Systems; Semiconductor Devices and Circuits Including Micro-Circuitry and Photo Electronic Applications.

To permit the development of well-integrated technical sessions, speakers are requested to furnish either complete papers or 400–500 word abstracts, in triplicate, plus 50-word summaries for advance program mailings.

All material should be mailed on or before July 15, 1960 to the 1960 NEREM Program Chairman, J. H. Mulligan, Jr., Dept. of Electrical Engineering, New York University, New York 53, N. Y. Authors will be notified of paper acceptance or rejection by August 15, 1960.

1922 receiver demonstrated at IRE Section Annual Banquet—The operation of the "Aeriola Sr. Receiver," a Westinghouse Product, is demonstrated by Captain W. F. Kirlin, Chairman of the Northwest Florida Section of the IRE, to Dr. R. L. McFarlan, International President of the IRE, and General R. H. Warren, Vice Commander, APGC. Ralph Coe, (left) Section Vice-Chairman, and Harold Hufnagle (right), Section Secretary-Treasurer, look on.

### May Schedule Planned By Air Force MARS

The following is the schedule of the Air Force MARS Eastern Technical Net (3295 kc, 7540 kc, and 15,715 kc, on Sundays from 2 to 4 P.M. EST):

May 1 "Quality Control Techniques," A. Stein, Statistical Engineer, Riverside Plastics Corp.

May 8 "Medical Electronics in Gastro-Intestinal Research," Dr. J. T. Farrar, Chief, Gastro-Neurology Section of the Veterans' Hospital of New York and R. Bostrom, Research Engineer, Airborne Instruments Lab.

May 15 "The Evolution of Modern Radar," Dr. N. J. Nilsson, Chief, Directorate of Control and Guidance, Advanced Developments Lab., Rome Air Development Center, USAF.

May 22 "Air Crew Escape Systems," Discussion by engineers from Frankford Arsenal, USA.

May 29 "Materials," Discussion by engineers from Frankford Arsenal, USA.

# 1960 IRE 7th Region Conference

Olympic Hotel, Seattle Wash., May 24–26, 1960

The cocktail party, to be held May 24 in the Olympic Hotel, Seattle, Wash., is the traditional opening of the IRE 7th Regional Conference. The All-Industry Luncheon will also be held on May 24, in the Spanish Ballroom of the Olympic Hotel.

On May 25 a field trip will be conducted to the Transport Division of the Boeing Airplane Company, Renton, Wash. This will provide views of the following: the factory, flight line (radar test), electronic shops (radar checkout), electronic mock-up landing simulator, computer—IBM 704 (evaluation of flight situations), and airplane mock-up, both present and future.

Women's activities, under the direction of Mrs. Frank S. Holman, will include a reception and several cruises and excursions to interesting sites in the area.

**Session 1—Opening General Session**

**Tuesday Morning, May 24**

Chairman: *O. G. Villard, Jr., Stanford Univ., Stanford, Calif.*

Speakers: *F. S. Holman, Chairman, 7th Region Conference, Boeing Airplane Co., Seattle, Wash.; R. L. McFarlan, President, IRE; R. N. Clark, Univ. of Washington, Seattle; O. G. Villard, Jr., Stanford Univ., Stanford, Calif.*

**Session 2**

**Control Systems I—Performance Criteria**

**Tuesday Afternoon**

Chairman: *G. F. Franklin, Stanford Univ., Stanford, Calif.*

Co-Chairman: *F. C. Fickeisen, Boeing Airplane Co., Seattle, Wash.*

"Optimum Performance Criteria with a Minimum Lead System," *G. S. Axelby, Westinghouse Corp., Baltimore, Md.*

"Consideration in the Design of Feedback Control Systems with Optimum Performance," *R. L. Cosgriff and E. J. Hagin, Ohio State Univ., Columbus.*

"Optimum Control System with Minimum Spectral Bandwidth," *J. C. Hung, New York Univ., New York, N. Y.*

"Performance Measures—Past, Present, and Future," *W. C. Schultz, Cornell Aero Lab., Buffalo, N. Y., and V. C. Rideout, Univ. of Wisconsin, Madison.*

**Session 3**

**Solid State Electronics I—Semiconductors**

"Negative Resistance Processes in Semiconductors," *R. E. Burgess, University of*

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*VSWR:* 1.15 maximum

*Attenuation Range:* 60 db

*Accuracy:* ±0.1 db or ±2%, whichever is greater, from 0 to 50 db; ±3% from 50 to 60 db.

**The table below indicates maximum insertion loss and dimensions.**

| Type No. | Freq. Range | Max. Insertion Loss | Insertion Length | Height | Depth |
|---|---|---|---|---|---|
| G 101 | 3.95 — 5.85 | 0.5 db | 18 7/8 | 6 5/16 | 7 3/16 |
| C 101 | 5.3 — 8.2 | 0.5 db | 14 7/16 | 6 5/16 | 7 3/16 |
| H 101 | 7.05 — 10.0 | 0.5 db | 11 3/8 | 6 5/16 | 7 3/16 |
| X 101 | 8.2 — 12.4 | 0.5 db | 9 | 6 1/8 | 6 1/4 |
| U 101 | 12.4 — 18.0 | 0.7 db | 7 11/16 | 5 1/8 | 6 1/4 |
| K 101 | 18.0 — 26.5 | 0.7 db | 7 9/16 | 5 1/8 | 6 1/4 |
| A 101 | 26.5 — 40.0 | 1.0 db | 6 13/16 | 5 1/8 | 6 1/4 |

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*British Columbia, Vancouver, Canada.*

"Recent Progress in the Development of High Frequency Transistors," *G. N. Hanson, Bell Telephone Labs., Allentown, Pa.*

"Some Aspects of Semiconductor Noise," *A. Van Der Ziel, Univ. of Minnesota, Minneapolis.*

"Maser Operation at Infrared and Optical Frequencies," *L. C. Levitt, Hughes Research Labs., Culver City, Calif.*

### Session 4

### Control Systems II—Optimal Design Techniques

**Wednesday Morning, May 25**

Chairman: *A. H. Koschmann, Univ. of New Mexico, Albuquerque.*

Co-Chairman: *R. M. Hubbard, Boeing Airplane Co., Seattle, Wash.*

"Performance Criteria in Adaptive Control," *C. W. Sarture and J. A. Aseltine, Space Technology Labs., Los Angeles, Calif.*

"Limit Cycle Efficiency of On-Off Reaction Control Systems," *G. W. Freeman, Boeing Airplane Co., Seattle, Wash.*

"Design Aspects of Attitude Control Systems," *M. F. Marx, General Electric Co., Schenectady, N. Y.*

"A Simulator Study of a Two-Parameter Adaptive System," *V. C. Rideout and R. J. McGrath, Univ. of Wisconsin, Madison.*

### Session 5

### Solid State Electronics II—Solid State Energy Conversion

### Session 6

### Electromagnetics I—Radio Astronomy

"Radio Emission from the Sun at Decametric Wavelengths," *J. W. Warwick, High Altitude Observatory Univ. of Colorado, Boulder.*

B. S. Yaplee, *Radio Astronomy Br., U. S. Naval Research Lab., Washington, D. C.*

D. D. Cudaback, *Electrical Engineering Dept. Stanford Univ., Stanford, Calif.*

A. E. Lilley, *Harvard College Observatory, Cambridge, Mass.*

### Session 7

### Control Systems III—Nonlinear and Sampled Data Systems

**Wednesday Afternoon**

Chairman: *R. E. Hanna, Douglas Aircraft Co., Santa Monica, Calif.*

Co-Chairman: *E. Noges, Univ. of Washington, Seattle.*

"Nonlinear Effects in Servo Control Systems," *R. B. Higley, Autonetics, Downey, Calif.*

"Control of Higher Order Systems Based on Time Optional Regulations," *F. B. Smith, Minneapolis Honeywell, Minneapolis, Minn.*

"An Error Minimization Technique for Sampled-Data Systems," *A. F. Engelbrecht and C. W. Steeg, Jr., Radio Corporation of America, Burlington, Mass.*

### Session 8

### Electromagnetics II—Very Large Aperture Antennas

"Radar Astronomy: A New Technique for the Study of the Solar System," *R. L. Leadabrand and R. B. Dyce, Stanford Research Inst., Menlo Park, Calif.*

"The Design and Operation of a Two-Mile Aperture Antenna," *W. C. Erickson, Convair Scientific Research Lab., San Diego, Calif.*

"Environmental Antenna Patterns," *J. F. Carpenter, Dalmo Victor Co., Division of Textron, Inc., Belmont, Calif.*

"The Ohio State 360 Foot Radio Telescope," *R. T. Nash, Radio Observatory, Dept. of Electrical Engineering, Ohio State Univ., Columbus.*

### Session 9

### Student Prize Paper Contest—IRE 7th Region Finals

**Wednesday Evening**

Chairman: *F. D. Robbins, Univ. of Washington, Seattle.*

### Session 10

### Engineering Management Symposium—Technical Management of Large Systems

### Session 11

### Control Systems IV—Biological Control Systems

**Thursday Morning, May 26**

"The Design of Man-Machine Systems by Means of Quantitative Analysis Techniques of Human Factors Engineering," *O. H. Lindquist, Minneapolis-Honeywell, Minneapolis, Minn.*

"Control Systems Characteristics of the Respiratory System," *A. C. Young, Univ. of Washington, Seattle.*

"Relaxation and Transit Time Oscillations in the Heart," *J. W. Woodbury, Univ. of Washington, Seattle.*

### Session 12

### Electromagnetics III—Arctic Ionospheric Phenomena

"Distribution of Auroral Radar Disturbances in Alaska During the IGY," *R. S. Leonard, Geophysical Inst., College, Alaska.*

"Sweep-Frequency Backscatter Studies in the Auroral Zone," *H. F. Bates, Geophysical Inst., College, Alaska.*

"High Frequency Studies of the Arctic Ionosphere," *L. Owren and R. D. Hunsucker, Geophysical Inst., College, Alaska.*

"A High Latitude Study of Spread F Echoes," *Z. A. Ansari and L. Owren, Geophysical Inst., College, Alaska.*

### Session 13

### Solid State Electronics III—Magnetics and Dielectrics

**Thursday Afternoon**

"Ferroelectric Power Converters," *S. R. Hoh, IT and T Co., Nutley, N. J.*

"New Magnetic Devices for Digital Computers," *D. H. Looney, Bell Telephone Labs., Murray Hill, N. J.*

*L. Rimai, Raytheon Co., Waltham, Mass*

### Session 14

### Electromagnetics IV—Terrestrial Electromagnetic Effects

"Terrestrial Propagation of VLF Radio Waves," *J. R. Wait, National Bureau of Standards, Boulder, Colo.*

"Whistlers and Related Phenomena," *R. A. Helliwell, Radioscience Lab., Stanford Univ., Stanford, Calif.*

"Effects of Terrestrial Electromagnetic Disturbances on Wireline Communications," *R. Sanders, Hughes Aircraft Co., Culver City, Calif.*

"Fading of Radio Waves Vertically Incident Upon the Ionosphere," *D. H. Schrader and H. M. Swarm, Dept. of Electrical Engineering, Univ. of Washington, Seattle.*

# Fourth National Convention on Military Electronics

SHERATON PARK HOTEL, WASHINGTON, D.C., JUNE 27–29, 1960

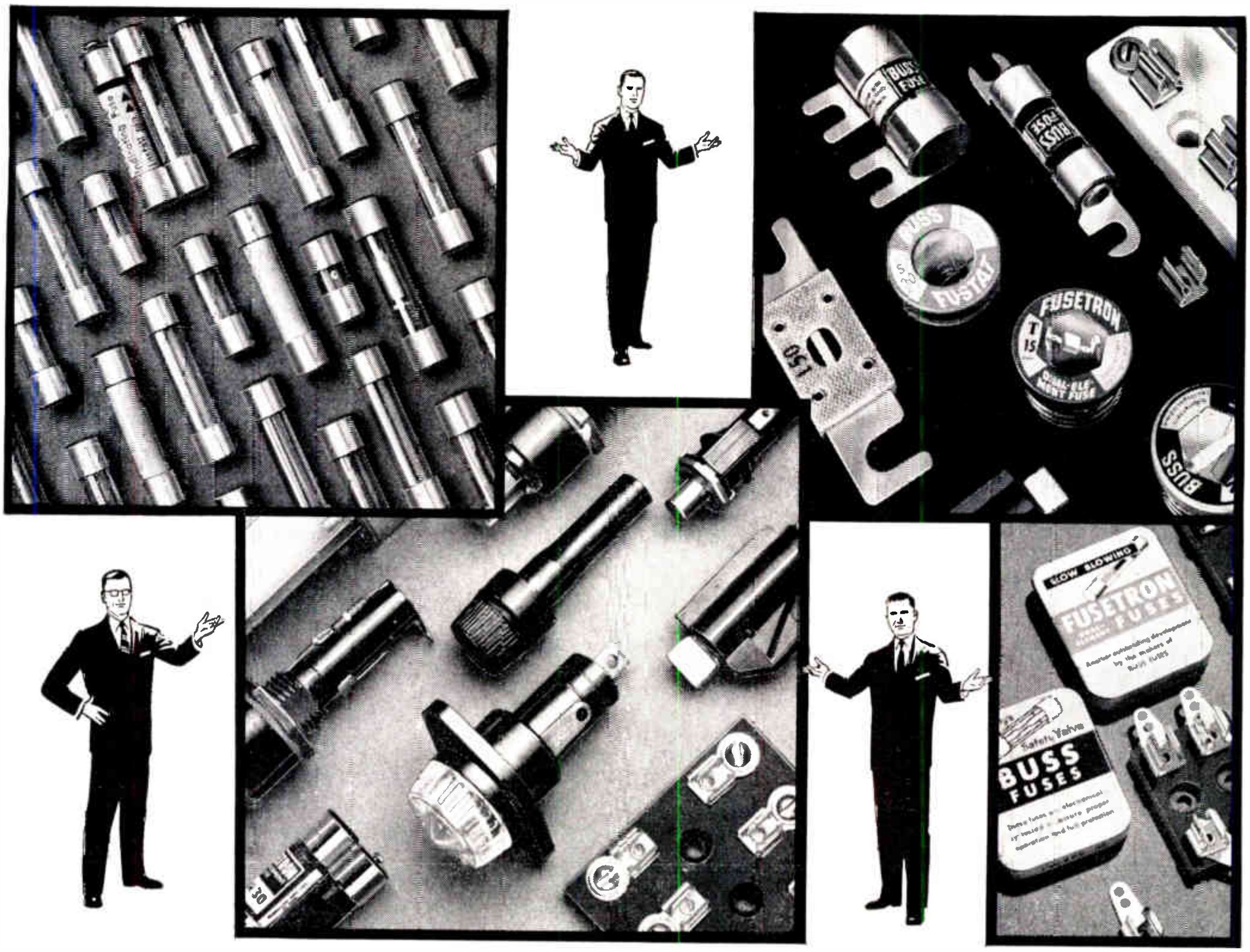
A panel discussion on military research and development will highlight the opening session of the 4th National Convention on Military Electronics (MIL-E-CON 1960) which will be held again this year in Washington, D.C. on June 27–29. This annual meeting is sponsored by the Professional Group on Military Electronics.

Dr. Jerrold R. Zacharias, Professor of Physics at the Massachusetts Institute of Technology, will moderate the discussion by officers from the three military services, including Vice Admiral John T. Hayward, USN, Deputy Chief of Naval Operations (Development) and Major General Leighton I. Davis, USAF, Assistant Deputy Chief of Staff, Development, U.S. Air Force.

The technical program includes 25 sessions, 20 of which will be unclassified. The Air Force Research and Development Command will sponsor five classified sessions at MIL-E-CON 1960; security clearance is required for attendance at these classified meetings. Printed copies of the 1960 *Conference Proceedings*, containing the unclassified papers, will be distributed free of charge to each registrant.

Exhibits of the latest in military components and equipment will fill the exhibit areas of the Sheraton-Park Hotel. The exhibits will run concurrently with the technical sessions.

On the social side, there will be a Keynote Luncheon on Monday, June 27, a buffet and entertainment Monday evening, a Ladies' Breakfast on Tuesday, and the An-

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FUSETRON · TRUSTWORTHY NAMES IN ELECTRICAL PROTECTION · BUSS · McGRAW-EDISON nual Banquet Tuesday evening, featuring a prominent guest speaker and the presentation of the Barry M. Carlton Award. The Washington Chapter of PGMIL will be the host at the Keynote Luncheon, with Major General Earle F. Cook, USA, Deputy Chief Signal Officer, as the speaker. Dr. Edward G. Witting, Deputy Director of Research and Development, Office of the Secretary of the Army, and chairman of the Washington Chapter, PGMIL will be the master of ceremonies at this luncheon. A meeting of the Administrative Committee of PGMIL is scheduled for Tuesday morning.

Advance registration fees, which include the *Conference Proceedings*, are $2 for IRE members, $3 for nonmembers, and $1 for students. Deadline for advance registration is June 1. At-the-door registration fees will be $4 for IRE members, $5 for nonmembers, and $1 for students. Tickets for the luncheon are $3.50; for the Ladies' Day Breakfast, $2; for the buffet $5; and for the banquet, $10. Tables seating eight may be reserved for the banquet at $80 each. Mr. Jack Carter, Jansky & Bailey, Inc., 3269 M Street, N. W., Washington 7, D.C., is chairman of the Registration Committee.

Robert H. Cranshaw, Manager, Advanced Space Products, General Electric Company, Utica, New York, is President of MIL-E-CON 1960. Dr. Craig M. Crenshaw, Chief Scientist, Office of the Chief Signal Officer, Department of Defense (Army), is Chairman of the Technical Program Committee.

### Monday Afternoon, June 27

#### Session 1.1—Reconnaissance and Ranging I (Confidential)

Sponsor: Air Research and Development Command.

Moderator: *To be announced.*

"Experimental Evaluation of a Diversity Radar," *P. W. Crist, Airborne Instruments Lab., Melville, N. Y.*

"Radar Density Related to Tactical Troop Concentrations," *R. T. Stefancik, G. C. Arrowsmith, and G. A. Pitsenbarger, Sylvania Electronic Defense Lab., Mountain View, Calif.*

"Instrumentation System for Three-Dimensional Tracking of Underwater Missiles," *C. S. Soliozy and J. M. Formwalt, U. S. Naval Underwater Ordnance Station, Newport, R.I.*

"ITT Secure Ranging and Communication System," *A. E. Nashman, ITT Labs., Nutley, N. J.*

"Identification and Evaluation of Magnetic Field Sources Associated with Magnetic-Anomaly Detector Equipped Aircraft," *P. Leliak, The Martin Co., Baltimore, Md.*

"Inertialess Scanning and Tracking Radar (INSTAR)," *J. R. Karp, The W. L. Maxson Corp., New York, N. Y.*

#### Session 1.2—Satellite Electronics

Moderator: *To be announced.*

"A Satellite Microwave Telemetry Oscillator Using Traveling-Wave Tube Techniques," *L. A. Roberts, Watkins-Johnson Co., Palo Alto, Calif.*

"Application of Microminiaturization Concepts to Space Guidance Computers," *E. Keonjiam, American Bosch Arma Corp., Hempstead, N. Y.*

"Criteria for the Optimum Design of Active Satellite Communication Systems," *A. R. Giddis, Philco Western Development Lab., Palo Alto, Calif.*

"Satellite Ionosounder," *S. Horowitz, AF Cambridge Research Center, Bedford, Mass., and L. Humphrey, General Electric Co., Ithaca, N. Y.*

"Satellite Reliability Achieved Through Comprehensive Environmental and Functional Testing," *J. A. Chambers, U. S. Army Ordnance Missile Command, Redstone Arsenal, Ala.*

"A Compact UHF Diplexer for Applications Involving Rockets or Satellites," *S. E. Parker, Hughes Aircraft Co., Culver City, Calif.*

#### Session 1.3—Microwave Devices and Techniques

Moderator: *G. R. Kilgore, Westinghouse Electric Corp., Baltimore, Md.*

"Status of Ultra-Low-Noise Traveling-Wave Tubes and Beam-Type Parametric Amplifiers," *K. Kotzebue, B. P. Israelsen and G. E. St. John, Watkins-Johnson Co., Palo Alto, Calif.*

"New Microwave Devices with Bulk Semiconductors," *H. Jacobs, F. A. Brand, M. Benanti, J. Meindl, and R. Benjamin.*

"Phase Stable Limiting Amplifiers Using Beam Deflection Tubes," *E. R. Wingrove, Jr., General Electric Co., Syracuse, N. Y.*

"Applications of Traveling Wave Tubes to Microwave Circuits," *G. E. Austin, Sylvania Electronic Defense Lab., Mountain View, Calif.*

"Recent Electronic Scanning Developments," *J. P. Shelton and K. S. Kelleher, Aero Geo Astro Corp., Alexandria, Va.*

"Practical Stripline Component Design," *V. T. Norwood, Hughes Aircraft Co., Culver City, Calif.*

#### Session 1.4—Instrumentation

Moderator: *To be announced.*

"The Pulsed Light Theodolite," *L. A. Jay, U. S. Army Electronic Proving Ground, Fort Huachuca, Ariz.*

"Multiple High-PRF Ranging," *D. H. Mooney and W. A. Skillman, Westinghouse Electric Corp., Baltimore, Md.*

"Recent Achievements in Missile-Borne Magnetic Tape Recorders," *M. M. Siera, Lockheed Aircraft Corp., Palo Alto, Calif.*

"Hit Indicator Techniques for Direct Fire Weapons," *H. Chaskin, U. S. Naval Training Device Center, Port Washington, N. Y.*

"Effects of Atmospheric Pollutants on Electronic Equipment," *H. C. McKee, Southwest Research Inst., San Antonio, Texas.*

"A Delay-Line Synthesized Filter Bank with Electronically Adjustable Impulsive Response," *H. J. Bickel and E. Brookner, Federal Scientific Corp., New York, N. Y.*

#### Session 1.5—Noise Effects on Precision and Data

Moderator: *To be announced.*

"0.1% Accuracy Variable Speed Control System," *M. Hartman, Fairchild Camera and Instrument Corp., Syosset, L. I., N. Y.*

"Pulse Operation of DC Servo Motors for Lower Thresholds," *D. J. Salonimer and W. E. Yoakum, Guided Missile Agency, Redstone Arsenal, Ala.*

"A Mathematical Analysis of Transients Caused by AGC Reset in Line Switching Amplifier as Used in AN/MSQ-18 (Missile Monitor) Equipment," *1st. Lt. R. A. Perry and SP-4 J. M. Dugan, U. S. Army Air Defense Board, Fort Bliss, Texas.*

"An Analogue Computer for Separating Evoked Physiological Potentials from Background Noise," *W. Korpfl, R. Robinson and J. C. Armington, Walter Reed Army Inst. of Res., Washington, D. C.*

"Precision Frequency Measurement of Noisy Doppler Signals," *W. A. Dean, Ballistic Measurements Lab., Aberdeen Proving Ground, Md.*

"Output Signal-to-Noise Characteristics of Correlators," *B. R. Mayo and D. K. Cheng, General Electric Co., Syracuse, N. Y.*

### Tuesday Morning, June 28

#### Session 2.1—Communications and Data Handling (Confidential)

Sponsor: Air Research and Development Command.

Moderator: *F. Brady, Research and Development Div., Office of The Chief Signal Officer, Dept. of the Army, Washington, D. C.*

"Engineering Analysis of Qualitative Data to Provide a Missile System for Simulation and Vulnerability Studies," *N. Johnson, Sylvania Electronic Defense Lab., Mountain View, Calif.*

"Spasur Automatic Digital Data Assembly System, Part I—The Digital Data Transmission Problem, Part II—Description of the Digital System," *W. B. Poland, Jr., U. S. Naval Research Lab. and M. S. Maxwell, and J. Pinker, U. S. Naval Weapons Lab., Dahlgren, Va.*

"Simulation by Interpretation," *F. W. Sinn, Jr. and J. J. Wolf, Burroughs Corp., New York, N. Y.*

"A Transistorized Digital Range Unit," *R. M. Lucas, Bell Telephone Labs., Inc., Whippany, N. J.*

"Pacific Missile Range Communications," *S. H. Vogt, Dept. of the Navy, Washington, D. C.*

"Evaluation of Video and IF MTI Cancellation Techniques," *E. C. Nordell, General Electric Co., Dewitt, N. Y.*

#### Session 2.2—Communications I

Moderator: *To be announced.*

"Military Applications for Speech Compression Techniques," *A. J. Strassman, Hughes Aircraft Co., Los Angeles, Calif.*

"Instrumentation Used for Ionosphere Electron Density Measurements," *W. J. Cruickshank, Ballistic Research Lab., Aberdeen Proving Ground, Md.*

"Electron Density Measurements in Hypersonic Projectile Trails," *R. S. Hebbert, U. S. Naval Ordnance Lab., White Oak, Silver Spring, Md.*

"Topology Engineering of Communication Networks," *Dr. K. Ikrath and C. C. Comstock, Hqs. U. S. Army Signal Res. and Dev. Lab., Fort Monmouth, N. J.*

"Frequency Selection," *H. R. Smith, Sierra Vista, Ariz.*

"The Economic Design of Radio Communication Systems by Matching the Message Urgency to the Fading Conditions," *L. P. Yeh, Page Communications Engineers, Inc., Washington, D. C.*

#### Session 2.3—Reliability

Moderator: *To be announced.*

"Serviceability: Complement to Reliability," *R. H. Wilcox and Cdr. V. R. Wanner, Office of Naval Res., Washington, D. C.*

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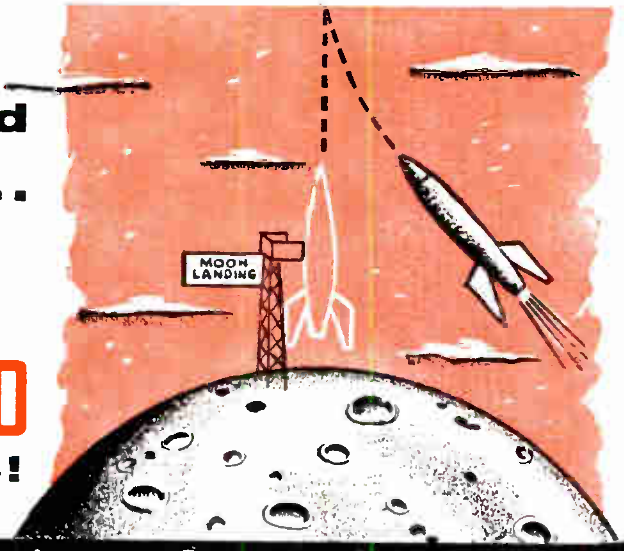


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| 400 WVDC — | .0082 to .33 MFD |
| 600 WVDC — | .0018 to .25 MFD |
| 1000 WVDC — | .001 to .1 MFD |
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- **INSULATION RESISTANCE AT 25°C:** For .05MFD or less, 100,000 megohms minimum. Greater than .05 MFD, 5000 megohm-microfarads.
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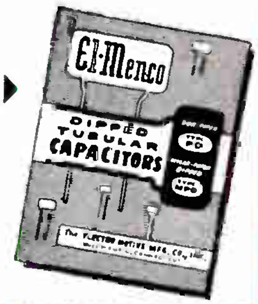


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"Reliability Anatomy for System Design Engineers," *E. S. Winlund, General Electric Co., Phoenix, Ariz.*

"A Complete Reliability Analysis of a One-Unit System," *R. E. Barlow and L. C. Hunter, Sylvania Electronic Defense Lab., Mountain View, Calif.*

"Statistical Pitfalls for the Reliability Engineer," *G. H. Beckhart, Radio Corp. of America, Moorestown, N. J.*

"The Use of IBM Cards to Predict, Control, and Measure Reliability of a Missile Electronics Unit," *G F. Dolan, Hughes Aircraft Co., Culver City, Calif.*

"System Improvement Through Failure Effect and a Reliability Model," *G. E. Unruh, Paramount Electronics, Inc., Hicksville, N. Y.*

### Session 2.4—Antennas

Moderator: *Dr. W. J. Otting, Jr., Director of Physical Sciences, Air Force Office of Scientific Res., Washington, D. C.*

"Ferromagnetic Antennas," *R. New, American Electronic Labs., Inc., Lansdale, Pa.*

"Effect of Antenna Phase Pattern on Doppler System Operation," *H. S. Rothman and W. E. Scharfman, Stanford Research Inst., Menlo Park, Calif.*

"A Generalized Analysis of Electronic Antenna Beam Steering," *P. D. Kennedy, Lockheed Aircraft Corp., Sunnyvale, Calif.*

"The Effect of Field Wire Stability on the Maximum Length of Loop," *N. W. Feldman and G. P. Tripp, Hqs, U. S. Army Signal Research and Development Lab., Fort Monmouth, N. Y.*

"The Shroud Antenna for High Speed Missiles," *V. W. Richard, Ballistic Research Lab., Aberdeen Proving Ground, Md.*

"Ring Arrays," *W. D. Nelson, General Electric Co., East Dewitt, N. Y.*

### Session 2.5—Ranging, Tracking and Reconnaissance

Moderator: *Dr. J. A. Boyd, Director, Willow Run Labs., University of Michigan, Ann Arbor, Mich.*

"A Continuous Wave Range System," *F. C. Lanza, Philco Corp., Palo Alto, Calif.*

"An Experimental Study of Monopulse Technique for Ground Clutter Discrimination," *S. Y. Chang and V. Stabilito, U. S. Army Ordnance, Frankford Arsenal, Philadelphia, Pa.*

"Tracking Research at the Naval Training Device Center," *G. Micheli, U. S. Naval Training Device Center, Port Washington, N. Y.*

"On the Tracking and Geodetic Potentialities of a Doppler Rate Measuring System," *D. C. Brown, RCA Service Co., Patrick Air Force Base, Fla.*

"Instrumentation Error Analysis of the AMR Missile Tracking System," *B. U. Glass, RCA Service Co., Patrick Air Force Base, Fla.*

"Statistical Method of Calculating Measurement Errors in Ranging and Tracking Checkout Systems" *L. G. Larson, Philco Corp., Palo Alto, Calif.*

## Tuesday Afternoon

### Session 3.1—Guidance and Space Technology (Confidential)

Sponsor: Air Research and Development Command.

Moderator: *To be announced.*

"Integrated Design of Antennas for Ballistic Missiles and Space Vehicles," *D. A. Alsberg, Bell Telephone Lab., Inc., Whippany, N. J. and H. W. Redlien, Wheeler Lab., Great Neck, L. I., N. Y.*

"The Space Surveillance System," *Dr. C. E. Cleeton, U. S. Naval Research Lab., Washington, D. C.*

"Orbit Determination for Passive Satellite Detection," *R. B. Patton, Jr., Ballistic Research Lab., Aberdeen Proving Ground, Md.*

"Evaluation of Reliability Prediction Techniques of the Electronics System of the Falcon Missile," *F. A. Barta, Hughes Aircraft Co., Culver City, Calif.*

"Reflections from Meteor Trails Meteorite Experiment," *D. Lynch and C. A. Bartholomew, U. S. Naval Research Lab., Washington, D. C.*

"A Proposed 24-Hour Communications Satellite System," *J. V. Michaels, G. N. Krassner and J. E. Bartow, U. S. Army Signal Res. and Dev. Lab., Fort Monmouth, N. J.*

### Session 3.2—Data Handling II

Moderator: *To be announced.*

"Research and Development of New Computer Programming Techniques Required for Mechanization of Machine Learning," *Dr. R. E. Smith, Control Data Corp., Minneapolis, Minn.*

"Pattern Recognition," *J. W. Brouillette and C. W. Johnson, General Electric Co., Syracuse, N. Y.*

"New Techniques in Residual Arithmetic," *M. R. Levine and J. Marx, American Bosch Arma Corp., Hempstead, N. Y.*

"A Note on the Applicability of Error-Correcting Codes," *J. E. Palmer, Radio Corp., of America, Camden, N. J.*

"A Real Time Telemetry Data Transmission System," *H. E. Rennacker, Collins Radio Co., Burbank, Calif.*

"Computer Controlled Automatic Diagnostic and Checkout System for Field Use," *R. J. Brachman, Frankford Arsenal, Philadelphia, Pa.*

### Session 3.3—Special Electrical Components

Moderator: *To be announced.*

"Some Aspects of Tunnel Diode Applications," *T. O. Krueger, U. S. Army Signal Res. and Dev. Lab., Fort Monmouth, N. J.*

"The 'Rayistor' an Electrical Transformer Using Optical Coupling," *J. C. Davis, Jr., Raytheon Co., Bedford, Mass.*

"Thin Film Components Based on Tantalum," *R. W. Berry and N. Schwartz, Bell Telephone Lab., Inc., Murray Hill, N. J.*

"Non Steady-State Thermoelectric Generators," *S. R. Hawkins, Lockheed Aircraft Corp., Sunnyvale, Calif.*

"New Developments in the Field of Military Quartz Crystals," *G. K. Guttwein, U. S. Army Signal Res. and Dev. Lab., Fort Monmouth, N. J.*

### Session 3.4—Radar

Moderator: *To be announced.*

"Precision Recording of Radar Operation," *C. M. Redman, Hq, White Sands Missile Range, N. M.*

"System Evaluation of Low Noise Radar Sensitivity," *S. Charton and G. Ver Wys, Radio Corp. of America, Moorestown, N. J.*

"The Implementation of the Integrated Mapping System," *J. Boyajean, Fairchild Camera and Instrument Corp., Syosset, L. I. N. Y.*

"A Flush-Mounted VHF Telemetry Antenna with Hemispherical Coverage," *R. C. Payne and P. Painter, Jr., Dynatronics, Inc., Orlando, Fla.*

"The Limitations of Angular Radar Resolution," *Dr. E. Eichler, U. S. Army Ordnance, Frankford Arsenal, Philadelphia, Pa.*

"Internal Ballistic Measuring System," *L. Adelson, Picatinny Arsenal, Dover, N. J.*

### Session 3.5—Simulation General

Moderator: *Dr. R. A. Weiss, Scientific Director, Army Research Office, Washington, D. C.*

"Space Simulation with High Gas Release Rates," *W. W. Balwanz and J. M. Singer, Naval Res. Lab., Washington, D. C.*

"Tank vs Tank Synthetic Gunnery Trainer," *I. Friedland, U. S. Naval Training Device Center, Port Washington, N. Y.*

"Radar Simulation," *C. Colbert, Westgate Lab., Inc., Yellow Springs, Ohio.*

"Mathematical Models of Multiple-Gimbal Systems," *Dr. A. Rosenfeld, Budd Lewyt Electronics, Inc., Long Island City, N. Y.*

"Optimization of Test Systems," *J. C. O'Brien, Cooper Development Corp., Monrovia, Calif.*

"Optimum Search Routines for Automatic Fault Location," *S. I. Firstman, The Rand Corp., Santa Monica, Calif., and B. Gluss, Armour Research Foundation of Illinois, Chicago.*

## Wednesday Morning, June 29

### Session 4.1—Electronic Generation, Switching and Radiation (Confidential)

Sponsor: Air Research and Development Command.

Moderator: *R. I. Cole, Manager, Military Projects Planning, Melpar, Inc., Falls Church, Va.*

"A Very High Gain Experimental Millimeter Foster Scanner," *C. A. Hacking, I-T-E Circuit Breaker Company, Philadelphia, Pa.*

"A Special Purpose Microwave Switch for Anti-jam Operation of Conical Scanning Radars," *S. D. Schreyer and G. Klein, Westinghouse Electric Corp., Baltimore, Md.*

"A Periodically-Focused 10 KW Microwave Traveling-Wave Amplifier," *O. T. Purl and K. W. Slocum, Watkins-Johnson Co., Palo Alto, Calif.*

"Electromagnetic Radiation in Sea Water," *E. J. Hilliard, U. S. Naval Underwater Ordnance Station, Newport, R. I.*

"Self-Focusing Technique for Large Arrays," *P. W. Howells, General Electric Co., Dewitt, N. Y.*

"A Radar Technique Using an Electro-Optical Two-Dimensional Filter, Part I—Principles of Operation, Part II—An Experimental Model Employing a Delay-Line Light Modulator," *L. Lambert, Moses Arm, and Isaac Weissman, Columbia Univ., New York, N. Y.*

### Session 4.2—Communications II

Moderator: *To be announced.*

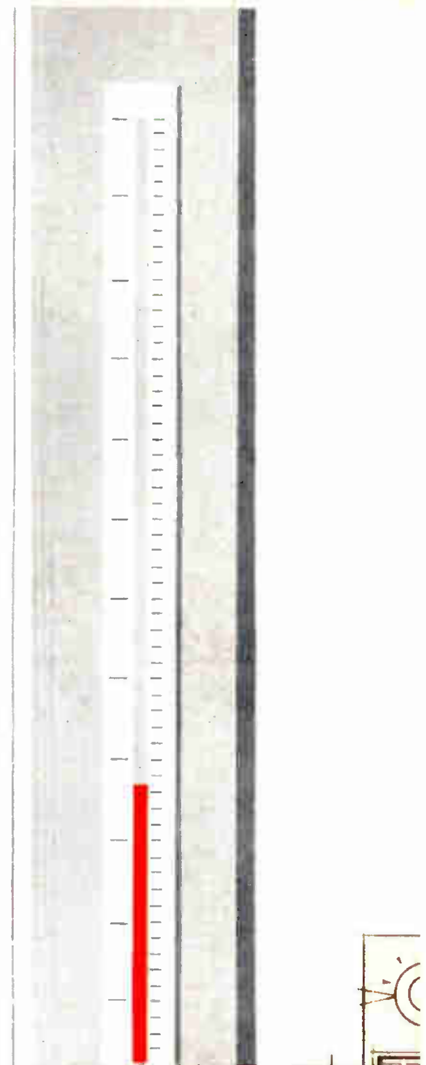
"Operational Testing of a Long Range Rocket Communication System," *B. J. Huffman, Hughes Aircraft Corp., Culver City, Calif., and W. F. O'Neil, C & N Lab. WADD, Wright-Patterson AFB, Ohio.*

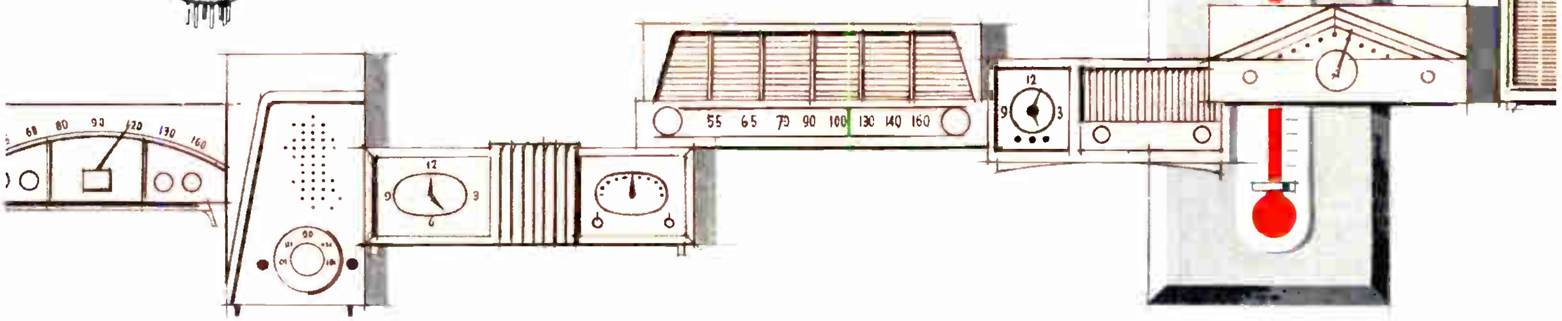
"A Long Range Rocket Communication System," *W. L. Exner and E. R. Gaul, Hughes Aircraft Co., Los Angeles, Calif.*

# Electron Tube News ...from SYLVANIA

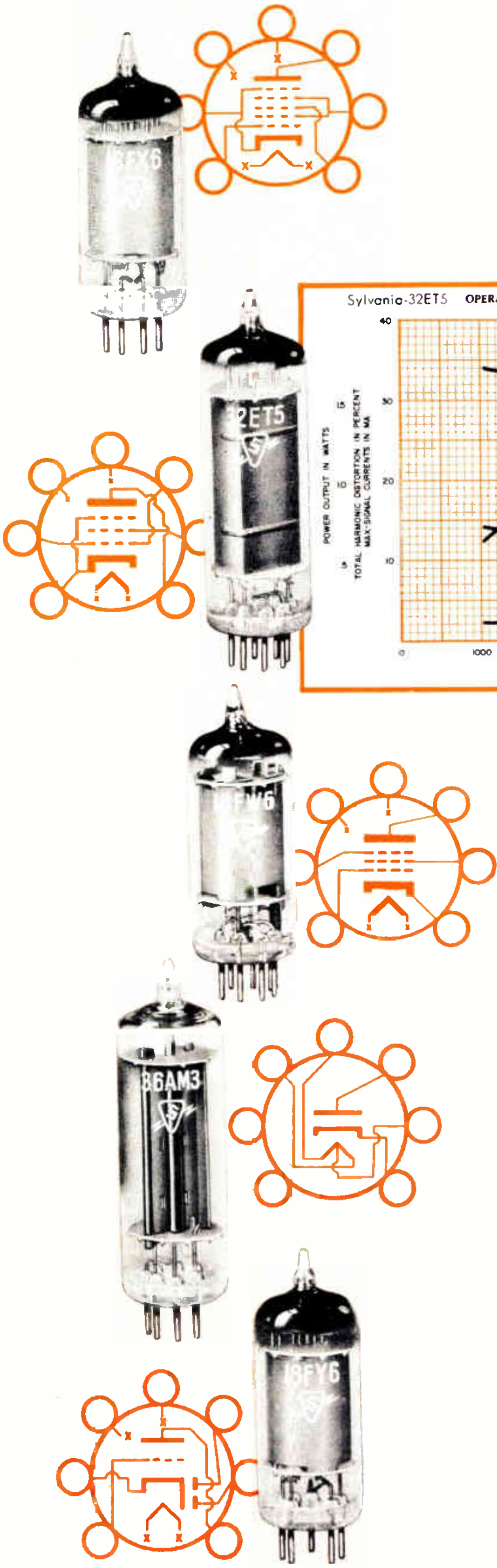
*Cool operation sparks home-radio sales when you design around*

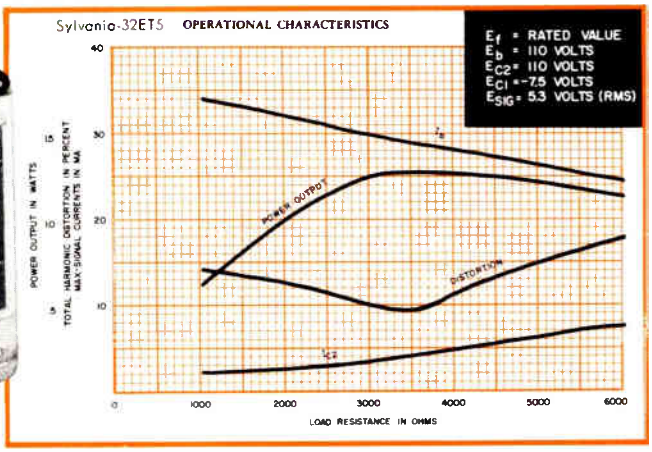
# SYLVANIA 100-mA ALL-AMERICAN FIVE





**Originated by Sylvania**—the 100-mA All-American Five requires ⅓ less heater power, opens new design possibilities and offers significant merchandising opportunities. Now, tube layout is comparatively unrestricted, cabinet styling is more flexible. Cost reductions in cabinetry, circuitry and components are within easy grasp. Tube reliability is enhanced. Printed circuit techniques can be used advantageously. Here, then, are important advances in home radio design—made possible by the Sylvania 100-mA All-American Five.



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**Lower ambient temperatures** increase design flexibility and offer substantial economies. Radio cabinets utilizing this carefully mated complement show temperature reductions of 20-25%. The area of the power output tube shows an even greater temperature decrease—as much as 30%. As a result, less expensive plastics can be used. Vertical chassis can be designed without special heat shielding. Placement of the power output tube is no longer critical because of heat—wide, outside "berths" are unnecessary—designs can be compact. Printed circuit boards may be used without deterioration in set life and performance caused by high ambient temperatures.

**Tube reliability is increased.** Sylvania heater design of the 100-mA line provides for more balanced distribution of the heater voltages in the heater string. Surge voltages across individual tubes are minimized.

**Sylvania 100-mA All-American Five** can be used in existing 150-mA designs with a minimum of redesign time. The 100-mA tube complement presents many advantages that can be directly translated into consumer benefits and increased home radio sales.

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"Impact of the Recent International Radio Conference, Geneva, on USAF Communications-Electronics Programs," *C. W. Loeber, Dept. of Air Force, Washington, D. C.*

"Communication by Re-radiation from Chaff," *B. V. Blom, Benson, Ariz.*

"Use of Faraday Rotations in Prediction of Ionospheric Disturbances," *H. S. Marsh, Watkins Johnson Co., Palo Alto, Calif.*

"Digital Battlefield Communications," *W. C. Slagle, Stromberg-Carlson, San Diego, Calif.*

### Session 4.3—Reliability II

Moderator: *W. S. Marks, Jr.*

"Participation in the Fleet Ballistic Missile Weapon System Component Reliability and in the Interservice Data Exchange Programs," *S. I. Pollock, U. S. Naval Ordnance Laboratory, Corona, Calif.*

"Application of an Environmental Probe Test Technique for Improving the Reliability of a Guided Missile Fuze," *B. W. Teres, Diamond Ordnance Fuze Lab., Dept. of the Army, Washington, D. C.*

"Reliability of a Parallel System Considering Load Redistribution," *C. H. Tsao and H. L. Leve, Hughes Aircraft Corp., Culver City, Calif.*

"Understanding and Improving System Reliability and Maintainability, Using Information in Engineering/Environmental Malfunction Data Samples," *G. H. Allen, Raytheon Co., Maynard, Mass.*

"The Reliability of Hermetically Sealed Equipment," *W. B. Rossnagel, Kearfott Div. of General Precision, Little Falls, N. J.*

### Session 4.4—Systems Ancillary to Missiles

Moderator: *To be announced.*

"Equipment Design Trends in Missile Scoring Devices," *W. Ficklin, A. H. Maciszewski, J. J. Pakan and K. Ringer, A. R. F. Products, Inc., River Forest, Ill.*

"System Integration Factors in V/Stol Launched Air-to-Surface Missile," *I. H. Rubaii, International Business Machines Corp., Owego, N. Y.*

"Electric Firing of Fully Combustible Ammunition," *F. J. Dashnaw, Watervliet Arsenal, Watervliet, N. Y.*

"Airborne Instrumentation Systems Utilized in First and Second Generation Ballistic Re-entry Vehicles," *L. E. Foster, General Electric Co., Philadelphia, Pa.*

"Flight Measurements on the JUPITER R&D Missile," *C. T. N. Paludan, Huntsville, Ala.*

### Session 4.5—Simulation-Electronic

Moderator: *To be announced.*

"Electromagnetic Environment Simulation for System Trainers," *F. P. Cullen, W. Helf, and J. K. Scully, The Marquardt Corp., Pomona, Calif.*

"The Development of a Dynamic Target and Countermeasures Simulator," *R. L. Norton, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. M.*

"All Electronic Visual Flight Simulator," *P. L. Fox, Aerojet-General Corp., Azusa, Calif.*

"Celestial Navigation Trainer," *G. Jaquiss, U. S. Naval Training Device Center, Port Washington, N. Y.*

"ASW Submarine Target, Device 21B12, Type 1," *R. H. Dickman, U. S. Naval Training Device Center, Port Washington, N. Y.*

"Tank Turret Trainer, Device 3T1," *T. Mongello, U. S. Naval Training Device Center, Port Washington, N. Y.*

## Wednesday Afternoon

### Session 5.1—Instrumentation IV —(Confidential)

Sponsor: Air Research and Development Command.

Moderator: *D. J. McLaughlin, U. S. Naval Res. Lab., Washington, D. C.*

"Transmission of Electromagnetic Waves Through An Ionized Medium in the Presence of a Stron Magnetic Field," *T. P. Harley, Boeing Airplane Co., Seattle, Wash.*

"The Exploitation of Millimeter Waves for Military Applications," *H. N. Tate, Hq. U. S. Army Signal Res. and Dev. Lab., Fort Monmouth, N. J.*

"A Millimeter Wave Radar System," *J. M. DeBell, Jr., Allen B. DuMont Lab., Inc., Clifton, N. J.*

"Increased Jamming and Reconnaissance Effectivity Through Polarization Diversity," *E. F. Henry, Melpar, Inc., Falls Church, Va.*

"Countermeasures Techniques for Use Against Frequency-Jump Radars," *G. E. Austin, Sylvania Electronic Defense Lab., Mountain View, Calif.*

### Session 5.2—Space Technology

Moderator: *Dr. H. K. Ziegler, Chief Scientist, U. S. Army Signal Res. and Dev. Lab., Fort Monmouth, N. J.*

"Maintenance, Repair and Assembly in Space by Remote Means," *J. W. Clark, Hughes Aircraft Co., Culver City, Calif.*

"The Able-4 Thor Deep Space Probe," *P. F. Glaser, Space Technology Labs., Inc., Los Angeles, Calif.*

"Communication in Space by Deflected Sunlight," *K. W. Otten, Wright Air Development Div., Wright-Patterson AFB, Ohio.*

"Optimum Capacitor Charging Efficiency for Space Systems," *Dr. P. M. Moston, Dr. J. L. Neuringer and D. S. Rigney, Republic Aviation Corp., Farmingdale, N. Y.*

"Application of Inertial Techniques to Interplanetary Navigation," *M. J. Minneman, Republic Aviation Corp., Farmingdale, N. Y.*

### Session 5.3—Camera Display Devices

Moderator: *To be announced.*

"High Performance Camera Tube Program," *S. Gray, RCA Labs., Princeton, N. J.*

"High Speed Direct Electronic Printing Cathode Ray Tube," *N. Fyler, D. Cone, R. Dorr, J. Wurtz, Litton Industries, San Carlos, Calif.*

"Extending the Dynamic Range of Camera Tubes Employing Return Beam Modulation," *A. D. Cope and H. Borkan, Radio Corp. of America, Princeton, N. J.*

"Image Orthicon Tubes as Image Intensifiers," *N. Swanson, U. S. Army Engineer Res. and Dev. Lab., Fort Belvoir, Va.*

"Three-Dimensional Direct-View Display Tube," *R. D. Ketchpel, Huges Aircraft Co., Culver City, Calif.*

### Session 5.4—Vulnerability, Guidance and Control

Moderator: *W. S. Hinman, Jr. Technical, Director, Diamond Ordnance Fuze Lab., Ordnance Corps, U. S. Army, Washington, D. C.*

"Loran-C Navigation System," *W. Dickinson, Jansky and Bailey, Inc., Washington, D. C.*

"Abstract of MATTS System (Multiple Airborne Target Trajectory System)," *W. J. Zable, Cubic Corp., San Diego, Calif.*

"A New Gyro for Autopilot Use," *S. Dardarian, General Precisions, Inc., Little Falls, N. J.*

"Lightweight Inertial Systems," *R. E. Marcille, Litton Industries, Beverly Hills, Calif.*

"Inertial Accelerometers—Their Nature, Character and Limitations," *M. Manerer, General Precision, Inc., Little Falls, N. J.*

"Jamming Effectiveness Instrumentation," *Capt. C. H. Redwin and C. H. Meyer, III, Rome Air Dev. Center, Griffiss AFB, N. Y.*

### Session 5.5—Data Handling

Moderator: *To be announced.*

"High Speed Auto-Data System for Blast Studies," *R. D. Jones and J. D. Smith, Sandia Corp., Sandia Base, Albuquerque, N. M.*

"Data Acquisition for a Research and Development Test Stand," *T. Wong and R. L. Thomason, U. S. Naval Ordnance Test Station, China Lake, Calif.*

"The Handling of UDOP Data," *D. H. Parks, Radio Corp. of America, Patrick AFB, Fla.*

"Description of Automatic Data Reduction Facility Combining Maximum Versatility and Speed," *W. R. Schumacher, U. S. Navy Underwater Sound Lab., New London, Conn., and H. M. Wilkinson, Epsco, Inc., Cambridge, Mass.*

"The Digitron—A High Speed Data Display System," *P. J. Meredith, D. J. Griffin, and F. A. Paulus, The Marquardt Corp., Pomona, Calif.*

# Professional Groups*

**Aeronautical & Navigational Electronics (G-11)**—L. M. Sherer, RTCA, Bldg. T-5, 16 and Constitution Ave., N.W., Washington 25, D. C.; H. R. Mimno, Harvard Univ., Cambridge, Mass.

**Antennas & Propagation (G-3)**—A. Dorne, Dorne and Margolin, Westbury, L. I., N. Y.; S. A. Bowhill, Pennsylvania State Univ., University Park, Pa.

**Audio (G-1)**—H. S. Knowles, Knowles Electronics, 9400 Belmont Ave., Franklin Park, Ill.; Prof. A. B. Bereskin, E.E. Dept., Univ. of Cincinnati, Cincinnati 21, Ohio; M. Camras, Armour Res. Found. Tech. Ctr., Chicago 16, Ill.

**Automatic Control (G-23)**—J. E. Ward, Servomechanisms Lab., M.I.T., Cambridge 39, Mass.; G. S. Axelby, Westinghouse Air Arm Div., Friendship Airport, Baltimore 3, Md.

**Broadcast & Television Receivers (G-8)**—R. R. Thalner, Sylvania Home Electronics, 700 Ellicott St., Batavia, N. Y.; C. W. Sall, RCA, Bldg. 13-4, Camden, N. J.

**Broadcasting (G-2)**—G. E. Hagerty, Westinghouse Elec. Corp., 122 E. 42 St., Suite 2100, N. Y. 17, N. Y.; W. L. Hughes, E.E. Dept., Iowa State College, Ames, Iowa.

**Circuit Theory (G-4)**—S. Darlington, Bell Telephone Labs., Murray Hill, N. J.; W. Bennett, Bell Telephone Labs., Murray Hill, N. J.

**Communications Systems (G-19)**—J. E. Schlaikjer, IT&T Co., 67 Broad St., N. Y. 4, N. Y.; M. R. Donaldson, Electronic Comm. Inc., St. Petersburg, Fla.

**Component Parts (G-21)**—J. J. Drvostep, Sperry Gyroscope Co., Mail Station 1A 36, Great Neck, L. I., N. Y.; G. Shapiro, Engineering Electronics Sec., Div. 1.6, NBS, Connecticut Ave. and Van Ness St., Washington, D. C.

**Education (G-25)**—J. G. Truxal, Head, Dept. of E.E., Polytechnic Inst. of Brooklyn, Brooklyn, N. Y.; W. R. LePage, Dept. of E.E., Syracuse Univ., Syracuse, N. Y.

**Electron Devices (G-15)**—W. M. Webster, Semi-Conductor Div., RCA, Somerville, N. J.; E. L. Steele, Hughes Prods., Inc., International Airport Station, Los Angeles 45, Calif.

**Electronic Computers (G-16)**—A. A. Cohen, Remington Rand Univac, St. Paul 16, Minn.; R. O. Endres, Rese Engrg. Co., Philadelphia, Pa.; H. E. Tompkins, Moore School of E.E., Univ. of Pennsylvania, Philadelphia.

**Engineering Management (G-14)**—H. M. O'Bryan, Sylvania Elec. Prods., 730 3rd Ave., N. Y. 17, N. Y.; A. H. Rubenstein, Northwestern Univ., Evanston, Ill.

**Engineering Writing and Speech (G-16)**—T. T. Patterson, Jr., RCA, Bldg. 13-2, Camden, N. J.; H. B. Michaelson, IBM Res. Center, Box 218, Yorktown Heights, N. Y.

**Human Factors in Electronics (G-28)**—C. M. Jansky, Royal McBee Corp., Portchester, N. Y.; J. I. Elkind, Bolt, Beranek and Newman, Cambridge, Mass.

**Industrial Electronics (G-13)**—J. E. Eiselein, RCA Victor Div., Camden, N. J.; R. W. Bull, Armour Res. Found., Chicago, Ill.

**Information Theory (G-12)**—P. Elias, M.I.T., Rm. 26-347, Cambridge 39, Mass.; A. Kohlenberg, Melpar Inc., 43 Leon St., Boston 15, Mass.

**Instrumentation (G-9)**—C. W. Little, C-Stellerator Assoc., Box 451, Princeton, N. J.; G. B. Hoadley, Dept. of E.E., North Carolina State College, Raleigh, N. C.

**Medical Electronics (G-18)**—W. E. Tolles, Airborne Instruments Lab., 160 Old Country Rd., Mineola, L. I., N. Y.; L. B. Lusted, Univ. of Rochester Medical School, Strong Memorial Hosp., Rochester 20, N. Y.

**Microwave Theory and Techniques (G-17)**—A. A. Oliner, Microwave Res. Inst., 55 Johnson St., Brooklyn 1, N. Y.; D. D. King, Electronic Comm., Inc., 1830 York Rd., Timonium, Md.

**Military Electronics (G-24)**—H. Randall, 1208 Seaton Lane, Falls Church, Va.; D. R. Rhodes, Radiation Lab., Instrument Div., Orlando, Fla.

**Nuclear Science (G-5)**—A. B. Van Rennes, United Res. Inc., Tech. Div., 128 Alewife Brook Pkwy., Cambridge, Mass.; R. F. Shea, Dig Power Plant Engrg., Knolls Atomic Power Lab., General Electric Co., Schenectady, N. Y.

**Production Techniques (G-22)**—L. M. Ewing, General Electric Co., HMEED CSP-3, Syracuse 1, N. Y.; A. R. Gray, Rte. #1, Box 940, Orlando Vineland Rd., Wintergarden, Fla.

**Radio Frequency Interference (G-27)**—J. P. McNaul, U. S. Signal Corps., Hdqrs. Ft. Monmouth, N. J.; P. O. Schreiber, Technical Wire Prods., Springfield, N. J.

**Reliability and Quality Control (G-7)**—P. K. McElroy, General Radio Co., 22 Baker Ave., West Concord, Mass.; E. J. Breiding, IBM Corp., Kingston, N. Y.

**Space Electronics and Telemetry (G-10)**—C H. Hoeppner, Radiation, Inc., Melbourne, Fla.

**Ultrasonics Engineering (G-20)**—W. Roth, Roth Lab., 1240 Main St., Hartford 3, Conn.; O. Mattiat, Aerophysics Dev. Corp., P.O. Box 689, Santa Barbara, Calif.

**Vehicular Communications (G-6)**—A. A. MacDonald, Motorola, Inc., 4545 Augusta Blvd., Chicago 51, Ill.; R. P. Gifford, General Electric Co., Syracuse, N. Y.

* Names listed are Group Chairmen and Transactions Editors.

# Sections*

**Akron (4)**—C. D. Morrill, 2248 16th St., Cuyahoga Falls, Ohio; C. M. Kelly, 2915 Silver Lake Circle, Cuyahoga Falls, Ohio.

**Alamogordo-Holloman (7)**—M. W. Jones, 2302 Willow Dr., Alamogordo, N. Mex.; A. F. La Pierre, 1500 Roosevelt Ave., Alamogordo, N. Mex.

**Albuquerque-Los Alamos (7)**—R. C. Spence, 3020 W. Sandia Dr., Sandia Base, Albuquerque, N. Mex.; E. C. Davis, Neely Enterprises, 107 Washington St. S. E., Albuquerque, N. Mex.

**Anchorage (7)**—R. O. Voight, HQ Alaskan Command, APO 942, Seattle, Wash.; J. T. Little, Star Route B, Box 3453, Spenard, Alaska.

**Atlanta (3)**—W. L. Fattig, 1643 N. Gatewood Rd., Atlanta 6, Ga.; R. L. Ellis, Jr., 77 Karland Dr., N.W., Atlanta, Ga.

**Baltimore (3)**—B. Wolfe, 6112 Talles Rd., Baltimore 7, Md.; J. T. Wilner, 2610 No. Charles St., Sta. WBAL, Baltimore 18, Md.

**Bay of Quinte (8)**—H. L. Blacker, Northern Electric Co., Ltd., 250 Sidney St., Belleville, Ont., Canada; G. M. Turney, R.R.2, Carrying Place, Ont., Canada.

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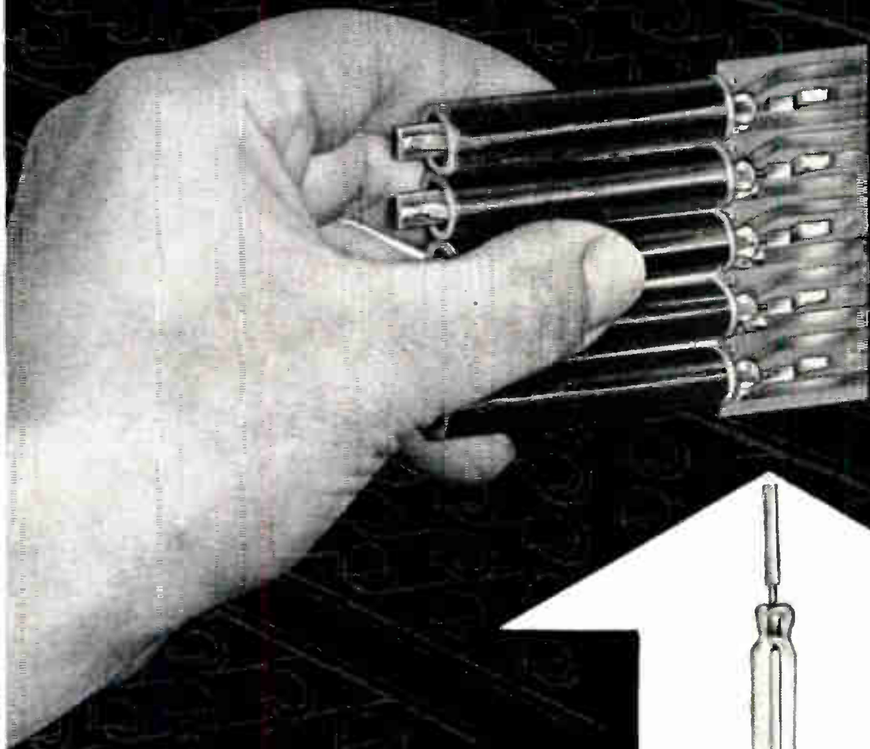

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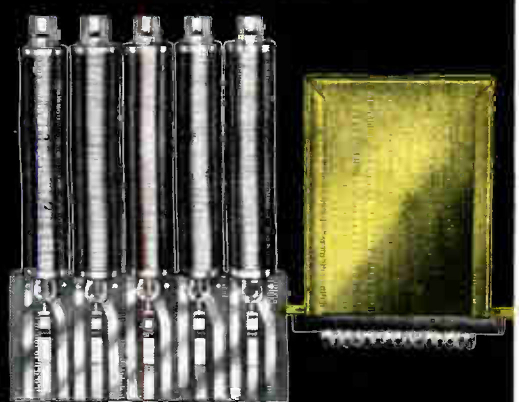

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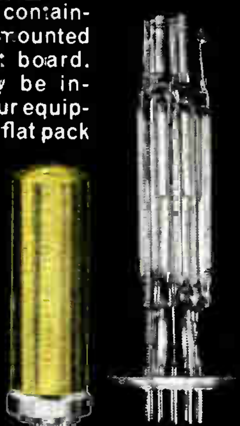

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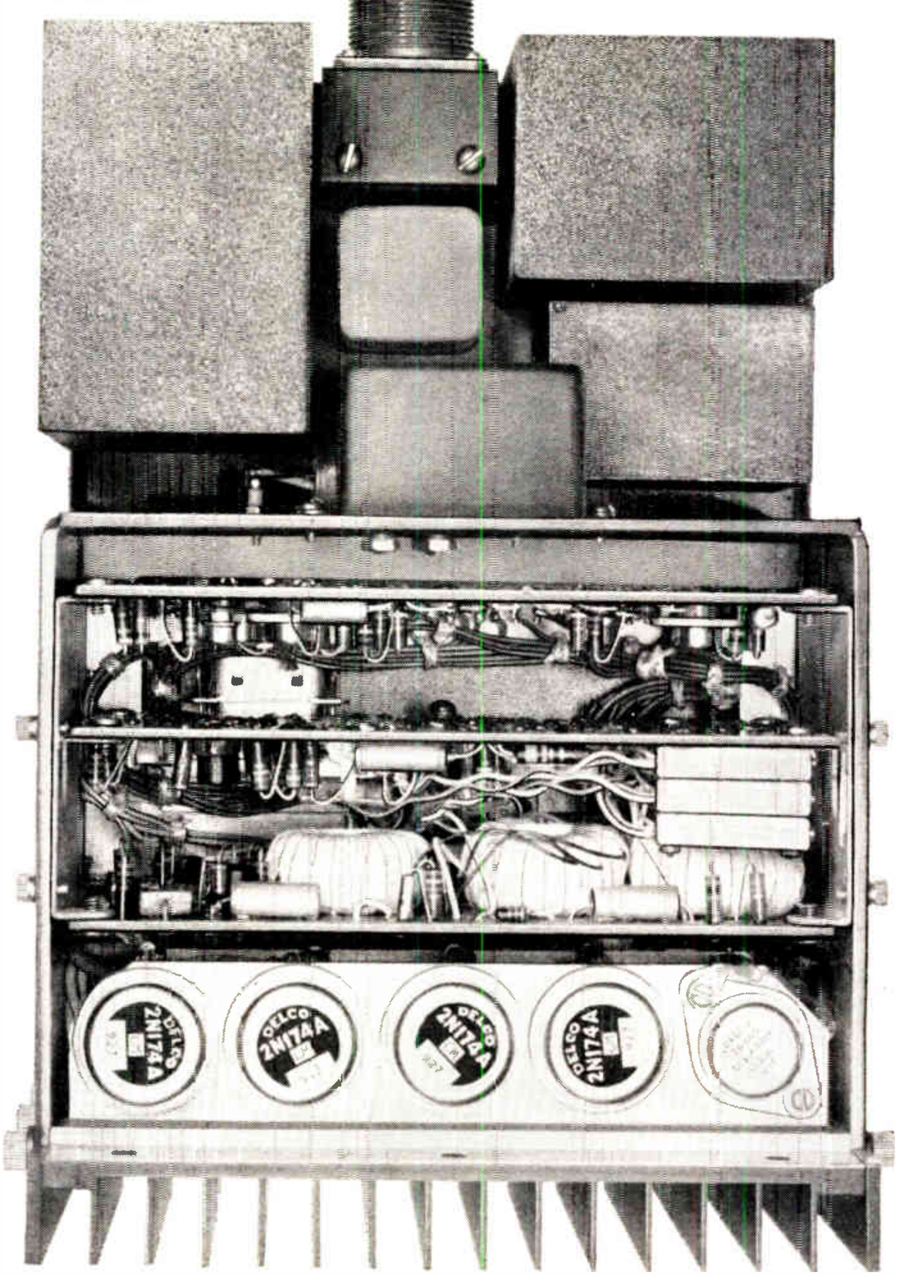

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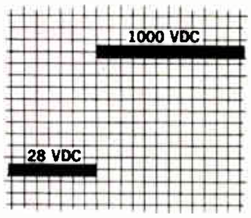


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Three years of research & development in the laboratories of **Thomas Electronics Inc.**, Passaic, N. J., have resulted in a new technique in the manufacture of industrial-military cathode ray tubes used in instrument and radar applications. The development, involving new processes, techniques and materials, permits the aluminizing of cathode ray tubes operating with anode potentials of as low as 2 kilovolts. Previously tubes were aluminized only at high voltages greater than 5 to 6 kilovolts.

Aluminized cathode ray tubes offer many advantages, one of which is a substantial increase in the screen brightness. Brightness can now be augmented by as much as 90% in low voltage cathode ray tubes, resulting in an increase in the writing rate, which is especially desirable in photographic and visual applications. Alternatively, the increase in brightness permits a reduction in the beam current for the average display which results in a consequent reduction in line width and better overall resolution.

When the faceplate of an ordinary cathode ray tube is touched with the hand, the effect may be an impairment of the resolution of the display, or the display may shift its position. These adverse effects are eliminated with an aluminized screen, since its overall screen potential is made uniform by the conductivity of the aluminum layer.

Another advantage is the elimination of cathode glow and the back reflection of light from the walls of an aluminized cathode ray tube resulting in a marked improvement in contrast for photographic and visual applications. Other improvements include the reduction or elimination of ion burns for magnetic deflection types and significantly longer overall tube life and reliability.

The aluminizing development can be incorporated into the manufacture of all existing JEDEC cathode ray tubes operating in the range between 2 to 8 kilovolts. Prototypes of the 5ADP- and 5AQP-types will be made available shortly.

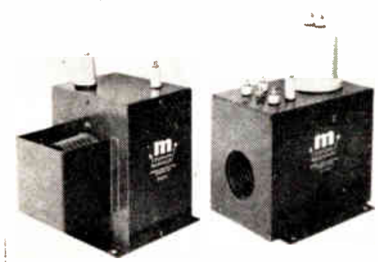
The first user of one of the low-voltage aluminized tubes is Analab Instrument Corp. which has worked jointly with Thomas in setting the specifications and has been evaluating performance of prototypes for oscilloscope applications.

In addition to oscilloscope applications, the tubes are suited for radar displays and any other display systems requiring the ultimate in light output and screen stability.

**These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.**

## Pulse Transformers And Reactors

Custom engineered pulse transformers and their associated charging reactors are now available from **Manson Laboratories**, P. O. Box 1214, Stamford, Conn. Pulsed viewing transformers, mono-and bifilar types, and transformers for magnetron and klystron applications can be produced in quantity for circuits rated up to 250 kv. Illustrated in photo are two examples of this custom engineering: On the left a bifilar pulse transformer with recessed bellows providing a wide temperature tolerance, 30 kv rated output, step up ratio 1:5, the Bifilar Secondary supplies a magnetron with 3 amperes heater current. On the right; a charging reactor (4.5 henry), high "Q," linear over a wide dc current range, insulated for operation at 10 kv dc supply voltage. All components will meet applicable MIL specs when required.



Inquiries regarding special applications and specifications are invited. Brochure #XFR260 and data application forms are available upon request.

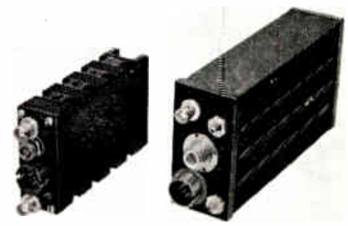
## CGS Laboratories Now Trak Electronics

Elton T. Barrett, president, **CGS Laboratories, Inc.**, Wilton, Conn., announces that henceforth the company will carry on operations under the name of **Trak Electronics Co.** The corporate name remains unchanged for the present, and the business will be conducted under the name Trak Electronics Co., Division of CGS Laboratories, Inc.

In announcing the change, Mr. Barrett said: "The principal reasons for the change are the adoption of a name by another company similar to our corporate name, a desire to avoid the limitations implied by the word 'Laboratories,' and to facilitate promotion to the trade mark 'TRAK,' which already has acceptance in the trade."

## Radar Beacon

**Telerad Manufacturing Corp.**, 1440 Broadway, New York 18, N. Y., announces a new, compact radar beacon MODEL SRT-3081. The outstanding features of this beacon are:



Environmental conditions—Temperature: −54°C to +125°C. Vibration: 10 to 100 cps at 25 G. Acceleration: 50 G. Altitude: 60,000 ft. Shock: 15 G.

Receiver—Frequency range: 2750–2950 mc. Bandwidth: 6–12 mc at 3 db points 35 mc maximum at 40 db down.

Triggering sensitivity: −41 db (min.). Interrogation: Single or double pulse. Frequency stability: ±2 mc. Size $1\frac{1}{4}'' \times 2\frac{7}{8}'' \times 5\frac{3}{4}''$.

Transmitter—Frequency range: 2750–2950 mc. Frequency stability: ±2 mc. Pulse power: 100 watts peak (min.) Pulse repetition rate: 2000 pp. Pulse width: 0.65±0.05 microsecond. Delay: 1.5 microseconds. Range jitter: 0.1 microsecond. Size: $2'' \times 3\frac{5}{8}'' \times 7\frac{9}{16}''$. Weight: 3.45 lbs. Power supplies available on special order.

For more detailed information on this beacon and other Telerad products that embrace the L, S, C, X and K bands, write to the firm.

## Connector Catalog

**Automatic Metal Products Corp.**, 323 Berry St., Brooklyn 11, N. Y., has published a radio frequency connector guide and technical manual.

Over two years of extensive research, development and preparation has gone into the production of this coaxial connector volume.

In addition to the connector illustrations, diagrams, and numerical designations, this volume will contain technical information on the use of connectors, a comprehensive section devoted to coaxial cables, and complete cable assembly instructions for all connectors listed. An additional section devoted to Automatic's coaxial relays and switches is also included.

Further information may be obtained by writing to the firm.

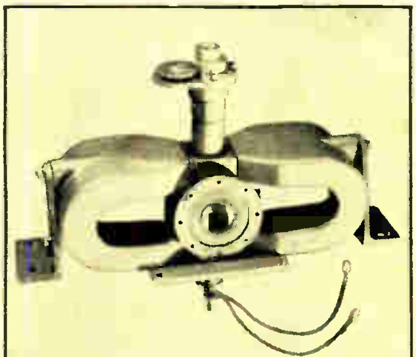
*(Continued on page 192A)*

# Creative Microwave Technology

Published by MICROWAVE AND POWER TUBE DIVISION, RAYTHEON COMPANY, WALTHAM 54, MASS., Vol. 1, No. 9

## NEW RAYTHEON MAGNETRONS FOR A WIDE RANGE OF APPLICATIONS

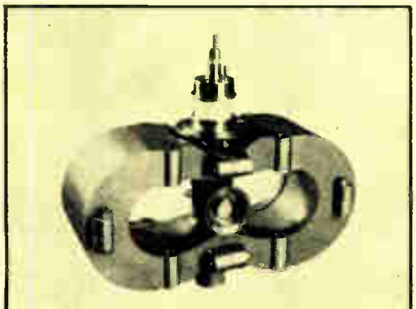
Designed for C-band systems requiring tunability, the RK-7156 magnetron has a minimum peak power output rating of 250 kilowatts over a frequency range of 5,450 to 5,825 megacycles. Applications include a flight-tested, revolutionary airborne weather radar system. The RK-7156 is in quantity production.



RK-7156

* * *

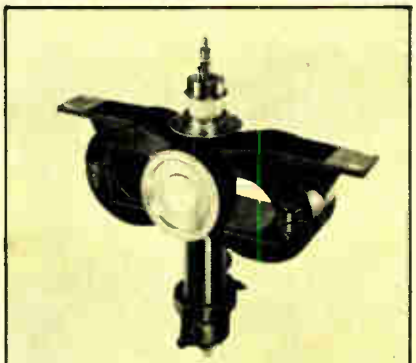
X-band magnetron for airborne search radar provides one megawatt minimum peak power and 875 watts average power within a frequency range of 9,340 to 9,440 Mc. Designated QK-624, this pulsed-type tube is liquid cooled and should give at least 1,000 hours of reliable service.



QK-624

* * *

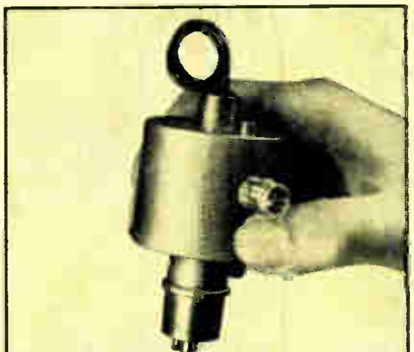
For ground-based and airborne radar systems, the RK-7529 magnetron provides a 2.0 microsecond pulse of 3.5 megawatts minimum peak power over 2,700 to 2,850 Mc. This liquid-cooled tube is interchangeable with other fixed-frequency S-band tubes operating at similar power levels.



RK-7529

* * *

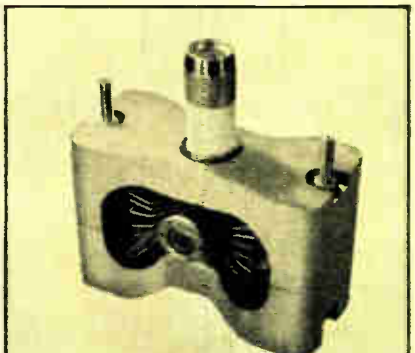
A one kilowatt beacon magnetron, the RK-7578 weighs only 14 ozs., yet will withstand vibrations of 15 G's at 20 to 2,000 cycles and shock up to 100 G's. It is mechanically tunable and covers the 5,400 to 5,900 Mc range.



RK-7578

* * *

Developed to withstand extreme environmental conditions, the RK-7449 magnetron is a lightweight, compact tube with a minimum peak power output of 45 kilowatts at the operating frequency of 24 kmc. The RK-7449 is required to withstand repeated shocks of 50G. Stable operation is guaranteed at vibration frequencies up to 2,000 c.p.s. with 30G applied.



RK-7449

*For the highest standard of Accuracy and Reliability*

# MARCONI INSTRUMENTS
## for Precise Measurement

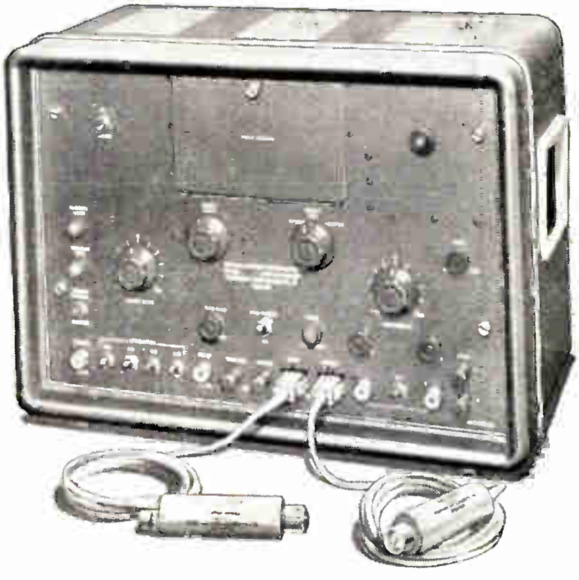
## LOW CAPACITANCE BRIDGE Model 1342

- Capacitance range: 0.002 $\mu\mu$F to 1.111 $\mu\mu$F, ± 0.2% accuracy.
- Shunt-resistance range: 1 to 1,000 MΩ.
- Suitable for in-situ measurements.
- Decade switching and readout.
- Independent indication of resistive component.

Capacitances down to 0.002 $\mu\mu$F can be measured with speed and precision by means of this three-terminal transformer ratio-arm bridge. Its exceptional discrimination and stability make it suitable for such applications as the measurement of the temperature coefficient of capacitors or changes in tube interelectrode capacitance. The bridge measures the capacitance between any two terminals of a 3-terminal network and is virtually unaffected by the impedance between either of these terminals and the third point. Connection to the component under test can be made via long leads without affecting measurement accuracy. Remote or wired-in components can be measured in-situ without the need to disconnect associated circuits.

## 20-MC SWEEP GENERATOR Model 1099

Can be used in conjunction with any oscilloscope for direct display of video response characteristics up to 20 MC. Frequency is indicated by crystal-controlled marker pips, and a special circuit provides for differential amplitude measurements, enabling relative response to be determined with a discrimination better than 0.01dB. **Frequency Swept Output:** Frequency Range: Lower limit 100 kc. Upper limit 20 MC. Output level: Continuously variable from 0.3 to 3 volts. Output Impedance: 75Ω. **Time Base:** Repetition Rate: 50 to 60 cps. Output for c.r.o. X deflection: 250 volts. **Frequency Markers:** At 1 MC intervals: every fifth pip distinctive and crystal controlled.




## SHORT-FORM CATALOG OF MARCONI INSTRUMENTS

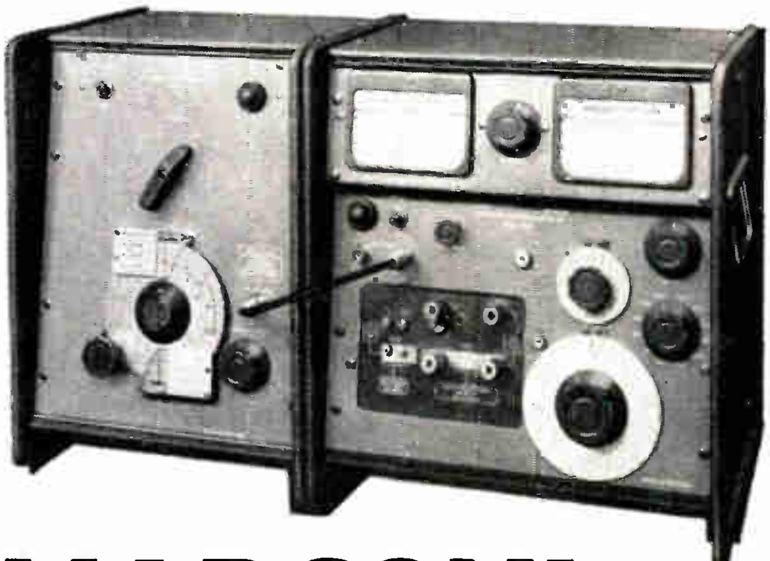
Keeps you up to date. Facilitates the rapid identification of the Marconi instrument most suitable for a prescribed purpose. More detailed information freely available.

Marconi Instruments wide range of test equipment covers VLF to EHF. The latest short-form Catalog is now freely available.

*Designers and Manufacturers of*
AM & FM SIGNAL GENERATORS
AUDIO & VIDEO OSCILLATORS
FREQUENCY METERS · VOLTMETERS
POWER METERS · DISTORTION METERS
FIELD STRENGTH METERS
TRANSMISSION MONITORS
DEVIATION METERS · OSCILLOSCOPES
SPECTRUM & RESPONSE ANALYZERS
Q METERS & BRIDGES

## Model 1064A/2 for MOBILE RADIO

This FM Signal Generator provides RF outputs of 30 to 50, 118 to 185, and 450 to 470 MC, with FM at one fixed deviation and 0-15 kc variable: IF crystal outputs at five spot frequencies, (xtals not supplied) and also an AF output. High frequency stability, quick warm up and accurate FM have been obtained by use of modern semi-conductor components. FM is produced by a varactor and the power supply is transistor stabilized with zener diode reference.



## Q METER
## Model 1245

**Here for the first time is a single Q Meter covering the range AF to VHF.**

**Frequency Range:** 1 kc to 300 MC. Measures Q: 5 to 1,000: accuracy 5% at 100 MC. **Q Multiplier:** x0.9 to x2. **Delta Q:** 25-0-25. Test Circuits: separate LF and HF test circuits have ranges of 1 kc to 50 MC and 20 to 300 MC. **Capacitance Range:** 7.5 to 110 μμF with 1-0-1 μμF incremental, for either test circuit; 20 to 500 μμF for LF test circuit. **Shunt Loss:** 12 MΩ at 1 MC, 0.3 MΩ at 100 MC. **External Oscillators:** Model 1247, 20 to 300 MC. Model 1246, 40 kc to 50 MC. Model 1101, 20 cps to 200 kc.

# MARCONI INSTRUMENTS

**111 CEDAR LANE · ENGLEWOOD · NEW JERSEY**

*Telephone: LOwell 7-0607*

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TC170

# IRE People

**Wayne D. Brodd** (A'54), has been promoted to the position of advisory engineer in the IBM 7070 Engineering Department of the IBM Product Development Laboratory at Poughkeepsie, N. Y., where he is engaged in the New Product Engineering effort on the 7070 Unit Record Equipment, and system coordination with Endicott and Rochester Engineering groups.

He joined IBM in 1950 as a customer engineer trainee at Evanston, Ill. He was transferred to Poughkeepsie in 1953 as a technical engineer on the 702 input/output development and advanced to associate engineer in 1955 where he became engaged in work on the 774 Tape Data Selector. He attained the status of staff engineer in 1958, his position until his recent advancement.

Mr. Brodd is a graduate of the University of Illinois, Urbana, in 1950 with the B.S.E.E. degree.

❖

**Donald W. Burns** (A'56), has been advanced to the position of technical assistant to Arthur J. Hatch, vice president and general manager of Stromberg-Carlson's Commercial Products Division, according to an announcement issued by Mr. Hatch. Stromberg-Carlson is a division of General Dynamics Corporation.

D. A. Burns

In this new position Mr. Burns will be responsible for development and coordination of a variety of technical programs. Prior to this appointment he was chief engineer in the Commercial Products Division.

He has been with Stromberg-Carlson since 1954, when he joined the firm as a staff engineer to the manager of quality control in the Radio and Television Division. Subsequently he served as an engineer in the Research Division, as a senior design engineer in the Special Products Division, and as chief engineer of the Commercial Products Group in the Special Products Division. Earlier he had been a design development engineer with Sylvania Electric Products Corporation in Buffalo.

Mr. Burns attended the University of Buffalo and received the B.A. degree in mathematics from the University of Rochester. He is a member of the Rochester Society for Quality Control, and is chairman of the Committtee on Sound Apparatus of the Electronic Industries Association.

❖

Roy J. Sandstrom, Bendix Systems Division, General Manager, has announced the appointment of **James A. Burns** (A'54) as Director of Long Range Planning for the Bendix Systems Division. He will fill the position vacated by L. B. Young who recently became Assistant General Manager of the Division. Mr. Burns was formerly Head of Technical Planning under Mr. Young.

As the new Director of Long Range Planning, he will direct the Technical Planning and Marketing activities of the division and will coordinate customer requirements into the preliminary design studies as well as preparation and presentation of proposals. He will also integrate the capabilities of other Bendix Divisions and potential subcontractors into major systems investigation.

He received the B.S. degree in electrical engineering from the University of Michigan, Ann Arbor, in 1952, majoring in electronics. After graduation, he joined the Willow Run Laboratories of the University of Michigan Engineering Research Institute where he participated in the fields of analog computation, weapons systems design and analysis, air defense system design, communication equipment design and test, and battle area surveillance system and equipment design and analysis. During this period, he was Project Engineer on systems design for low-altitude defense and other weapons systems work.

In the field of battle area surveillance, he served from 1953 to 1957 in various capacities on Project Michigan, a triservice program to improve the intelligence gathering capabilities of the service. He was engaged primarily in radar system design and analysis, particularly in the field of MTI and the processing and display of radar data. He performed a survey of all existing or development radar equipment to establish its application to battle area surveillance. In addition, he performed detailed evaluation and test of several specific radar systems, particularly those employing MTI.

In addition to his work in radar, he also participated in the establishment of requirements for battle area surveillance systems, including evaluation and test, using television, microwaves, infrared, acoustics, and optical devices as well as navigational subsystems of both the ground-based and self-contained types. In this connection, he performed system design involving sensory devices, data processing and display techniques, and communications. He also participated in the test of battle area surveillance and intelligence processing equipment in large-scale Army maneuvers. He was a consultant to the Bendix Systems Division on air defense and air traffic control problems in 1956, and joined Bendix in January, 1957.

(Continued on page 50A)

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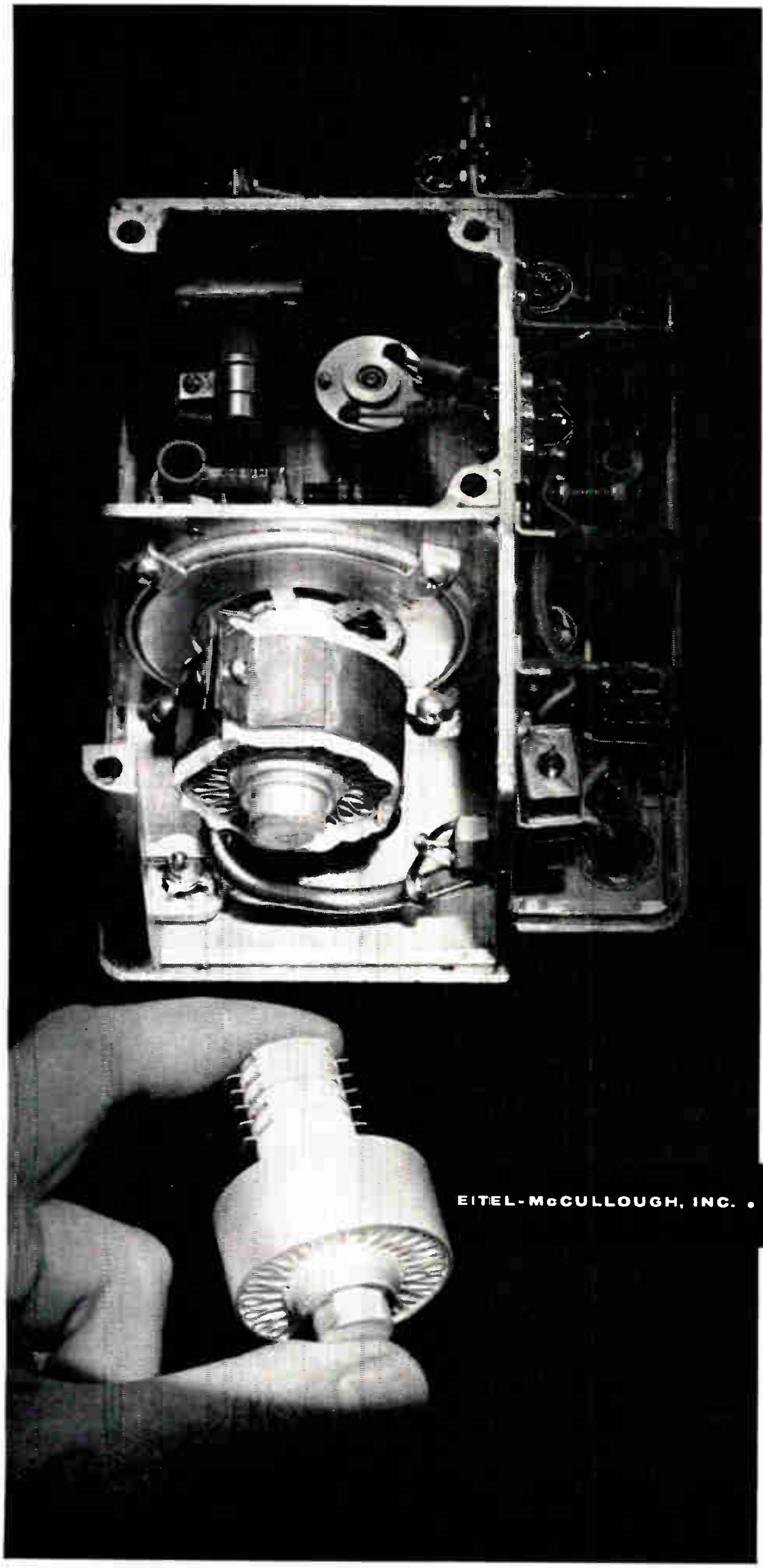


# SPACE AGE TV—WITH EIMAC CERAMIC TUBES

Lockheed's new miniature TV transmitter and camera have special significance for a space-curious world. They may one day help unravel some of the mysteries of the unknown as they soar through the outer reaches of space in a sophisticated sattelite.

At the heart of the tiny transmitter is an Eimac ceramic tetrode, the 4CX300A. Eimac ceramic tubes can take tough assignments like this in their stride, with performance "extras" that mean outstanding reliability.

Eimac advanced ceramic design makes possible a compact tube capable of maintaniing exceptional stability. Even under conditions of severe shock, vibration and accelerations up to 20g at frequencies from 20 to 2000 cycles per second no tube damage will result. Rugged, reliable power in a small package.

**EITEL-McCULLOUGH, INC.** • San Carlos, California

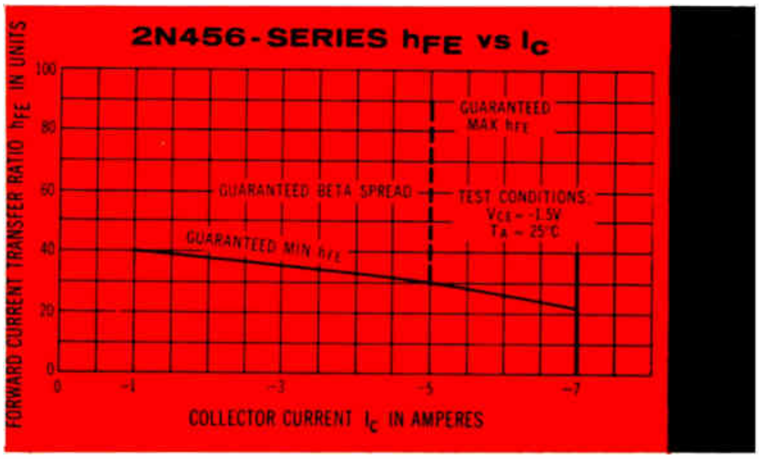
Eimac

Today, over 40 ceramic tube types pioneered by Eimac engineering and research are available for use under adverse conditions. Whenever you have an application that requires compact tubes that *can take it*, investigate the many advantages of Eimac advanced ceramic-metal construction.

# FULL LINE OF HIGHEST BETA GER

# New TI high-efficiency emitter gives you high beta germanium power transistors!

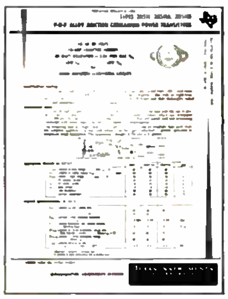

Now minimum and maximum betas are guaranteed from 20 to 60 at the maximum current rating of $I_C$ = 25 amps in new TI 2N514 series transistors. New high efficiency emitter makes possible greatly improved specifications for TI 2N456, 2N511, 2N512, 2N513, 2N514, and 2N1021 series alloy-junction germanium power transistors.




## TI gives you design leadership in quality germanium power transistors

### INCREASED BETA THROUGH HIGH-EFFICIENCY EMITTER

Emitter efficiency can be improved by increasing the ratio of resistivities between the emitter and base region. For example, when a 10 ohm-centimeter resistivity germanium wafer is used as the base material, it is advantageous to have less than a .01 ohm-centimeter resistivity emitter regrowth region. Since initial doping of the germanium crystal establishes base resistivity, the ratio can be changed only by varying the emitter material. TI utilizes an emitter material that results in a lower emitter resistivity and an increased emitter efficiency, plus providing the higher beta at high currents.



Optimum reliability for all TI germanium power transistors is assured by . . . 100% testing . . . 100% temperature cycling . . . 100% hermetic seal testing . . . continuous and intensive quality assurance program. Write on your company letterhead for germanium power transistor specifications.

GERMANIUM

*POWER/SWITCHING/DEFLECTION CIRCUIT*

TRANSISTORS

TEXAS INSTRUMENTS INCORPORATED

SEMICONDUCTOR-COMPONENTS DIVISION
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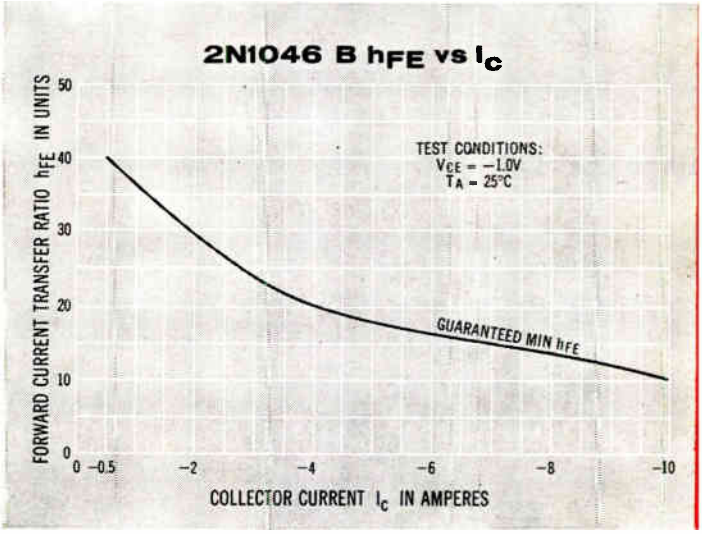
POST OFFICE BOX 312 • DALLAS, TEXAS

# MANIUM POWER TRANSISTORS

# New high current 2N1046-A-B give you high frequency/dissipation/voltage with high beta!


New TI 2N1046B germanium power transistors give you 10 amp $I_C$ with typical 18 mc $f_T$* . . . 130 volt $BV_{CBO}$ . . . guaranteed beta of 10 at 10 amp $I_C$ . . . 30 watt dissipation . . . high frequency/high current operating characteristics. The 2N1046 series alloy-diffused P-N-P transistors provides maximum reliability for your core driving, hi-fi amplification, and other high frequency power applications.

$f_T$* *Frequency at which common emitter current gain of the device is unity.*




Call on your nearest TI distributor or sales office for immediate delivery of TI germanium power transistors including the 1-amp 2N1038 series and the 3-amp 2N1042 series power transistors.

## TI GERMANIUM POWER TRANSISTOR CHARACTERISTICS AT 25°C

| Type | Dissipation at 25°C watts | Collector to Base Voltage-v max | Collector to Emitter Voltage min $BV_{CEO}$ | Emitter to Base Voltage-v min $BV_{EBO}$ | Collector Current Amps max | $h_{FE}$ @ $I_c$ min | $h_{FE}$ max | Collector Reverse Current $I_{co}$ max ma | Collector Reverse Current $I_{co}$ max v | Typ $R_{CS}$ @ $I_c$ ohms | Internal Cutoff Frequency avg $f_T$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2N456A | 50 | −40 | −20 | −20 | −7 | 30 @ 5a | 90 | −0.5 | −20 | 0.040 @ 5a | 430 kc |
| 2N457A | 50 | −60 | −30 | −20 | −7 | 30 @ 5a | 90 | −0.5 | −30 | 0.040 @ 5a | 430 kc |
| 2N458A | 50 | −80 | −40 | −20 | −7 | 30 @ 5a | 90 | −0.5 | −40 | 0.040 @ 5a | 430 kc |
| 2N1021 | 50 | −100 | −50 | −20 | −7 | 30 @ 5a | 90 | −0.5 | −50 | 0.040 @ 5a | 430 kc |
| 2N1022 | 50 | −120 | −50 | −20 | −7 | 30 @ 5a | 90 | −0.5 | −60 | 0.040 @ 5a | 430 kc |
| 2N511 | 80 | −40 | −20 | −30 | −25 | 20 @ 10a | 60 | −2 | −20 | 0.025 @ 10a | 260 kc |
| 2N511A | 80 | −60 | −30 | −30 | −25 | 20 @ 10a | 60 | −2 | −30 | 0.025 @ 10a | 260 kc |
| 2N511B | 80 | −80 | −40 | −30 | −25 | 20 @ 10a | 60 | −2 | −40 | 0.025 @ 10a | 260 kc |
| 2N512 | 80 | −40 | −20 | −30 | −25 | 20 @ 15a | 60 | −2 | −20 | 0.033 @ 15a | 280 kc |
| 2N512A | 80 | −60 | −30 | −30 | −25 | 20 @ 15a | 60 | −2 | −30 | 0.033 @ 15a | 280 kc |
| 2N512B | 80 | −80 | −40 | −30 | −25 | 20 @ 15a | 60 | −2 | −40 | 0.033 @ 15a | 280 kc |
| 2N513 | 80 | −40 | −20 | −30 | −25 | 20 @ 20a | 60 | −2 | −20 | 0.038 @ 20a | 300 kc |
| 2N513A | 80 | −60 | −30 | −30 | −25 | 20 @ 20a | 60 | −2 | −30 | 0.038 @ 20a | 300 kc |
| 2N513B | 80 | −80 | −40 | −30 | −25 | 20 @ 20a | 60 | −2 | −40 | 0.038 @ 20a | 300 kc |
| 2N514 | 80 | −40 | −20 | −30 | −25 | 20 @ 25a | 60 | −2 | −20 | 0.040 @ 25a | 350 kc |
| 2N514A | 80 | −60 | −30 | −30 | −25 | 20 @ 25a | 60 | −2 | −30 | 0.040 @ 25a | 350 kc |
| 2N514B | 80 | −80 | −40 | −30 | −25 | 20 @ 25a | 60 | −2 | −40 | 0.040 @ 25a | 350 kc |
| 2N1038 | 20 | −40 | −30 | −20 | −3 | 20 @ 1a | 60 | −125μa | −20 | 0.150 @ 1a | 8.0 kc $f_{\alpha e}$ min |
| 2N1039 | 20 | −60 | −40 | −20 | −3 | 20 @ 1a | 60 | −125μa | −30 | 0.150 @ 1a | 8.0 kc $f_{\alpha e}$ min |
| 2N1040 | 20 | −80 | −50 | −20 | −3 | 20 @ 1a | 60 | −125μa | −40 | 0.150 @ 1a | 8.0 kc $f_{\alpha e}$ min |
| 2N1041 | 20 | −100 | −60 | −20 | −3 | 20 @ 1a | 60 | −125μa | −50 | 0.150 @ 1a | 8.0 kc $f_{\alpha e}$ min |
| 2N1042 | 20 | −40 | −30 | −20 | −3 | 20 @ 3a | 60 | −125μa | −20 | 0.167 @ 3a | 8.0 kc $f_{\alpha e}$ min |
| 2N1043 | 20 | −60 | −40 | −20 | −3 | 20 @ 3a | 60 | −125μa | −30 | 0.167 @ 3a | 8.0 kc $f_{\alpha e}$ min |
| 2N1044 | 20 | −80 | −50 | −20 | −3 | 20 @ 3a | 60 | −125μa | −40 | 0.167 @ 3a | 8.0 kc $f_{\alpha e}$ min |
| 2N1045 | 20 | −100 | −60 | −20 | −3 | 20 @ 3a | 60 | −125μa | −50 | 0.167 @ 3a | 8.0 kc $f_{\alpha e}$ min |
| 2N1046 | 30 | −100 | −50 | −1.5 | −10 | 40 @ 0.5a | | −1 | −40 | 0.500 @ 1a | 15 mc min |
| 2N1046A | 30 | −140 | −50 | −1.5 | −10 | 20 @ 4a | | −1 | −40 | 0.125 @ 4a | 15 mc min |
| 2N1046B | 30 | −140 | −50 | −1.5 | −10 | 10 @ 10a | | −1 | −40 | 0.050 @ 10a | 15 mc min |

## IRE People

(Continued from page 46A)

Mr. Burns is a member of Tau Beta Pi, Eta Kappa Nu, Sigma Xi and Phi Kappa Phi. He has authored several classified publications and technical articles in the electronics field.

❖

**Jack G. Anderson** (A'56) has been appointed vice president for government relations at Stromberg-Carlson, Vice President and General Manager Allan R. Shilts has announced. Stromberg-Carlson is a division of General Dynamics Corporation.

J. G. Anderson

Mr. Anderson comes to Stromberg-Carlson from Hoffman Electronics Corporation of Los Angeles, where he was vice president for marketing. He had been with Hoffman since 1954, first as manager of Air Force operations and later as director of military marketing.

From 1942 to 1954 he served with the U. S. Air Force in many assignments throughout the United States, Europe, Africa and the Pacific. He was a major when discharged.

Mr. Anderson attended the University of Louisville and received the B.S. degree from the USAF Institute of Technology in Dayton, Ohio.

He is a past president of the Dayton Wright Chapter of the Armed Forces Communications and Electronics Association and is a member of many other organizations, including the American Rocket Society, Institute of Aeronautical Sciences, Air Force Association, Air Traffic Control Association, American Ordnance Association, Association of the U. S. Army, and the Navy League.

❖

**Ralph J. Bahnsen** (S'54-A'55-M'59), has been promoted to the position of advisory engineer in the Systems Engineering Department of Advanced Computational Systems at the IBM Product Development Laboratory in Poughkeepsie, N. Y. He is in charge of analysis work on an advanced Data Processing System.

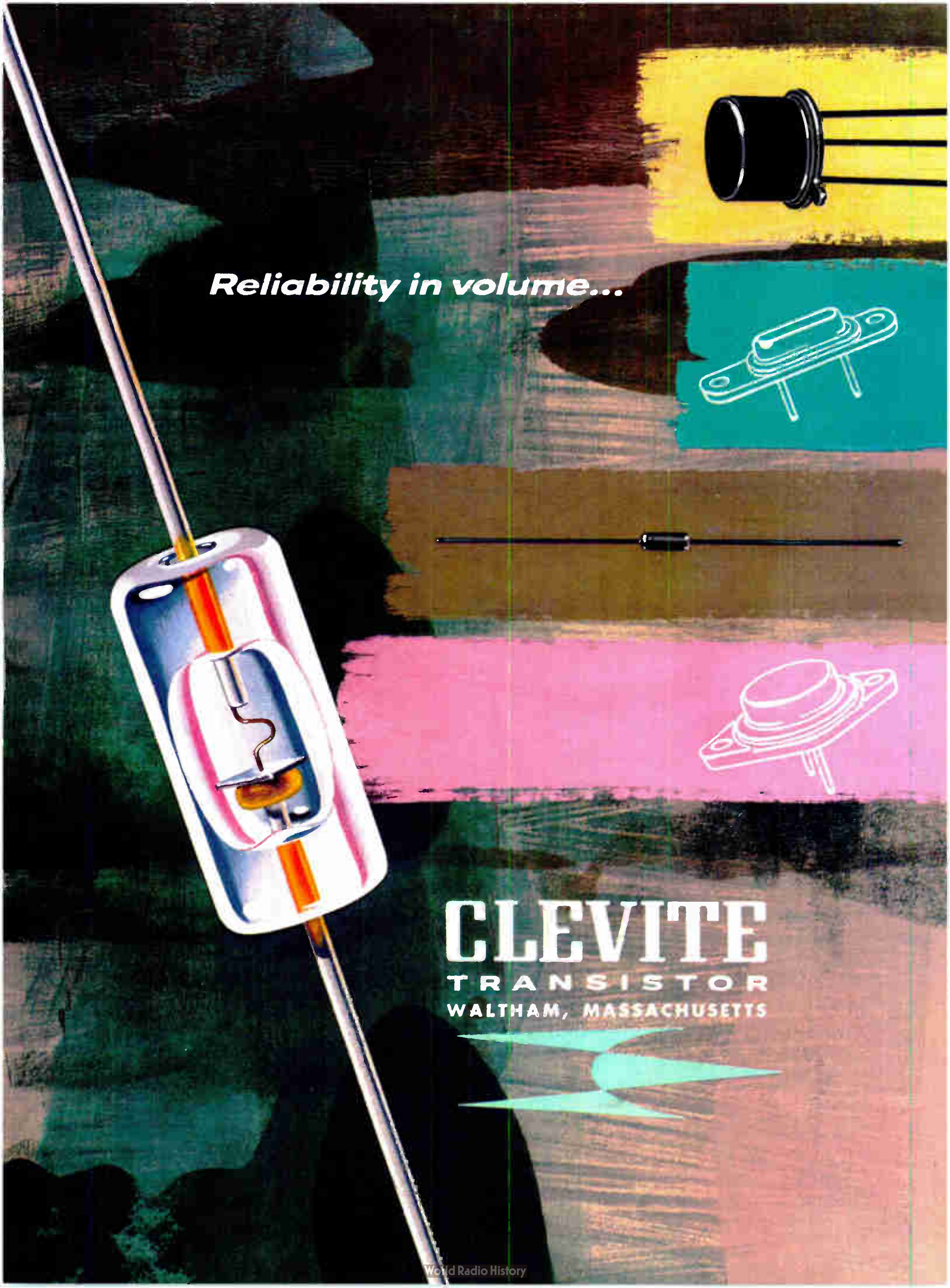
He joined the company in June, 1954 as a technical engineer working on the 702 Computer. He was transferred to Kingston in 1955 and returned to Poughkeepsie in 1956, attaining the status of associate engineer. He was engaged in the 738 memory and logical design of an advanced data processing system. He became a staff engineer in 1958, his position until his recent promotion.

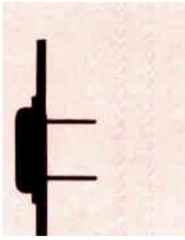
Mr. Bahnsen attended Queens College and received the B.E.E. degree from the College of the City of New York in 1954.

❖

**Dr. Nicholas A. Begovich** (S'41-A'48-M'58), has been appointed assistant man-

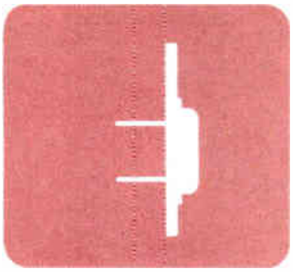
(Continued on page 54A)


Reliability in volume...
CLEVITE
TRANSISTOR
WALTHAM, MASSACHUSETTS



# NEW!





## ADVANCED DESIGN POWER TRANSISTORS FROM CLEVITE

Three new lines of germanium power transistors by Clevite feature new advances in controlled gain spread, fully specified collector-to-emitter voltage characteristics and low current leakage — even at maximum voltages and high temperatures.

*The new 8 ampere switching series* can be used to replace the older, more costly ring-emitter types in 3 to 8 ampere service.

*The new 25 ampere switching type* offers exceptionally low saturation voltage and is available with either pin terminals or solder lugs.

*The new Spacesaver design* not only affords important savings in space and weight, but its significantly improved frequency response means higher audio fidelity, faster switching and better performance in regulated power supply applications. Its low base resistance gives lower input impedance for equal power gain and lower saturation resistance, resulting in lower "switched-on" voltage drop. Lower cut off current results in better temperature stability in direct coupled circuits and a higher "switched-off" impedance.

**CLEVITE NOW OFFERS THESE COMPLETE LINES**

| Switching Types | Amplifier Types |
|---|---|
| 5 ampere | 2 watt |
| 8 ampere | 4 watt |
| 15 ampere | 2 watt Spacesaver |
| 25 ampere | |
| 3 ampere Spacesaver | |

All Clevite germanium power transistors are designed for low thermal resistance, low base input voltage, low saturation voltage and superior current gain.

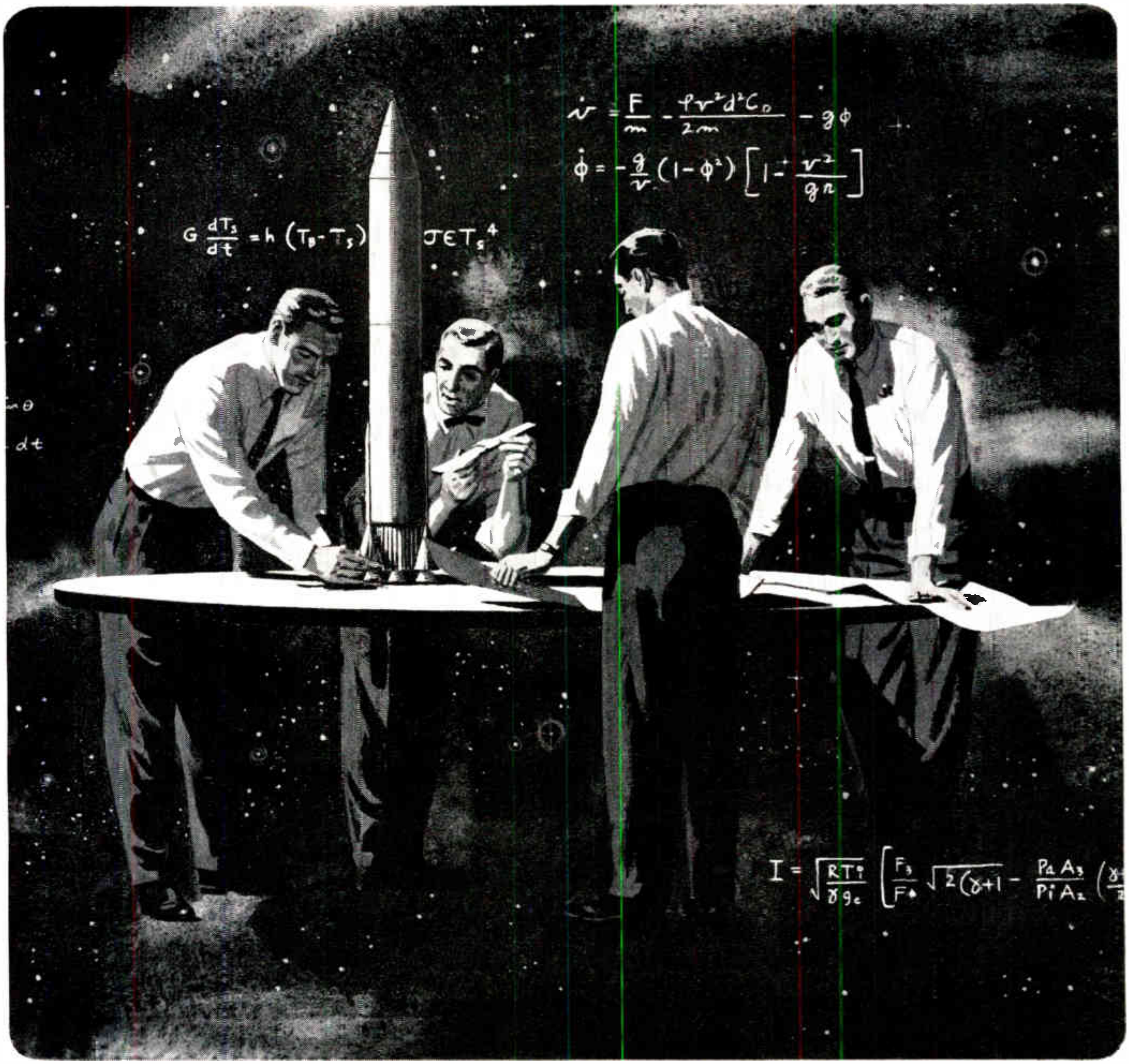
*For latest data and prices or application assistance, write for Bulletin 60 . . .*

A DIVISION OF CLEVITE CORPORATION

*Reliability in volume . . .*

**CLEVITE TRANSISTOR**

254 Crescent Street Waltham 54, Mass. Tel: TWinbrook 4-9330



## ENGINEERING TEAMWORK IN SPACE EXPLORATION

Engineers and scientists interested in a wide range of activities will appreciate the advanced nature of research and development projects under way at JPL. These projects include research, basic and applied, in Electronics, Solid State Physics, Propulsion, Aerodynamics, Structures and Materials and the design, development and analysis of space probes and satellites. Individually responsible engineers and scientists work together as a thoroughly integrated team in accomplishing the complete objective.

Programs involve guidance, telemetering, data recording and reduction, instrumentation, structures, propulsion, materials, solid state physics, components, heat transfer problems and systems analysis and are constantly influenced by continuing JPL space exploration research providing individuals with challenging assignments in almost every phase of engineering and science. Staff progress in diverse fields of activity is constantly being made.

Pioneering in basic research, applied research and development engineering in space exploration proves to be a stimulating attraction for engineers and scientists with innate curiosity and intense interest in the future of space exploration.

More men of this type are needed — if you believe you are qualified for the JPL team, send in your resume today.

jpl

CALIFORNIA INSTITUTE OF TECHNOLOGY

**JET PROPULSION LABORATORY**

A Research Facility operated for the National Aeronautics and Space Administration

**PASADENA, CALIFORNIA**

*Employment opportunities for Engineers and Scientists interested in basic and applied research in these fields:*

COMMUNICATIONS • MICROWAVE • SERVOMECHANISMS • COMPUTERS • LIQUID AND SOLID PROPULSION • STRUCTURES • CHEMISTRY • INSTRUMENTATION • MATHEMATICS • AND SOLID STATE PHYSICS •

***Send professional resume, with full qualifications and experience, for our immediate consideration***

## IRE People

(*Continued from page 50A*)

ager of Hughes Aircraft Company's Ground Systems Group, C. Harper Brubaker, vice president and Group manager, has announced.

N. A. Begovich

Dr. Begovich, formerly director of engineering at the Hughes plant, also will serve as director of product line operations.

He developed the principle of radar frequency scanning which, as incorporated in Hughes' "Frescanar," provides pinpoint three-dimensional information (range, bearing and altitude) using only one antenna, one transmitter and one receiver. Frescanar is the "eyes" of Missile Monitor, an advanced mobile air defense developed by Hughes for the U. S. Army.

Joining Hughes as a research physicist in 1948, he has also served as a consultant to the weapons system evaluation group for the Department of Defense, as a research engineer for the War Metallurgy Committee and the War Production Board, and as an instructor in electrical engineering at California Institute of Technology.

(*Continued on page 56A*)

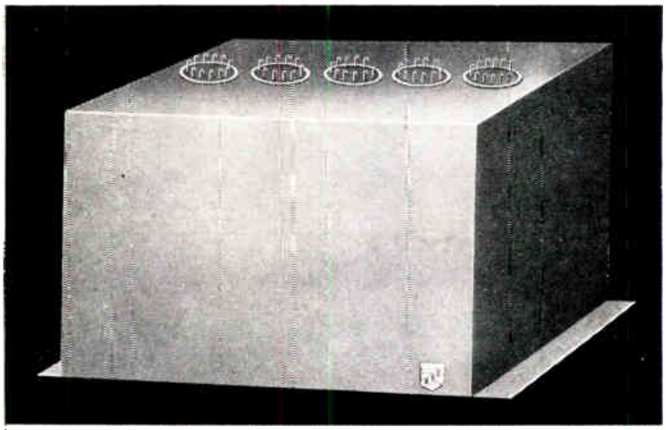
Distributed constant delay lines • Lumped-constant delay lines • Variable delay networks • Continuously variable delay lines • Pushbutton decade delay lines • Shift registers •

# ESC EXTRA

Pulse transformers • Medium and low-power transformers • Filters of all types • Pulse-forming networks • Miniature plug-in encapsulated circuit assemblies

# ESC DEVELOPS DELAY LINE WITH 170 to 1 DELAY TIME/RISE TIME RATIO

**Model 61-34 Perfected For Specialized Communications Application**



PALISADES PARK, N. J.—An entirely new Lumped-Constant Delay Line, with a proven 170 to 1 delay time/rise time ratio, has been announced by the ESC Corporation, Palisades Park, N. J. The new delay line, known as Model 61-34, was specifically designed for a specialized communications application calling for the exceptionally high delay time/rise time ratio.

ESC, the world's leading manufacturer of custom built and stock delay lines, is already widely recognized in the electronics industry for its exceptional engineering advances. In October, 1958, ESC broke through an existing design barrier and produced a delay line with a 145 to 1 delay time/rise time ratio. It had been thought, prior to the announcement of the Model 61-34, that ESC had reached the ultimate in this type of delay line.

SPECIFICATIONS OF NEW DELAY LINE MODEL 61-34

Delay time/rise time ratio: 170/1
Delay: 200 usec.
Rise time: 1.16 usec.
Attenuation: less than 2 db
Frequency response: 3 db = 325 KC
50 taps with an accuracy of ±0.2 usec. at each tap.

Complete technical data on the new unit can be obtained by writing to **ESC Corporation, 534 Bergen Boulevard, Palisades Park, New Jersey.**

## IRE People

(*Continued from page 54A*)

Dr. Begovich received the B.S., M.S. and Ph.D. degrees from Caltech. He has published papers on high frequency vacuum tube theory, electro-magnetic radiation problems and radar detection theory.

❖

**Carl W. Burrows, Jr.,** (M'59), has been appointed director of headquarters sales at Stromberg-Carlson Division of General Dynamics Coporation, according to an announcement by Allan R. Shilts, vice president and general manager of the division.


C. W. Burrows Jr.

Mr. Burrows comes to Stromberg-Carlson from Hoffman Electronics Corporation where he was associated with the military products division as director of headquarters sales. Prior to this he was with the Bendix-Pacific Division of Bendix Aviation Corporation.

From 1943 to 1955 he was on active duty with the Navy. For two and a half years during this time he served as an instructor at the U. S. Naval Postgraduate School, Monterey, Calif. in communications and anti-submarine warfare. He resigned from the Navy in 1955 as a lieutenant commander.

He attended Pasadena City College and was graduated from the U. S. Naval Academy at Annapolis, Md., in 1943. He is also a graduate of the communications course at the U. S. Naval Postgraduate School, Annapolis.

He is a member of the Institute of Aeronautical Sciences and the American Rocket Society.

❖

**Solomon Charp** (A'43–M'44–SM'50), has been appointed Manager of Navigation and Control Electronic Equipment for General Electric's Missile and Space Vehicle Department, Philadelphia, Pa.

He is responsible for three basic functions: investigation of complete navigation and control electronic systems; design and development of control components such as sensors and computers; and the design of electronic circuitry.

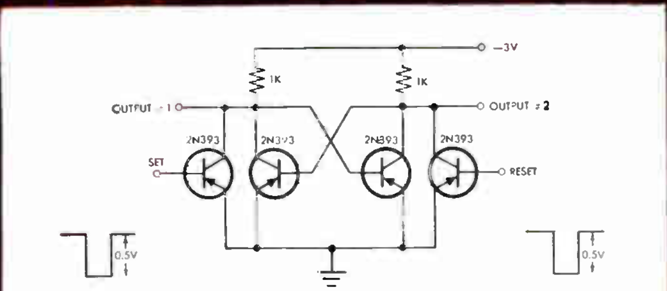
He joined the company in July, 1959, as a Consultant in radiation and data comparison and electronic systems. For eleven years previous to that he was a member of the research staff of The Franklin Institute.

A native of Jersey City, N. J., he attended public schools in Philadelphia. He graduated from the University of Pennsylvania, Philadelphia, in 1940 with the B.S. degree in Electrical Engineering and received the M.S. degree from that university in 1941.

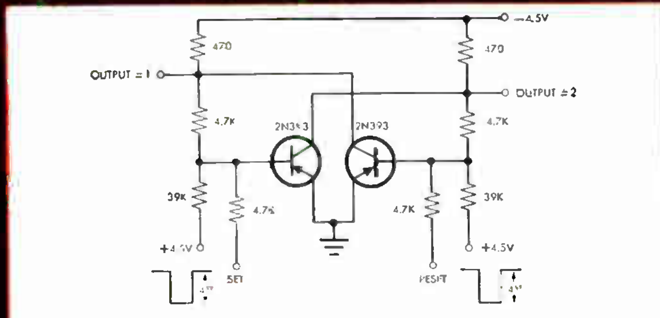
He was an instructor and research associate at the University of Pennsylvania for seven years previous to joining

(*Continued on page 58A*)

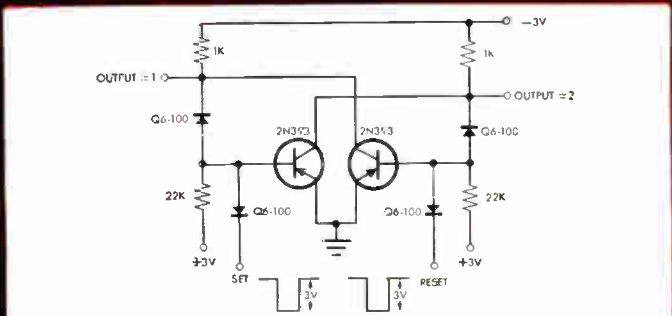
# PHILCO MAT* TRANSISTORS are UNIVERSALLY APPLICABLE To All Logic Circuits Up To 5mc



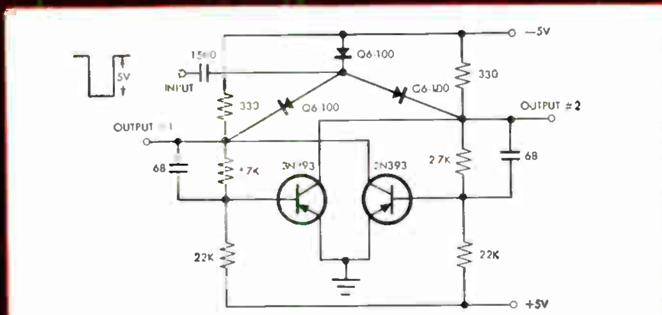

**DIRECT COUPLED TRANSISTOR LOGIC FLIP-FLOP**
TYPICAL SWITCHING TIMES: $t_r = 12$ mμsec. $t_f = 15$ mμsec.




**RESISTOR COUPLED TRANSISTOR LOGIC FLIP-FLOP**
TYPICAL SWITCHING TIMES: $t_r = 40$ mμsec. $t_f = 110$ mμsec.




**DIODE COUPLED TRANSISTOR LOGIC FLIP-FLOP**
TYPICAL SWITCHING TIMES: $t_r = 20$ mμsec. $t_f = 60$ mμsec.




**RESISTOR CAPACITOR COUPLED TRANSISTOR LOGIC BINARY STAGE**
TYPICAL SWITCHING TIMES: $t_r = 30$ mμsec. $t_f = 44$ mμsec.

## high frequency performance . . . at medium frequency prices

2N393

The Philco 2N393 Micro Alloy Transistor (MAT) has proved its complete reliability in millions of operating hours in every type of computer logic circuit up to 5 mc. It combines all the advantages of high frequency performance with low price. The 2N393 is easily designed into any logic circuit and offers the designer these important advantages:

- High beta
- Low saturation voltage
- High speed
- High $V_{BE}$ rating
- Low $I_{CO}$
- Low hole storage time

When you can buy so much for so little . . . don't settle for less in *your* equipment.

The 2N393 is also available in a military version . . . Mil 5-19500/77A (Sig.C.)

**Other Philco MATs to Meet Your Special Requirements:**
2N1122 . . . with 11 volt rating
2N1122A . . . with 14 volt rating
2N1427 . . . with additional parameter control

For data sheets, write Department IR 560.

*Reg. U.S. Pat. Off.

*Immediately available in quantities 1-999 from your local Philco Industrial Semiconductor Distributor.*

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*Famous for Quality the World Over*

LANSDALE DIVISION • LANSDALE, PENNSYLVANIA

TRANSISTOR CENTER U.S.A.

## IRE People

*(Continued from page 56A)*

The Franklin Institute in 1948.

He has conducted research in naval anti-aircraft fire control systems, electro-mechanics, statistical-type analogue computers, radar reflections, and radar guidance systems.

Mr. Charp is a member of Tau Beta Pi, Pi Mu Epsilon, Sigma Xi, the Research Society of America, and the AIEE. He is a member of the Executive Board of the Philadelphia Section of the AIEE and serves as Treasurer, 1960 International Solid State Circuits Conference.

❖

**L. Berkley Davis** (SM'53), has been elected a vice-president of the General Electric Company. He is general manager of the company's electronic components division which is made up principally of the Receiving Tube Department (Owensboro, Ky., also site of division headquarters); the Cathode Ray Tube Department (Syracuse, N. Y.); the Power Tube Department (Schenectady, N. Y.); and the Semiconductor Products Department (Syracuse, N. Y.)

L. B. Davis

He was born in Lewisport, Ky., October 27, 1911, and graduated from high school there. He attended the Engineering College of the University of Kentucky at Lexington, a member of the class of 1934.

After starting work in 1934 as an engineer with the former Ken-Rad Tube and Lamp Corporation in Owensboro, Ky., subsequent advancements placed him in charge of tube production engineering and brought him the position of chief engineer for the Ken-Rad Transmitting Tube Corporation. During World War II he became plant manager of the Owensboro Transmitting Tube operation. General Electric acquired the Ken-Rad tube facilities on January 2, 1945, and near the end of that year Mr. Davis was made manager of the Owensboro operations.

In December, 1949 he was appointed general manager of General Electric Receiving Tube operations, with headquarters in Owensboro. He became general manager of the newly-created Electronic Components Division of the General Electric Company in June, 1956, and retains this position with his appointment as a vice-president of the company.

❖

**Warren C. Foin** (S'53–A'54), has been promoted to the position of development engineer in the 7080 Engineering Department of Advanced Data Systems Development at the IBM Product Development Laboratory in Poughkeepsie, N. Y. He is now project manager, responsible for the design of the IBM 7080 Data Processing System.

*(Continued on page 60A)*

RMC

SUBMINIATURE

**DISCAPS**

# DESIGNED FOR COMPACT PRODUCTS

## SPECIFICATIONS

POWER FACTOR: 1.5% Max. @ 1 KC (initial)

WORKING VOLTAGE: 500 V.D.C.

TEST VOLTAGE (FLASH): 1000 V.D.C.

LEADS: No. 22 tinned copper (.026 dia.)

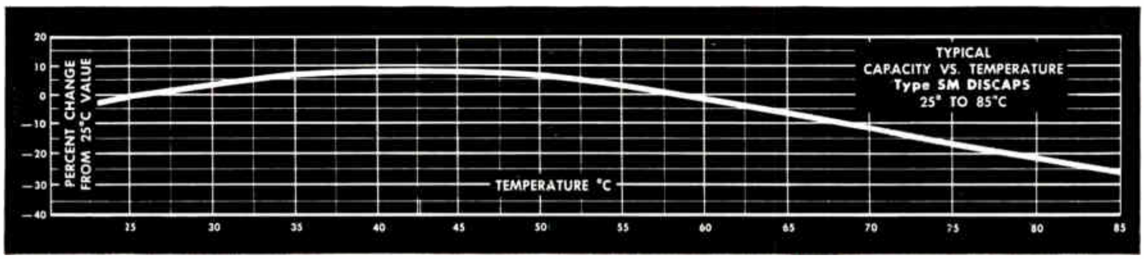
INSULATION: Durez phenolic (1/8" max. on leads)—vacuum waxed

STAMPING: RMC—Capacity—Z5U

INITIAL LEAKAGE RESISTANCE: Guaranteed higher than 7500 megohms

AFTER HUMIDITY LEAKAGE RESISTANCE: Guaranteed higher than 1000 megohms

RMC Type SM DISCAPS are designed for applications in compact radios, testing products, communication equipment and other products where space is of prime importance. These DISCAPS are rated at a working voltage of 500 volts and exhibit a minimum capacity change between +10° and +85° C. Type SM DISCAPS can be specified with the complete assurance of quality and reliability that is inherent in all RMC DISCAPS.




DISCAP CERAMIC CAPACITORS

RMC

**RADIO MATERIALS COMPANY**

A DIVISION OF P. R. MALLORY & CO., INC.

GENERAL OFFICE: 3325 N. California Ave., Chicago 18, Ill.

Two RMC Plants Devoted Exclusively to Ceramic Capacitors

**FACTORIES AT CHICAGO, ILL. AND ATTICA, IND.**

## IRE People

(Continued from page 58A)

Mr. Foin joined IBM in December, 1950 as a customer engineer and became a technical engineer on the IBM 770 in 1954. He has subsequently held positions as associate engineer and project engineer, his position until his recent advancement. Prior to his affiliation with the Company, Mr. Foin was associated with the Chance Vought Division of United Aircraft.

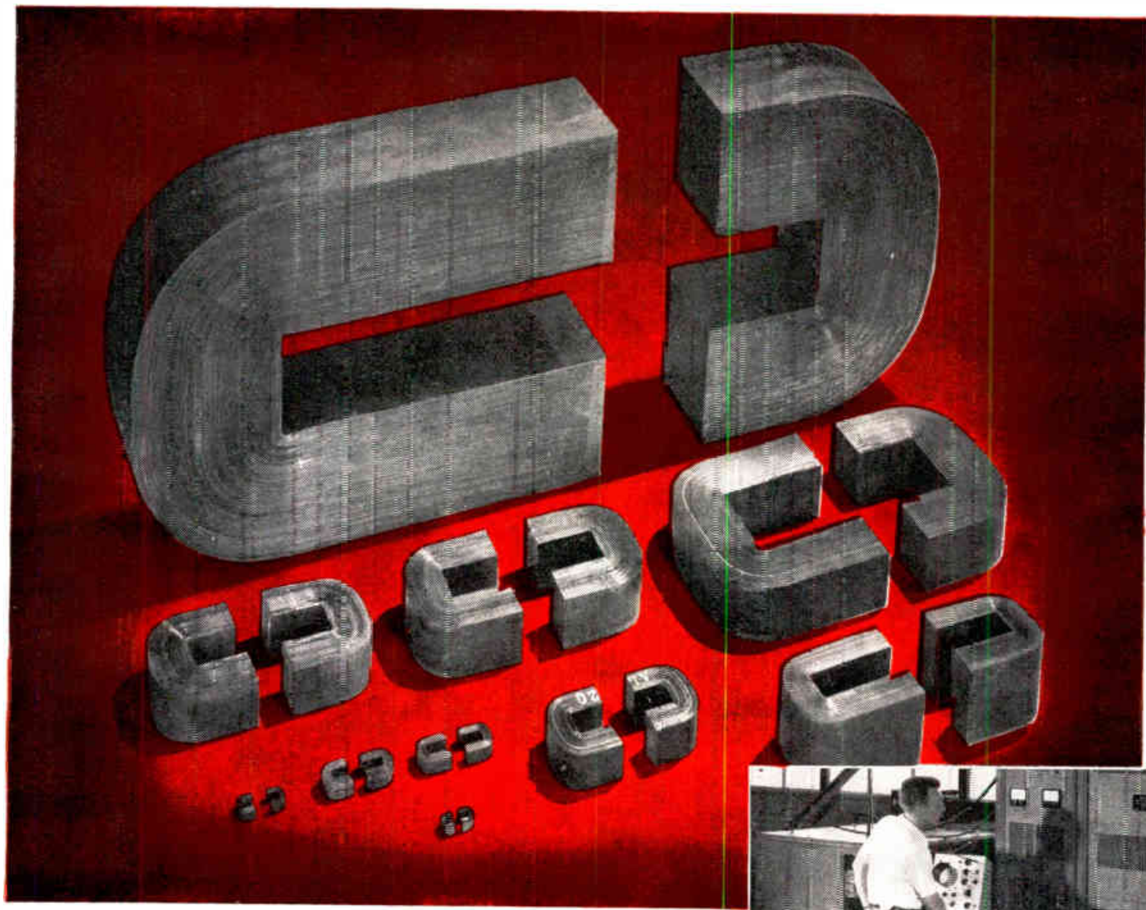
Mr. Foin received B.S.M.E. degrees from the Universities of New Hampshire and Illinois in 1945 and 1947 respectively, and the M.S.M.E. degree from Columbia University, New York, N. Y., in 1950. He is a member of Pi Tau Sigma.

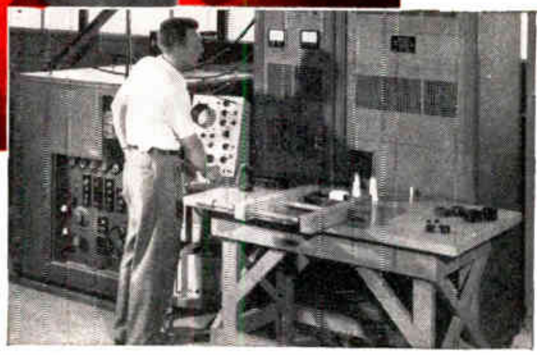
❖

**Steve J. Gadler** (SM'59), Col. USAF (Ret.), has been elected a Vice President of Hitchcock & Estabrook, Inc., Consulting Engineers and Architects. Mr. Gadler, who is director of the firm's newly established Electronic Division, is a graduate of the University of Minnesota in Electrical Engineering, is a registered professional engineer, and is considered an authority in Electronic Communications Systems Engineering.

He was decorated with the Legion of Merit for his outstanding contributions in the Communications Electronic field while he was Director of Electronics for

(Continued on page 61A)



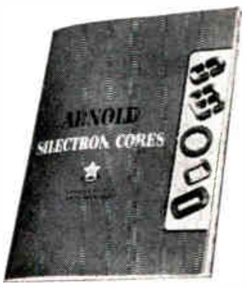


7372 C

# Arnold Pulse Transformer Cores are individually tested under actual pulse conditions

**Here's technical data on**

## ARNOLD SILECTRON CORES




*Bulletin SC-107 A*
. . . this newly-reprinted 52-page bulletin contains design information on Arnold Tape Cores wound from Silectron (grain-oriented silicon steel). It includes data on cut C and E cores, and uncut toroids and rectangular shapes. Sizes range from a fraction of an ounce to more than a hundred pounds, in standard tape thicknesses of 1, 2, 4 and 12 mils.

Cores are listed in the order of their power-handling capacity, to permit easier selection to fit your requirements, and curves showing the effect of impregnation on core material properties are included. A valuable addition to your engineering files—*write for your copy today.*

**ADDRESS DEPT. P-5**

The inset photograph above illustrates a special Arnold advantage: a 10-megawatt pulse-testing installation which enables us to test-prove pulse cores to an extent unequalled elsewhere in the industry.

For example, Arnold 1 mil Silectron "C" cores—supplied with a guaranteed minimum pulse permeability of 300—are tested at 0.25 microseconds, 1000 pulses per second, at a peak flux density of 2500 gausses. The 2 mil cores, with a guaranteed minimum pulse permeability of 600, receive standard tests at 2 microseconds, 400 pulses per second, at a peak flux density of 10,000 gausses.

The test equipment has a variable range which may enable us to make special tests duplicating the actual operating conditions of the transformer. The pulser permits tests at .05, .25, 2.0 and 10.0 microsecond pulse duration, at repetition rates varying anywhere from 50 to 1000 pulses per second.

This is just another of Arnold's facilities for better service on magnetic materials of all description. ● Let us supply *your* requirements.
*The Arnold Engineering Company, Main Office & Plant, Marengo, Ill.*

**ARNOLD**
**SPECIALISTS in MAGNETIC MATERIALS**

BRANCH OFFICES and REPRESENTATIVES in PRINCIPAL CITIES
*Find them FAST in the YELLOW PAGES*

# SILICON RECTIFIERS

| | | P. R. V. | Max. DC Current at T°C Resistive Load | Max. One Cycle 60 C.P.S. Surge Full Load | Max. Rev. Peak Current @ Max. Temp. & P.I.V. |
|---|---|---|---|---|---|
| LOW POWER RECT.  | 1N1217 SERIES | 50-1000 V. | 500 MA @ 110°C. AMB. | 15 AMPS. | 1.5 MA @ 150°C. JUNCTION |
| | 1N1227 SERIES | 50-1000 V. | 1.6 A @ 140°C. CASE | 15 AMPS. | |
| MEDIUM POWER RECT.  | 1N1341 SERIES | 50-600 V. | 6 A @ 150°C. CASE | 160 AMPS. | 10 MA @ 190°C. JUNCTION |
| | 1N1199 SERIES | 50-600 V. | 12 A @ 150°C. CASE | 200 AMPS. | |
| | 1N1191 SERIES | 50-600 V. | 18 A @ 140°C. CASE | 220 AMPS. | |
| | 1N1183 SERIES | 50-600 V. | 35 A @ 140°C. CASE | 220 AMPS. | |
| HIGH POWER RECT.  | 1N1396 SERIES | 50-500 V. | 70 A @ 150°C. CASE | 1200 AMPS. | 30 MA @ 190°C. JUNCTION |
| | 1N1660 SERIES | 50-500 V. | 160 A @ 125°C. CASE | 2000 AMPS. | 40 MA @ 190°C. JUNCTION |
| | 1N1670 SERIES | 50-500 V. | 240 A @ 125°C. CASE | 3000 AMPS. | 50 MA @ 190°C. JUNCTION |
| | 439 SERIES | 50-600 V. | 240 A @ 125°C. CASE | 3000 AMPS. | |

# GERMANIUM TRANSISTORS

| | Class | Typical Operation | | | Maximum Ratings | | | |
|---|---|---|---|---|---|---|---|---|
| | | $I_{CBO}$ μa | $h_{FE}$ | f mc/s | $V_{CE}$ V | $I_C$ ma | $P_C$ mw | $T_J$ °C |
| 2N59 | AUDIO-PNP | 10 | 100 | 1.2 | 20 | 200 | 180 | 85 |
| 2N60 | AUDIO-PNP | 10 | 70 | 1.1 | 20 | 200 | 180 | 85 |
| 2N403 | AUDIO-PNP | 10 | 33 | 0.85 | 20 | 200 | 180 | 85 |
| 2N614 | IF -PNP | 3 | 5 | 3 | 20 | 150 | 125 | 85 |
| 2N616 | IF -PNP | 3 | 20 | 9 | 20 | 150 | 125 | 85 |
| 2N617 | IF -PNP | 3 | 14 | 7 | 20 | 150 | 125 | 85 |

# SILICON POWER TRANSISTORS

| | Type | $h_{fe}$ or $h_{FE}$ | $f_{\alpha mc}$ | $V_{CEX}$ Volts | $I_C$ Amps | $T_J$ °C |
|---|---|---|---|---|---|---|
| 2N1015 SERIES—2 AMP. | NPN | 10 ($V_{CE}$=4 V $I_C$=2 A) | ALPHA CUTOFF .300 | 30-200 | 7.5a | 150 |
| 2N1016 SERIES—5 AMP. | NPN | 10 ($V_{CE}$=4 V $I_C$=5 A) | ALPHA CUTOFF .300 | 30-200 | 7.5a | 150 |

# 50 AMPERE SILICON "TRINISTOR"* CONTROLLED RECTIFIER

| Breakover Voltage @ 125°C $T_J$ | Reverse Blocking Voltage @ 125°C $T_J$ | Turn-on Time | Turn-off Time |
|---|---|---|---|
| | | TYPICAL | |
| 50-200 VOLTS | 50-200 VOLTS | 1.0 μ SEC. | 15-20 μ SEC. |

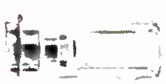
# RECTIFIER ASSEMBLIES

Standard rectifier assemblies are available in all types of circuit configurations, and are designed for either forced air or natural convection cooling with a wide range of ratings. Nickel-plated copper plates and other materials used in these assemblies have been chosen to insure satisfactory performance in corrosive atmospheres and high ambient temperatures.

# THERMOELECTRIC COOLING DEVICES

Two types are available in commercial quantities: WX814 (2.5 oz.) and WX816 (3.0 oz.). Both types measure about an inch and a half square and will find immediate application in cooling germanium transistors, infrared detectors, optical systems, mechanical and electric instruments, laboratory and portable medical equipment, and related fields where spot cooling below ambient is necessary.

# INFRARED DETECTORS



| Type | Noise Equivalent Power (NEP) Watts | Wave-length Response. Microns | Time Constant, μ SEC. |
|---|---|---|---|
| 812 | TYPICAL 5x10⁻¹¹ LIMIT 10⁻¹⁰ MAX. | 1-12 | TYPICAL 0.1 LIMIT 0.2 MAX. |

The types listed are just a small sampling of the complete line which can be supplied in volume quantities for prompt deliveries.

## IRE People

(Continued from page 60A)

the Air Defense Command Headquarters at Colorado Springs, Colo.

He is the author of many articles on technical matters and has several electronic developments to his credit. Mr. Gadler is a member of the American Institute of Electrical Engineers the Minnessota Society of Professional Engineers, the National Society of Professional Engineers, the North St. Anthony Park Business Men's Association and a Senior member of the Institute of Radio Engineers. He has been officially commended by the Norwegian and Japanese Governments for his work in Electronics.

❖

**Dr. Albert C. Hall** (A'39–SM'46–F'58), director of research and engineering for The Martin Company, has been named the company's vice president of engineering, George M. Bunker, chairman of the board, has announced.

A. C. Hall

Dr. Hall was elected by the missile, electronic and nuclear firm's board of directors at its regular monthly meeting last Friday. He will make his

(Continued on page 66A)

*NEW from RHEEM!*

# MILLI-MICRO-SECOND SWITCHING DIODES

15 advanced types including IN903 through IN908: IN251 • IN914 • IN916

*These new Millimicrosecond Diodes feature:*

## RECOVERY TIME

*.004 μsec.*

## VERY LOW CAPACITANCE

*1 μμf @ —6 volts*

RHEEM OFFERS THE INDUSTRY'S BROADEST LINE OF SILICON DIODES

## RHEEM SEMICONDUCTOR CORPORATION

*A SUBSIDIARY OF RHEEM MANUFACTURING COMPANY*

Dept. E4, P.O. Box 1327, Mountain View, California, Phone YOrkshire 8-9211. **Regional Sales Offices:** LOS ANGELES, 5150 Wilshire Blvd. • SAN FRANCISCO, 327 Moffett Blvd., Mountain View, Calif. • MINNEAPOLIS, 6519 Nicollet Ave. • DETROIT, 18450 Livernois Ave. • CHICAGO, 1919 N. Harlem Ave. • ENGLEWOOD, N. J., 610 East Palisade Ave. Distributors: NEW JERSEY, Eastern Radio Corp., 312 Clifton Ave., Clifton, New Jersey, Phone, GRegory 1-6600 • CHICAGO, Allied Radio Corp., 100 Northwestern Ave., Chicago, Illinois, Phone, HAymarket 1-6800 • PHILADELPHIA, Almo Radio Co., 412-16 N. 6th St., Philadelphia, Penn., Phone, WA 2-5918 • SAN FRANCISCO, Avnet Electronics Corp. of Northern Calif., 1262 N. Lawrence Station Rd., Sunnyvale, Calif., Phone, REgent 6-0300 • LOS ANGELES, Avnet Corp., 5877 Rodeo Rd., Los Angeles, Calif., Phone, UPton 0-6141 or VErmont 7-7111 • Westates Electronics Corp., 11334 Playa St., Culver City, Calif., Phone, EXmont 1-6201 or UPton 0-4544.







*(Continued from page 64A)*


headquarters in Denver, Colo.

Since joining Martin in 1958, his major effort has been with the TITAN program. Martin is prime contractor for airframe design, fabrication and testing of the weapon system.

A leading guidance and control systems scientist, he was general manager of the Bendix Aviation Corporation's Research Laboratories Division, Detroit, before he came to Martin as research director. He became engineering director for the TITAN in January, 1959.

The new vice president founded the Dynamic Analysis and Control Laboratory at the Massachusetts Institute of Technology, where he was a faculty member for 13 years.

A native of Port Arthur, Texas, where he was born on June 27, 1914, Dr. Hall earned the B.S. degree in electrical engineering from Texas A. & M. in 1936. He received the M.S. degree in 1938 and the D.Sc. degree in 1943, both from M.I.T.

He joined the M.I.T. faculty in 1937 as associate professor of electrical engineering. He founded and became the first director of the Dynamic Analysis and Control Laboratory in 1946.

While at M.I.T., he helped to develop missile control design techniques and directed the control system design effort for the World War II BAT, the first successful Navy air-to-surface guided missile.

As laboratory director, he supervised the development of the first missile simulator. He also was a Martin consultant for the Navy VIKING high altitude research rocket.

He left M.I.T. in 1950 to become associate director of the Bendix Research Laboratories Division. He was named division technical director in 1952 and general manager two years later. At Bendix, he directed research and development of electronic and hydraulic controls, including guidance and control systems for several guided missiles and automatic machine tool controls.

He was a member of the first Automation Exchange group sent to Russia in 1955 under the auspices of the American Society of Mechanical Engineers.

Dr. Hall holds the Naval Ordnance Development Award and the Eta Kappa Nu Outstanding Young Electrical Engineer Award. He is a member of Tau Beta Pi, Sigma Xi and several engineering societies.

❖

**Cecil S. Bidlack** (A'35–VA'39–SM'55), of Smith Electronics, Inc. and formerly of the National Association of Educational Broadcasters has joined the firm of Carl E. Smith Consulting Radio Engineers, Brecksville, Ohio. He will be responsible for consulting work in Television and FM broadcast.

His last assignment was with the sister firm of Smith Electronics, Inc., where as


*(Continued on page 68A)*

Other type numbers in the RHEEM Mesa line: 2N497, 2N498, 2N696, 2N697, 2N656, 2N657, 2N699, 2N1252, 2N1253, 2N1420

*another RHEEM FIRST!*

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## IRE People

(Continued from page 66A)

Supervisor of Systems Engineering he was charged with the design of audio and control circuitry for the Consolidated East Coast Facilities sites of the Voice of America at Greenville, North Carolina. With the NAEB at Urbana, Illinois, Mr. Bidlack served as engineering advisor to the executive director of the association.

Mr. Bidlack's affiliations include the Society of Motion Picture and Television Engineers, the American Institute of Electrical Engineers and the Audio Engineering Society. He is a registered Professional Engineer in the State of Ohio and holds radiotelephone first-class and amateur radio class "A" licenses.

❖

**Donald C. Bright** (SM'49), formerly a division sales manager with Radio Corporation of America, has been appointed general manager of the new Industrial Electronics Division of Hoffman Electronics Corp.

D. C. Bright

Before joining Hoffman, he was with RCA nine years and most recently was manager of government contracts and sales for its West Coast missile and surface radar division in Los Angeles.

Mr. Bright's earlier experience included assignments as chief engineer of Liberty Manufacturing Co., Youngstown, Ohio; chief of the radio control section for the U. S. Air Force, Wright Field, Dayton, Ohio; and sales engineer with Westinghouse.

❖

**Earl H. Flath, Jr.**, (A'44–M'54), has joined Temco Electronics division of Temco Aircraft Corporation as a senior scientist to plan developments in the fields of radiation, antennas and microwave systems.

E. H. Flath, Jr.

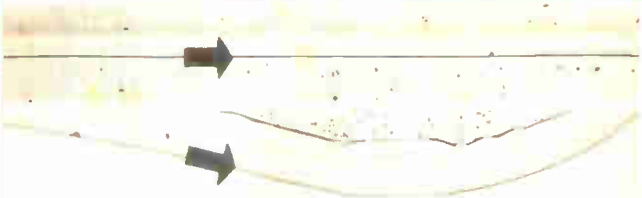
He was graduated from Southern Methodist University with honors in 1943 and received the M.S. Degree from the University of Cincinnati. He also studied at the University of Maryland.

He served as an electronic scientist with the Naval Research Laboratory and as senior aerophysics engineer with Convair prior to joining Chance Vought in 1952. With the latter company, he served in various supervisory positions in the fields of antenna development and electronics systems design, and finally as engi-

(Continued on page 72A)

**LOW POWER.** Consider the high-efficiency Raytheon 1N536 series.


**MEDIUM POWER.** Look into the Raytheon 1N253 and the new 1N2512 series.



**Raytheon diffused junction** (upper photo) gives utmost uniformity, highest performance, greatest reliability. Compare with irregular fusion junction (below).


**HIGH POWER.** Note the all-new Raytheon 1N248A, 1N1191A and 1N1195 series.

*For reliable power . . .*

# Depend on diffused junction rectifiers!

Here are reliable Raytheon diffused junction silicon rectifiers spanning the complete semiconductor power spectrum!

Raytheon manufacturing success in diffused junction rectifiers has long provided fast recovery, low forward voltage drop and extreme uniformity of device characteristics. Outstanding mechanical design and production under stringent quality control result in rectifiers with excellent ratings and characteristics. Utmost reliability is assured by constant life and environmental testing beyond the most stringent requirements of Mil 19500B, over the guaranteed temperature range of –65°C. to +165°C.

Of special interest in low current applications of the 1N536 series are the excellent reverse recovery, fast start and fast rise of Raytheon diffused junction rectifiers.

In the four amp range, the Raytheon 1N2512 series features low reverse current and is available in three package styles: with insulated stud, stud connected to anode, or stud connected to cathode.

In the higher current range, the new Raytheon diffused junction silicon rectifiers offer ratings up to 22 amps (at 150°C.)—plus the important advantages of low forward voltage drop and high efficiency, for exceptional regulation in power applications.

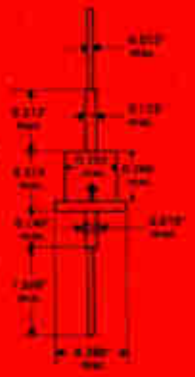
Further information on all these reliable Raytheon rectifiers is given on the following page. Semiconductor Division, Raytheon Company, 215 First Avenue, Needham Heights 94, Massachusetts.

RAYTHEON

# RAYTHEON SEMICONDUCTORS

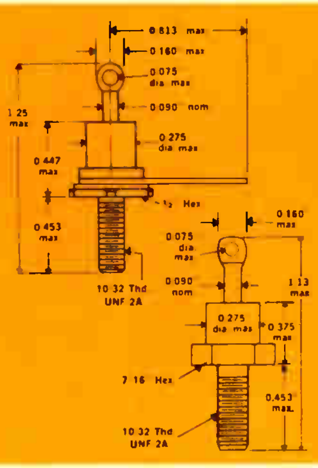
# Raytheon diffused junction silicon rectifiers

**LOW CURRENT SERIES.** The fast reverse recovery, low current Raytheon rectifiers. Feature both fast start and fast rise. Temperature range —65°C. to +165°C.



| Type | P.I.V. | Ave. Rectified Current 25°C mA | Ave. Rectified Current 150°C mA | Reverse Current (Max.) in µA at rated P.I.V. 25°C | Reverse Current (Max.) in µA at rated P.I.V. 150°C |
|---|---|---|---|---|---|
| 1N536 | 50 | 750 | 250 | 2 | 400 |
| 1N537 | 100 | 750 | 250 | 2 | 400 |
| 1N538 | 200 | 750 | 250 | 2 | 300 |
| 1N539 | 300 | 750 | 250 | 2 | 300 |
| 1N540 | 400 | 750 | 250 | 2 | 300 |
| 1N1095 | 500 | 750 | 250 | 2 | 300 |
| 1N547 | 600 | 750 | 250 | 2 | 300 |

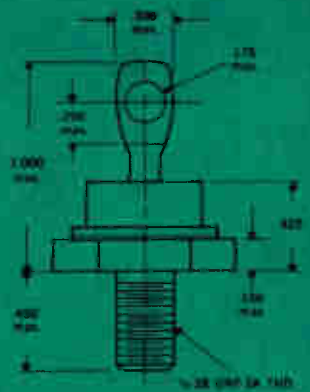
**MEDIUM CURRENT SERIES.** Workhorse of the Raytheon rectifier line. High efficiency and stability. Insulated or non-insulated stud, standard or reverse polarity. Temperature range —65°C. to +165°C.




| Cathode to Stud | Anode to Stud | INSULATED Stud | P.I.V. Volts | Ave. Rectified Current 30°C amps. | Ave. Rectified Current 150°C amps. | Reverse Current (max.) µA at rated P.I.V. 25°C | Reverse Current (max.) µA at rated P.I.V. 150°C |
|---|---|---|---|---|---|---|---|
| 1N2512 | 1N2512R | 1N2518 | 100 | 4.0 | 1.0 | 2.0 | 250 |
| 1N2513 | 1N2513R | 1N2519 | 200 | 4.0 | 1.0 | 2.0 | 250 |
| 1N2514 | 1N2514R | 1N2520 | 300 | 4.0 | 1.0 | 2.0 | 300 |
| 1N2515 | 1N2515R | 1N2521 | 400 | 4.0 | 1.0 | 2.0 | 300 |
| 1N2516 | 1N2516R | 1N2522 | 500 | 4.0 | 1.0 | 2.0 | 350 |
| 1N2517 | 1N2517R | 1N2523 | 600 | 4.0 | 1.0 | 2.0 | 400 |
| 1N253 | | | 95 | | 1.0* | | 100* |
| 1N254 | | | 190 | | 0.4* | | 100* |
| 1N255 | | | 380 | | 0.4* | | 150* |
| 1N256 | | | 570 | | 0.2* | | 150* |

*At 135°C.

**HIGH CURRENT SERIES.** The heavy current family of reliable Raytheon rectifiers. Features low forward voltage drop; high efficiency, exceptional regulation. Temperature range—65°C. to +175°C.



| Type | P.I.V. | Ave. Rectified Current, Amps @ 150°C | Reverse Current (Max.) at Rated P.I.V., mA @ 150°C |
|---|---|---|---|
| 1N248A | 50 | 20 | 5 |
| 1N249A | 100 | 20 | 5 |
| 1N250A | 200 | 20 | 5 |
| 1N1191A | 50 | 22 | 5 |
| 1N1192A | 100 | 22 | 5 |
| 1N1193A | 150 | 22 | 5 |
| 1N1194A | 200 | 22 | 5 |
| 1N1195 | 300 | 18 | 10 |
| 1N1196 | 400 | 18 | 10 |
| 1N1197 | 500 | 18 | 10 |
| 1N1198 | 600 | 18 | 10 |

J-6949

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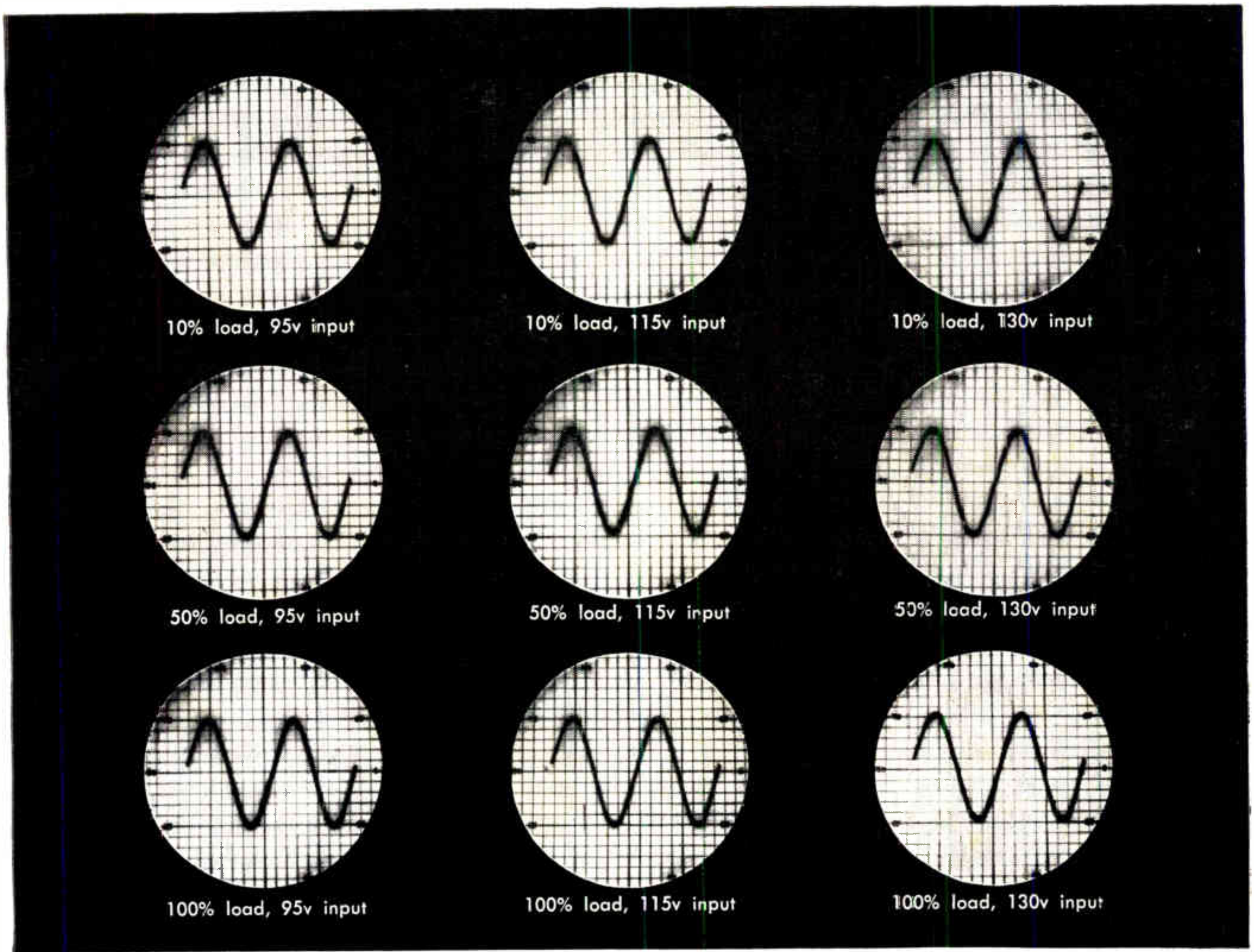



*Output wave shapes under varying input and load conditions. Sola Catalog No. 23-13-150 used in this test.*

# *Sola's moderate-cost static-magnetic voltage regulator has sine-wave output*

Sola now offers sinusoidal output in every standard-type regulator *with no price premium.* This development — a result of major design and production innovations — greatly widens the field of use for static-magnetic voltage regulation. The new standard sinusoidal design is now ideal for use with electrical and electronic equipment requiring a regulated input voltage with commercial sine wave shape — especially where harmonic-free supply had previously been too costly. The sinusoidal output also contributes to ease of selection and ordering, since this Sola stabilizer is virtually universal in application.

The Sola Standard Sinusoidal Constant Voltage Transformer provides output with less than 3% rms harmonic content. It automatically and continuously regulates output voltage within ±1% for line voltage variations of ±15%. Average response time is 1.5 cycles or less. The new line includes nine stock output ratings from 60va to 7500va.

Besides the improved electrical characteristics, these units are substantially smaller and lighter than previous models. Size and weight reductions were accomplished without any loss of performance or dependability.

With the Sola Standard Sinusoidal Constant Voltage Transformer you also get all the proved benefits of a static-magnetic regulator. It is simple and rugged. There are no tubes . . . no moving parts . . . no replaceable parts. Maintenance and manual adjustment are not necessary.

Its current-limiting characteristic protects against shorts on the load circuit. It is available in step-up and step-down ratios, allowing substitution for conventional, non-regulating transformers. These units can be used in any electronic or electrical application requiring a regulated sinusoidal power source where the peak power demand does not exceed the capacity of the constant voltage transformer. Circuit design formulae based on sinusoidal wave shape are directly applicable. Custom units to specific requirements are available in production quantities.

*Write for Bulletin CVS*

SOLA

SOLA ELECTRIC CO.

BPC A Division of Basic Products Corporation

4633 West 16th Street Chicago 50, Illinois

Characteristics and performance range of existing units:

## IRE People

(Continued from page 68A)

neering branch manager in charge of electromagnetic products.

Mr. Flath holds memberships in several professional societies, including the American Institute of Electrical Engineers, Texas Society of Professional Engineers, Sigma Tau and Eta Kappa Nu.

❖

**R. Karl Honaman** (A'23-SM'44), Director of Publication at Bell Telephone Laboratories, retired on March 1 after more than 40 years of Bell System service.

R. K. Honaman

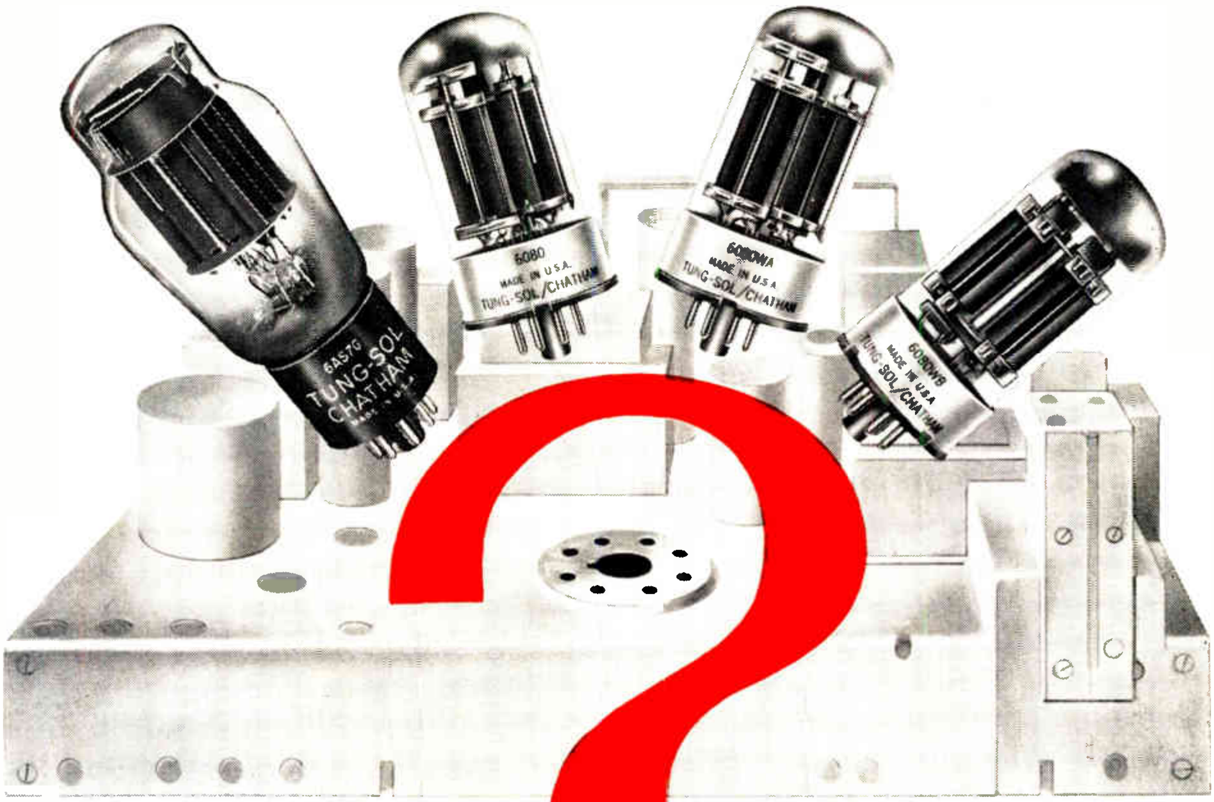
Since 1945 he had directed all public relations activities of Bell Laboratories, including press relations, employee information, advertising, technical and personnel magazines, technical libraries, and community relations.

A native of Lancaster, Pa., he received the B.S. and M.S. degrees from Franklin and Marshall College in 1916 and 1917, respectively.

(Continued on page 76A)

# TUNG-SOL/CHATHAM 6080 FAMILY

*All fit the same socket . . .*




# But which fits ? your application

Like most circuit designers, you're probably often confronted with a wide choice of tubes which meet the *electrical requirements* specified by your design. But depending on other factors, such as the kind of environment in which the tubes are expected to operate, your choice may be limited.

Consider the Tung-Sol/Chatham 6080 tube family, for example. The 6080, the 6080WA, the 6080WB and the prototype 6AS7G all fit the same socket. The electrical ratings of these series regulator tubes are the same. Would you know which to specify for your power supply? The differences are vital. Knowing them can make all the difference in the ultimate reliability of your design.

If economy in original component cost is paramount and size not a factor, then the 6AS7G may be your choice. If size is a factor, the smaller 6080 would be used. The 6080WA is the right tube if more closely controlled characteristics are important, if environmental conditions are severe, and if greater assurance of long life is needed. Where the tube is expected to operate under high ambient temperatures and severe vibration, and if many tubes are to be operated in parallel, then the 6080WB is best.

Of this you can be sure: Tung-Sol will recommend the "best" tube for your particular requirements. Once you have specified a Tung-Sol tube for your application, you'll be gratified by the superior performance and the highest operational reliability all Tung-Sol components provide. Every Tung-Sol tube is the product of the highest manufacturing standards and unexcelled quality control.

Full technical details on the Tung-Sol/Chatham 6080 family are also available to you on request.

And if you would like prompt and able assistance in selecting the correct tube for your application, get in touch with Tung-Sol tube experts. They'll be glad to study your design and recommend the tubes best for you. Tung-Sol Electric Inc., Newark 4, N. J. TWX:NK193

Technical assistance is available through the following sales offices: Atlanta, Ga.; Columbus, Ohio; Culver City, Calif.; Dallas, Texas; Denver, Colo.; Detroit, Mich.; Irvington, N. J.; Melrose Park, Ill.; Newark, N. J.; Philadelphia, Pa.; Seattle, Wash. Canada: Toronto, Ontario.

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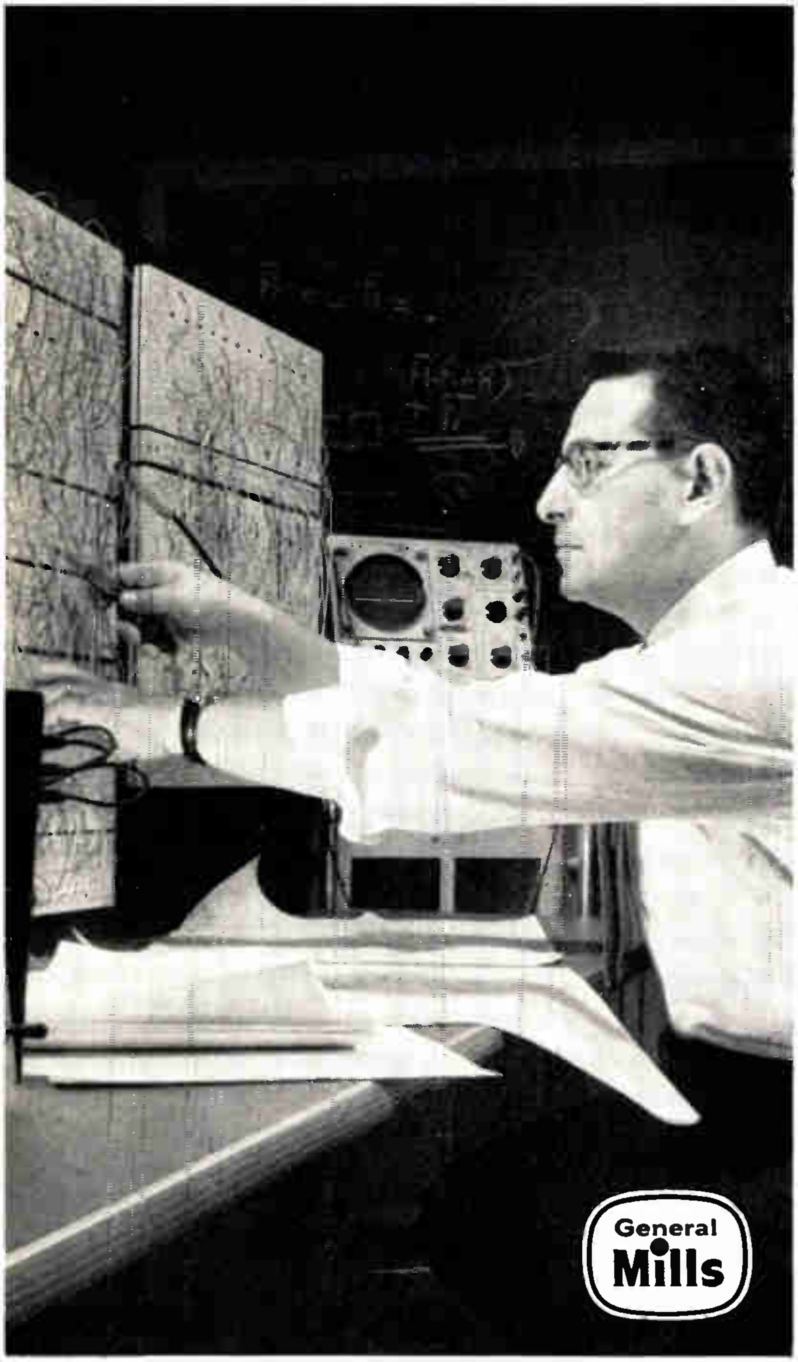


Here is Francis Alterman, Manager of General Mills Digital Computer Laboratory, checking one of our newest computers which he helped design. General Mills computers, both analog and digital, are being used in missile guidance, bombing and navigation systems, automatic surveying and in industrial control. In future space travel, computers will help control navigational systems of space vehicles and will process data gathered in outer space.

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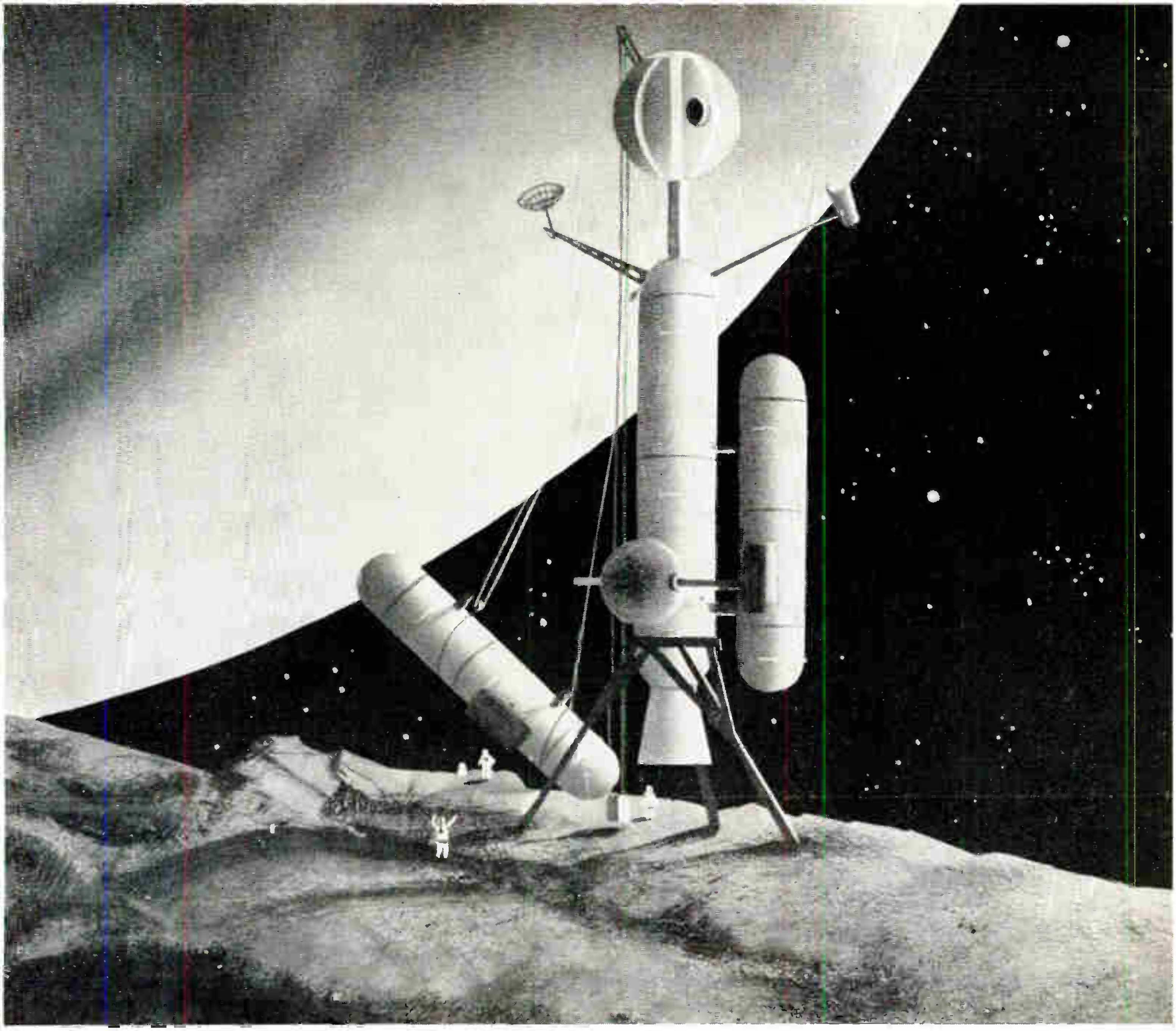
Our research activities cover broad areas in physics, chemistry, mechanics, electronics and mathematics. Some of the studies representative of these activities are: ions in vacuum, deuterium sputtering, dust erosion, magnetic materials, stress measurements, surface friction and phenomena, trajectory data and infrared surveillance.

In our engineering department, current projects include: specialized inflatable vehicles and structures, airborne early warning systems, micro wave radar test equipment,



Mars seen from one of its moons . . . illustration from book written for General Mills by Willy Ley.

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General Mills

## IRE People

(Continued from page 72A)

He began his telephone career in 1919 with the Development and Research Department of the American Telephone and Telegraph Company in New York. For the next 20 years his work dealt principally with the protection of telephone circuits, and a number of patents were granted to him for inventions in this field. As Assistant Protection Development Engineer, he transferred with his group to Bell Laboratories in 1934.

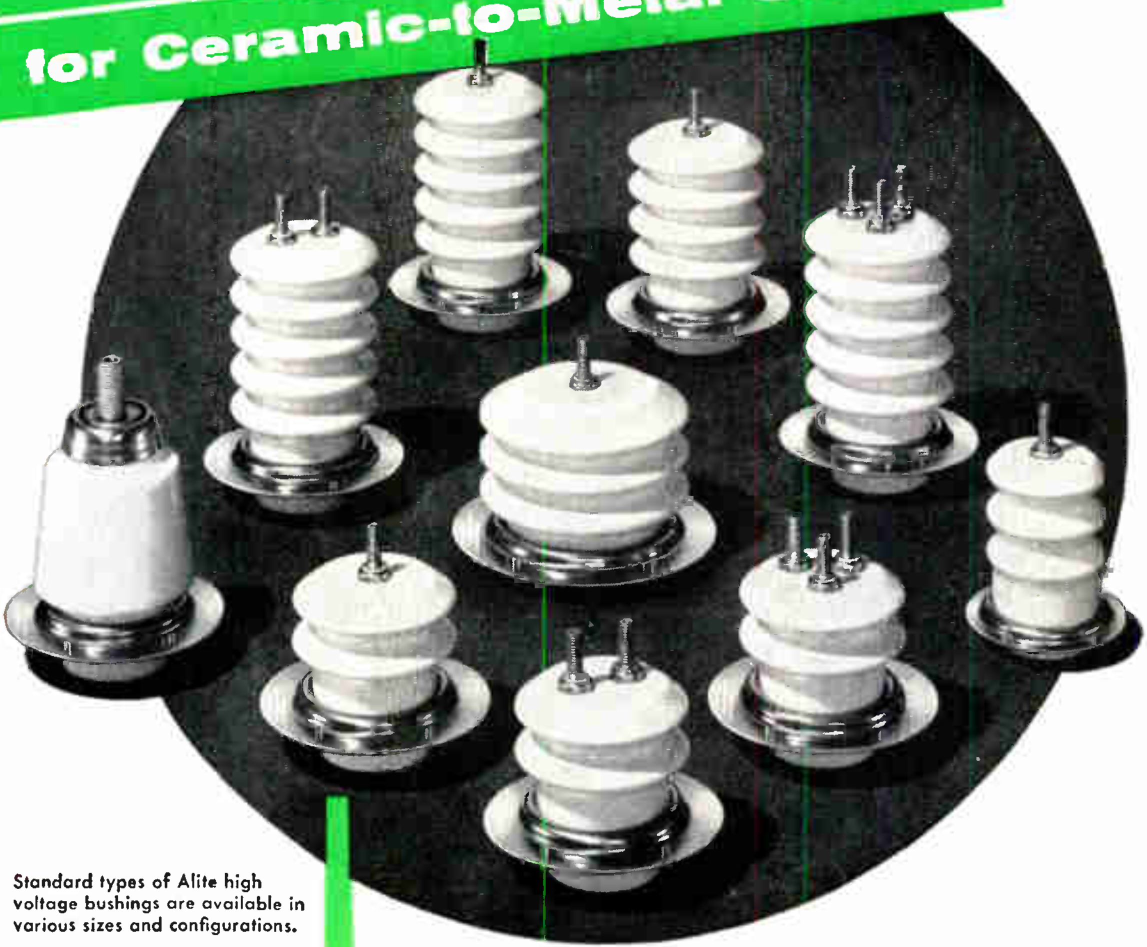
At the beginning of World War II, and at the request of the Army and Navy, Bell Laboratories instituted its School for War Training to instruct military personnel in radar and related developments. Mr. Honaman organized the school and served as its director until 1945. More than 4,000 officers and men were trained during this period and extensive text material was prepared for the program. At the end of the war, the school had a faculty of almost 100 members.

After the war, he was appointed Director of Publication, with responsibility for all publication and public relations programs of Bell Laboratories.

From October, 1954 to January, 1956, he was on leave from Bell Laboratories to serve with the Federal Government. During the first part of this period he was Consultant to the Secretary of Commerce, and organized and served as Director of the

(Continued on page 80A)

# ONE INTEGRATED SOURCE for Ceramic-to-Metal Seals



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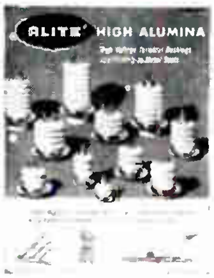


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ALITE DIVISION

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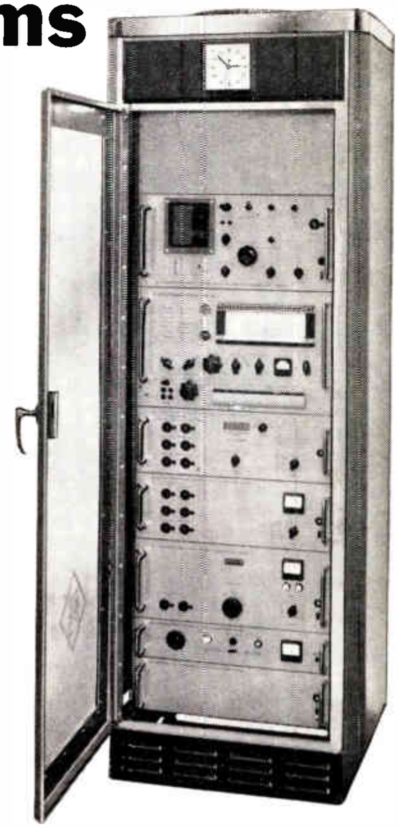
MEASUREMENT & COMMUNICATION

# NEWS

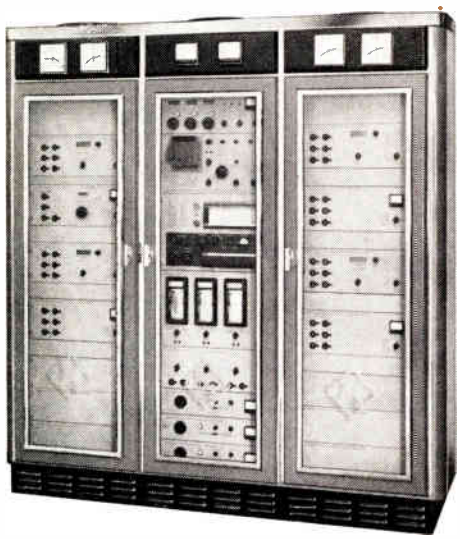
**Another Example of ROHDE & SCHWARZ Contribution to Precise Measurement.**

# Standard Time Systems

## Type CAA



- Combine high precision crystal clocks with carefully designed auxiliary units for time measurement and distribution.
- Are the most versatile and practical equipment for use in observatories, standard time institutes, hydrographic observatories, geodetic institutes, and all operations where precise time measurements are needed.
- Can be supplied in several models differing in size and facilities.
- 21 years experience in crystal chronometry.
- Write for detailed 8 page brochure CAA.



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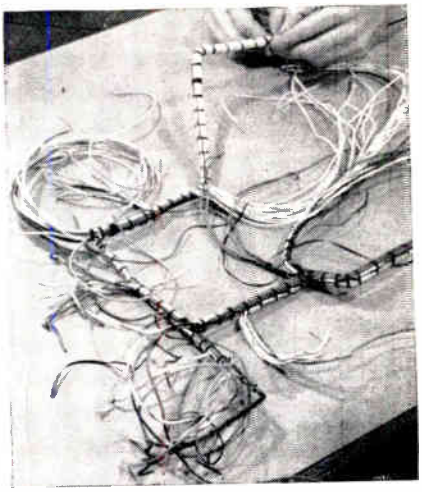
# GUDELACE
## is engineered for problem-free lacing



It's no accident that Gudelace is the best lacing tape you can buy. Excellence is *engineered* into Gudelace. A sturdy nylon mesh is meticulously combined with the optimum amount of special microcrystalline wax. Careful selection of raw materials and superior methods of combining them give Gudelace outstanding strength, toughness, and stability. Gudelace is the original *flat* lacing tape which distributes stress evenly over a wide area. It is engineered to stay flat; it will not stretch out of shape when pulled. Gudelace's nonskid surface prevents slipping, eliminating the too-tight pull that causes strangulation and cold flow. Durability and dependability make Gudelace your most economic buy—with no cut insulation, fingers, or feelings.

Write for Data Book with specifications on Gudelace and Gudebrod's complete line of braided lacing tapes and dial cords—Temp-Lace, Stur-D-Lace, and Gude-Glass.

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## measures peak, or peak to peak
# PULSES
## as short as 0.5 μs

**AT PULSE RATES AS LOW AS 5 pps**
**...VOLTAGES OF 1 mv TO 1000 v**

*Also measures*

### Complex Waveforms
having fundamental of 5 cps to 500 kc with harmonics to 2 mc.

### Accuracy
is 2% to 5% OF INDICATED VOLTAGE, depending upon waveform and frequency.

### Scale
is the usual Ballantine log-voltage and linear db, individually hand-calibrated for optimum precision.

### Input Impedance
is 2 meg, shunted by 10 pf to 25 pf.


Price: $395.

THIS "A" MODEL is the result of improvements and new features AFTER 11 YEARS OF MANUFACTURING THE VERY SUCCESSFUL MODEL 305

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## IRE People

(Continued from page 76A)

Office of Strategic Information. From April to December, 1955, he was Deputy Assistant Secretary of Defense, having responsibility for the public affairs activities of the Defense Department.

He was awarded the 1956 Alumni Citation of Franklin and Marshall College for "outstanding contributions to the greater community." In 1958 he received the Centennial Medal of Seton Hall University.

He is Chairman of the Committee for Engineering Information Services, an Engineers Joint Council sub-committee for cooperation with the National Science Foundation.

He is a Fellow of the American Association for the Advancement of Science and of the American Institute of Electrical Engineers. He is a past president of the New York Electrical Society. He is also a member of the American Management Association, The Society for the Advancement of Management, Public Relations Society of America, Public Relations Society of New York, The Commerce and Industry Association of New York, The New Jersey State Chamber of Commerce, The American Ordnance Association and the Armed Forces Communications and Electronics Association.

He is a director of the Rand Development Corporation, Cleveland, Ohio, of Floating Floors, Inc., New York, N.Y., and of the New Jersey Council on Economic Education.

Mr. Honaman was a member of a delegation which visited Moscow in 1958 to discuss trade relations with the Soviet Union. In 1959 he visited a number of countries of Western Europe, where he discussed industrial and technological problems.

❖

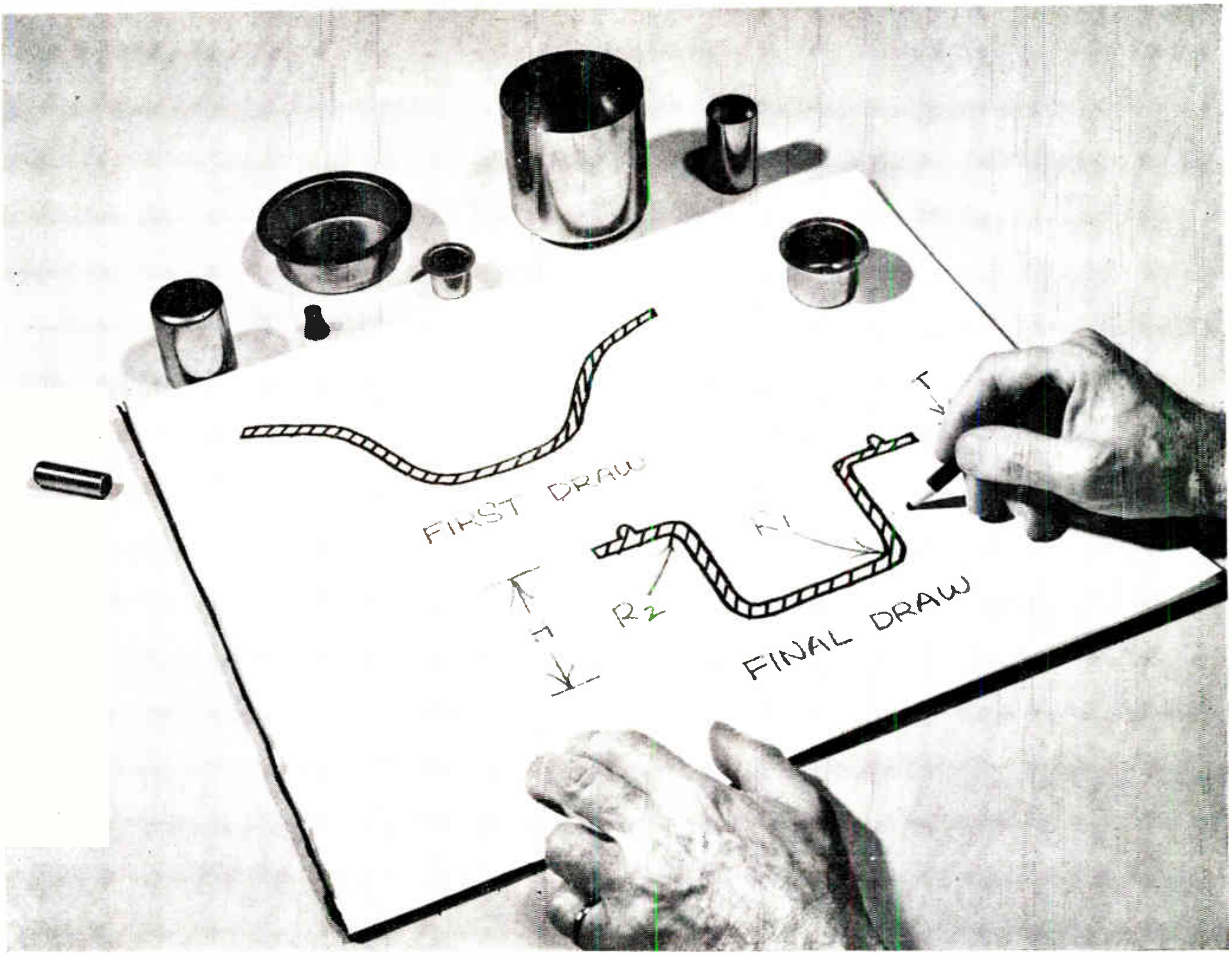
Ark Engineering Company, established in July 1952 as a sole proprietorship under the direction of **Albert R. Kall** (A'49–M'55), announces its incorporation as of January 1, 1960 under the name of Ark Electronics Corporation. The main activities of the company, as before, are consulting engineering specializing in the field of radio interference studies and tests, interference-susceptibility studies of complex weapons and communications systems, custom filter development and production, and custom electromagnetic shielding design. The personnel and policies of the company remain the same. Mr. Kall has been elected president; other executive positions will be announced at a later date.

A. R. Kall

❖

**E. H. Lockhart** (A'53–M'56) has been elected Vice-President of R. O. Roberts

(Continued on page 85A)




*Engineering hints from Carborundum*

# Correct techniques simplify production of KOVAR® Alloy drawn shapes

KOVAR is an iron-nickel-cobalt alloy with thermal expansion characteristics essentially matching those of several hard glasses. It is the ideal material for making high-quality drawn shapes required for vacuum- or pressure-tight glass-to-metal seals in equipment such as electron tubes and semi-conductors.

KOVAR has deep drawing qualities similar to cold-rolled steel. Satisfactory results are assured by observing a few simple precautions:

1. On the initial draw, punch radius should be a minimum of four times the material thickness. Reduce successively on re-draws.
2. Inside radii at the corners on the final draw should be not less than the thickness of the metal.
3. Sharper radii, if absolutely essential, should be produced by a subsequent coining operation.
4. Hold-down pressures in drawing should be kept to a minimum to insure metal flow from the outside rather than stretching.

Obviously, to prolong tool life and simplify production, maximum permissible tolerances should be allowed. More detailed information on deep drawing of KOVAR alloy is supplied in Technical Data Bulletin 100 EB11.

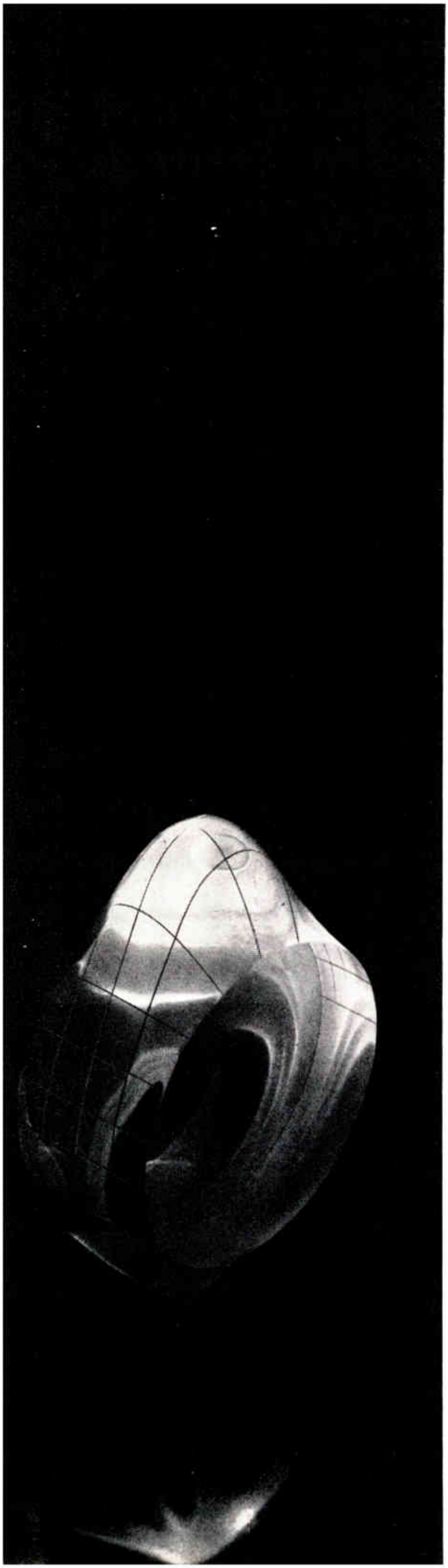
Carborundum maintains large stocks of KOVAR alloy in a wide variety of sizes and forms. This alloy can be welded, brazed, soldered and plated with other metals. It can be either oxide bonded to hard glass or brazed to metallized-ceramic insulators. Technical service is available to help you solve processing and application problems. Contact The Carborundum Company, Refractories Division, Dept. P-50, Latrobe Plant, Latrobe, Pa.

**FIND OUT ABOUT KOVAR -- WHERE IT IS USED AND WHY**

Bulletin 5134 gives data on composition, fabrication techniques and applications. Send for your free copy today.


*For permanent vacuum and pressure-tight sealing . . . count on*

**CARBORUNDUM®**



One of a series

# Catching Up with a Slippery Equation

What goes on when two moving surfaces are separated by a film of oil?

Simple question? Maybe. but engineers and mathematicians have been trying to answer this classic question of lubrication ever since Osborne Reynolds neatly stated the problem in equation form back in 1886.

Unfortunately, analytical methods for solving Professor Reynolds' partial differential equation worked only for unrealistic oil bearings, bearings with widths approaching zero or infinity. And approximate methods were crude. requiring a complete recalculation for each slight change in the bearing.

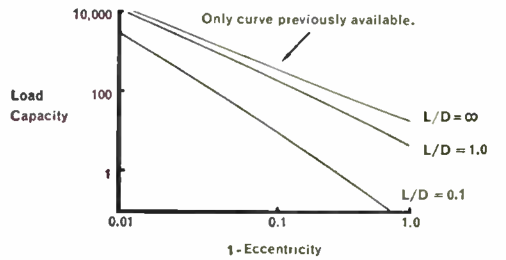
Recently. mathematicians at the General Motors Research Laboratories came up with the most versatile and efficient method of solution yet made. Their analytical method for solving the two-dimensional Reynolds' equation applies to all finite journal bearings — as well as other hydrodynamic bearings — with *no* assumptions or approximations about boundary locations. The new method uses a long-neglected energy theorem recorded by Sir Horace Lamb instead of the force relationship tried by Reynolds and others.

Besides being a valuable contribution to the theory of lubrication. this work has its practical side: namely. accurate, serviceable design curves for engineers. At GM Research. we believe delving into both the theoretical and applied sides of a problem is important to progress. It is a way of research that helps General Motors fulfill its pledge of "more and better things for more people."

## General Motors Research Laboratories

Warren, Michigan

Hydrodynamic analyses have led to specific answers about bearing operation. Shown here are the oil pressure distribution (main illustration) and load-carrying capacity for a non-rotating journal with a reciprocating load.



EXTRA QUALITY AT NO EXTRA COST WITH BENDIX TRANSISTORS

# Bendix Bulletin

*Up-to-the-minute news about transistors*

# NEW DRIVER TRANSISTORS SWEEPING THE FIELD

## Extra-versatile Bendix units beat high costs, design limitations over wide front

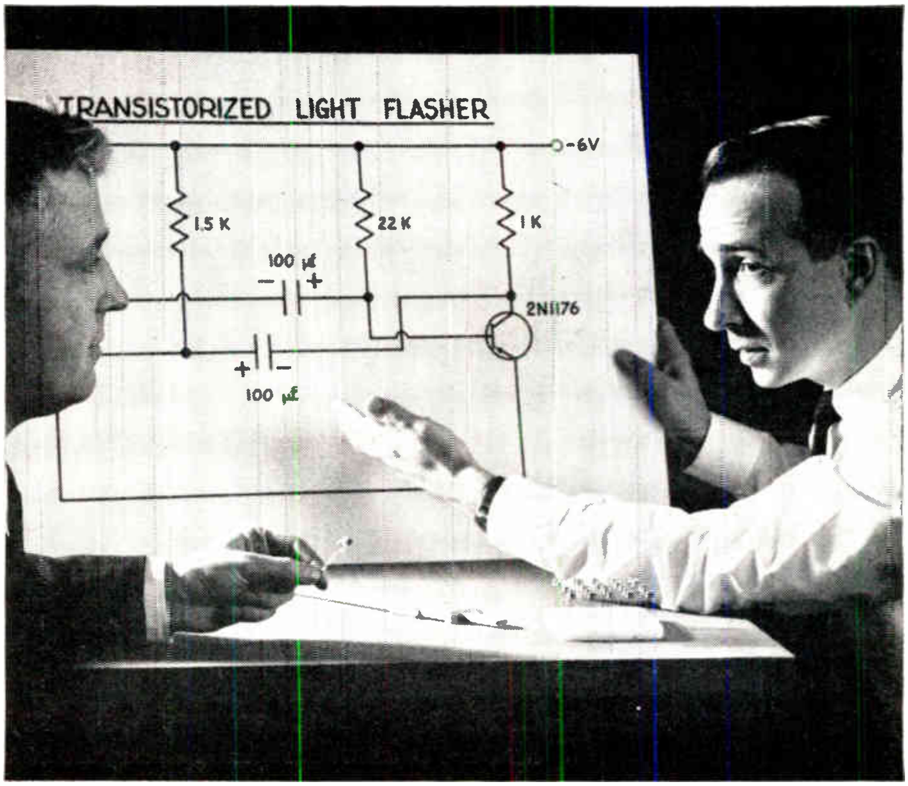
Called the "workhorse of the transistor industry," the new Bendix* Driver Transistor series is winning the nod from more and more engineers daily. These men find it the answer to audio frequency and switching applications requiring extra performance without extra cost.

Here is a special device for use where reliability, versatility, and low cost are primary requirements. The Bendix units combine higher voltage rating and high current gain with more linear current gain characteristics for low distortion and more efficient switching.

They're now in high production for rapid delivery in JEDEC TO-9 packages.

NEW BENDIX SEMICONDUCTOR CATALOG on our complete line of power transistors, power rectifiers, and driver transistors available on request. Write SEMICONDUCTOR PRODUCTS, BENDIX AVIATION CORPORATION, LONG BRANCH, N. J. For information about employment opportunities write personnel manager.

*TRADEMARK




ENGINEERS KNOW the new Bendix Driver Transistor line-up meets an unusually wide range of circuitry applications. Bendix Applications Engineering Department suggestions on circuitry problems are helpful, too.

### APPLICATION, PERFORMANCE DATA INDICATE BROAD USAGE

| TYPE NUMBERS | MAXIMUM RATINGS | | | | | TYPICAL OPERATION | | |
|---|---|---|---|---|---|---|---|---|
| | Vce Vdc | Ic mAdc | Pc mW | Tj °C | T storage °C | hfe Ic = 10 mAdc | fαb | Vce(Sat) Ic = 100 mAdc Ib = 10 mAdc |
| 2N1008 | −20 | 300 | 400 | 85 | −65 to +85 | 90 | 1.2 mc | 0.15 Vdc |
| 2N1008A | −40 | 300 | 400 | 85 | −65 to +85 | 90 | 1.2 mc | 0.15 Vdc |
| 2N1008B | −60 | 300 | 400 | 85 | −65 to +85 | 90 | 1.2 mc | 0.15 Vdc |
| 2N1176 | −15 | 300 | 300 | 85 | −65 to +85 | 65 | 1.2 mc | 0.15 Vdc |
| 2N1176A | −40 | 300 | 300 | 85 | −65 to +85 | 65 | 1.2 mc | 0.15 Vdc |
| 2N1176B | −60 | 300 | 300 | 85 | −65 to +85 | 65 | 1.2 mc | 0.15 Vdc |

Ideal for such applications as:

**TRANSISTOR DRIVER • AUDIO AMPLIFIER (CLASS A OR B)
POWER SUPPLY • SERVO CONTROL • AUDIO OSCILLATOR
MOTOR CONTROL • RELAY DRIVER • POWER SWITCH**

SEMICONDUCTOR PRODUCTS
Red Bank Division
LONG BRANCH, N. J.

Bendix AVIATION CORPORATION

West Coast Sales Office:
117 E. Providencia Avenue, Burbank, California

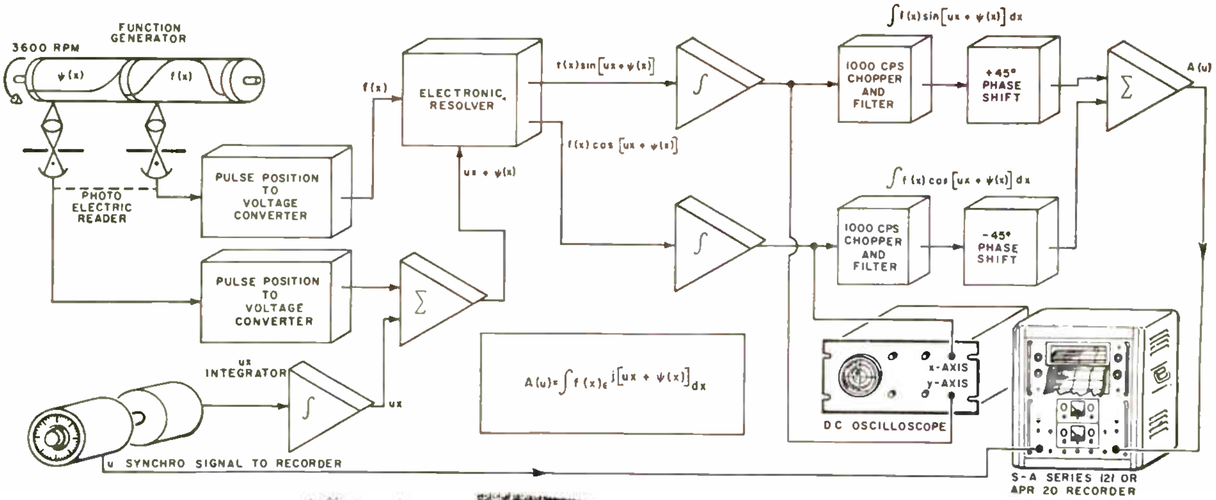
Midwest Sales Office:
2N565 York Road, Elmhurst, Illinois

New England Sales Office:
4 Lloyd Road, Tewksbury, Massachusetts

Export Sales Office: Bendix International Division,
205 E. 42nd Street, New York 17, New York

Canadian Affiliate: Computing Devices of Canada, Ltd.,
P. O. Box 508, Ottawa 4, Ontario, Canada

*Simplified block diagram of Model CF-1. Amplitude and phase input functions are plotted on graph paper for presentation. Integration is observed on a dc oscilloscope. Absolute magnitude is recorded on any S-A Series 121 or APR 20 Antenna Pattern Recorder with a logarithmic response.*

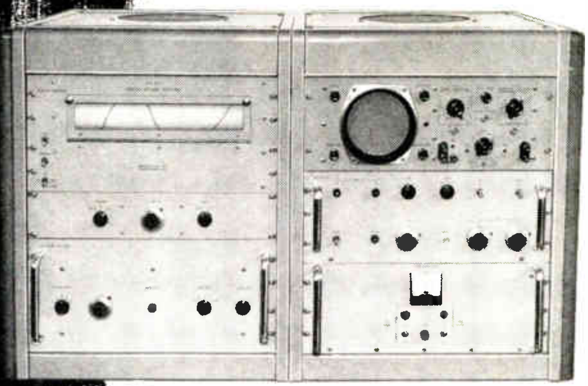



# To solve

$$A(u)=\int_{-1}^{1} f(x)\,\epsilon^{j[ux+\psi(x)]}\,dx$$

## investigate the new

# FOURIER INTEGRAL COMPUTER



*Model CF-1*

A sophisticated solution to the vexing problem of solving bounded Fourier integrals quickly and accurately, Scientific-Atlanta designed the Model CF-1 especially for the antenna design engineer.

The computer has broad general application including determination of the far fields of aperture antennas from the distribution of the field in the aperture, the far fields of arrays from the magnitude and phase of the currents in the elements, the frequency spectra of voltage pulses, and other physical problems involving Fourier transforms and their inverse transforms over finite limits.

**PRICES**

**Model CF-1 Fourier Integral Computer . . . $9,000**

**Model APR 22 Antenna Pattern Recorder (logarithmic response) . . . $4,300**

*Consult your nearby S-A engineering representative for more information. Or you may write directly to the factory for complete specifications. Address Dept. 86.*

**SCIENTIFIC-ATLANTA, INC.**

2162 PIEDMONT ROAD, N.E. • ATLANTA 9, GEORGIA

Tel. TRinity 5-7291

4

*(Continued from page 80A)*

Company, Inc., Santa Fe Springs, Calif.

E. H. Lockhart

A veteran of over 20 years with the electronics industry, he most recently was vice-president of Radiatronics Incorporated, Van Nuys, Calif. He has also had engineering and management experience with Hughes Aircraft Company, Stanford University Microwave Laboratory, Los Alamos Scientific Laboratory, University of California Radiation Laboratory, and General Electric Company.

He has been active in the Western Electronic Manufacturer's Association for many years, serving on the Membership Committee in 1955, Greeters Committee Chairman 1956, Program Chairman 1957, and as a Director in 1958 and 1959.

Mr. Lockhart served as Registration Chairman for the 1958 Wescon, and is Vice-Chairman of the All Industry Luncheon Committee for the 1960 Wescon. His affiliations include the Aircraft Electrical Society and AFCEA.

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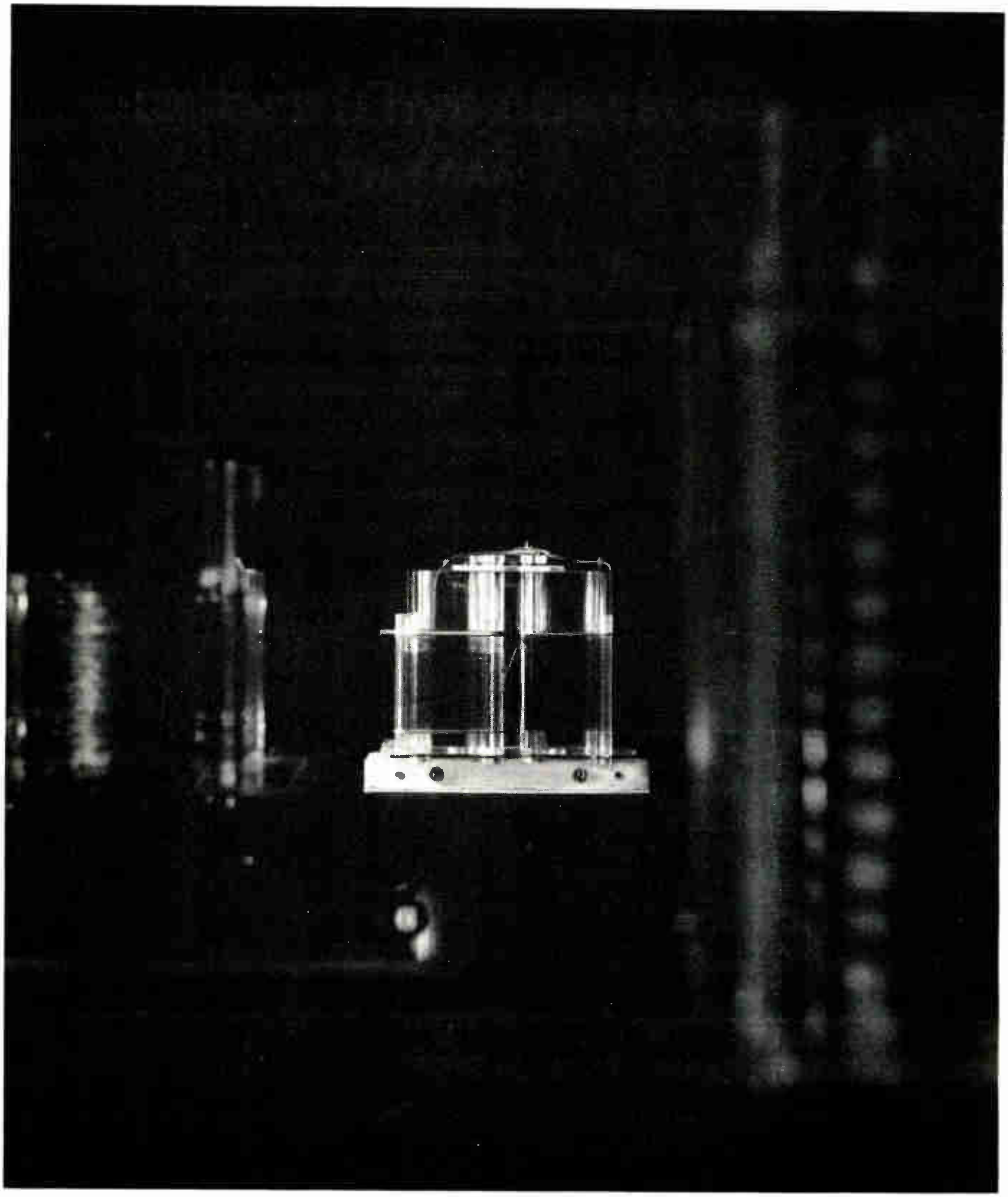


FROM **Transitron**...INDUSTRY'S BROADEST LINE OF

# MICRO-DIODES

## MICRO-MINIATURIZATION POSSIBLE NOW!

**YES — FASTEST DIFFUSED SILICON MICRO-DIODES AVAILABLE.** They combine advanced diffusion techniques with extremely small size, to provide milli-micro-second switching speeds, excellent static, forward and inverse characteristics.

**YES — ONLY SERIES OF HIGH QUALITY MICRO-REGULATORS.** Series of 8 diffused-silicon micro-regulators provides stable voltage regulation and reference sources previously found only in considerably larger devices. Excellent dynamic resistance characteristics.

**YES — BASIC FAMILY OF MULTI-PURPOSE MICRO-DIODES.** Series of 3 high quality diffused-silicon micro-diodes provides voltage ratings up to 200 volts, current rating up to 50 milliamperes. May be considered for switching applications. Exceptional static, forward and inverse characteristics.

**YES — EVEN A MICRO-STABISTOR.**

This diffused-silicon stabistor is the micro-counterpart of Transitron's universally-known SG-22.

All of these new micro-diodes are COMPLETELY COMPATIBLE with present circuitry . . . provide the same excellent performance as larger Transitron diodes in 1/10th the space! Here is your chance to micro-miniaturize circuits TODAY!

**VERY FAST SWITCHING MICRO-DIODE**

| TYPE | PIV | $E_f$ @ 5 MA | RECOVERY TIME |
|---|---|---|---|
| TMD-50 | 50V | 0.75V | 4 mμsec |

**FAST SWITCHING MICRO-DIODE**

| TYPE | PIV | $E_f$ @ 20 MA | RECOVERY TIME |
|---|---|---|---|
| TMD-24 | 50V | 0.85V | 0.3 μsec |
| TMD-25 | 100V | 0.85V | 0.3 μsec |
| TMD-27 | 200V | 0.85V | 0.3 μsec |

**SILICON MICRO-REGULATOR**

| TYPE | VOLTAGE @ 5 MA | POWER RATING @ 25°C |
|---|---|---|
| TMD-01 | 5.1V | 100 MW |
| TMD-03 | 6.2V | 100 MW |
| TMD-07 | 9.1V | 100 MW |

**HIGH CONDUCTANCE MICRO-DIODE**

| TYPE | PIV | $E_f$ @ 100 MA | POWER RATING @ 25°C |
|---|---|---|---|
| TMD-41 | 50V | 1.0V | 100 MW |
| TMD-42 | 100V | 1.0V | 100 MW |
| TMD-45 | 200V | 1.0V | 100 MW |

**SILICON MICRO-STABISTOR**

| TYPE | $E_f$ @ 1 MA | DYNAMIC RESISTANCE |
|---|---|---|
| TMD-40 | 0.55V | 60 OHMS |

*For further information, write for Bulletins:*

PB-71A (High Conductance), PB-71B (Fast Switching), PB-71C (Very Fast Switching), PB-71D (Stabistor), PB-71E (Regulators); AN 1358A Application Notes.

See Transitron at the AFCEA Show, Booths 157-158

**Transitron**

electronic corporation • wakefield, massachusetts

*"Leadership in Semiconductors"* SEE YOUR LOCAL AUTHORIZED TRANSITRON DISTRIBUTOR FOR QUANTITIES FROM 1-999.

# Industrial Engineering Notes*

## Air Traffic Control

**The Federal Aviation Agency hopes to have air traffic control on a semi-automatic basis by 1963 and fully automatic "as soon as possible thereafter," FAA Administrator E. R. Quesada said**. Speaking at a meeting of the National Society of Professional Engineers, Mr. Quesada said a 400-engineer staff is working on R&D connected with modernization of the airways and that one of the most pressing projects is the automation of the air traffic control system. Automation has, he said, "terrifically far-reaching implications. The key to the project is the development of an air traffic control Data Processing Central that will remove many of the controller's bookkeeping chores and give him more time to analyze traffic situations and make control decisions." The Central's "most spectacular" function will be in probing, detecting, and predicting conflicts, he continued. It will warn of any unsafe situation and automatically suggest corrective alternatives. Present plans call for the Central to be controlling the New York, N. Y., area's air traffic in 1963, with systems to follow at Cleveland, Washington, Chicago, Los Angeles, and Oakland. Other plans for airway modernization call for increased installations of radar and other electronic equipment; improving the communications systems and the aeronautical weather service; and developing new control procedures, the administrator said.

## Engineering

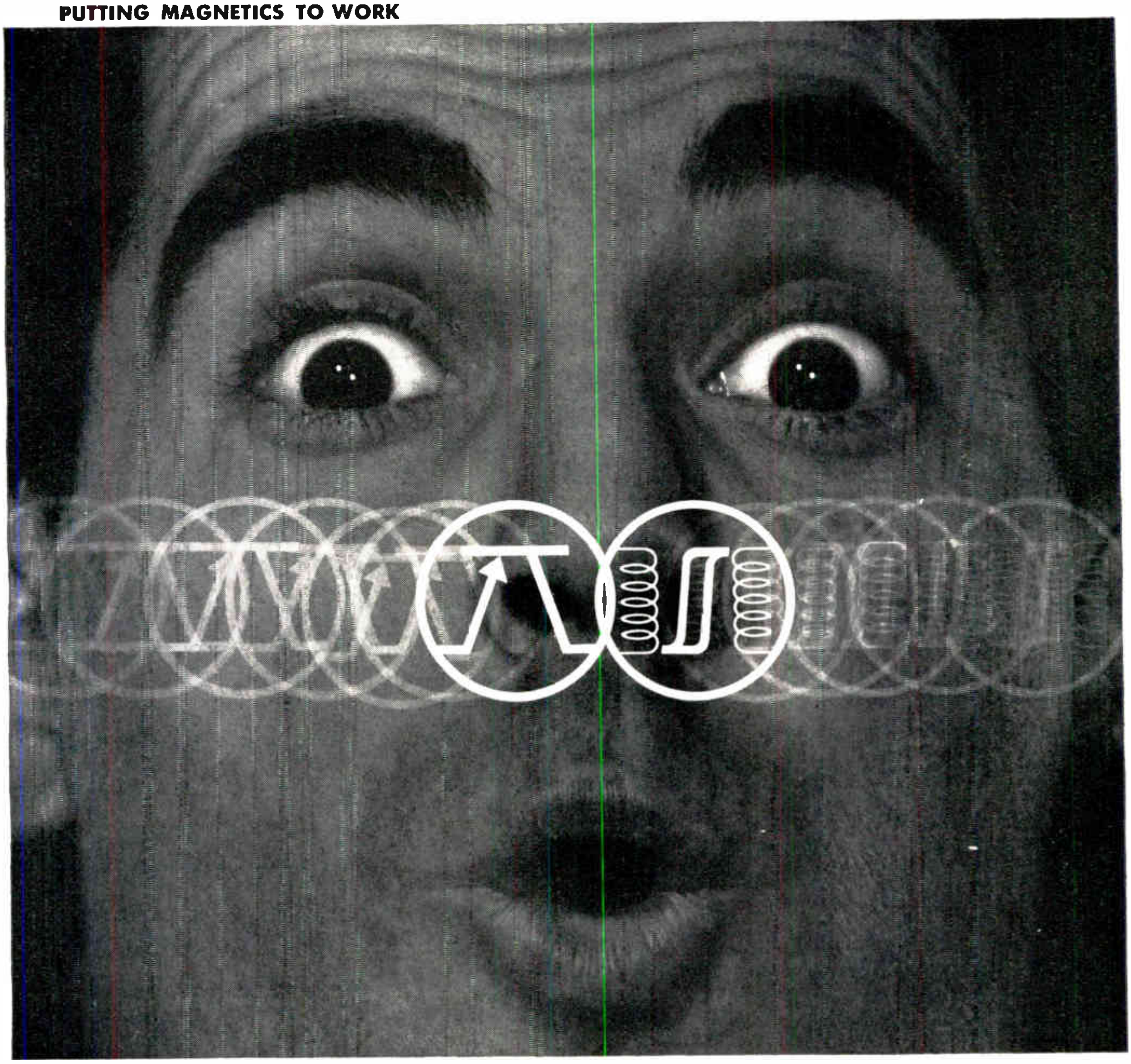
**Standards on resistors and capacitors have just been published by the American Standards Association.** Publication 115 applies to fixed resistors of types other than wire-wound, with a rate dissipation not exceeding 2 watts and a rated resistance value between 10 ohms and 10 megohms, suitable for use in circuits where high stability properties are essential. Publication 116 applies to fixed capacitors with a dielectric of mica with the electrodes directly deposited on the mica sheets and intended for use in telecommunication receiving equipment and for similar applications in other electronic equipment. Copies of these publications are available from ASA Headquarters 70 E. 45th St. New York, N. Y., $3.20 per copy. . . . **A two-part report of Air Force-sponsored research into magnetic amplifier circuits has been published for sale to industry through the Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C.**

* The data on which these Notes are based were selected by permission from *Weekly Report* issues of February 23 and March 7, 1960, published by the Electronic Industries Association, whose helpfulness is gratefully acknowledged.

## Military Electronics

**The Army has shown members of the press a device which can, it was claimed, perform many of the functions of electronic devices—without electricity or moving parts.** The device is a "pure fluid amplifier." The unit demonstrated by its inventors, scientists of the Army's Diamond Ordnance Fuze Laboratory in Washington, resembled a block somewhat larger than a pack of playing cards. It was airtight, except for tiny apertures, and contained passageways. Attached to a source of pressurized gas or liquid, the device can amplify, digitalize, remember, feedback, and compute, the scientists said. The new device "makes possible a whole new class of amplifiers, computers, logic circuits and control systems, and will bring automation and control more into industrial and personal life," its developers said. The "revolutionary" system will not replace the electronics industry, they declared, but in some specialized applications it "will do things better and more reliably than electronic systems." "Pure fluid amplifying and computing elements will take a place in hydraulic and pneumatic systems similar to the position that the vacuum tube and transistor occupy in the field of electricity," the scientists said. The amplifier works by injection into the internal passageways of one strong stream of gas or liquid and a second, weaker stream which displaces or redirects the main flow. The idea for the system is an old one—"an overlooked one," its developers said. Fluids in motion have been used in many applications, such as hydraulic systems, windshield wipers and autopilots. But those systems have moving parts. The advantage of the pure penumatic device is that it has none. Thus, the inventors claimed, it is trouble-free to an astonishing degree, easy to make and maintain, and as rugged as its few component materials are. It can operate, for example, in white heat. The inventors said a unit could be produced for 2/10ths of a cent which would do the work of a vacuum tube costing 50 cents. A unit the size of a pea with an aperture 5/1000ths of an inch in diameter was displayed. It was said that the size of the device could be adjusted to fit almost any applications "up into the horsepower range." The prime advantage is the speed of the device. "They will never compete with electronic systems for very high speed applications," the scientists said. The pure fluid amplifier will be described in an engineering handbook now being prepared by the Army and in a series of technical papers to appear in trade magazines. A full technical report will be issued later.

(Continued on page 92A)



# Open your eyes to new amplifier designs!

## See how to combine tape wound cores and transistors for more versatile, lower-cost, smaller amplifiers

Tie tape wound cores and transistors into a magnetic-transistor amplifier, and open your eyes to new design opportunities.

To start with, these are static control elements—no moving parts, nothing to wear or burn out. Next thing you find is that you reduce components' size—your amplifier is smaller and costs less. That's because between them the core and the transistor perform just about every circuit function . . . and then some.

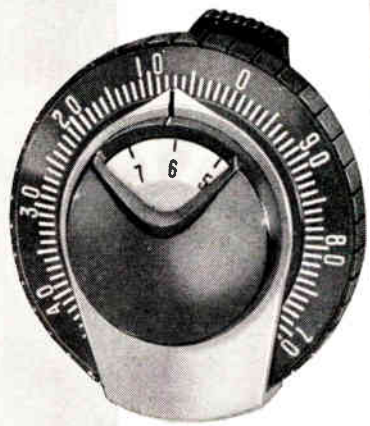
For instance? The core has multiple isolated windings. Thus you can feed many inputs to control the amplifier. The core also has a square hysteresis loop, and thus acts as a low loss transformer. That means you save power. In addition, the core can store and remember signals—so time delay becomes simple.

There's no need for temperature stabilization, either. The transistor acts only as a low loss, fast, static switch—and in this function it has no peer.

How do you want to use this superb combination? As a switching amplifier—or a linear one? In an oscillator? A power converter (d-c to d-c or d-c to a-c)? You'll have ideas of your own—and if they involve tape wound cores, why not write us? Ours are Performance-Guaranteed. *Magnetics Inc., Dept. P-81, Butler, Pennsylvania.*

**MAGNETICS inc.** ®

# NEW



## NEW BORG MICRODIALS ADD RICHNESS AND STYLE TO CONTROL PANELS AND INSTRUMENTS

Now from Borg, originator of famous Microdials, comes a fresh, new concept in turn-counting dial appearance . . . Series 1360 Microdials. These new Borg Microdials were specially developed to add style and color to electronic control panels and equipment. Available in five smart models of red, gray and black color variations. Colors are inlays of colored plastic . . . will never wear, scale or rub off. Quality mechanical features such as smoothness of action . . . absence of noise . . . fewer ambiguities in reading and setting assure accurate, reliable performance. Contoured brake arms lock settings in place, but do not interfere with reading and setting. Catalog data sheet BED-A137 gives complete color combinations and specifications. See your Borg technical representative or distributor, or let us put him in touch with you.

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***BORG EQUIPMENT DIVISION***

Amphenol-Borg Electronics Corporation
Janesville, Wisconsin

Micropot Potentiometers • Turns-Counting Microdials • Sub-Fractional Horsepower Motors • Frequency and Time Standards

# OHMITE RESISTORS

**THE EXACT RESISTOR YOU NEED—WHEN YOU NEED IT—FOR EVERY INDUSTRIAL AND MILITARY REQUIREMENT**

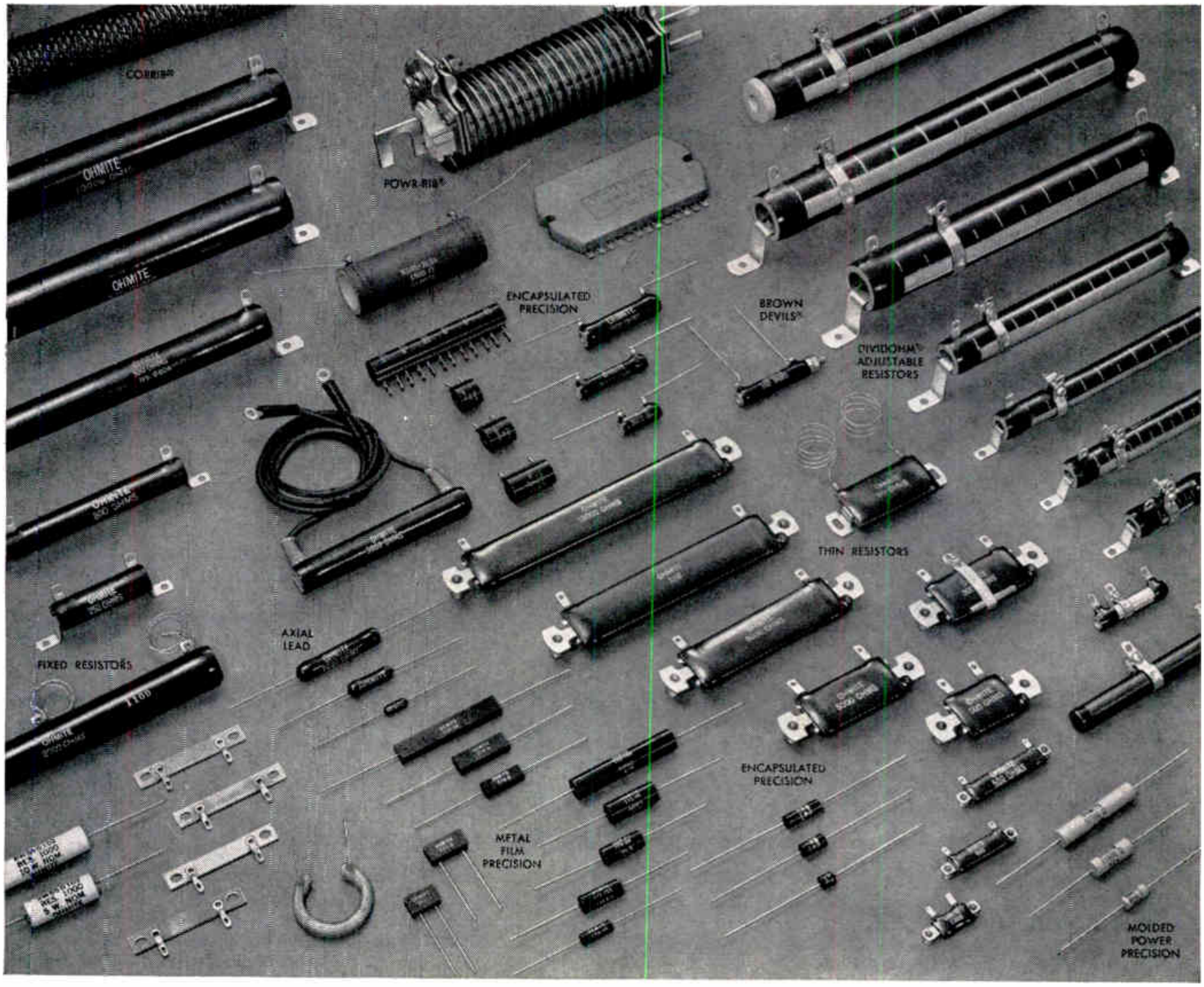
Fixed . . . adjustable . . . tapped . . . noninductive . . . precision metal film and encapsulated wire-wound . . . thin type . . . high-current—practically any resistor you need, you can find in the Ohmite line.

**WORLD'S LARGEST STOCK FOR IMMEDIATE DELIVERY**—Chances are Ohmite's huge stock of several million resistors in more than 2000 sizes and types contains a unit that fits your requirements. Many types are also available through Electronic Parts Distributors located across the Nation.

**YOUR CUSTOMERS KNOW THE VALUE OF OHMITE QUALITY**—When a purchaser sees Ohmite resistors in a piece of equipment, he knows that equipment is designed and built for dependability.

**OHMITE ENGINEERING ASSISTANCE ASSURES THE RIGHT UNIT**—Selecting the right resistor for the job is sometimes a tough problem. Why not call on Ohmite application engineers to help out. Take advantage of their specialized skills and background.

*Write on Company Letterhead for Catalog and Engineering Manual 58*




# OHMITE

## Quality Components

**OHMITE MANUFACTURING COMPANY**
**3617 Howard Street, Skokie, Illinois**

RHEOSTATS • RESISTORS • TAP SWITCHES
RELAYS • R.F. CHOKES • TANTALUM CAPACITORS
VARIABLE TRANSFORMERS • GERMANIUM DIODES

# Industrial Engineering Notes

*(Continued from page 88A)*

## EIA Proposal

EIA has submitted to the Labor Department its proposed definition of the Electronic Equipment Industry and urged that it be used in the upcoming survey preliminary to a Walsh-Healey wage determination for the industry. The EIA proposal defines the industry in terms of classes of products it manufactures, and limits the categories to those that are specifically electronic. It is intended to replace a more general definition proposed earlier by the Labor Department which identifies the industry as devoted to "... the manufacture of electrical apparatus and sub-assemblies therefor involving the use of electronic tubes and/or solid state semiconductor devices." In a statement accompanying its definition, EIA pointed out that the proposal would eliminate the possibility of including products of other electronic industries already covered by Walsh-Healey wage determinations, such as the electronic components and the tube and semiconductor industries. The definition proposed by EIA is "The manufacture of electronic equipment for the purpose of this survey, is defined as that industry which manufactures any of the following classes of

*(Continued on page 108A)*


*NEW THERMOPLASTIC RECORDING DISPLAY ACHIEVES*

# Detection to Projection in Less than a Second

Large-screen display of radar signals can be recorded and projected in less than a second. This advanced technique in information display is an example of one application of the new thermoplastic recording system developed by General Electric.

The grainless, thermoplastic film eliminates processing delays and permits, with higher resolution, much greater enlargement than is practical with high-speed photographic film. Target delineation is also significantly improved by optical filtering used to increase the signal-to-noise ratio.

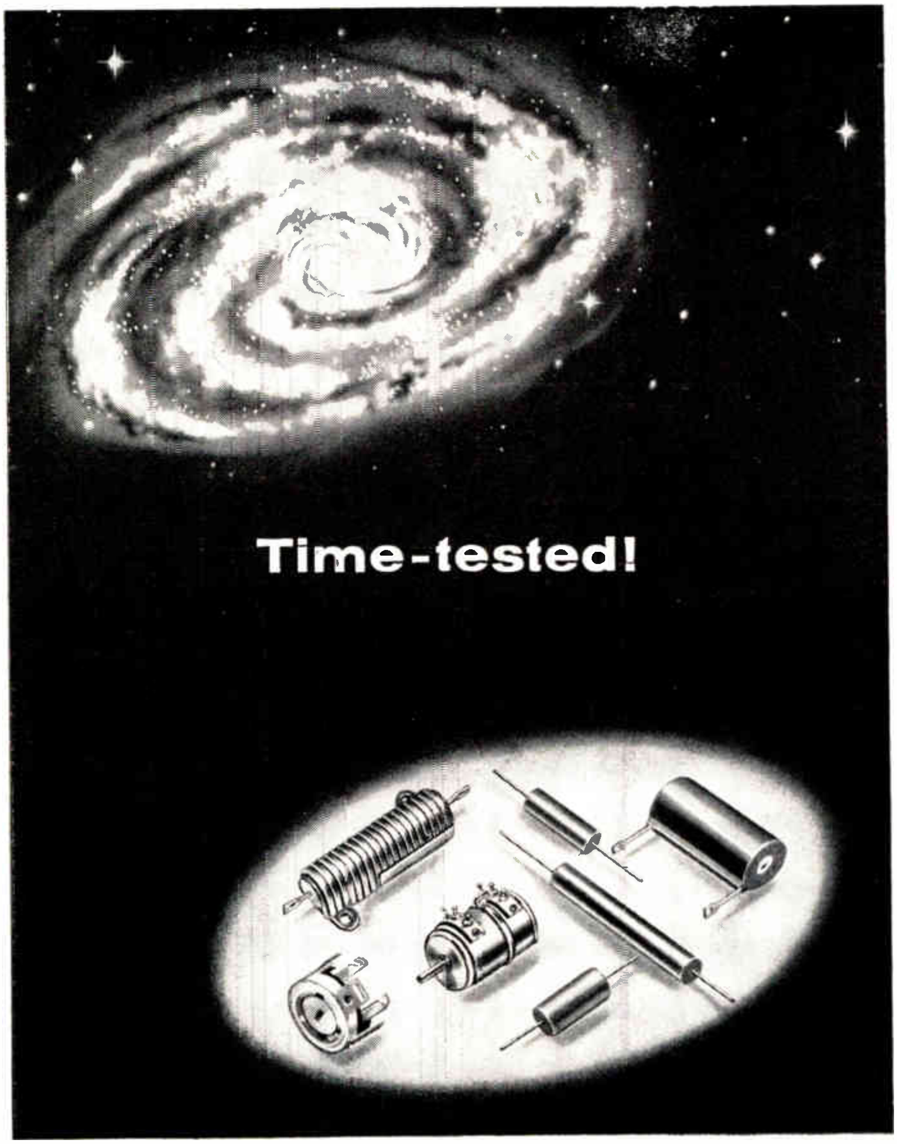
Now undergoing final development in General Electric's Electronics Laboratory, the "thermoplastic display" is expected to find maximum application in the high-speed radar systems of the future.

176-03

*Progress Is Our Most Important Product*

**GENERAL ELECTRIC**

DEFENSE ELECTRONICS DIVISION
HEAVY MILITARY ELECTRONICS DEPARTMENT
SYRACUSE, NEW YORK

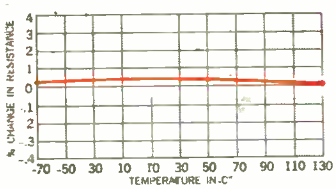



*— the time-tested standard of the resistor industry*

# Evanohm*

## RESISTANCE ALLOY

*— for resistors and precision instruments*




Percent change in resistance of an ideal sample of Evanohm. Normal production material (.002" and finer) is supplied within the range ±10 ppm (-65 to 25 C. and 25 to 125 C. referred to 25°C.)

Wherever exceptional stability over a wide temperature range is essential, EVANOHM is the accepted standard of performance. This high-reliability resistance alloy provides high specific resistance, low temperature coefficient, low thermal EMF to copper. EVANOHM is especially recommended for use in resistors, aircraft instruments, for guided missiles, rockets and other precision equipment. Available in bare wire, enamel, formvar, polyurethane, silk, cotton, nylon and glass insulation. Write for complete electrical and mechanical data and recommendations on your specific application.

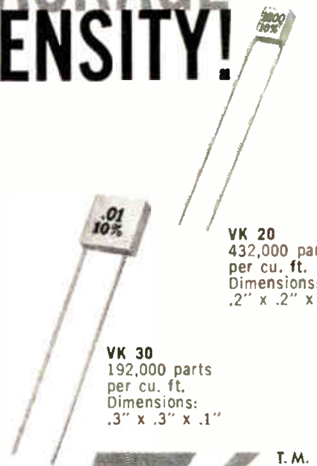
*Patents 2,293,878–2,638,425 — Tradename Registered*

**WILBUR B. DRIVER CO.**

Main Office: NEWARK, N. J.—Tel. HUmboldt 2-5550

Branch Offices and Warehouses in Principal Cities. Manufacturing Plants: 1875 McCarter H'way, Newark 4, N. J.; 2734 Industrial Way, Santa Maria, Calif. Canadian Wilbur B. Driver Co., Ltd., Rexdale (Toronto). Subsidiary: Western Gold and Platinum Co., 525 Harbor Blvd., Belmont, Calif.

# HIGH PACKAGE DENSITY!




**VK 20**
432,000 parts per cu. ft.
Dimensions: .2" x .2" x .1"

**VK 30**
192,000 parts per cu. ft.
Dimensions: .3" x .3" x .1"

VK T.M.

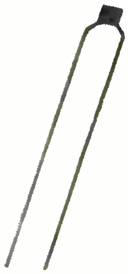
micro-miniature

## CERAMIC CAPACITORS

- Decimal dimensioned case
- Max. volumetric efficiency
- Contiguous flush-mount
- 47-10,000 mmf
- 200 vdc without derating
- −55°C to 150°C operation

"VK" capacitors are designed with square precision molded cases in only two sizes and a single standard 0.2" lead spacing for all values. Continuous life and environmental testing, plus 100% tests for Dissipation Factor, Insulation Resistance, and Capacitance guarantee that each "VK" capacitor in your circuit will perform as predicted.

**ALSO UNCASED FOR COMPLETE ASSEMBLY ENCAPSULATION**



Same electrical characteristics as standard "VK" series. Each unit coated with a resilient protective compound. Dimensions: 47-100 mmf, .100" square; 120-270 mmf, .130" square; 330-1000 mmf, .150" square; 1200-3300 mmf, .250" square; 3900-10,000 mmf, .265" square.

**Vitramon® Incorporated**
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# SIDE BY SIDE WITH ANY INSTRUMENTATION...


# CUBIC Digital systems speak for themselves

An uncluttered, human-engineered front panel and internal engineering and construction demonstrate to the eye that Cubic's is the *superior* digital instrument. Proof of this superiority is in the *operation* . . . and side by side in independent evaluations of many instruments, Cubic again and again provides the instrumentation that is *specified*.

Any phenomenon of science which can be converted to a usable DC Voltage can be measured with the Cubic 4 or 5-digit Voltmeter (Models V-41, V-51) powered by the Model C-1 Control Unit. Addition of an AC Converter (Model AC-1, manual ranging; Model AC-2, automatic ranging) or a Model PA-1 Preamplifier extends the systems capabilities to the measurements of AC voltages or lower level DC voltages.

Precise resistance measurement is possible with the 0-41 and 0-51 4 and 5-digit Ohmmeters, powered by the C-1 or C-2 Control Unit.

Multiple input channels may be sampled rapidly and accurately with the Model MS-2, a single unit for scanning up to 100 points, or the MS-1, AS-1 Master-Auxiliary combination for scanning up to 1000 points with multiples of one, two, four or five-wire inputs.

Voltage ratio measurements are made with the R-41 and R-51 4 and 5-digit models operating only as Ratiometers or with the VR-41 and VR-51 models, which operate both as Ratiometers and Voltmeters. Measurements can be permanently recorded with the addition of a PC-Series Printer Control Unit, providing input for any quality printer on the market.

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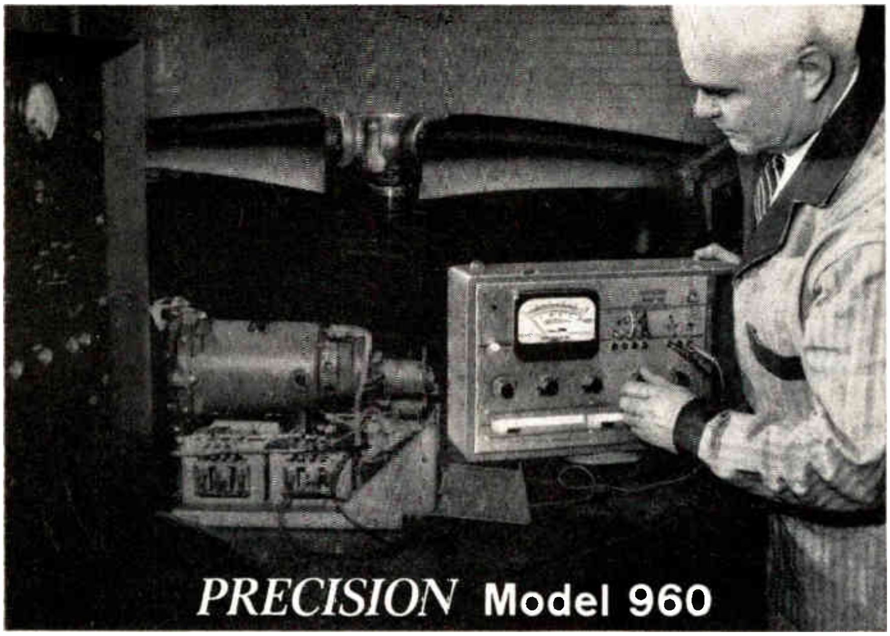


***transistor and crystal diode tester...***

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### THE PROBLEM:

Curtiss-Wright needed an accurate and reliable transistor tester, for field testing and maintenance of their transistorized Propeller Synchronizer and its associated equipment.

### THE SOLUTION:

After evaluating available test instruments, the ***PRECISION*** Model 960* was chosen on the basis of its design suitability, reliability and low unit cost.

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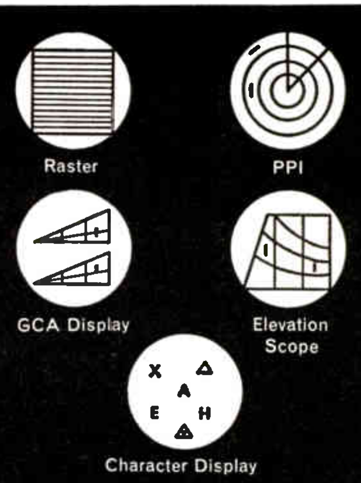


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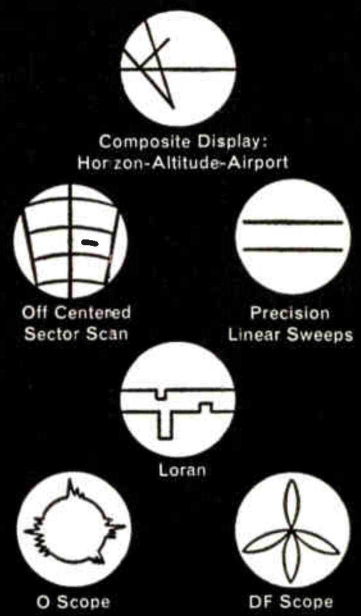


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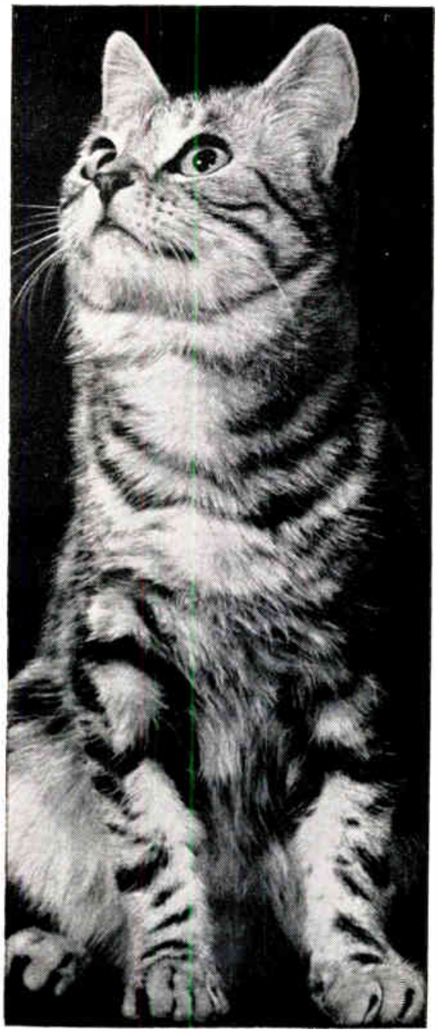
*


# WHAT HAS THE **7182 S BAND MAGNETRON** IN COMMON WITH THIS CAT?

*



A good question! According to legend, a cat has nine lives—something that has yet to be proved. The 7182, on the other hand, has a *proved* life 8 to 10 times greater than any similar S-Band magnetron.

The 7182 retains its remarkable stability and reliability during a life of 10,000 hours, and is one of a series of magnetrons now in production providing peak powers of 5 MW. These magnetrons operate at voltages and current densities usually associated with magnetrons rated at a fraction of the power output.

A parallel development in L-Band ensures that attainments in this field equal the phenomenal successes already achieved with S-Band magnetrons.

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AP 134

## BASIC BUILDING BLOCKS FROM KEARFOTT

# 20 SECOND SYNCHRO

This synchro, just one of a broad line offered by Kearfott, provides the extreme accuracy required in today's data transmission systems. Kearfott synchro resolvers enable system designers to achieve unusual accuracy without the need for 2-speed servos and elaborate electronics. By proper impedance, matches up to 64 resolver control transformers can also operate from one resolver transmitter.

**TYPICAL CHARACTERISTICS** — **SIZE 25**

| Type Resolver | Transmitter | Control Transformer |
|---|---|---|
| Part Number | Z5161-001 | Z5151-003 |
| Excit. Volts (Max.) | 115 | 90 |
| Frequency (cps) | 400 | 400 |
| Primary Imped. | 400/80° | 8500/80° |
| Secondary Imped. | 250/80° | 14000/80° |
| Transform. Ratio | .7826 | 1.278 |
| Max. Error fr. E.Z. | 20 seconds | 20 seconds |
| Primary | Rotor | Stator |

*Write for complete data.*

## BASIC BUILDING BLOCKS FROM KEARFOTT

# PRECISE ANGLE INDICATOR

Consisting of an angle position indicator, motor and servo amplifier, this small, versatile, rack panel mounted unit provides angular position indications for laboratory, production and field use. Input signals proportional to unknown angular position of synchro device being measured are resolved as an error voltage, which is amplified and used to drive an internal servo loop to null. Counter mechanism then provides direct visual readout of angular position.

**TYPICAL CHARACTERISTICS**

Input Signal: $S_1$, $S_2$, and $S_3$ of external synchro transmitter.

Repeatability: Within 0.6 minute in either a clockwise or counterclockwise direction for any angular position.

Readability: 0.5 minute through full range from zero to 360° Rotation is continuous.

Accuracy: ± 6 minutes in the standard unit. Other accuracies available on request.

Sensitivity: 0.5 minutes maximum.

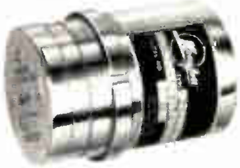
Slewing Speed: Phase sensitive, 180° in 7 seconds.

Input Voltages: 115 volts, single phase, 400 cycles, 23 VA max.

Size: Standard Rack Mounting—1¾" x 9½" x 8½"

*Write for complete data.*

## BASIC BUILDING BLOCKS FROM KEARFOTT



# FLOATED RATE INTEGRATING GYROS

Specifically designed for missile applications, these Kearfott miniature gyros operate efficiently at unlimited altitudes. Their outstanding accuracy and performance make them superior to any comparably-sized units on the market. Hermetically sealed within a thermal jacket, these gyros are ruggedly designed and completely adaptable to production methods. Performance characteristics that are even more precise can be provided within the same dimensions.

**TYPICAL CHARACTERISTICS**

Mass Unbalance:
  Along Input Axis: 1.0°/hr maximum untrimmed

Standard Deviation (short term):
  Azimuth Position: 0.05°/hr
  Vertical Position: 0.03°/hr

Drift Rate Due to Anisoelasticity
  Steady Acceleration: .015°/hr./$g^2$ maximum

Vibratory Acceleration: .008°/hr./$g^2$ maximum

Damping:
  Ratio of input angle to output angle is 0.2

Characteristic Time: .0035 seconds or less

Weight: 0.7 lbs.

Warm-Up Time: 10 minutes from −60°F

Life: 1000 hours minimum

*Write for complete data.*

*Tachometers*

*Servo Valve*

*Ferrites*

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**GENERAL PRECISION INC.**
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# NEW DELCO 50-AMP. TRANSISTORS

## HIGHER CURRENT THAN EVER BEFORE FOR MILITARY AND COMMERCIAL USE

| | 2N1518 | 2N1519 | 2N1520 | 2N1521 | 2N1522 | 2N1523 |
|---|---|---|---|---|---|---|
| Maximum Collector Current (Amps.) | 25 | 25 | 35 | 35 | 50 | 50 |
| Maximum Collector to Base Volts, Emitter Open, Max Ico 4ma | 50 | 80 | 50 | 80 | 50 | 80 |
| Minimum Open Base Volts (1-Amp. Sweep Method) | 40 | 60 | 40 | 60 | 40 | 60 |
| Maximum Saturation Volts at Maximum Collector Current | 0.7 | 0.7 | 0.6 | 0.6 | 0.5 | 0.5 |
| Gain at Ic at 15 Amps. | 15-40 | 15-40 | 17-35 | 17-35 | 22-45 | 22-45 |
| Minimum Gain at Maximum Collector Current | 12 | 12 | 12 | 12 | 12 | 12 |
| Thermal Resistance Junction to Mounting Base (°C/Watt) | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |

Characteristics at 25°C  Maximum Junction Temperature 95°C

A new family of high current transistors featuring the 50-ampere 2N1522 and 2N1523. Two 25- and two 35-ampere types round out the line. All thoroughly tested and completely reliable. Available in production quantities. Call or write your nearest Delco Radio sales office for full product information and applications assistance.

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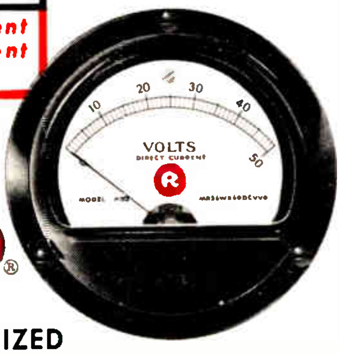
VOLTS
DIRECT CURRENT
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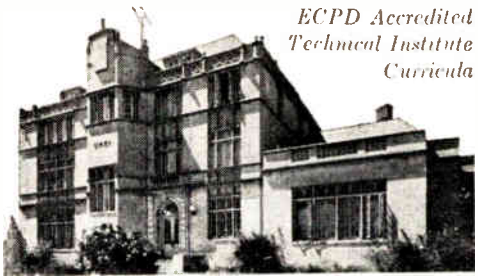





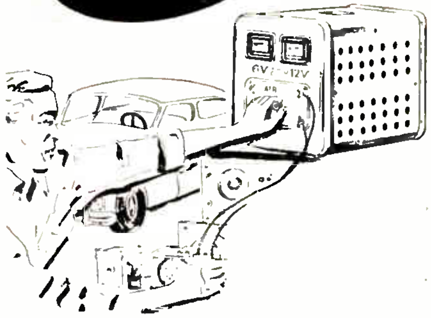




6V
12V
ATR


# This bulletin is news for you if you're looking for big military contracts

The annual AFCEA National Convention and Exhibit really is a top level meeting, where you join the upper sales echelons as your own ambassador, and introduce your products in the most strategic of all areas.

Here you mingle with the cream of the electronics and communications industry, and the top representatives of the Armed Forces and government. Your firm and its products will be on display for a large, exclusive audience of market V.I.P.'s – all of whom are prospective customers.

Because the Convention is a *common ground* meeting place, it affords you the perfect opportunity to get to know the most important members of the Armed Services and your industry.

You meet with military purchasers and manufacturing colleagues; personal contact with those in the know keeps you up to date on the latest needs and projects of the military, as well as current industry research and developments.

The Exhibit is a must for manufacturers who want to sell in the most profitable of all markets. It serves as a big, bright showcase which attracts buyers from all over the country, and you as an exhibitor identify yourself in the most practical way as being a supplier in *the* market. Remember, almost all of the viewers of your display are prospective purchasers. A good, working display makes the contacts for you, and can mean on-the-spot sales!

The AFCEA Convention and Exhibit are both held in Washington's Sheraton-Park Hotel, where for three days you are kept busy and stimulated by:

*Panel discussions* which feature carefully-prepared *professional papers* on timely military-electronics subjects, presented by well-known engineers and scientists.

Interesting *speeches* on significant themes, given by famous military and industry personalities.

A tour, conducted by the U.S. Army, through a large military installation.

*Banquets, receptions* and *luncheons* which provide still more occasions for profitable contacts.

And, of course, the 94 displays set up in the exhibition hall of the famous hotel.

"Communications and Electronics–the arm of control, the voice of command," is the theme of AFCEA's 1960 Convention and Exhibit. The Exhibit will reflect the amazing progress this young industry is making; wouldn't you like to show what your own firm has accomplished?

As a service to each exhibitor advertising in SIGNAL, the official publication of the AFCEA, a free ad in the exhibit listings of both SIGNAL and the official program is offered. Such wide advertising coverage gives added sales impact. The May issue of SIGNAL gives full coverage to the AFCEA Convention and Exhibit. In itself an "Exhibit in Print," this issue will be out in advance of the big event, spotlighting your products and serving to direct visitors to your display at the Exhibit. The issue will be indispensable as a guide to this year's Convention and Exhibit, since it will contain a complete list of exhibitors and the products to be displayed, as well as advance data about all technical papers, meetings, and other special activities.

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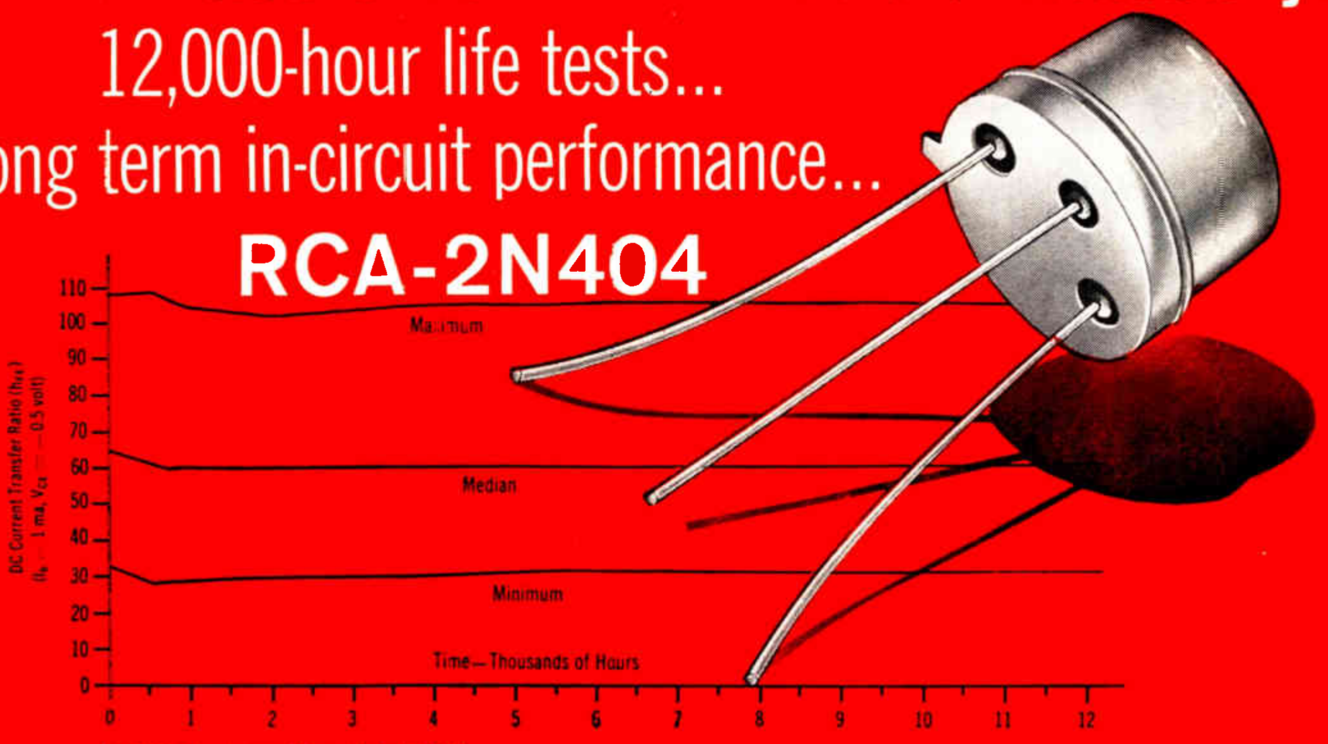
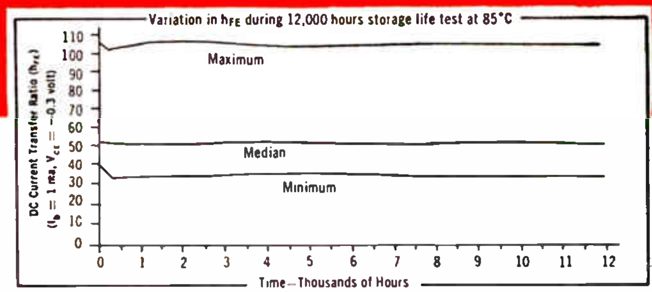
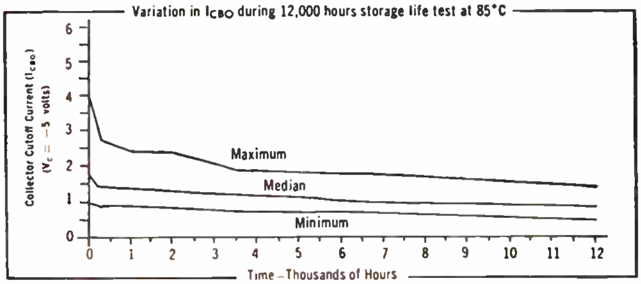
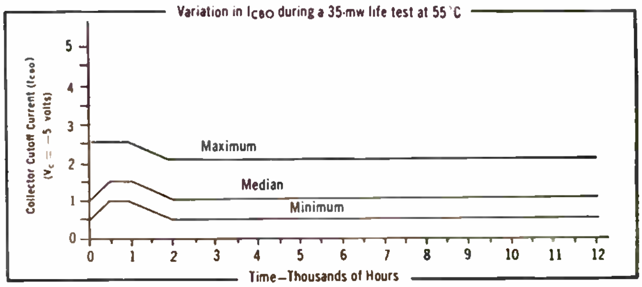
## RCA-2N404




Variation in $h_{FE}$ during a 35-mw life test at 55°C




**The transistor that helped build an industry ...designed, built and introduced by RCA... chosen by top manufacturers for the finest computers...the RCA-2N404 has set new standards of reliability for transistorized computers**

Outstanding new achievements of operating reliability, long life, and stability are being made by the RCA-2N404 germanium p-n-p medium-speed switching transistor. Stringent long-term life tests and dynamic in-circuit performance checks, both at maximum ratings, provide additional proof of the bedrock reliability of the RCA-2N404.

### Here are the results:

(1) Representative samples of the RCA-2N404 computer transistor have now passed 12,000 hours of operating life at *maximum* ratings. The curves at the right show the remarkable stability of transistor parameters over this exceptional time period.

(2) Samples from every lot of RCA-2N404 transistors are tested at *maximum* ratings for 1,000 hours. During 1959, almost 6,000,000 transistor test-hours at 85°C junction temperature were logged.

Why not call your RCA Field Representative today for the full story on the RCA-2N404 and the RCA-2N404 designed to meet military specification MIL-T-19500 20 USAF. For technical information write RCA Commercial Engineering, Section E-35-NN, Somerville, N.J.

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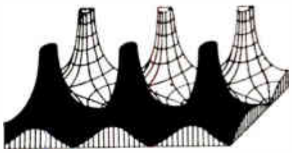
*May, 1960*
*Vol. 48 No. 5*

Proceedings of the IRE

# Poles and Zeros



**Section Publications.** The issuance, in March, 1960, of a new edition of the "Manual for IRE Section Publications" recalls again the local Section phase of IRE "information processing." Poles and Zeros tossed a bouquet (Roses to Ye Editors) to the Section publications in April, 1959. It can now report a little over a year later, not only that old standbys are flourishing but also that two new infants are born. The new additions are the "Denshi Tokyo" and "The Benelux Bridge" of the Tokyo and Benelux Sections, respectively. We wish the newcomers well and trust that they will take their rightful place in the sun. Sections that contemplate a publication venture should acquire a copy of the Sections Publication Manual; it is filled with pertinent and helpful information.

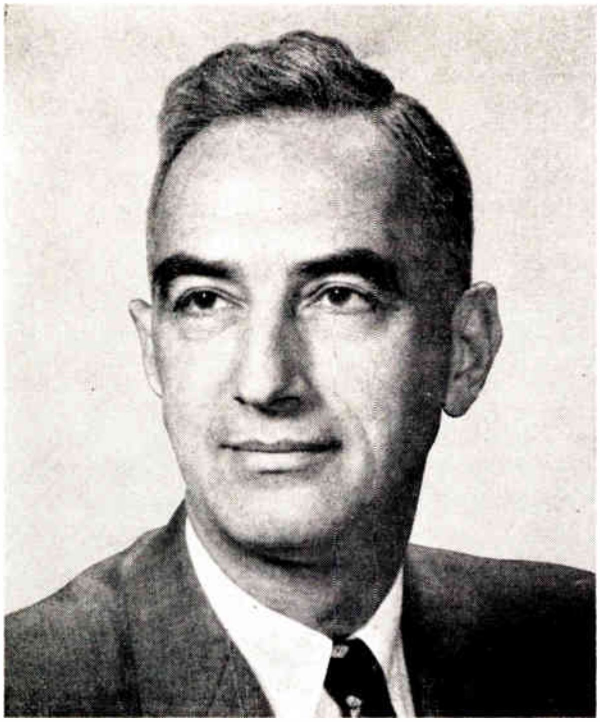
**Feedback.** The Editor of any publication receives mail from readers containing both constructive criticism, and destructive diatribe. Fortunately, the distribution of mail (to this Editor, so far) is weighted on the constructive side. Every letter has received, or is receiving, attention from the Editorial Board. Occasionally, the sequence of correspondence is in itself helpful. On two successive days letters were recently received. The first letter suggested that all issues of the PROCEEDINGS should be "Special Issues" and contain only material of general interest (twelve per year—what would we call them?). The same correspondent suggested that specific interest material be published in the TRANSACTIONS. The second letter deplored the use and existence of the TRANSACTIONS and, the writer felt, all material should be published in the PROCEEDINGS. Perhaps the present plan is the compromise which meets the need of most people!

Another correspondent struck a most responsive chord. He made an impassioned plea for the use of a consistent set of dimensional units for all PROCEEDINGS papers. A glance through several issues of the PROCEEDINGS validates his protest. As engineering writers we are certainly careless about dimensionality. In a given paper, on occasion, the same author mixes the English and the metric systems. This carelessness does not contribute either to smooth reading or to ease of continuity of interpretation. Without entering into the larger question of the ultimate adoption of the metric system in the United States (see, for example, page 584 of the April, 1959 issue of the PROCEEDINGS), it does seem that at least for scientific and technical articles, uniformity would be advantageous. Since the MKS system has been officially adopted, and all college and university text books have accepted the system, why not use it consistently in all engineering writing?

Another letter to the Editor has pointed out certain inconsistencies, to be deplored, in the use of abbreviations. What excuse is there, queries this communicator, for the small case "m," as an example, in "mc" as an abbreviation for megacycle and in "ms" as an abbreviation for millisecond? This complaint recalls the interesting article by Arnold P. G. Peterson, in the TRANSACTIONS ON ENGINEERING WRITING AND SPEECH, for December, 1959, in which he suggests a rational system for naming the prefixes for both positive and negative powers of ten, and he associates with each a suggested symbol. These suggestions avoid the difficulty quoted above by using capital letters as symbols, for positive values of the exponent of ten, and lower case letter symbols for the negative exponent.

These rambling comments, engendered by recent correspondence, emphasize the necessity for such a Professional Group as that on Engineering Writing and Speech; it behooves all IRE authors to make use of the opportunities this Professional Group offers for the improvement of their literary efforts. The Editorial Board is presently considering the revision and subsequent reissuance of the IRE document titled "Information for Authors." This brief document might well be supplemented ultimately by a more complete "style manual" produced in cooperation with the PGEWS.

**Aftermath.** Poles and Zeros in March took notice of the 1960 International Convention and Radio Engineering Show. In those comments attention was called to the Panel Session "Electronics—Out of This World" and now that the convention is history one reflects that much of it was "out of this world." To this observer a small sample of such reflections might be listed thus: opening ceremonies at the Coliseum contacted Pioneer V, already 1,449,000 miles from earth and going away at the rate of 6,000 miles an hour; components so minute that their containers must be labeled "This Box Is Not Empty;" solar powered electric automobile (1912 model), which prior to the convention operated in Central Park; the announcement of a search for intelligence coming from outer space at distances so great that the initiators may have been extinct for milleniums; passive satellite balloons ten stories high; eyes and brains too tired to take in more; possible clues to the diagnosis of muscular disease based on new ability to measure extremely weak high frequency electrical signals; miracles of microminiaturization—a one hundred tube digital computer the size of a cigarette box; the implantation of electronic equipment in the human body for periods up to five years; the use of electronic devices for prenatal diagnosis; etc., etc.; the largest attendance of all time totaling 69,760, exceeding 1959 by 15 per cent.—F. H., Jr.



# Ferdinand Hamburger, Jr.

*Editor, 1960*

Ferdinand Hamburger, Jr. (A'32–M'39–SM'43–F'53) was born in Baltimore, Md., on July 5, 1904. He received the degrees of Bachelor of Engineering in 1924, and Doctor of Engineering in 1931, from The Johns Hopkins University, Baltimore, Md. He was a Charles A. Coffin Fellow in 1930–1931.

During the period between the undergraduate and graduate degrees he participated in a program of dielectric research at The Johns Hopkins University. In 1931 he was appointed instructor in electrical engineering, in 1947 professor of electrical engineering, and in 1954 chairman of the Department of Electrical Engineering, and in addition, in 1958 Director of the Radiation Laboratory of The Johns Hopkins University. He served as chief test engineer for Bendix Radio Division from 1942 to 1945, while on partial leave of absence from the University. He has acted as consultant for the Research and Standard Section, Bureau of Ships, Navy Department; U. S. District Court; RCA, and others. He has served as Research Contract Director of a number of research investigations supported by the Department of Defense at The Johns Hopkins University.

Dr. Hamburger was IRE Regional Director of the Central Atlantic Region in 1950–1951, and a Director-at-Large in 1959. He has served on the Nominations, Appointments, Policy Advisory, and Education Committees. He has been a member of the Editorial Board since 1956 and was Vice Chairman in 1958–1959. He was IRE representative at The Johns Hopkins University from 1941 to 1955. He was largely responsible for the formation of the Baltimore Section of the IRE in 1939 and its reorganization in 1944; he served as its Chairman in 1940–1941.

He is a Fellow of the American Institute of Electrical Engineers and is presently serving as Vice Chairman of its Instrumentation Division. He is a member of Sigma Xi, Tau Beta Pi, and Eta Kappa Nu, and is a registered Professional Engineer in the State of Maryland.

# Scanning the Issue

**Some Notes on the History of Parametric Transducers** (Mumford, p. 848)—One would be hard put to name a subject which has caused more excitement in recent years than the parametric amplifier. What started as a small flurry of article writing a few years ago has since grown to near blizzard proportions. Well over 100 papers have been written on this subject in the last two years alone. Yet the parametric principle has been with us for many decades. Zenneck and Alexanderson described magnetic frequency doublers and magnetic amplifiers to IRE audiences 44 years ago. Indeed, this subject can be traced as far back as 1831 to Faraday's observations of the double period oscillation of surface waves of liquids. The history of the development of parametric principles and devices, from 1831 to the present, is briefly summarized in this excellent review of the subject. The chronology presented here, supported by 200 selected references, is little known and will do much to help readers orient in their minds the recent rash of new amplifiers having a common underlying principle.

**Low-Noise Tunnel-Diode Down Converter Having Conversion Gain** (Chang, *et al.*, p. 854)—A new and important use has been found for a device which is currently one of the most talked about components in the electronics field. As reported last July in the PROCEEDINGS, the tunnel, or Esaki, diode is a semiconductor device with negative resistance characteristics which give it exceptional high-frequency low-noise amplification capabilities. It is now shown that the nonlinearity of this negative resistance characteristic can be used for low-noise high-gain frequency conversion—from a high frequency to a lower frequency. This down-conversion capability is most significant. Although good up-converters have been developed recently, there is at present no mixer device capable of down-conversion that does not exhibit either a conversion loss or a poor noise factor. Thus the tunnel diode becomes the first device which can convert UHF or microwave signals to a lower frequency with low noise and conversion gain.

**Noise Limitations to Resolving Power in Electronic Imaging** (Coltman and Anderson, p. 858)—In recent years an increasingly large segment of the electronics profession has become concerned with the recognition of patterns on television and other cathode-ray-tube displays in the presence of noise. The study presented here of the limiting effects of noise on image resolution will be of fundamental interest to this group of readers. The authors show that the resolution limit can be accurately predicted in quantitative terms from a knowledge of noise power per unit bandwidth and the sine wave response of the system.

**Packaged Tunable L-Band Maser System** (Arams and Okwit, p. 866)—A maser normally requires cumbersome and highly precise supplementary equipment which limits its use to laboratory and a few other special types of installations. This paper describes a tunable maser system that has been packaged into a sufficiently compact form to make it suitable for field operational use without detriment to its low-noise performance. This "reduction to practice" of one of the important new developments in electronics will be of wide interest, especially to radio astronomers because its frequency range makes it suitable for studying the Doppler shift of the 21-centimeter hydrogen line in receding galaxies.

**Cadmium Sulfide Field Effect Phototransistor** (Bockemuehl, p. 875)—Cadmium sulfide has previously achieved fame as a photoconductive material. The author has now extended its utility by fabricating a cadmium sulfide transistor and obtaining useful power gain from it. This represents the first time that field effect amplification has been reported for any material in which virtually all the carriers are generated photoelectrically. Although CdS will never compete with germanium for general transistor applications, this work opens the door to many novel photocircuit functions which are not practicable with conventional circuit elements.

**The Optimum Formula for the Gain of a Flow Graph, or a Single Derivation of Coates' Formula** (Desoer, p. 883)—During the seven years since the first paper on the subject appeared in the PROCEEDINGS, signal flow graphs have become a popular and useful tool for analyzing a wide variety of engineering problems. This paper provides an important refinement of this tool—a new and simpler derivation of the gain formula for flow graphs. It has the added blessings of being a self-contained discussion of the subject and, in the author's words, being so simple "that even seniors can grasp it."

**A Broad-Band Cyclotron Resonance RF Detector Tube** (Turner, p. 890)—A novel method of detecting RF signals has been developed which utilizes the spiral motion of electrons as a tunable system which will become resonant when the frequency of spiraling is the same as that of an incoming signal. The tube is in essence a complete TRF receiver (less video amplifier) within one vacuum envelope. Its rapidly variable tuning and wide bandwidth (10 to 1) will make this development of considerable interest to engineers concerned with microwave systems for search, analysis and reception of signals over wide frequency ranges.

**Anomalies in the Absorption of Radio Waves by Atmospheric Gases** (Straiton and Tolbert, p. 898)—This paper will be of great interest to anyone concerned with propagation above 10,000 megacycles. The authors have gathered the results of recent propagation measurements in the millimeter range to shed new light on losses due to atmospheric absorption. They find that the measured losses in this relatively new part of the spectrum do not entirely agree with the losses predicted by classical theory developed over a decade ago, especially with respect to losses due to water vapor.

**Interaction Impedance Measurements by Propagation Constant Perturbation** (McIsaac and Wang, p. 904)—This paper is concerned with a technique for measuring the interaction impedance characteristics of microwave circuits by determining the change produced in the propagation constant when a rod is inserted in a waveguide. The technique is broadly applicable to various types of microwave structures, such as slow wave structures for traveling-wave tubes, and the results developed here will no doubt be regarded as a primary reference on the subject.

**Taylor-Cauchy Transforms for Analysis of a Class of Nonlinear Systems** (Ku, Wolf and Dietz, p. 912)—Since this paper is a companion to the paper that follows, the discussion of both papers have been combined below.

**Laurent-Cauchy Transforms for Analysis of Linear Systems Described by Differential-Difference and Sum Equations** (Ku and Wolf, p. 923)—This and the companion paper that precedes it describe a novel type of transform for solving problems described by linear and nonlinear differential and difference equations. The first paper, on Taylor-Cauchy transforms, deals with continuous nonlinear processes, while the second paper, on Laurent-Cauchy transforms, deals with discrete processes. They provide engineers with another tool of considerable usefulness in the analysis of a variety of physical systems.

**Scanning the Transactions** appears on page 965.

# Some Notes on the History of Parametric Transducers*

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**Summary—This paper summarizes briefly the chronology of the development of parametric transducers. The early works of Michael Faraday (1831), F. Melde (1859), and Lord Rayleigh (1883) are cited as mechanical examples and the pioneering work of L. Kühn, J. Zenneck, E. F. W. Alexanderson and R. V. L. Hartley are cited as electrical examples. A very brief résumé of selected contributions follows, dating from the work on H. Q. North's diodes in 1945 to the present flurry of excitement beginning in 1954, created by the development of the Signal Corps-Bell Laboratories Task 8 varactor diodes. A list of 200 selected references is included.**

THE recent interest in amplifiers which derive their gain from variable reactance circuit elements stems chiefly from the development of low-loss variable-capacitance diodes. There are two reasons for this interest. One reason is the fact that such amplifiers have low noise and the other is that the diodes are expected to have extremely long life. Either one of these properties is adequate justification for the excitement currently rampant throughout the world concerning the exploitation of this "new" type of amplifier, but, with two good reasons readily apparent, this excitation is doubled.

Mystery seemed to invade the thoughts of people when the scientists announced this new type of amplifier which was called a variety of names, such as: "Parametric Amplifier," "Reactance Amplifier" and "MAVAR" (Modulator Amplifier by Variable Reactance).[1] Some of this mystery could have been avoided had the modern men known or mentioned that the principle underlying the mechanism whereby electrical amplification was effected was an old principle. This principle may be broadly stated thus: *The energy of an oscillating system may be increased by supplying energy at a frequency which differs from the fundamental frequency of the oscillator.* One mechanical illustration of this principle is the simple pendulum. The child in the swing learns that he can "pump up" the amplitude of the oscillation of the swing by lowering his center of gravity on the down swing and raising it on the up swing. He thus "pumps" at twice the frequency of the swing. Who knows when this was invented? Could it have been in prehistoric times by a monkey swinging by his tail from the branch of a tree?

Faraday, Melde and Lord Rayleigh have published observations and calculations concerning this principle. Quoting Lord Rayleigh, "Faraday, . . . with great ingenuity and success (upon examining) . . . the crispations upon the surface of water which oscillates vertically, arrived at the conclusion experimentally that there were two complete vibrations of the support for each complete vibration of the liquid. Crispations (may be) observed upon the surface of liquid in a large wine glass or finger glass which is caused to vibrate in the usual manner by carrying the moistened finger round the circumference. All that is essential to the production of crispations is that the body of liquid with a free surface be constrained to execute a vertical vibration. Faraday's assertion that the waves have a period double that of the support has been disputed, but it may be verified in various ways." Faraday's work was published in 1831 and Lord Rayleigh verified his conclusions sixty years later, also with considerable ingenuity. The double period oscillation of the water is not readily proven by casual observation.

The following example of the principle, reported by Melde in 1859, is, however, readily observed and understood. Quoting again from Lord Rayleigh, "Perhaps the best known example is that form of Melde's experiment in which a fine string is maintained in transverse vibration by connecting one of its extremities with a vibrating prong of a massive tuning fork, *the direction of motion of the point of attachment being parallel to the length of the string.* Under these circumstances . . . the string may settle down into a permanent and vigorous vibration, whose period is the *double* of that of the fork." Lord Rayleigh analyzed and experimented with this and other similar mechanical phenomena in 1887. This led to analogous experiments with electrical circuits.

The electrical principle is readily understood by the following simple explanation. Suppose that we have a capacitor formed by two metal plates separated by air. Assume that a charge exists on the capacitor. The plates will be attracted to each other because of the equal and opposite charges so that to separate the plates requires work. Upon separating the plates, say to twice the original distance, the capacitance will be reduced to half its original value and, hence, the voltage must be twice the original value, since the charge upon the plates remains the same. The electrostatic energy, however, has been doubled, since it is proportional to the square of the voltage and directly proportional to the capacitance. The energy required to separate the plates now appears as electrostatic energy in the capacitor.

Now suppose that the capacitor is combined with an inductor to form an oscillating circuit. The voltage on the capacitor will reach a maximum value twice each cycle. Now if, on each half cycle, the capacitance is decreased when the voltage is maximum and increased when the voltage is zero, net energy will be imparted to the oscillations since no electrical energy is used to restore the capacitor to its original value when the voltage is zero.

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[1] These three names are considered herein to be synonymous and to apply to any device which derives its gain from the pumping of a variable reactance.

Similarly, it is apparent that energy could be imparted to the circuit had the *inductance* been varied in the appropriate phase. This electrical principle was expanded to include frequencies other than the two-to-one ratio and the resulting device was used successfully in radio telephone communication between Berlin and Vienna prior to World War I. This was described by L. Kühn in 1915. Prof. J. Zenneck, E. F. W. Alexanderson and R. V. L. Hartley pioneered with theoretical and experimental contributions within the next few years. Alexanderson called these devices "Magnetic Amplifiers," a name which remains with us today. The objective then was to modulate a continuous wave arc transmitter by means of a nonlinear inductance or saturable reactance. Here the voice currents constituted the signal, and the carrier was the pump. The resulting sidebands were radiated, together with the pump (or its harmonic in some cases).

I quote the following from a paper delivered by E. F. W. Alexanderson at an IRE meeting in New York City on February 2, 1916:

> The name "Magnetic Amplifier" has been given to a device for controlling the flow of radio frequency currents because this name seems to describe its function when it is used for radio telephony better than would any other. As the same device can be used for a variety of other purposes, the above name may in some cases not seem too appropriate. However, the essential part of the theory that will be given refers to the amount of amplification which is possible of attainment and the methods of securing a higher ratio of amplification than would be given by the device in its simplest form. . . .
> The ratio of amplification is proportional to the ratio between the frequency of the radio current and that of the controlling current.

(This conclusion was verified by R. V. L. Hartley and subsequently by Manley and Rowe.)

Alexanderson, in the discussion, also suggested amplification of incoming signals by cascaded stages of up-conversion, rectification and up-conversion, etc. The name of Alexanderson's device withstood the rigors of time. Currently, however, we recognize its radio frequency version as a type of parametric amplifier, reactance amplifier, or MAVAR.

In Alexanderson's magnetic amplifier, the chief interest resided in the mode of operation in which the input signal was in the voice frequency band and the useful output power was taken in some radio frequency band. Thus it was a modulator or up-converter.

Alexanderson presented curves to show that negative resistance effects could exist. Quoting again from his 1916 paper: Under some conditions "instability and generation of self-excited oscillations" can exist. "This is a condition that must be avoided for telephone control; whereas it may have useful applications for other purposes." (One useful application, pointed out by Eugene Peterson in 1930, was the negative resistance straight-through amplifier, in which the negative resistance effect was enhanced by the suppression of frequencies higher than the pumping frequency.)

Louis Cohen, in a communicated discussion of the paper, said:

> It appears to me that the fundamental principle . . . will find its application to other problems in connection with radio frequency circuits. One that suggests itself immediately is the amplification of incoming signals.

Alfred N. Goldsmith pointed out the advantages of Alexanderson's magnetic amplifier over the direct-current-controlled frequency doubler employed by Kühn.

Lee De Forest commented that the magnetic amplifier was far more practical as a high-power modulator than the ensemble of over 500 audion amplifiers used to obtain 11 kw at Arlington by the Western Electric Company. "No one can say, however, that the situation will not be altered very materially in one, two or three years after we learn how to build oscillions for large power outputs, say 5 or 10 kw each. That will create a very different situation."

Thus, there appears to be very old prior art on MAVAR, both as modulator and amplifier. However, the interest in magnetic amplifiers as radio frequency modulators subsided quickly with the advent of the high-power vacuum tube modulators. The "different situation" predicted by Lee De Forest in February, 1916, did, indeed, come to pass.

In the 1920's and '30's, interest developed in subharmonic oscillations in electrical circuits containing a variable reactance. These "parametric" oscillations could exist at any one of $f/n$ frequencies, where $n$ is the subharmonic fraction of the fundamental frequency. In 1954 Von Neumann and Goto independently recognized that a phase ambiguity existed in the subharmonic oscillations and that this ambiguity could be utilized in logic circuits. Goto calls this device a "parametron."

About thirty years after the pioneering work of Kühn, Zenneck, Alexanderson, and Hartley on inductive reactance modulators, interest developed in capacitance reactance modulators at microwave frequencies. The failure of reciprocity in some crystal converters observed in the middle 1940's by L. Apker of General Electric Co., Schenectady, N. Y., and R. N. Smith of Purdue University, Lafayette, Inc., and the peculiar behavior of welded contact germanium diodes made by H. Q. North of General Electric Co., Schenectady, N. Y., was interpreted to mean that the contact capacity varied with bias. H. C. Torrey of the Massachusetts Institute of Technology Radiation Laboratory, Cambridge, Mass., gave a thorough discussion of the theory of nonlinear capacity converters.

M. C. Waltz and R. V. Pound at the MIT Radiation Laboratory observed negative IF conductance when units like North's were used. Pound gave many interesting details about measured power and gain and also measured negative IF conductance. He obtained a 10-db gain and reasoned that such a receiver should have a better noise figure than that of a conventional converter which has conversion loss. He was unable, however, to achieve this.

In 1948, A. van der Ziel and, in 1949, V. D. Landon also derived the MAVAR gain relationships; the former also pointed out the low-noise figure possibilities.

In 1952, C. F. Edwards observed nonreciprocal behavior in converters when he used R. S. Ohl's bombarded silicon diodes which exhibited variable capacitance as well as variable resistance characteristics. This observation again triggered a sequence reminiscent of the North diode sequence of the 1940's in which Apker, Smith, Pound, and Waltz reported the experimental results and Torrey, van der Ziel, and Landon derived the theory. Corresponding names for the early 1950 sequence are Ohl, Edwards, Manley, and Rowe.

However, in neither of these sequences was a very low-loss variable capacitance diode available and hence the gain was limited and the noise figure was not especially good.

In 1954, the United States Signal Corps sponsored a project at Bell Telephone Laboratories, Murray Hill, N. J., to develop semiconductor devices. In the second interim report of this now famous "Task 8," A. E. Bakanowski published his derivation of the nonlinear capacitor as a mixer. The work of Bakanowski, Cranna and Uhlir led to the discovery of a technique for making low-loss units.

The technique of making low-loss silicon diode varactors or varicaps advanced rapidly and interest in these new units began to expand.

In the meantime, H. Suhl discovered that variable reactance in the microwave range was obtained in ferrite materials when properly excited by a pumping frequency. He proposed using this effect to obtain parametric amplification and discussed suitable materials in the paper published in 1957. M. T. Weiss verified Suhl's proposal experimentally.

M. E. Hines and H. E. Elder succeeded in demonstrating gain and oscillations in a reactance amplifier which used silicon varactors and suggested several microwave circuits for up-converters and negative resistance amplifiers. Their work stimulated activity in microwave applications of "varactor" diodes.[2]

In 1957, Heffner and Wade considered theoretically the noise, gain and bandwidth of parametric amplifiers.

Early in 1958, the low-noise properties predicted by theory were verified experimentally at the Bell Telephone Laboratories at 6000 mc by Uenohara and at 380 mc by Engelbrecht. Salzberg at Airborne Instruments Laboratory, Mineola, N. Y., and Heffner and Kotzebue at Stanford University, Stanford, Calif., also achieved low-noise performance working at 1 mc and 1200 mc, respectively.

Miyakawa in Japan, Cullen in England and Tien and Suhl in America considered the amplification and frequency conversion in propagating circuits in which the variable reactors were distributed along a transmission line while Bloom, Chang and Wittke of RCA Laboratories, Princeton, N. J., took up the theory of parametric amplification and discussed the new approaches to amplification of microwaves. Bloom and Chang also discussed the case of low frequency pumping.

R. S. Engelbrecht at Bell Telephone Laboratories designed a traveling wave UHF parametric amplifier using varactor diodes and achieved over 200-mc bandwidth at UHF with 8 to 10 gain. Measurements indicated an "astronomy" noise figure of one db, corresponding to a "radar" noise figure of about 3.5 db. (This compares favorably with the best commercially available vacuum tube, whose noise figure is about 5 db.)

In the meantime, Adler of Zenith, Chicago, Ill. (in June, 1957), suggested a novel principle of signal amplification using a pumped electron beam, and Bridges (in February, 1958) suggested and constructed a parametric amplifier using the variable reactance of a floating drift tube klystron. Louisell and Quate discussed the capabilities of this type of amplifier, and Adler demonstrated that the conclusions concerning the low-noise capabilities were indeed correct. He achieved a noise figure capability of 1.4 db, of which 0.4 db represented the loss in the input coupler.

The development of the vacuum tube in Alexanderson's time curtailed the interest in radio frequency parametric transducers. Thirty or so years later, the invention of the transistor then diminished the interest in vacuum tubes. But the interest in radio frequency parametric transducers was resurrected by the development of the low-noise variable capacitance diode, and this resurrection, in turn, has stimulated the interest in vacuum tubes as parametric transducers.

What is the next cycle in this see-saw pattern?

[2] It should be pointed out that, unknown to Hines and Elder, Kita and Fujii in Japan had been successful in demonstrating gain and oscillations at microwave frequencies independently while working with variable capacitance diodes in 1954.

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# Low-Noise Tunnel-Diode Down Converter Having Conversion Gain*

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*Summary*—**This paper describes the use of the new tunnel diode in a down converter. An experimental UHF circuit converting from a signal frequency of 210 mc to an intermediate frequency of 30 mc is used to illustrate the feasibility of this new converter. Conversion power gain of 22 db with less than 3 db noise has been achieved with gallium arsenide diodes. The circuit analysis proceeds from the basic nonlinear resistance of the tunnel diode I-V characteristic. Equations are developed for conversion gain, bandwidth and noise figure. From these equations, criteria are derived for the choice of diode characteristics and circuit parameters to obtain optimum performance.**

## Introduction

The low-noise, high-gain, conversion of a high-frequency signal to a lower-frequency signal has not been possible with previous mixer devices. Ordinary crystal mixers, which make use of the nonlinearity of their positive resistance, exhibit a conversion loss and a poor noise factor. The recently introduced parametric converters, which operate on a nonlinear capacitance or inductance basis, have achieved good noise factors with *up-conversion* gain. The parametric *down converters*, however, have poor noise factors. For such down converters, it is found that the excess noise factor (*i.e.*, the noise factor minus unity) varies roughly as the ratio of the input frequency to the output frequency. Thus, for a ten-to-one frequency down-conversion, the noise factor is around 10 db. Because of this frequency dependence, it is almost impossible to convert a microwave frequency into a low intermediate frequency with a reasonable noise factor by parametric converters.

The purpose of this paper is to report on a down converter using a tunnel diode (Esaki diode[1,2]) as the nonlinear resistance element. The fact that the negative resistance characteristic of a tunnel diode can be utilized to achieve low-noise amplification has already been demonstrated.[3] It is now shown that the nonlinearity of this negative resistance characteristic can be used for frequency conversion. Since the nonlinearity of a resistance, *not* a reactance, is utilized for frequency conversion, the noise factor is independent of the ratio of the input frequency to the output frequency. Thus, by using a tunnel diode, a low-noise down converter with conversion gain has been achieved.

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## Analysis

The converter circuit to be analyzed is shown in Fig. 1, which also establishes the notation to be used in the following analysis. The three tank circuits which resonate at $\omega_1$, the input signal frequency; $\omega_2$, the difference frequency; and $\omega_3=\omega_1+\omega_2$, the local oscillator frequency, are coupled together by the tunnel diode.

The analysis proceeds in a manner entirely similar to that for the small signal nonlinear reactance case.[4] The I-V characteristic of the tunnel diode (Fig. 2) at the operating point $P$ can be represented by a quadratic relation:

$$I = G_0V - \mathcal{G}V^2. \qquad (1)$$

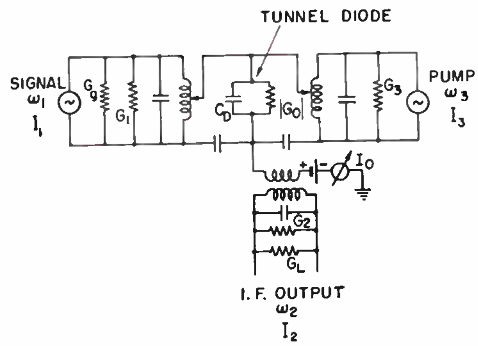


Fig. 1—Schematic diagram of converter circuit.

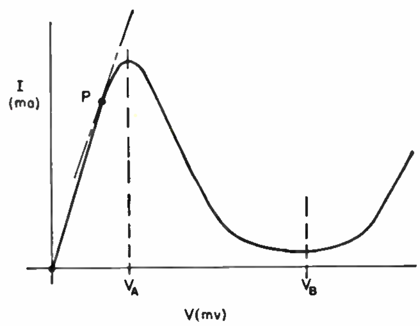


Fig. 2—Tunnel-diode I-V characteristic.

An operating point in the positive resistance region is chosen for reasons to be discussed later. The currents at the three frequencies are:

$$I_1 = V_1(\overline{G}_1 + j\overline{B}_1) - \mathcal{G}V_2{}^*V_3$$
$$I_2 = V_2(\overline{G}_2 + j\overline{B}_2) - \mathcal{G}V_1{}^*V_3$$
$$I_3 = V_3(\overline{G}_3) - \mathcal{G}V_1V_2 \qquad (2)$$

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where

$$\overline{G}_1 = G_1 + G_g + G_0$$
$$\overline{G}_2 = G_2 + G_L + G_0$$
$$\overline{G}_3 = G_3 + G_0$$
$$\overline{B}_1 = \omega_1 C_1\left(\frac{\omega}{\omega_1} - \frac{\omega_1}{\omega}\right)$$
$$\overline{B}_2 = \omega_2 C_2\left(\frac{\omega_3 - \omega}{\omega_2} - \frac{\omega_2}{\omega_3 - \omega}\right). \qquad (3)$$

The small signal analysis neglects the effect of the nonlinear interaction on the local oscillator current. Hence, $\mathcal{G} V_1 V_2$ is neglected in the third equation of (2).

In (3), $G_1$, $G_2$ and $G_3$ are the loss conductances of the respective circuits. These loss conductances consist of the circuit and the tunnel diode ohmic losses. The capacitances, $C_1$ and $C_2$, similarly consist of the circuit and tunnel diode capacitance, $C_D$.

### A. Conversion Power Gain

The conversion power ratio under matched conditions is defined as

$$g_c = \frac{V_2^2 G_L}{\frac{I_1^2}{4G_g}}. \qquad (4)$$

Solving (2), one obtains

$$g_c = \frac{4\mathcal{G}^2 V_3^2 G_g G_L}{[\overline{G}_1\overline{G}_2 - \mathcal{G}^2 V_3^2]^2}. \qquad (5)$$

Eq. (5) is a general expression for the conversion power ratio. When $G_0$ is positive, the ratio can be either greater or less than unity, depending on the I-V characteristic of the nonlinear conductance. In order to obtain a conversion gain (*i.e.*, $\sqrt{g_c} > 1$) with a positive $G_0$, it follows from (5) that

$$\sqrt{g_c} = \frac{2\frac{\mathcal{G}V_3}{G_0}}{\frac{1}{\sqrt{G_g G_L}}\left\{\frac{(G_g + G_1)(G_L + G_2)}{G_0} + G_1 + G_2 + G_0\left(1 - \frac{\mathcal{G}^2 V_3^2}{G_0^2}\right)\right\} + \sqrt{\frac{G_L}{G_g}} + \sqrt{\frac{G_g}{G_L}}} > 1. \qquad (6)$$

Since

$$\sqrt{\frac{G_L}{G_g}} + \sqrt{\frac{G_g}{G_L}} > 2 \qquad (7)$$

when $G_0$ is positive, (6) is satisfied if

$$\frac{\mathcal{G}V_3}{G_0} > 1. \qquad (8)$$

Eq. (8) is the necessary condition for gain. This equation shows, together with (1), that the I-V characteristic whose origin is at the operating point (such as $P$ in Fig. 2) must exhibit a maximum value, and that the local oscillator voltage $V_3$ must be sufficiently large so that it swings the current below the value of the current at the operating point. In the case of an ordinary crystal detector, the I-V characteristic exhibits no such maximum and (1) and (8) can never be satisfied simultaneously. It is important to note that (8) can be satisfied when the operating point is chosen in the region where $V < V_A$ and where $G_0$ is positive.

For the region $V > V_B$, (8) still applies. In this region, however, the diode current is due to minority carriers and so it is probably not suitable for high frequency conversion.

For the region $V_A < V < V_B$, the $G_0$ is negative and stable biasing becomes critical. It is difficult to find a stable operating point without having the device break into spurious oscillations, because of the large voltage swing of the local oscillator.

In order to normalize the conversion power ratio (5), let:

$$\lambda = \frac{\mathcal{G}^2 V_3^2}{\overline{G}_1\overline{G}_2} \qquad (9)$$

$$Q_g = \frac{\omega_1 C_1}{G_g} \qquad (10)$$

$$Q_L = \frac{\omega_2 C_2}{G_L} \qquad (11)$$

$$\overline{Q}_1 = \frac{\omega_1 C_1}{\overline{G}_1} \qquad (12)$$

$$\overline{Q}_2 = \frac{\omega_2 C_2}{\overline{G}_2} \qquad (13)$$

$$\bar{g}_c = \left(\frac{Q_g}{\overline{Q}_1}\frac{Q_L}{\overline{Q}_2}\right) g_c. \qquad (14)$$

Eq. (5) then becomes

$$\boxed{\bar{g}_c = \frac{4\lambda}{(1-\lambda)^2}}. \qquad (15)$$

### B. Bandwidth

Assuming that the half-power frequencies are near the resonant frequency, the following approximation can be made:

$$\overline{B}_1 = \omega_1 C_1\left(\frac{\omega}{\omega_1} - \frac{\omega_1}{\omega}\right) \doteq 2(\omega - \omega_1)C_1 \qquad (16)$$

$$\overline{B}_2 = \omega_2 C_2\left(\frac{\omega_3 - \omega}{\omega_2} - \frac{\omega_2}{\omega_3 - \omega}\right) \doteq 2(\omega_1 - \omega)C_2. \quad (17)$$

By defining the relative bandwidth as $B_1 = \Delta f_1/f_1$ and defining

$$S_1 = 2\overline{Q}_1 B_1 \quad (18)$$

and

$$c = \frac{\overline{Q}_2\omega_1}{\overline{Q}_1\omega_2}, \quad (19)$$

one obtains

$$S_1^2 = \frac{[2c(1-\lambda) - (1+c)^2] + \sqrt{[2c(1-\lambda) - (1+c)^2]^2 + 4c^2(1-\lambda)^2}}{2c^2}. \quad (20)$$

For the case of high gain, *i.e.*, $\lambda \doteq 1$, (20) becomes

$$S_1 \doteq \frac{1-\lambda}{1+c} \doteq \frac{1}{1+c}\,\frac{2[\sqrt{1+\bar{g}_c} - 1]}{\bar{g}_c} \quad (21)$$

and the voltage gain-bandwidth product is

$$\sqrt{\bar{g}_c}\, B_1 \doteq \frac{1}{1+c}\,\frac{1}{\overline{Q}_1}. \quad (22)$$

### C. Noise Figure

The noise figure can be found by considering the currents in (2) to be due to the thermal noise sources of the circuits:

$$|\mathcal{I}_1|^2 = 4k\Delta f(G_g T_0 + G_1 T + G_e T)$$
$$|\mathcal{I}_2|^2 = 4k\Delta f(G_L T + G_2 T + G_e T) \quad (23)$$

where

$k$ = Boltzmann's constant,
$T_0$ = reference temperature (290°K),
$T$ = ambient temperature,
$G_e$ = equivalent shot noise conductance of the tunnel diode,
$G_e = eI_0/2kT$, $I_0$ = dc current of the tunnel diode, and
$|\mathcal{I}|$ = equivalent noise currents.

Eq. (2) can then be written as:

$$|\mathcal{I}_1|^2 = |V_1\overline{G}_1 - \mathcal{G}V_2^*V_3|^2$$
$$|\mathcal{I}_2|^2 = |V_2\overline{G}_2 - \mathcal{G}V_1^*V_3|^2$$
$$|I_3|^2 = |V_3\overline{G}_3 - \mathcal{G}V_1V_2|^2. \quad (24)$$

From the definition for the noise figure, one obtains

$$F = \frac{P_{in}}{P_{out}}\frac{N_{out}}{N_{in}} = \frac{1}{g_c}N_{out}\frac{1}{kT_0\Delta f} = \frac{|V_2|^2 G_L}{g_c kT_0\Delta f}. \quad (25)$$

After solving (24) for $|V_2|^2$ and substituting, (25) becomes

$$F = 1 + \frac{T}{T_0}\left[\frac{G_e}{G_g} + \frac{G_1}{G_g} + \frac{(G_L + G_2 + G_e)\overline{G}_1}{G_g\overline{G}_2}\;\frac{1}{1 - \dfrac{2(\sqrt{1+\bar{g}_c} - 1)}{\bar{g}_c}}\right]. \quad (26)$$

## Experimental Results

An experimental circuit based on Fig. 1 and using coaxial lines has been built. The operating frequencies were $f_1 = 210$ mc, $f_2 = 30$ mc, and $f_3 = 240$ mc. Representative results are shown in Table I, and compared with computed values.

Figs. 3 and 4 show typical curves of the I-V characteristic of the germanium and gallium arsenide tunnel diodes that were used in the experiments in Table I. The germanium diode had a peak current of 35 ma at 62 mv; its operating point was chosen at 18 ma and 29 mv yielding a positive $G_0 = 0.42$ mho. The gallium arsenide diode had a peak current of 23.6 ma at 100 mv; the operating point was at 20 ma and 60 mv with a positive $G_0 = 0.20$ mho.

To complete the calculations according to (15), (22), and (26), it is necessary to know the values of certain circuit parameters. For the case of the experimental circuit of Fig. 1, the following values were measured. The values of $\lambda$ were chosen to give agreement with measured gain ratios.

Germanium Diodes: $\lambda = 0.43$ $c = 0.1$ $\overline{Q}_1 = 100$ $G_g = G_L = 4$ mhos $G_1 \doteq G_2 \doteq 0$ $G_e \doteq 20I_0 \doteq 0.36$ mho: $G_0 = 0.42$ mho.

Gallium Arsenide: $\lambda = 0.88$ $c = 0.1$ $\overline{Q}_1 = 100$ $G_g = G_L = 4$ mhos $G_1 \doteq G_2 \doteq 0$ $G_e = 0.40$ mho $G_0 = 0.21$ mhos.

TABLE I

| Diode | Power Gain | | Bandwidth | | Noise Figure | | Sensitivity |
|---|---|---|---|---|---|---|---|
| | Measured | Computed | Measured | Computed | Measured | Computed | Measured |
| Germanium | 6.0 db | 6.0 db | 0.9 mc | 0.6 mc | 5.2 db | 4.4 db | 1.5 μv |
| Gallium arsenide* | 22.7 db | 22.7 db | 0.15 mc | 0.26 mc | 2.8 db | 3.8 db | 0.25 μv |

* The gallium-arsenide diode is an experimental sample developed by A. Wheeler of the Advanced Development Group of RCA Semiconductor Division, Somerville, N. J.

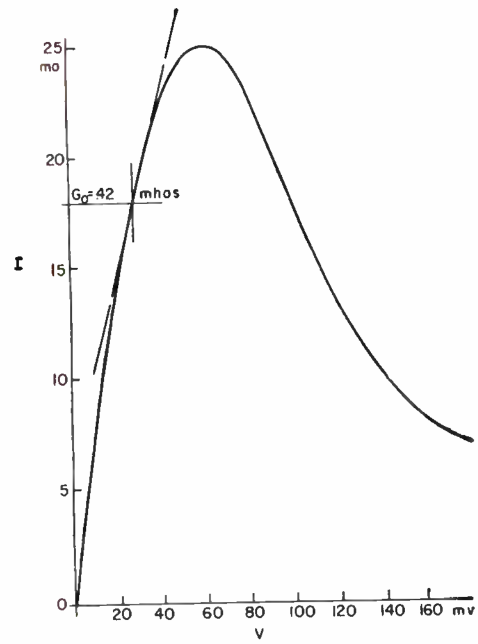


Fig. 3—Germanium tunnel diode.

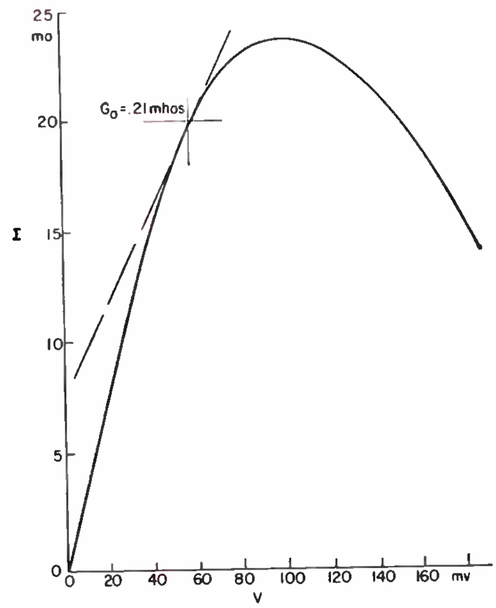


Fig. 4—Gallium arsenide tunnel diode.

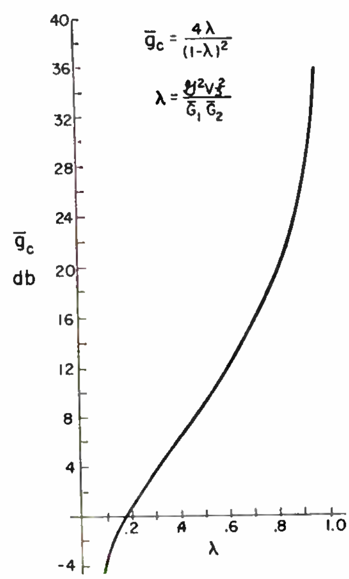


Fig. 5—"Normalized" conversion power ratio.

## Discussion

It is noted from Figs. 3 and 4 that the operating points for the diodes were chosen at a region where the slope of the I-V characteristic is positive. These operating points were established by the initial dc current from the bias supply and the rectified RF current of the local oscillator.

Conversion gain will result for positive $G_0$ when the requirements of (1) and (8) are met simultaneously (see Fig. 5). $\mathcal{G}V_3$ will be larger than $G_0$ when the RF voltage swing of the local oscillator is large enough to drive across the peak of the I-V curve and into the negative slope region until the instantaneous values of the current are smaller than the dc current at the operating point.

However, any appreciable voltage swing into the negative slope portion will make the system unstable, particularly when the negative slope is very steep. For this reason, it is more difficult to obtain high gain with germanium diodes, where the negative slope is much steeper, than for gallium arsenide. Had it not been for this stability problem, the germanium diodes would have yielded the same low-noise figure as the gallium arsenide diodes.

Further consideration of (22) and (26) will show the theoretical approach to optimum bandwidth and noise figure (Figs. 6 and 7). For improved bandwidth, the parameter $c$ should be made small and the circuit's $Q$ values should also be made small. Since $\bar{Q}_1 = \omega_1 C_1/\bar{G}_1$, this immediately suggests that the circuit capacitances and

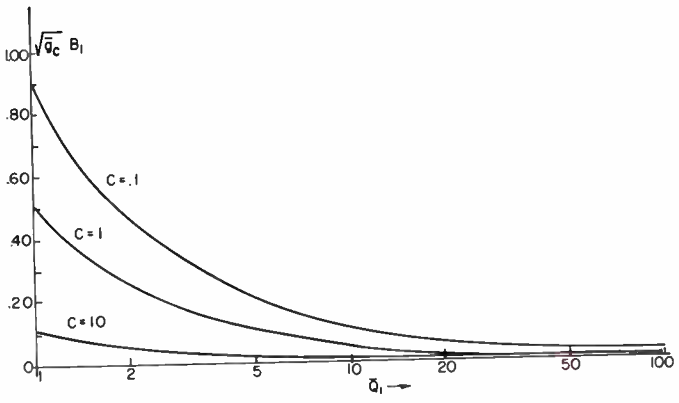


Fig. 6—Gain times bandwidth vs circuit $Q$ for various

$$C = \frac{\overline{Q}_2}{\overline{Q}_1} \frac{\omega_1}{\omega_2}.$$

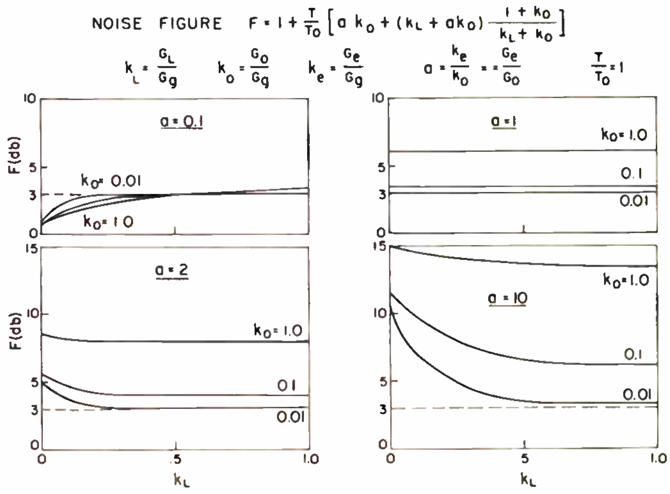


Fig. 7—Noise factor as a function of diode and circuit conductances.

especially the diode capacitance $C_D$ should be made as small as possible. For a similar reason, $G_g$ should be made larger than $G_e$ to yield a low-noise figure.

The possibility of obtaining conversion using a lower pump frequency is to be noted. In this case, the nonlinearity of the diode characteristic could be used to produce the desired harmonic of the lower pump frequency for mixing. It is also noted that the possibility of making the diode-pump circuit self-oscillatory exists. Thus, direct down conversion can be obtained without a separate local oscillator.

## Conclusions

The present experiments have demonstrated that the tunnel diode can be utilized as a *low-noise, high-gain down converter* in the UHF range. It seems feasible to extend the operating frequencies into the microwave region. The diodes for such applications should be designed with as low a capacitance as possible. The associated circuits, and especially the input circuit, should have high conductance and low $Q$'s in order to realize optimum bandwidth and noise figures.

# Noise Limitations to Resolving Power in Electronic Imaging*

J. W. COLTMAN† AND A. E. ANDERSON†

*Summary*—**A theoretical derivation, verified by experiment, shows that the maximum visible line number of a displayed bar pattern is directly proportional to the signal-to-white-noise ratio. The constant of proportionality and the effect of finite screen boundaries have been experimentally determined. It is found both theoretically and experimentally that the masking effect of white noise depends only on the noise power per unit bandwidth, and is independent of the upper frequency limit of the noise spectrum, provided that this exceeds the frequency limit set by the eye.**

**These results can be used together with the aperture response of any imaging system to predict in quantitative terms the resolution limit as a function of the signal and noise levels. As an example, the theorems postulated are used together with the measured amplitude response function of the 5820-image orthicon to obtain a universal resolution vs signal-to-noise ratio curve for beam-noise-limited tubes of the image orthicon type. The predicted performance is in good agreement with experimental results. A similar set of curves for quantum-noise-limited image tubes is also given. The effects of object contrast variation, signal integration in time, and the presence of spurious background are presented.**

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## I. Introduction

In recent years, there has been a widening interest in electronic imaging devices whose capabilities, with respect to sensitivity or spectral response, lie beyond that of the unaided eye. Television techniques, which permit arbitrarily high brightness amplification and contrast intensification, essentially remove most limitations of the human eye, so that performance is limited only by two system characteristics, the fidelity with which the image is reproduced, and the noise introduced into the information-bearing channel.

This paper deals quantitatively with the manner in which system noise interferes with image resolution. In the first section, there are derived, from pure scaling arguments, some completely general relationships between visual image detectability and noise intensity. These relationships are then particularized to the case of television presentation, and some experimental data in verification of the theory are presented. In the second section, it is shown how deterioration of the signal for fine patterns, together with the previously established demands on signal-to-noise ratio, combine to set a quantitative limit on resolving power.

## II. Noise Considerations

### *A. Signal-to-Noise Ratio Required for Detection of an Image*

The ability of the eye to distinguish a pattern in a noisy signal has been previously investigated[1,2] for cases in which the noise was assumed to result from the quantum nature of the signal itself. The formulation is ordinarily in terms of pattern contrast and population of events (light or X-ray quanta) giving rise to the noise. In the case being treated here, and indeed in essentially all cases of television presentation, one deals with a different situation, where there is an additive noise independent of the signal strength, and the final image contrast, brightness, and magnification can be adjusted at will by the observer. This paper establishes image detection limits which are independent of these last named quantities. Limiting resolutions are expressed solely by the signal-to-noise ratio as measured at some critical point in the system.

It is possible to derive certain relationships between image detail and signal-to-noise ratio required without recourse to any experiment. The argument which follows is not restricted to television-type displays, but, subject to the postulates given, applies to any display whatever.

This thought experiment is best conducted by first postulating a viewing screen, infinite in extent, producing light at an average brightness $B$, which fluctuates in time and space. Let the nature of this fluctuation correspond to "white" noise, that is, the light flux $L$ per steradian from any area $A$ has an average value $AB$ and is distributed in a Gaussian fashion with a standard deviation $\Delta L = m\sqrt{AB}$. (This kind of "noisy" illumination is typified, for example, by an area emitting light in the form of uniform flashes, randomly distributed in time and space.) No particular value of $m$ need be assumed, *i.e.*, it is permissible to subtract a constant value $B_0$ from the average brightness or to change the gain of the system, provided that the occurrence (mathematically speaking) of a negative value of light flux is a very rare event in any area of practical interest.

[1] A. Rose, "Sensitivity of the human eye on an absolute scale," *J. Opt. Soc. Amer.*, vol. 38, pp. 196–208; February, 1948.

[2] J. W. Coltman, "Scintillation limitations to resolving power," *J. Opt. Soc. Amer.*, vol. 44, pp. 234–237; March, 1954.

A viewer stands before this screen, and an operator superimposes on the noisy background described above a signal image of specified form and size. The operator then slowly reduces the signal strength until the image is no longer visible to the observer. During this process, the observer is free to change his viewing distance, add or subtract a constant brightness $B_0$ (subject to the condition mentioned above) and change the "gain" of the system, which operates on both the signal and noise alike. These are the operations known as "contrast enhancement" in a television system. Eventually, a value of signal will be reached which no longer permits the image to be distinguished in the noise, in spite of optimum adjustments on the part of the viewer. This is the threshold signal for the particular image and noise chosen, which we call Condition I.

Now three changes are made. The operator makes the image larger by a factor $g$, while the signal strength is left constant. He also increases the strength of the noise $m\sqrt{AB}$ by a factor $g$, to $gm\sqrt{AB}$. The viewer meanwhile is asked to increase his viewing distance by the same factor, $g$, and to leave all other parameters fixed. This is Condition II.

It is evident that the signal image is unchanged as far as the viewer is concerned; the increased viewing distance exactly compensates for the increase in pattern size, while the average apparent brightnesses, being independent of viewing distance, are fixed. What about the apparent fluctuation? This is unchanged also. In Condition I, an area $A$ on the screen is projected to some area $A'$ on the observer's retina. Under Condition II, this same element $A'$ encompasses an area $g^2A$ on the screen, because of the increased viewing distance. The operator has also changed the strength of the noise by a factor $g$, so that the standard deviation in the light flux per steradian corresponding to the area $A'$ is now $gm\sqrt{g^2AB} = g^2m\sqrt{AB}$. The solid angle subtended by the observer's pupil is, however, less by a factor $g^2$, so we find that the fluctuation in brightness for any area $A'$ on the observer's retina is exactly as in Condition I.

Thus, the visual effect received by the observer in Condition II is identical in all respects to that of Condition I. Since Condition I was an optimum as far as viewing distance, gain, and background brightness were concerned, then Condition II must also be an optimum, and represents again a threshold. Referring back to the changes made by the operator at the screen, we infer: *The strength of white noise required to mask an image signal is directly proportional to the linear size of the image.*

Because it is assumed that the viewer can change at will the gain, background brightness, and viewing distance, it is apparent that only the signal-to-noise *ratio* is important in determining the threshold. We may thus restate the results: *The signal-to-white-noise ratio required for detection of an image is inversely proportional to the linear dimension of the image.*

A corollary of the above may also be inferred from the same argument: *The optimum viewing distance for detection of an image in white noise is directly proportional to the image size.*

### B. Signals and Noise in Television Displays

In deriving the theorems of Section II-A, noise was specified only by the constant $m$ in the expression $m\sqrt{AB}$ and the image size by a linear dimension. In the television case, it is more convenient to measure the signal and noise in the electrical channel prior to conversion to a pattern, and to use for a standard of length the width of the frame of the picture. For convenience in the derivations which follow, it is assumed that the light produced on the kinescope face is directly proportional to the impressed signal. While this is not the case in practice, the threshold signals with which we deal are small, and since the "gamma" of the kinescope acts on signal and noise alike, the effect of the kinescope nonlinearity is equivalent, in the first order, to a simple change in system gain.

Assume a television image of a vertical sine wave bar pattern, having enough lines showing in the picture so that the effect of the finite frame size may be ignored. The theorem proposed states that the threshold signal-to-noise ratio is inversely proportional to the linear dimension of the image, or proportional to the number of lines $N$ per cm.

$$N_{\text{threshold}} = \text{const}\left(\frac{\text{screen signal}}{\text{screen noise}}\right)\text{lines/cm.} \qquad (1)$$

In (1) the screen noise is measured by the brightness fluctuation on some small area of the screen. It remains to relate this fluctuation to the noise impressed on the scanning beam.

Let the scanning beam current be $i_0$ and let it fluctuate with a noise of rms value $i_n$, measured over the bandwidth $\Delta f$. Consider an area $A$ on the picture, small compared to the frame size but large enough to contain several resolution elements. In a time $t$ larger than several frame times, there will be deposited in this area a total charge $q=(A/A_0)i_0t$, where $A_0$ is the frame area, or, more accurately, an extended frame area which takes account of the blanking and return times of the scans. This value of $q$ will vary due to the fluctuation in $i$, but the fractional variation will be much smaller than that of $i$, because there are many samples of the beam current going to make up $q$. In measuring the noise current over a bandwidth $\Delta f$, we have effectively sampled the beam current by collecting charge over short times $1/2\Delta f$ in duration. In measuring $q$, however, the beam spends a time $(A/A_0)t$ in the area $A$, so that $q$ contains $(A/A_0)2\Delta ft$ independent samples of the beam current. The fractional variation in $q$ compared to that in the beam is reduced by the square root of this number. Thus

$$dq/q = (2\Delta ftA/A_0)^{-1/2}i_n/i_0. \qquad (2)$$

The screen signal is related to $q$ by a modulation factor which is the same as that for the beam current. Therefore

$$\frac{\text{screen signal}}{\text{screen noise}} = (2\Delta ftA/A_0)^{1/2}\left(\frac{\text{signal}}{\text{noise}}\right), \qquad (3)$$

where both the signal and noise in the right-hand member are measured as currents or voltages in the electrical channel. It should be emphasized here that $\Delta f$ is not necessarily the bandwidth of the system, but represents merely the frequency interval over which the noise was measured. It will be recognized that for white noise, the noise is directly proportional to $\sqrt{\Delta f}$, so that $\sqrt{\Delta f}$/noise is a constant independent of the bandwidth chosen, and is a measure of the spectrum level of the noise.

Combining (1) and (3),

$$N_{\text{lines/cm}} = \text{const}\,(2\Delta ftA/A_0)^{1/2}\left(\frac{\text{signal}}{\text{noise}}\right). \qquad (4)$$

If the width of the displayed picture is $W$ cm, the number of lines per picture is $NW$, and if $A_0$ is replaced by $HW/e_ve_h$, where $H$ is the height and $e_v$ and $e_h$ are the sweep efficiencies, then (4) can be written as

$$N_{\text{lines/picture}} = k\left(\frac{Ate_he_v\Delta f}{R}\right)^{1/2}\frac{\text{signal}}{\text{noise}}, \qquad (5)$$

where $R$ is the aspect (height to width) ratio. Note that only this factor and the sweep efficiencies enter; the expression is independent of the number of scanning lines or the frame rate of the system.

It will be noted that in the derivation of (2) it was required that the minimum sample area $A$ extend far enough to encompass several independent samples of $i_n$; *i.e.*, in terms of the television scan it must be several times wider than the resolution element set by the bandwidth. If the pattern detail is sufficiently large so that the eye can integrate over such an elemental area without decreasing the pattern contrast, then (5) can be expected to hold.

Now, if the noise in question arises, as is usually the case, from a white noise source located prior to the bandwidth-limiting circuits of the system, the noise current is itself proportional to $\sqrt{\Delta f}$. Eq. (5) in this case implies that *the threshold value for signal recognition is independent of the system bandwidth.*

The requirement on the sample area $A$ noted above, and the use of an integrating time $t$ larger than the frame time, is essentially equivalent to assuming that the eye, and not the system, sets the bandwidth. Since it is probable that the eye does not curtail the bandwidth sharply, pattern detectability may decrease somewhat as the bandwidth is gradually increased over the minimum required. Eventually, however, pattern detectability will become constant and independent of further increases in bandwidth.

The fact that the spectrum level of white noise required just to perceive the noise itself is independent of the noise bandwidth, is discussed by Mertz.[3] In that work, he finds a square "sampling area" for the eye of about 5 minutes of arc in linear dimension; this is consistent with the optimum viewing distance indicated in Fig. 3.

### C. Experimental Determination of the Visibility Thresholds for a Bar Pattern

To test the relationships derived in the previous section, an experimental investigation of the visibility of sine wave bar patterns was carried out using a television monitor displaying accurately-measured sine wave signals and white noise. It should be noted that television kinescopes do not, in general, respond linearly (in light flux) to the voltage applied to the grid, so that we depart in this respect from the conditions postulated in the theory. For small signals and noise, this lack of linearity is of no consequence, as it merely introduces an extra gain in the system. For large signals, the noise will no longer be Gaussian. The extent of the departure from theory is left for experimental determination.

A block diagram of the equipment is shown in Fig. 1.

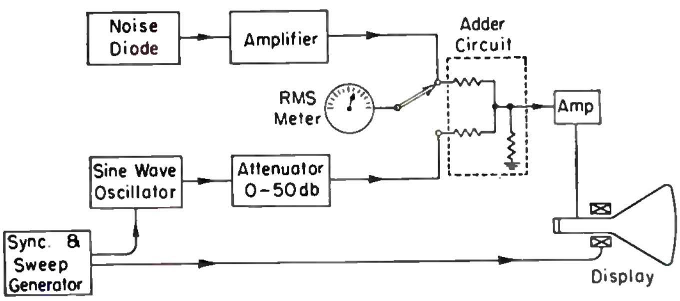


Fig. 1—Arrangement for displaying measured signals and noise. The synchronized sine wave oscillator produced a vertical sine wave bar pattern of variable intensity on the display, while a fixed measured white noise was superimposed.

The noise source was a temperature-limited thermionic diode, operating into a high-gain video amplifier. The amplifier characteristic was such as to give a noise power uniformly distributed within ±1 db from a few kilocycles to about 4.5 mc, with a rapid drop-off to a few per cent at 5.5 mc. The total curve could be approximated by a rectangular distribution extending to 5.0 mc. A coherent sine wave oscillator generated a sinusoidal bar pattern variable over the entire frequency band. An rms milliammeter with response flat to 8 mc was used to measure either the noise or the signal, which were then mixed and fed to the display kinescope. An attenuator was provided in the oscillator circuit to reduce the signal to any desired value. Brightness and contrast could be controlled on the monitor after the signals were measured and mixed.

[3] P. Mertz, "Perception of television random noise," *J. Soc. Motion Picture and Television Engrs.*, vol. 54, pp. 8–34; January, 1950.

The experimental procedure was to seat the subject before the television screen at a chosen distance, select a bar pattern of the desired number of lines (the number of line pairs per picture was taken as the number of cycles of the oscillator between blanking pulses, not all of which were visible on the screen because of masking) and set the noise and signal power equal by means of the noise meter. Correction was made for blanking periods, so the signal-to-noise ratios quoted represent those during the active period. The signal attenuator was then set to a value near the threshold of pattern visibility. The subject was asked whether or not he could discern the presence of the pattern, and after a "yes" or "no" response, the attenuator was reset to a neighboring value. At each condition, some 18 to 24 responses were requested, the attenuator being varied at random among three or four settings separated by 2 db. The setting (or interpolated setting value) at which the observer responded "yes" 50 per cent of the time was taken as the threshold of visibility. In almost all cases, a clean dividing line could be made, a typical situation being that in which six out of six responses were "yes" at 20 db, three out of six were "yes" at 22 db, and all were "no" at 24 db. Signal-to-noise ratios used in this paper are based on current rather than power, so that a 2-db step represents a 26 per cent change in signal current.

While an unequivocal result could usually be obtained in a single test, it was evident that an individual's threshold for a given set of conditions was not constant, but could vary by 50 per cent or more with time. Variations among individuals were also apparent. The amount of data taken was limited, and conditions of surround brightness, time interval between tests, etc., were not carefully controlled, so that the data presented here do not constitute a definitive study of this particular visual parameter. They suffice, however, to demonstrate the relationships derived above, to provide a numerical value of the constant $k$ in (5), and to outline the area of validity of the theoretical treatment.

### D. Experimental Results

Since the theory presupposes an optimum viewing angle for a given pattern, an attempt was made to establish this angle. With a fixed pattern, a single subject was tested at viewing distances ranging from $\frac{1}{4}$ to 7 meters. Several repeats at two meters were taken to check for uncontrolled shift of the threshold. Evidence of a considerable shift is given in Fig. 2, where threshold attenuator settings are plotted, not against distance, but against order number of the trials. The circled points are all for two meters. The points are labeled with the distance. In an attempt to extract some information, it was assumed that the threshold shift was gradual, and could be represented by the dotted line through the two-meter points. Deviations from this line by the other points were taken as representing a distance effect.

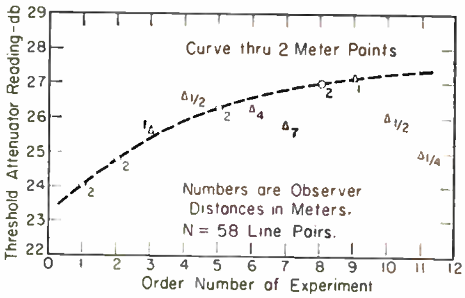


Fig. 2—Threshold readings taken at various distances as labeled on the points. Drift of the threshold is evident from the curve through the 2-meter points. All readings are with $N=58$.

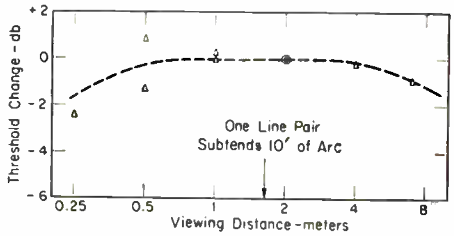


Fig. 3—Relative threshold as a function of viewing distance. Data are taken as the departure of points from the curve of Fig. 2. The extreme broadness of the optimum is evident.

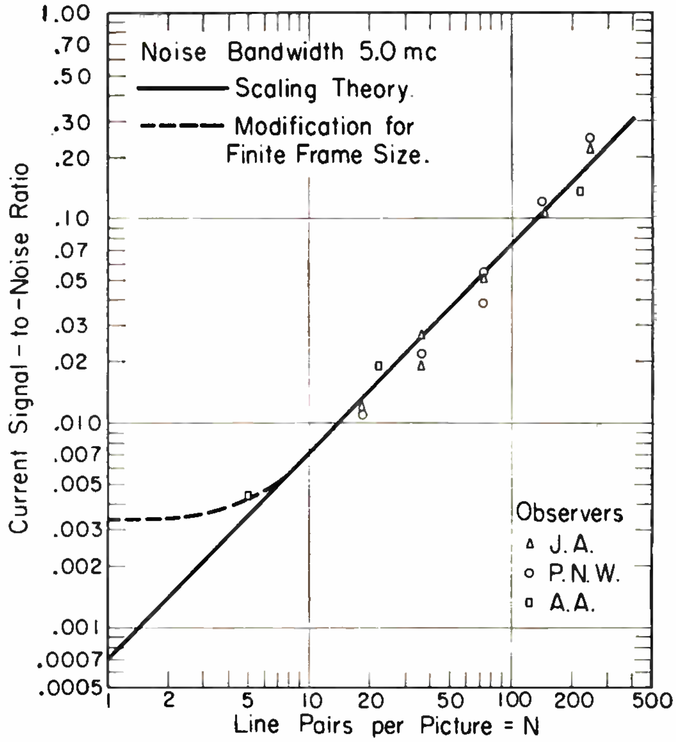


Fig. 4—Threshold signal-to-noise ratio as a function of number of cycles of the sine wave bar pattern displayed. The linear relationship extends over two decades, and departure is observed only for very small line numbers.

The results are plotted in Fig. 3. There is some suggestion of an optimum near 1.5 meters, where one line pair subtends about 10 minutes of arc, but the most striking result is the broadness of the distribution. The effect of changing distance over a range of 30:1 is hardly outside the experimental error in determining the threshold. Thus, in succeeding tests, the subject assumed viewing distances roughly proportional to the pattern line width, but no attempt was made to control this factor rigidly.

The results of a series of runs using varying numbers of line pairs (cycles) per picture are given in Fig. 4. The solid line drawn with a 45-degree slope demonstrates the expected proportionality between line number and signal-to-noise ratio. It is of great interest to note the extremely small signal-to-noise ratios required, clearly showing the great extent to which integration takes place in the eye. From the position of this line and the 5.0-mc bandwidth used, we can evaluate the constant in (5) and write:

$$N_{\text{threshold}} = 615\sqrt{\Delta f}\cdot(\text{signal/noise}), \qquad (6)$$

where $\Delta f$ is measured in megacycles, and $N$ is line pairs per picture width.

The earlier work on scintillation limited square wave bar patterns by Coltman[2] can be reformulated in terms of signal-to-noise ratio by calculating the noise power which the scintillations would generate in a circuit of bandwidth $\Delta f$, and taking account of blanking times and picture aspect ratio. When this is done, we arrive at the expression: $N=640\sqrt{\Delta f}\cdot$ (signal/noise), which is in good agreement with (6). The constant in both cases is independent of the number of scanning lines and frame times, but will depend on the aspect (height to width) ratio and the fraction of the time spent in blanking, in the manner expressed by (5).

It is clear that while the scaling argument predicts a straight-line relationship over all values, the finite size of the screen will introduce departures for large line spacing. In order to determine the shape of the curve for very low numbers of line pairs per picture, a separate experiment was run. Here, the displayed picture was left fixed, and a series of cardboard aperture masks were employed to vary the number of lines seen by the observer.

The results, plotted in Fig. 5, show that the observer probably uses no more than seven line pairs in making an identification. As the number which he is permitted to see is decreased, the signal required rises rapidly, being greater by a factor of four when only one line pair is presented. The curve of Fig. 5 was used to draw the dotted lower portion of the curve of Fig. 4 by applying to the extension of the straight line the measured increase in signal required. A lower limit to the threshold signal-to-noise ratio for the largest complete sine wave pattern which can be shown is thus found to be about 1/300, where the noise is measured over 5 mc.

A fourth experiment was made to demonstrate the effect of bandwidth. A capacitor was arranged to be switched across the input circuit so as to reduce the bandwidth from 5 mc to about 600 kc. The total integrated noise power was thereby reduced by a factor of 7.6, and the rms noise current by a factor of 2.8. An 11-line pattern, whose frequency was so low as to be essentially unaffected by the bandwidth change, was dis-

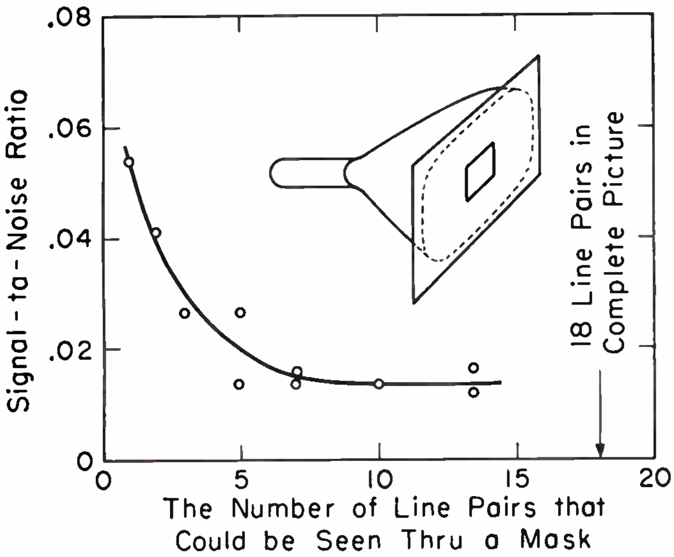


Fig. 5—Effect of frame limitation on signal-to-noise ratio required. These data were used to extend the curve of Fig. 4 to low line numbers.

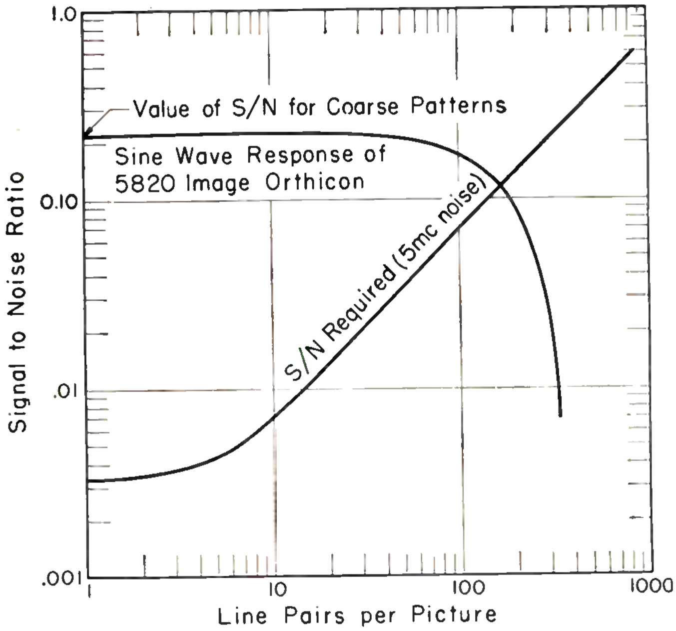


Fig. 6—Limiting resolution established by the intersection of curves representing available and required signal-to-noise ratio.

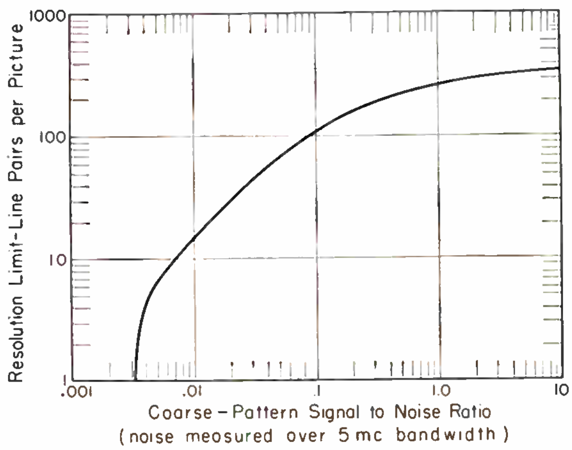


Fig. 7—Calculated resolution limit for a typical image orthicon as a function of the signal-to-noise ratio for large patterns.

played. Threshold measurements were taken while the capacitor was switched in and out at random intervals. It was found that the observer required 25 per cent less signal when the narrow bandwidth was used. While the shift was not zero, it was small compared to the large factor in noise current. This indicates that the over-all bandwidth was being set primarily by the eye, though it was still being affected somewhat by the system. A more carefully arranged experiment with sharp cutoff filters and optimum viewing distance for the observer would delineate more clearly the manner in which the eye can ignore high frequencies when looking for a low-frequency pattern.

## III. Establishing the Resolution Limit

The theoretical and experimental information presented in Section II establishes the signal-to-noise ratio required to perceive a given line number. In many types of imaging systems, it is possible to determine by calculation what signal-to-noise ratio will be obtained, and this is also a function of line number. With these two pieces of information, one can determine quantitatively the resolution limit—the line number which can no longer be perceived by the eye—as a function of the input conditions and system parameters. A few cases which represent basic situations are discussed below.

### *A. Noise Independent of Signal*

The signal current in the information channel will, of course, be a function of many system parameters. In particular, as a result of finite scanning apertures, electron-optical aberrations, etc., the signal response will diminish for fine patterns. It is convenient to describe this effect by the sine wave response function,[4] which gives the relative signal strength as a function of the space frequency of a sine wave test pattern. Such a response curve for a typical image orthicon is plotted as the upper curve in Fig. 6. The intercept at a signal-to-noise ratio of 0.22 is arbitrarily chosen for an example. The value is maintained essentially unchanged for low line numbers, and is called here the coarse-pattern signal-to-noise ratio. At higher line numbers the signal (and therefore the signal-to-noise ratio) diminishes as shown. Also plotted in Fig. 6 is the previously derived curve of Fig. 4 which establishes for each line number the threshold of signal-to-noise ratio. The abscissa of the intersection of the two curves gives the resolution limit corresponding to the coarse-pattern signal-to-noise ratio chosen.

By making a series of such choices, the curve of Fig. 7 is derived, which gives the resolution limit as a function of the coarse-pattern signal-to-noise ratio. The curve approximates over a decade a direct proportion

[4] J. W. Coltman, "The specification of imaging properties by response to a sine wave input," *J. Opt. Soc. Amer.*, vol. 44, pp. 468–471; June, 1954.

between signal-to-noise ratio and resolution limit; it drops rapidly at the lower end due to the inability of the finite picture to display enough lines, while at the upper end it flattens out as the effects of finite focal spots reduce the available signal.

It should be noted that these curves assume an electrical channel of flat response and wide bandwidth. The 5-mc band over which the noise is measured is used only to establish a numerical value for the signal-to-noise ratio. Both noise (assumed white) and signal may extend well beyond this limit.

For an image orthicon operated at low light levels, the noise is essentially fixed, so that the signal-to-noise scale can be replaced by a properly established scale of scene illumination. The conversion factor will be a function of the photo-surface response, the optics used, and the object contrast, but the shape of the curve will remain fixed. Experimental confirmation is afforded by some data taken by Hannam[5] on two image orthicons employing different target materials, giving the observed resolution as a function of illumination. These data have been plotted in Fig. 8 with the illumination scale shifted for each tube to obtain the best fit to the theoretical curve. Considering the semi-subjective nature of such measurements, the agreement is satisfactory.

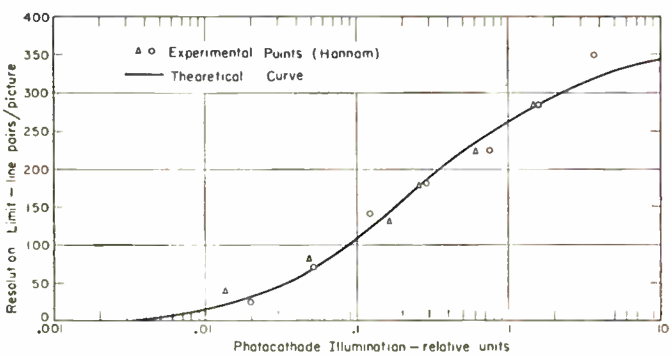


Fig. 8—Comparison of experimental and calculated resolution for two image orthicons.

### B. *Noise a Function of Signal*

Optical imagining systems will finally be limited in detectivity by the quantum noise inherent in the light itself. The relationship between highlight illumination and resolution limit will no longer have the form of Fig. 7, since the noise is a function of the signal strength. The case of a signal pattern of 100 per cent contrast and a pickup system where no noise is introduced other than that associated with the quantum nature of the light represents the ultimate in detectivity. The coarse-pattern signal-to-noise ratio now becomes proportional to the square root of the signal itself. Rather than working in terms of a signal-to-noise ratio which remains to be measured on the particular equipment at hand, the results can be generalized by employing as an independent variable the number of quanta registered per unit time. This number will be directly proportional to the illumination on the scene, the constant of proportionality being determined by the effective size of the optical aperture and the dimensions and quantum efficiency of the receiving photosurface.

Let $n$ be the number of photoelectrons ejected per second from the entire photosurface when it is uniformly illuminated at the level corresponding to the highlight scene brightness. If a sine wave pattern of 100 per cent contrast is then used as a test object, the peak-to-peak signal current during the scan is $ne/e_he_v$ where $e$ is the electronic charge and $e_h$ and $e_v$ the horizontal and vertical scan efficiencies. The corresponding rms signal current is $ne/\sqrt{8}e_he_v$. The average current $\bar{i}$, which is just half of the peak current, gives rise to an rms noise current equal to $\sqrt{2e\bar{i}\Delta f}$. The signal-to-noise ratio during the active portion of the scan is then:

$$\text{SNR} = \sqrt{n/8e_he_v\Delta f}. \quad (7)$$

In order to use the curves of Fig. 6 and Fig. 7, the values of $\Delta f = 5\times 10^6$ and $e_he_v = 0.79$ corresponding to the test conditions are substituted, to yield

$$\text{SNR} = 1.80 \times 10^{-4}\sqrt{n}. \quad (8)$$

The validity of this procedure may be questioned for values of $n$ such that less than one impulse is received in a half-cycle of the upper frequency of 5 mc. It is necessary again to point out that the 5-mc bandwidth assumed for the calculation of Figs. 6 and 7 is an arbitrary means of specifying the noise power per unit bandwidth of a white noise spectrum. Because the eye integrates in time and space, (7) is a valid transformation factor for relatively small values of $n$, even though it does not predict the result which would be obtained by measurement in the electrical channel with a wide-band noise meter. The correctness of this argument is borne out by the visual experiments by Coltman,[2] which show that the relationship (6) is followed for values of $n$ at least as low as 1000 per second.

Using (8) and the curve of Fig. 7, it is possible to calculate the performance of a hypothetical imaging system whose optical fidelity is the same as that of the image orthicon, but which has no noise other than the inherent shot effect of the initial photoelectric surface. The relation between the resolution limit and the photoelectron emission rate for this case is shown as curve 1 of Fig. 9. It is extremely broad and extends to the remarkably low limit of about 400 flashes per second.

In practice, complete freedom from extraneous noise is an ideal rarely to be expected. For example, at room temperature, thermionic emission from the photoelectric surface will contribute a fixed electron emission rate which should be included in $\bar{i}$ in calculating the signal-to-noise ratio. If $n_0$ is the fixed emission rate which must be added to the rate $n/2$ due to the signal, we obtain as a modification of (8) the expression

$$\text{SNR} = 1.8 \times 10^{-4}\frac{n}{\sqrt{n + 2n_0}}. \quad (9)$$

[5] H. J. Hannam, "Development of New Thin Film Targets for the Image Orthicon," U. S. ERDL, Fort Belvoir, Va., Third Quarterly Rept., Contract DA-44-009 ENG-3652.

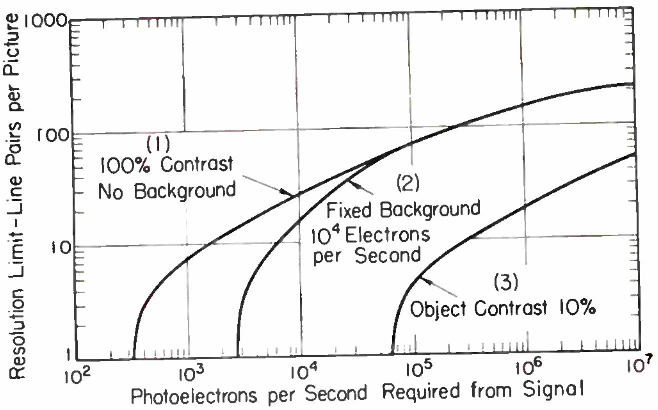


Fig. 9—Calculated resolution limits for cases where noise originates solely in the photocathode of an image orthicon type tube.

The effect of a fixed background emission of $10^4$ electrons per second is illustrated by curve 2 of Fig. 9.

## C. Effect of Contrast Reduction

While a 100 per cent contrast test pattern makes a convenient test object for specifying system performance, the scenes to be viewed in practice may often have relatively low contrast values. Contrast is defined here in terms of the highlight brightness, *i.e.*, for a sinusoidal test pattern, as follows:

$$C = (B_{\max} - B_{\min})/B_{\max}.$$

In the case where the noise is independent of the signal, loss of contrast simply means a corresponding loss of signal, so that the curve of Fig. 7 retains its shape while the scale of illumination is appropriately altered. Thus, in going from a 100 per cent to a 10 per cent contrast test pattern, the illumination must be increased by a factor of 10 to achieve the same resolution.

When the noise is due purely to the shot effect in the photosurface, a loss of contrast is attended by a similar loss of signal, but an increase of illumination to counteract this loss will also increase the noise. By a procedure similar to that used in the derivations of (7) and (9), a general expression is obtained which takes account both of fixed noise $n_0$ and contrast $C$, both referred to the maximum emission rate $n$ due to the light alone, as follows:

$$\text{SNR} = 1.8 \times 10^{-4} \frac{nC}{\sqrt{n(2 - C) + 2n_0}}. \qquad (10)$$

Curve 3 of Fig. 9 shows the relatively drastic effect of contrast reduction in the case of quantum noise only. A reduction of contrast from 100 per cent to 10 per cent now requires for compensation not ten times the illumination but 190 times. It will be appreciated, however, that the quantum noise is always present, and that the fixed noise case represents merely the situation where the additive noise is so large that it swamps out the quantum noise. When $n_0 \gg n$, (10) reduces to the case where the signal-to-noise ratio is directly proportional to the illumination and the contrast.

## D. Effect of Integration in Time

The integration time of the eye is generally accepted to be approximately 0.2 second, a value which can be determined by comparing still photographs taken with various exposure times with impressions received of live pictures of noisy material. While this was not done quantitatively in the above work, some remarks on the expected effect of time integration may be appropriate. In a conventional television pickup system, light is collected for a time $\tau$ (1/30 second) before the information is scanned off and presented. If this time is lengthened to $T$ the signal may be enhanced (in a properly operating storage medium) by a factor $T/\tau$. If the noise arises solely in the subsequent system, it need not be presented to the eye during storage, and the visual signal-to-noise ratio is improved by a similar factor.

In the case of noise arising solely from the photoelectric shot noise, the situation is quite different. As long as the frame time is short compared to the integration time of the eye (0.2 second) the visual signal-to-noise ratio will be independent of the frame time or the duration of the individual flashes. Integration by storage means or by a long persistence phosphor will be effective only if it extends the integration time beyond that of the eye. The exact effect of added integration can be calculated only through a convolution of the decay characteristic of the eye with that of the storage system employed. However, a rule-of-thumb frequently employed in convolution processes indicates that the effective total integration time will approximate the square root of the sum of the squares of the two individual times. Thus the illumination required to achieve a given resolution will vary as

$$[(T/0.2)^2 + 1]^{-1/2},$$

where $T$ is the system integration time in seconds. For values of $T$ much less than 0.2 second, the illumination required is independent of $T$; for large values it is inversely proportional to $T$, so that the product of the illumination and the time, *i.e.*, the exposure, is constant.

## Conclusions

For imaging systems whose output is viewed by the eye, and which are limited by white noise, the resolution limit can be predicted from a knowledge of two parameters, the noise power per unit bandwidth, and the sine wave response of the system. Because the demands on signal-to-noise ratio increase linearly with the line number, and the sine wave response usually falls off with at least the square of the line number, the resolution limit varies only slowly with signal input. The range of object illumination over which the resolution is appreciably varying may extend over several decades. In specifying the performance of systems designed to operate in the noise-limited region, it is thus highly desirable to give the entire resolution vs illumination curve, since neither the large-object detection limit nor the resolving power in the absence of noise (the two most frequently used characteristics) is a well-defined quantity.

# Packaged Tunable L-Band Maser System*

F. R. ARAMS†, SENIOR MEMBER, IRE, AND S. OKWIT†, ASSOCIATE MEMBER, IRE

**Summary—A low-noise tunable *L*-band maser system is described. The maser uses a pink ruby crystal oriented at 90° and is tunable from 850 to 2000 mc. The voltage-gain bandwidth product is as high as 37.5 mc at a liquid helium bath temperature of 1.5°K. An *L*-band circulator has been developed for use with the maser. It has an insertion loss of 0.3 db, operates over a 200-mc frequency range at *L*-band, and determines the usable tuning range of the circulator-maser system. The maser and circulator have been packaged into an operational unit that includes all auxiliary components, and has a system noise factor of 0.5 db (35°K). Electrical and mechanical features of the system are described and performance data are given.**

## I. Introduction

The low-noise characteristic of the three-level solid-state maser amplifier has stimulated the interest of workers in a number of fields where the ultimate in receiver sensitivity is required. Radio astronomers, for example, are particularly interested in using a maser as a preamplifier for a 21-cm interstellar hydrogen-line receiver. Because of the Doppler shift in the frequency of the hydrogen line in receding galaxies, an *L*-band maser amplifier, which covers 1420 mc and tunes down in frequency, is of great practical interest. A packaged tunable maser system is described that tunes over a 200-mc frequency range at *L*-band.

Fixed-frequency *L*-band masers have been operated using chromium-doped potassium cobalticyanide.[1,2] Furthermore, gadolinium-doped hydrated lanthanum ethyl sulfate with cerium impurity[3] and chromium-doped aluminum oxide (ruby) had given satisfactory operation at higher microwave frequencies.[4–7] Ruby was chosen for our maser, because of its excellent physical, mechanical, and chemical characteristics, even though it had not previously to our knowledge been used as a material for *L*-band maser operation. Its characteristics include favorable "zero-field" splitting of the energy levels, good crystal line width, favorable relaxation times, low dielectric loss, machinability to accurate dimensions, resistance to cracking upon repeated temperature cycling, chemical inertness, and availability.

It was found[8] that *L*-band maser operation using ruby could be achieved, and satisfactory gain-bandwidth products obtained. In our design we placed emphasis on the feature of tunability. A tuning range from 850 to 2000 mc was obtained. Since a low-loss four-port *L*-band circulator was not available, such a unit, having a 200-mc frequency range for use with the maser, was developed.[9]

The maser and circulator were then packaged with the necessary auxiliary equipment to form a complete low-noise *L*-band preamplifier having a system noise factor of 0.5 db (35°K).

## II. System Description

A schematic diagram of the maser system is shown in Fig. 1. The signal received by the antenna is directed by the four-port circulator into the single-port cavity maser; the amplified signal leaves the maser by the same

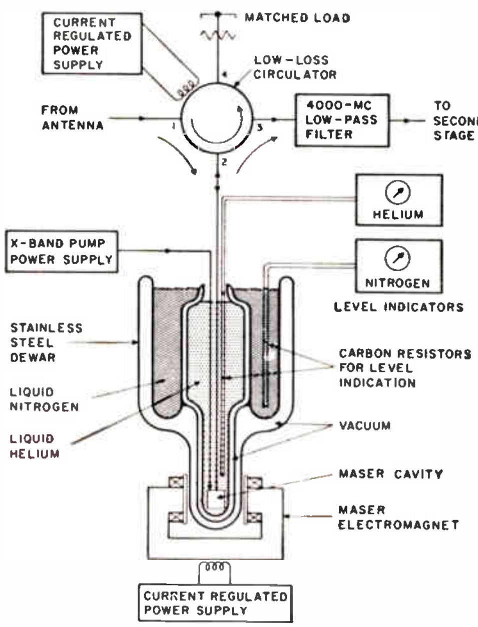


Fig. 1—Schematic diagram of maser system.

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† Airborne Instruments Lab., Cutler-Hammer, Inc., Melville, L. I., N. Y.

[1] J. O. Artman, N. Bloembergen, and S. Shapiro, "Operation of a three-level solid-state maser at 21 cm," *Phys. Rev.*, vol. 109, pp. 1392–1393; February 15, 1958.

[2] S. Autler and N. McAvoy, "21-centimeter solid-state maser," *Phys. Rev.*, vol. 110, pp. 280–281; April, 1958.

[3] H. E. D. Scovil, G. Feher, and H. Seidel, "Operation of a solid-state maser," *Phys. Rev.*, vol. 105, pp. 762–763; January 1, 1957.

[4] G. Makhov, C. Kikuchi, J. Lambe, and R. W. Terhune, "Maser action in ruby," *Phys. Rev.*, vol. 109, pp. 1399–1400; February 15, 1958.

[5] R. W. DeGrasse, E. O. Schulz-DuBois, and H. E. D. Scovil, "Three-level solid-state traveling wave maser," *Bell Sys. Tech. J.*, vol. 38, pp. 305–334; March, 1959.

[6] T. H. Maiman, "Solid-state masers—design and performance," *Proc. NSIA-ARDC Conf. on Molecular Electronics*, Washington, D. C.; November 13, 1958.

[7] J. A. Giordmaine, L. E. Alsop, C. H. Mayer, and C. H. Townes, "A maser amplifier for radio astronomy at *X*-band," Proc. IRE, vol. 47, pp. 1062–1069; June, 1959.

[8] F. R. Arams, S. Okwit, and A. Penzias, "Maser action in ruby at 21 cm," *Bull. Amer. Phys. Soc.*, ser. II, vol. 4, p. 21; January 28, 1959.

[9] F. R. Arams, G. Krayer, and S. Okwit, "Low-loss *S*- and *L*-band circulators," 1959 IRE National Convention Record, pt. 3, pp. 126–133.

port and is directed by the circulator to the second stage. A low-pass filter having a cutoff frequency of 4000 mc is placed at the output of the maser system to prevent feed-through of pump power into the receiver. At this location, the filter will not adversely affect system noise factor.

A matched load is connected to the fourth port of the circulator. This load can be refrigerated if it is necessary to reduce its noise contribution caused by antenna mismatch (which reflects load noise into the maser).

The maser cavity (which is described more fully in Section III) is located near the bottom of a 2-inch inner diameter stainless-steel double Dewar flask. The inner portion of the Dewar flask is filled with $2\frac{1}{4}$ liters of liquid helium, which is allowed to enter the maser cavity. One charge of liquid helium yields approximately 16 hours of operation. The outer jacket of the Dewar flask is filled with liquid nitrogen to reduce liquid helium evaporation. The Dewar flask is constricted at the bottom to a $2\frac{1}{4}$-inch outer diameter to keep the dimensions of the maser electromagnet to a minimum. The maser electromagnet employs a 5-inch diameter pole-face and provides a magnetic field that is homogeneous within $\pm 5$ gauss out of 2000 gauss over the volume occupied by the ruby crystal.

Liquid level indicators are provided for the refrigerants. These use three carbon resistors connected in parallel and located at various heights in the Dewar flask. Liquid levels are displayed on two ammeters. A relay-actuated warning light indicates when a new charge of liquid helium is required.

The $X$-band pump power circuitry (shown in Fig. 2) consists of 1) a Varian X-13, 100-mw, klystron with a dial mounted on its tuning shaft that is directly calibrated in frequency, 2) an isolator that helps to stabilize the klystron by protecting it from load variations, 3) a variable attenuator that allows for pump power level adjustment, and 4) a 20-db bidirectional coupler to sample the pump output that is detected and displayed on a microammeter (this monitors the pump power level). The power reflected from the maser cavity is also sampled by the bidirectional coupler, detected, and fed to an oscilloscope to permit observation of the maser cavity resonance. For this purpose, the klystron is frequency-modulated using sawtooth modulation from the klystron power supply. A reaction frequency meter is included to permit accurate determination of pump frequency.

## III. Tunable Maser Cavity Design

For maser operation, it is desirable that the cavity containing the paramagnetic material (ruby) be resonant at both the signal and pump frequencies. Furthermore, it is desirable that 1) these two cavity resonances be independently tunable, 2) the tuning be accomplished from the top of the Dewar flask while the cavity is in the liquid helium, and 3) the cavity coupling at the signal frequency be adjustable so that gain and bandwidth can be varied during operation.

The cavity design used, which meets all of these requirements, is shown in Fig. 3. This structure has the additional feature of simple mechanical design for making the required tuning and coupling adjustments.

The signal-frequency mode consists of a quarter-wavelength TEM-mode resonator.[1] This resonator is a thin-rod center conductor between parallel ground planes provided by the broad walls of a small $X$-band waveguide. This type of structure has the advantages that 1) resonant wavelength is proportional to rod length, 2) cavity coupling remains reasonably constant with frequency, and 3) the RF magnetic field distribution over the paramagnetic material remains essentially unchanged while the cavity is tuned. Because the TEM mode is dominant, the problem of spurious responses is minimized. A tuning range of more than one octave is obtained simply by varying the length of the center-conductor rod. The rod length is reduced by a factor of about three because of the high dielectric constant of the ruby. This is desirable at $L$-band to keep physical dimensions small. The unloaded $Q$ of this structure is 550 at room temperature and increases to 1100 at 4.2°K.

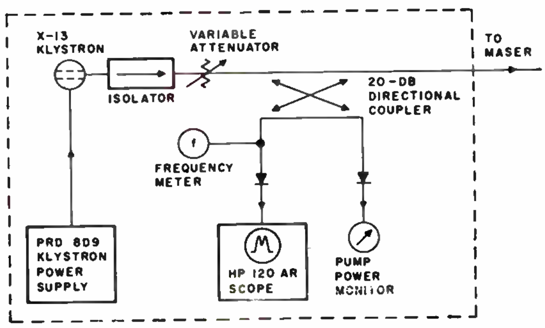



Fig. 2—Schematic diagram of $X$-band pump power supply.

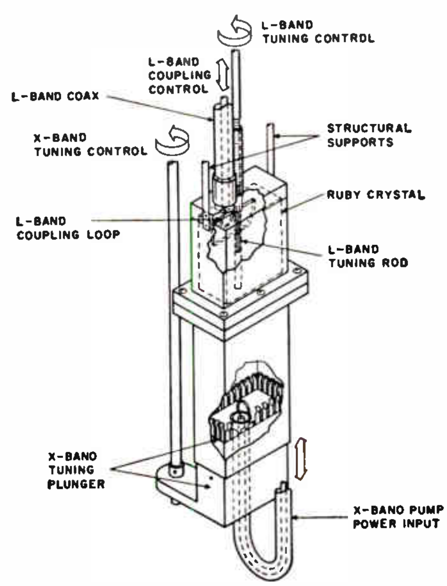



Fig. 3—Tunable maser cavity structure.

The waveguide region not occupied by the rod is beyond cutoff for the signal frequency. Therefore, a contacting plunger located in this region can serve as the tuning element for the $X$-band pump resonance (which operates in a $TE_{107}$ mode) without affecting the $L$-band resonance (Fig. 3). The $X$-band pump power is loop-coupled into the cavity, through the backplate of the $X$-band tuning plunger, by means of a coaxial line having a bead-supported center conductor. Such a line has an $X$-band dissipative loss of only a few tenths of a db, has a much smaller cross section compared with waveguide, and the coupling remains reasonably constant over a broad tuning range. The $X$-band cavity is conveniently tuned from the top by a tuning rod directly connected to the tuning plunger. All low-temperature moving joints (except where electrical contact is required) consist of metal-to-teflon bushings.

Two factors were considered in choosing the 0.086-inch diameter of the $L$-band tuning rod: 1) the diameter should be as small as possible to minimize its effect on the $X$-band resonant frequency, and 2) the diameter dimension should yield a high unloaded $Q$ at the $L$-band signal frequency. Measurements showed that the $X$-band resonance goes through a cyclical variation of only $\pm 3$ mc when the $L$-band resonance is tuned. The $X$-band tuning plunger is, as previously stated, in a region beyond cutoff for the $L$-band mode. Thus, the two resonances are independently tunable.

The coupling to the $L$-band mode is accomplished by means of a loop that penetrates into a thin slot in the ruby. The loop is oriented in a plane parallel to the broad waveguide dimension to minimize coupling to the $X$-band pump resonance. The coupling is variable from the top of the Dewar flask by means of a micrometer head that moves the $L$-band coaxial line in the vertical direction. This varies the penetration of the coupling loop into the maser cavity. Two other micrometer heads located at the top of the Dewar flask are used to tune the $L$- and $X$-band cavity resonances. The cavity assembly and the superstructure are shown in Figs. 4 and 5, respectively.

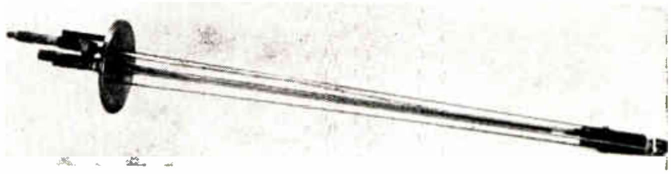


Fig. 4—Maser cavity assembly.

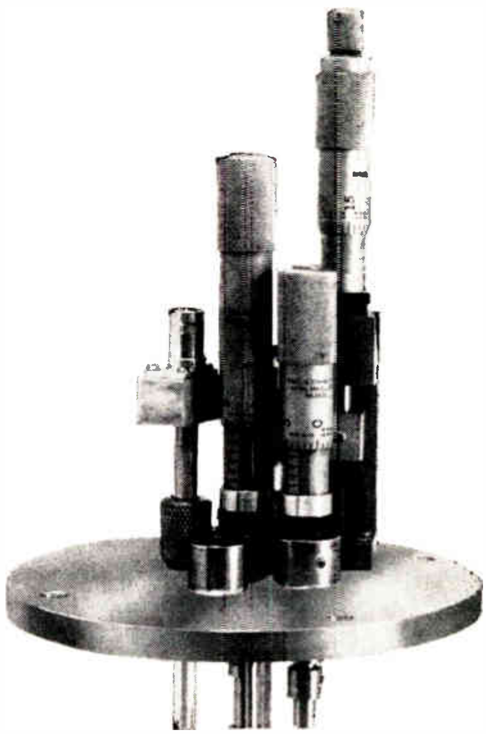


Fig. 5—Cavity superstructure.

## IV. Maser Performance

The relationship between the pump and signal resonant frequencies of the cavity and the external magnetic field required for maser operation are determined by the inherent quantum-mechanical properties of the paramagnetic crystal. These quantum-mechanical properties (energy levels, RF transition probabilities, and relaxation times) are strongly dependent upon the external magnetic field $H$ and the angular orientation $\theta$ between the external magnetic field and the crystal $C$-axis.

Best $L$-band maser performance was obtained for an angular orientation $\theta$ of 90° at high magnetic fields ($H \approx 2000$ gauss). The energy level diagram for ruby when $\theta$ is equal to 90° is shown in Fig. 6. It shows four (low-lying) energy levels, since $Cr^{+++}$ in $Al_2O_3$ has a spin $S = 3/2$. The $L$-band signal transition and $X$-band pump transition that were used are between levels 1 and 2, and levels 1 and 3, respectively. The high-field 90° operating point is attractive on theoretical grounds because the calculated signal and pump transition probabilities are high.[10,11] At this operating point, the signal transition probability is maximum when the microwave signal magnetic field is nearly perpendicular to the external magnetic field and parallel to the ruby $C$-axis. This condition is realized to a fair degree in our design, since the ruby crystal that we utilized had its $C$-axis oriented in a plane parallel to the broad face of the $X$-band waveguide, and at 60° to the $L$-band tuning rod (see Fig. 3), and the signal magnetic field is elliptically shaped for slabline TEM mode employed.

[10] W. S. Chang and A. E. Siegman, "Characteristics of Ruby for Maser Applications," Electron Devices Laboratory, Stanford University, Stanford, Calif., Tech. Rept. 156-2, Figs. 14 and 15; September 30, 1958. Also, J. Weber, "Masers," *Rev. Mod. Phys.*, vol. 31, pp. 681–710; July, 1959.

[11] E. O. Schulz-DuBois, H. E. D. Scovil, and R. W. DeGrasse, "Use of active material in three-level solid-state masers," *Bell Sys. Tech. J.*, vol. 38, pp. 335–352; March, 1959.

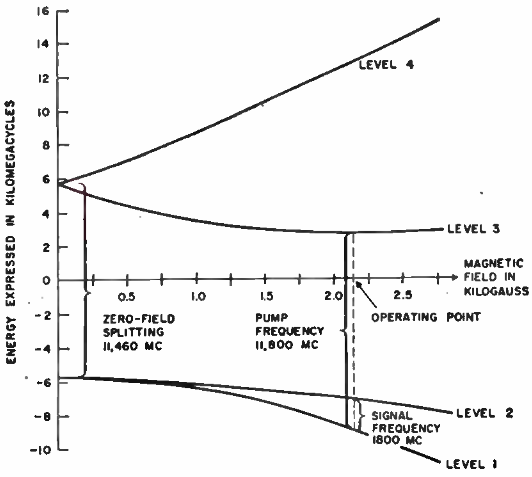



Fig. 6—Energy levels utilized for *L*-band maser.

Measurements of the voltage-gain bandwidth product at high magnetic fields were made at liquid helium bath temperatures of 4.2°K and 1.5°K. The results of these measurements are listed in Table I.

Table I shows that a voltage-gain bandwidth product of 37.5 mc was measured at 1750 mc for a temperature of 1.5°K. Thus, for a half-power bandwidth of 3.75 mc, a gain of 20 db will be obtained. Furthermore, operation was also obtained at an operating temperature of 4.2°K, where a voltage-gain bandwidth product as high as 20 mc was measured.

The gain-bandwidth products measured were used to calculate the effective magnetic $Q$. For such calculations, Fig. 7 and (3) (Appendix I) can be used, under the condition that the cavity unloaded $Q$ is much greater than the external $Q$. The effective magnetic $Q$ calculated at 1200 mc (Table I) is 140 and 210 for operation at 1.5°K and 4.2°K, respectively. The magnetic $Q$ is approximately constant over the *L*-band region. There is a deterioration in magnetic $Q$ at the low-frequency end that is probably due to cross-relaxation effects.[12] The pump power that was required varied between 5 and 150 mw for the various measurements.

A four-level experiment was also performed for $\theta$ equal to 90° at high magnetic fields. Here, pumping was done between levels 1 and 4, with the signal transition again between levels 1 and 2. Maser operation at a liquid helium bath temperature of 4.2° K was readily obtained at frequencies from 850 to 1750 mc (Table II). However, the measured voltage-gain bandwidth product did not show the expected improvement of greater than 100 per cent (assuming equal relaxation times between all levels) over the three-level arrangement. This may have been due in part to the limited pumping power available from the 20-kmc klystron that was used. Of the 50 mw available from a Raytheon QK306 klystron, only an estimated 10 mw reached the maser cavity. This power level was insufficient to saturate the 20-kmc pump transition, which has a low calculated transition probability.[10]

[12] N. Bloembergen, S. Shapiro, P. S. Pershan, and J. O. Artman, "Cross-relaxation in spin systems," *Phys. Rev.*, vol. 114, pp. 445–459; April 15, 1959.

TABLE I

SUMMARY OF *L*-BAND MASER PERFORMANCE (THREE-LEVEL OPERATION)

| Liquid Helium Bath Temperature (°K) | Signal Frequency (mc) | Voltage-Gain Bandwidth Product Measured (mc) | Voltage-Gain Bandwidth Product Determined from External $Q$ Measurement (mc) | Pump Frequency (mc) | Magnetic Field (gauss) |
|---|---|---|---|---|---|
| 4.2 | 2000 | * | * | 12,150 | 2260 |
| 4.2 | 1815 | 20 | 22 | 11,860 | 2150 |
| 4.2 | 1200 | 11 | 13 | 10,950 | 1740 |
| 4.2 | 1010 | 9 | 12 | 10,700 | 1650 |
| 4.2 | 850 | * | * | 10,460 | 1510 |
| 1.5 | 1750 | 37.5 | 37.5 | 11,795 | 2100 |
| 1.5 | 1200 | 19 | 20 | 10,845 | 1740 |

* Not measured.

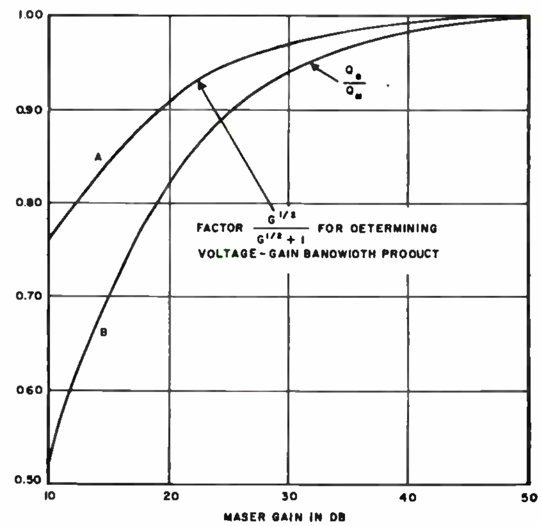



Fig. 7—Relationship of external $Q$ to gain-bandwidth product and magnetic $Q$ for cavity maser [when the cavity unloaded $Q(Q_u)$ is much greater that the external $Q(Q_e)$]. Curve A: Correction factor, due to finite gain, on gain-bandwidth product determined from external-$Q$ measurement. Curve B: Relationship of external $Q$ to magnetic $Q$ as a function of gain.

TABLE II

SUMMARY OF *L*-BAND MASER PERFORMANCE (FOUR-LEVEL OPERATION)

| Liquid Helium Bath Temperature (°K) | Signal Frequency (mc) | Voltage-Gain Bandwidth Product Measured (mc) | Pump Frequency (mc) |
|---|---|---|---|
| 4.2 | 1750 | 13 | 21,750 |
| 4.2 | 1005 | 6 | 19,180 |
| 4.2 | 855 | 5 | 18,420 |

For convenient reference, we have plotted the energy levels in ruby in a manner that is particularly suitable for three-level tunable maser operation [Fig. 8(a) and 8(b)]. By plotting pump frequency as a function of magnetic field, with angular orientation $\theta$ and signal frequency as parameters, the variation in pump frequency and magnetic field for a given signal tuning range are readily determined. The region of operation used in our maser is indicated by a heavy line in Fig. 8(b).

This form of plotting the energy levels brings out an interesting and useful point, namely, that the ruby crystal can be readily oriented to 90° by varying the crystal orientation until the dc magnetic field required for resonance absorption is maximized. As Fig. 8(b) shows, this alignment technique can be applied to either the pump or signal transition.

## V. Low-Loss Circulator

This is a four-port circulator having an insertion loss near 0.3 db and isolations greater than 23 db over a 200-mc frequency range.[9] Fig. 9 shows the circulator. Electrically, it consists of dual 90° non-reciprocal phase-shift sections connected to two hybrids.[13] Our unit used strip-transmission-line hybrids with transitions to a MgMnAl-ferrite-loaded *L*-band waveguide, which was reduced in height to one inch to keep the electromagnet dimensions at a minimum and to reduce the ferrite material requirements.

The strip-transmission-line hybrids are shown in detail in Fig. 10, with the top ground plane removed. The ring hybrid is equivalent in its operation to the waveguide folded tee, and the other hybrid is equivalent to the waveguide short-slot hybrid. The use of the strip-transmission-line hybrids results in reasonable physical size.

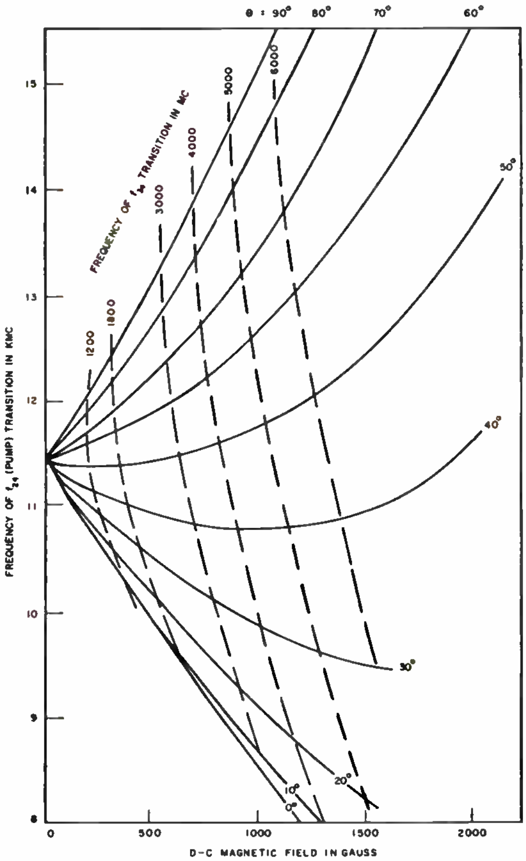
## VI. Package Description and Performance

### *A. Description of Package*

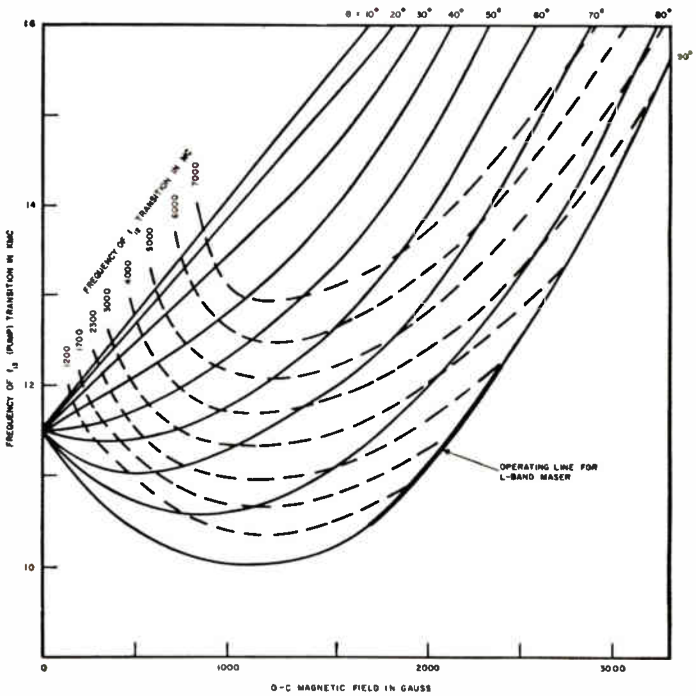
The over-all maser system is housed in two standard relay cabinets (Fig. 11). The smaller cabinet contains the maser cavity structure, stainless-steel Dewar flask, and maser magnet. The larger cabinet contains the associated auxiliary equipment, including (from top to bottom in Fig. 11):

1) oscilloscope to view either the pump or signal frequency cavity resonance and to observe and optimize maser action;
2) current-regulated power supplies to drive circulator and maser electromagnets;

[13] C. L. Hogan, "Elements of non-reciprocal microwave devices," Proc. IRE, vol. 44, pp. 1345–1368; October, 1956.




(a)




(b)

Fig. 8—Frequency relationships for three-level ruby maser as a function of magnetic field and angular orientation. (a) Upper three energy levels. (b) Lower three energy levels.

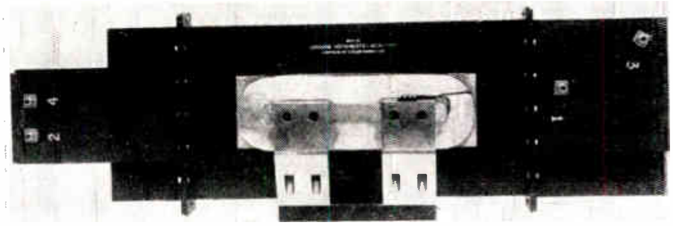
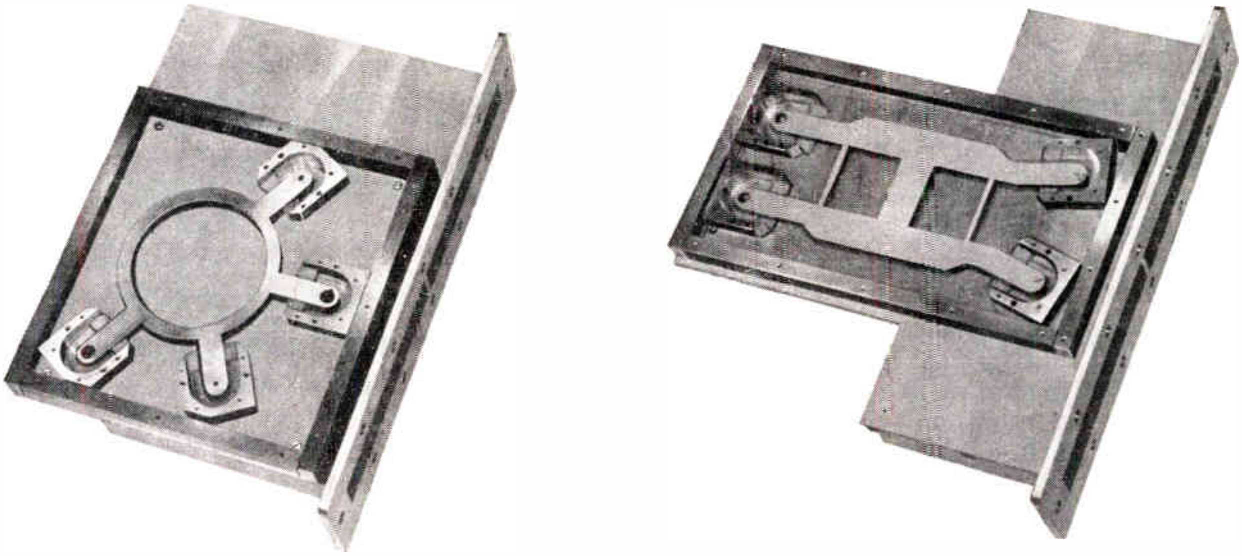


Fig. 9—Low-loss $L$-band circulator.



(a) (b)

Fig. 10—Strip transmission line hybrids used in $L$-band circulator. (a) 180° 3-db hybrid. (b) 90° 3-db hybrid.

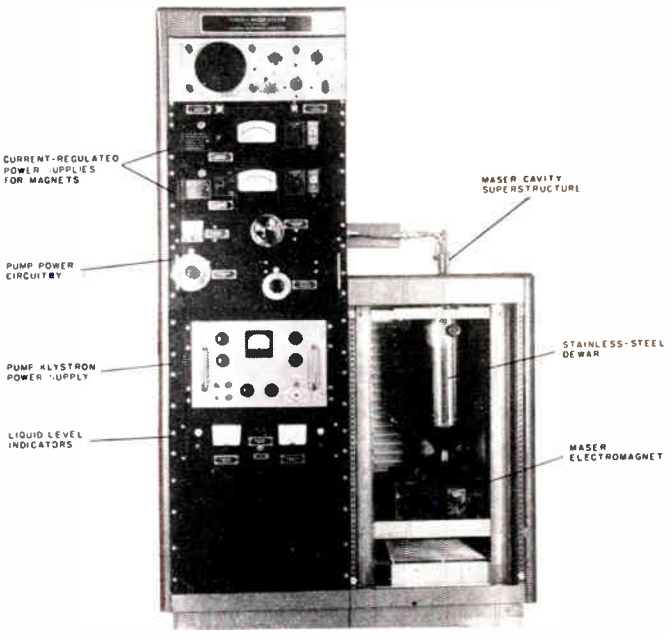



Fig. 11—Packaged maser system.

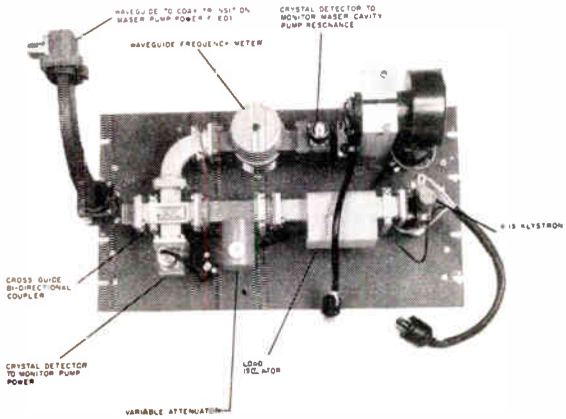



Fig. 12—Pump power circuitry.

3) pump power circuitry, including klystron, isolator, variable attenuator, frequency meter, bidirectional coupler, and detectors (shown in detail in Fig. 12);
4) klystron power supply; and
5) liquid level indicators for the refrigerants.

The circulator (which cannot be seen in Fig. 11) is located in the rear of the larger cabinet and is connected to the maser by a low-loss strip transmission line having $1\frac{1}{2}$-inch ground-plane spacing. The input to the maser system consists of $1\frac{5}{8}$-inch coaxial line.

### B. General Performance

The maser is easily tuned to any operating frequency over the 200-mc range by adjusting the dc magnetic field, the pump frequency, and the two cavity resonances. All the adjustments necessary for tuning the maser to a specific operating frequency have been calibrated. The signal-frequency cavity-resonance adjustment can be set to any specified frequency within $\pm 2$ mc with the calibrated micrometer head. One of the required adjustments, the dc magnetic field, is critical and requires fine tuning. The other two adjustments (pump cavity resonance and pump frequency) are not critical; maser operation can be obtained with the pump cavity resonance and pump frequency detuned as much as 75 mc.

The angular orientation $\theta$ of the ruby-loaded maser cavity with respect to the dc magnetic field is not critical. Maser operation has been obtained, without serious degradation in gain-bandwidth product, at angular deviations of several degrees from 90° throughout the tuning range. Consequently, controls for fine-tuning the alignment of the maser cavity were deemed unnecessary. A mechanical feature ensures that the maser cavity structure is correctly oriented when it is inserted into the system.

### C. System Noise Temperature

Noise-temperature measurements were made on the maser system using the technique described in Appendix I. The noise generators used for the measurement consisted of two matched loads—one at room temperature and one at liquid nitrogen temperature (Appendix II). A series of measurements, made with the maser operating at high gains, yielded a noise factor of $0.5 \pm 0.1$ db, which is equivalent to a noise temperature of 35°K.

The main contributing noise sources are:

1) The dissipative losses of the circulator and input coaxial feed lines; these give a noise temperature of approximately 28°K (0.4 db).
2) The second-stage amplifier and other components at the output of the maser having an over-all noise factor of 7.2 db (1230°K). The amplifier consists of a balanced mixer utilizing 1N21EMR crystals and a 30-mc IF amplifier. Its measured noise factor was 6.6 db. With a net maser system gain of 23 db, this contribution is 6.15°K.
3) The maser signal frequency spin temperature, which is calculated to be 1.5°K, for a bath temperature of 4.2°K, assuming equal idler and signal spin-lattice relaxation times.

Thus, good correlation is obtained between the calculated and measured noise temperatures.

### D. Maser Saturation Characteristics

A saturation curve that was measured on the maser system is shown in Fig. 13. As can be seen, the gain drops 3 db at a power output of $-35$ dbm. This yields a dynamic range of 68 db for a post-receiver bandwidth of 1 mc.

Susceptibility of the maser to nearby CW signals is shown in Fig. 14. The power level of the interfering signal, at which the maser gain drops 3 db at its center frequency, is plotted as a function of the frequency of the interfering signal. The shape of the measured response can be closely determined from the frequency response of the active maser cavity. The measurement was made with a three-cavity filter between the maser and the second stage receiver to ensure that the interference effect measured was primarily due to the maser proper. The filter had a 3-db bandwidth of 15 mc and an insertion loss of 25 db at 15 mc from center frequency.

It is essential that the input level of interfering signals be kept below the microwatt range (Figs. 13 and 14). To insure this, it is desirable to use a preselector cavity and/or passive ferrite limiter that has its limiting

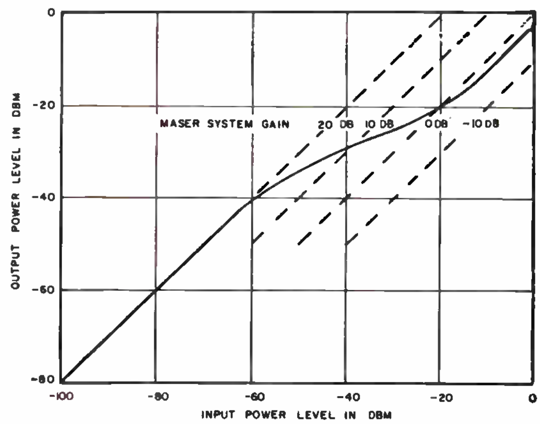



Fig. 13—Maser saturation characteristic due to main signal.

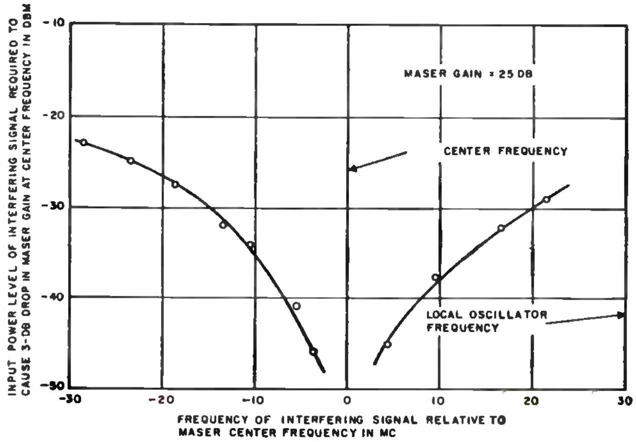



Fig. 14—Maser saturation characteristic due to nearby signals.

threshold at microwatt power levels.[14] These can be placed in the low temperature bath to minimize their noise contribution. The relatively low saturation power level (and relatively long recovery time) of the ruby maser is a result of the relatively long spin-lattice relaxation time of the idler transition, which (for $\theta$ equal to 90°) is in the tens of milliseconds at 4.2°K. Future masers will show marked improvements in saturation level and recovery time by using new materials or "impurity-doped" ruby to reduce the idler relaxation time.

To prevent maser saturation effects due to the local oscillator in the second-stage receiver, a balanced mixer should be used. A balanced mixer provides a local-oscillator isolation of 30 db, which, in combination with the circulator isolation and maser cavity selectivity, is more than sufficient to prevent maser saturation effects due to local-oscillator power leakage.

### *E. Gain Stability*

The results of a number of stability measurements at a helium bath temperature of 4.2°K and a maser gain of 22 db yielded a long-term peak-to-peak drift of $\pm 0.55$ db, and a short-term peak-to-peak stability of $\pm 0.1$ to $\pm 0.2$ db over a period of several hours. These figures represent the fluctuations of a complete receiver with the maser front end fed by a standard signal generator. Hence, a portion of the output variation must be ascribed to parts of the measurement setup rather than the maser.

Turbulence in the liquid helium appears to be responsible for some of the short-term gain variations observed in the maser. This effect is reduced by the use of polyfoam loading of the microwave structure. The fluctuations are also significantly reduced by reducing the helium bath temperature below the $\lambda$-point (2.2°K), where the liquid helium becomes a superfluid.

The parameter having the greatest detrimental effect on long-term gain stability was found to be the maser magnetic field, which is controlled by a current-regulated power supply. This is evident when it is noted that the regulation must be substantially better than the magnetic line width of the ruby, which is about 1 per cent of the external magnetic field that was used. The electromagnet is designed to permit maser operation over the entire 850 to 2000 mc tuning range of the cavity. Improved stability can be obtained by using a permanent magnet employing an adjustable mechanical shunt or bucking coils for tuning, since a variation in magnetic field of about 6 per cent is needed to cover the 200 mc tuning range of the maser system.

## VII. Conclusion

It can be concluded that a cavity maser can be satisfactorily operated over frequency bands greater than one octave. In packaging such a maser together with a circulator for field operational use, the usual 12-inch diameter laboratory magnet and other highly precise supplementary equipment have been eliminated without detrimental effect on gain-bandwidth product, noise figure, and other system parameters. The resulting equipment is reasonably compact and easily operated by semi-skilled personnel.

## Appendix I

### Techniques for Measuring Maser Gain-Bandwidth Product

The voltage-gain-bandwidth product was determined by two methods. In the first method, gain and half-power bandwidth were measured directly, using the setup shown in Fig. 15. Maser gain is measured by noting the increase in generator output required to maintain a constant output meter reading when the maser is disconnected from the circuit and replaced by a short-circuit at point $A$ of Fig. 15.

In the second method, the external $Q$ of the maser cavity was measured with the pump power and magnetic field turned off. The voltage-gain bandwidth product $G^{1/2}B$ can then be calculated since, for the condition of high gain ($G^{1/2} \gg 1$), it is approximately

$$G^{1/2}B \approx \frac{2f}{Q_e}, \tag{1}$$

where $f$ is the signal frequency and $Q_e$ is the external $Q$. The more exact expression[15] for $Q_u \gg Q_e$ is

$$G^{1/2}B = \frac{2f}{Q_e}\left[\frac{G^{1/2}}{G^{1/2}+1}\right]. \tag{2}$$

The bracketed term in (2) is the correction factor on the approximation. It is plotted in Fig. 7, and is seen to be less than 10 per cent for gains greater than 20 db.

For comparison with theoretical computations of maser performance, it is desirable to determine $Q_m$, the magnetic $Q$, which is a measure of the negative resistance introduced by the paramagnetic maser material.

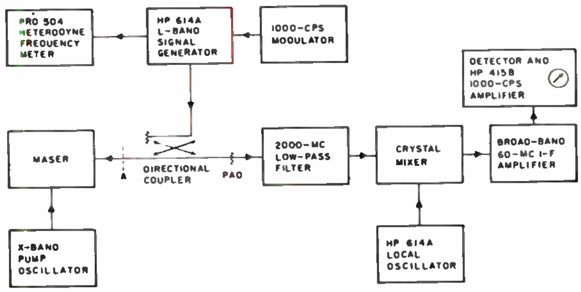



Fig. 15—Measurement setup for maser gain and bandwidth.

[14] R. W. DeGrasse, "Low-loss gyromagnetic coupling through single crystal garnets," *J. Appl. Phys.*, vol. 30, suppl. 4, pp. 155.S–156.S; April, 1959.

[15] J. O. Artman, "The Solid-State Maser," *Proc. Symp. on Role of Solid-State Phenomena in Electric Circuits*, Polytechnic Inst. of Brooklyn, Brooklyn, N. Y., sec. 3, p. 77; April, 1957.

The magnetic $Q$ is related to $Q_e$ by the expression

$$\frac{Q_e}{Q_m} = \frac{G^{1/2} - 1}{G^{1/2} + 1}, \quad (3)$$

and is plotted in Fig. 7. Obviously, $Q_e \approx Q_m$ for high gains. The correction factor is less than 20 per cent for gains greater than 20 db.

## Appendix II

### Measurement of System Noise Temperature

Of the several methods used for the measurement of noise temperature,[16] the $Y$-factor method appeared to be most satisfactory for low noise temperatures. In this method, the output noise power of the receiver, when the input source resistance is at a high temperature $T_2$, is compared with the output noise power of the receiver when the input source resistance is at a lower temperature $T_1$. The ratio of these two noise powers is called the $Y$-factor, which is related to the noise temperature, $T_e$, by the expression

$$T_e = \frac{T_2 - T_1}{Y - 1} - T_1. \quad (4)$$

The accuracy with which $T_e$ can be determined depends upon how accurately $T_1$, $T_2$, and $Y$ are known.

Fig. 16 shows the experimental arrangement used for the noise measurement. The available noise power from the two loads (one maintained at a liquid nitrogen temperature of 77.3°K, and the other at room temperature) is alternately coupled to port 1 of the circulator through a coaxial switch. These noise powers are directed by the circulator into the maser (port 2) and from the maser into a second-stage amplifier consisting of a mixer and an AIL Type 130 Test Receiver. The $Y$-factor is then accurately determined by using a precision calibrated attenuator that is part of the AIL Type 130 Test Receiver.

It is estimated that the absolute temperature of the two loads can be determined to within ±1°K and that the $Y$-factor can be measured to within ±0.5 per cent.

[16] M. Wind, "Handbook of Electronic Measurements," Microwave Res. Inst., Polytechnic Inst. of Brooklyn, Brooklyn, N. Y., ch. 13; 1954–1955.

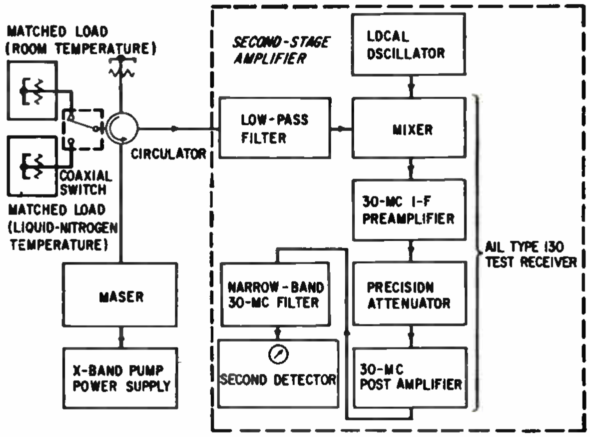



Fig. 16—Measurement setup for maser system noise temperature.

Application of these errors to a variational form of (4) yields a calculated over-all measurement accuracy of better than ±3°K.

In measuring low noise temperatures, the following precautions were taken.

1) The two noise generators (ambient temperature load and the liquid nitrogen load) were well matched.
2) Linearity measurements of the second-stage amplifier were made over a 40-db range. The linearity was found to be within ±0.05 db. In addition, the bandwidth of the second stage was made narrower than that of the first stage, to eliminate bandwidth corrections from the noise-factor measurement.
3) The over-all receiving system was tested for spurious responses. Since broad-band noise sources were used, all spurious responses must be known to reduce the measurement data accurately. All spurious responses were found to be negligible.

### Acknowledgment

The advice and aid of C. H. Townes and A. Penzias of Columbia University during the early phases of the project are gratefully acknowledged. The authors also wish to express their gratitude to their co-workers, J. G. Smith and M. Grace, who helped with the packaging and with the measurements.

# Cadmium Sulfide Field Effect Phototransistor*

R. R. BOCKEMUEHL†

*Summary*—**The experimental evaluation of cadmium sulfide field effect transistors indicates that, although the material does not compete with germanium for general transistor application, useful power gain was achieved and certain advantages exist for CdS in phototransistor applications. Many unique circuit functions can be performed by the device. The active electronic properties vary greatly with the intensity and wavelength of incident light, and with photoconductivity quenching infrared radiation. Voltage gains greater than 500, mutual transconductances up to 20 μmho and input resistances near 100 megohms have been observed. Electron-hole pairs are generated photoelectrically in the highly pure, single crystal CdS. The holes are virtually immobile and form a space charge when an applied electric field removes the mobile electrons from a region. Modulation of the space charge boundary by application of a potential to one terminal of the device produces modulation of the conductance between two other terminals and signal amplification results. Attempts to correlate the illumination sensitivity of the terminal characteristics with theoretical field effect parameters indicates the carrier distribution in the crystal is complex and varies with illumination wavelength and quenching intensity.**

## Introduction

The group II–VI compound semiconductors have potential advantages as specialized electronic components with transistor configurations. For example, the utility of photoconductive materials may be extended when fabricated as a transistor. Furthermore, transistor configurations facilitate observation of additional material properties and mechanisms which may extend theoretical understanding of semiconductors. The group II–VI compounds are not expected to compete with elemental or group III–V compounds as general-purpose transistor materials, inasmuch as those studied possess a prohibitively low carrier mobility, or low band gap, or high "intrinsic" carrier concentration.[1] The study of group II–VI transistors is important, however, on the basis of improvement of understanding and utilization of specialized properties, particularly photoelectric properties.

Cadmium sulfide was selected for transistor experimentation because its properties are probably the best known of the II–VI compounds and because it is available in sufficiently pure, single-crystal form.[2] The relatively low mobility of CdS ($\approx 200$) requires an excessively thin base layer in a junction transistor configuration. However, the unipolar field effect transistor configuration permits practical device dimensions even though mobility is relatively low.

The field effect transistor was first given detailed consideration by Shockley.[3] Modulation of the conductance of a unipolar semiconductor slab is achieved by applying an electric field, perpendicular to the current flow, creating a space charge region which effectively reduces the conducting cross section of the slab. In practice, the transverse field is applied through an intimate, but non-carrier-injecting contact such as a *p-n* junction. Application of the transverse field through an insulating medium does not produce an appreciable space charge in the semiconductor slab because of trapped charges which develop on the slab surface.[3]

Experimental field effect transistors have been fabricated from Ge[4] and Si,[5] and the effect has been observed in InP and GaAs.[6] However, no previous observation of field effect amplification has been reported for any group II–VI compound, nor for any material in which virtually all of the carriers are generated photoelectrically.

## Fabrication

The experimental field effect phototransistors were cut from thin single-crystal plates with a special air-abrasive cutting machine to dimensions of 3 mm×3 mm square. Thickness was not modified and ranged from 0.15 to 0.5 mm in various units. The thin CdS crystal plates were grown by the vaporization-crystallization method by Boyd and Sihvonen.[2] The placement of the contacts is illustrated in Fig. 1. The contact nomenclature is consistent with that proposed by Shockley.[3] The gate contact is vacuum deposited copper, a few hundredths of a micron thick. The necessary rectifying characteristic is obtained by heating at 400°C for ten minutes in room air. The gate contact is transparent and back resistance is greater than $10^7$ ohms. The formation of the rectifying junction is similar to that described by Reynolds, *et al.*;[7] however, the presence of air was found to be necessary during the heating process.

* Original manuscript received by the IRE, October 22, 1959.
† Res. Labs., General Motors Corp., Warren, Mich.

1 D. A. Jenny, "The status of transistor research in compound semiconductors," Proc. IRE, vol. 46, pp. 959–968; June, 1958.

2 D. R. Boyd and Y. T. Sihvonen, "Vaporization-crystallization method for growing CdS single crystals," *J. Appl. Phys.*, vol. 30, pp. 176–179; February, 1959.

3 W. Shockley, "A unipolar 'field effect' transistor," Proc. IRE, vol. 40, pp. 1365–1376; November, 1952.

4 G. C. Dacey and I. M. Ross, "Unipolar field effect transistor," Proc. IRE, vol. 41, pp. 970–979; August, 1953.

5 G. L. Pearson, "High impedance field effect silicon transistors," *Phys. Rev.* vol. 90, p. 336; April, 1953.

6 A. Herczog, R. R. Haberecht, and A. E. Middleton, "Preparation and properties of aluminum antimonide," *J. Electrochem. Soc.*, vol. 105, p. 535; September, 1958.

7 D. C. Reynolds, L. C. Greene, and L. L. Antes, "Properties of a cadmium sulfide photo-rectifier," *J. Chem. Phys.*, vol. 25, pp. 1177–1179; December, 1956.

The ohmic source and drain contacts were prepared by electroplating indium from an indium fluoroborate solution after the gate contact heat treatment. All surfaces were cleaned and etched in HCl before contact application. Leads were connected to contacts with silver conducting paint. The units were mounted first on special printed circuit boards, and later in standard transistor headers with transparent cover as shown in Fig. 2.

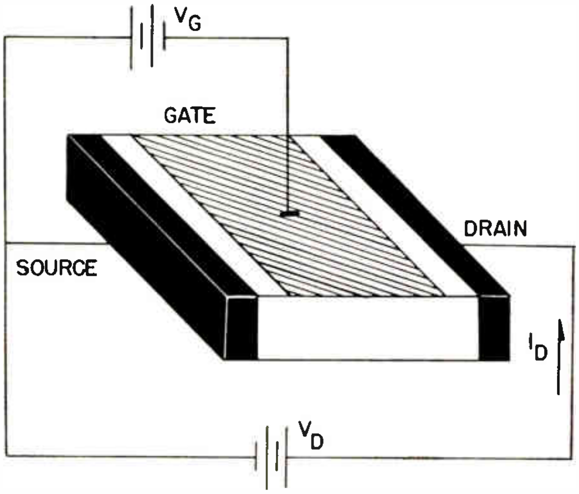
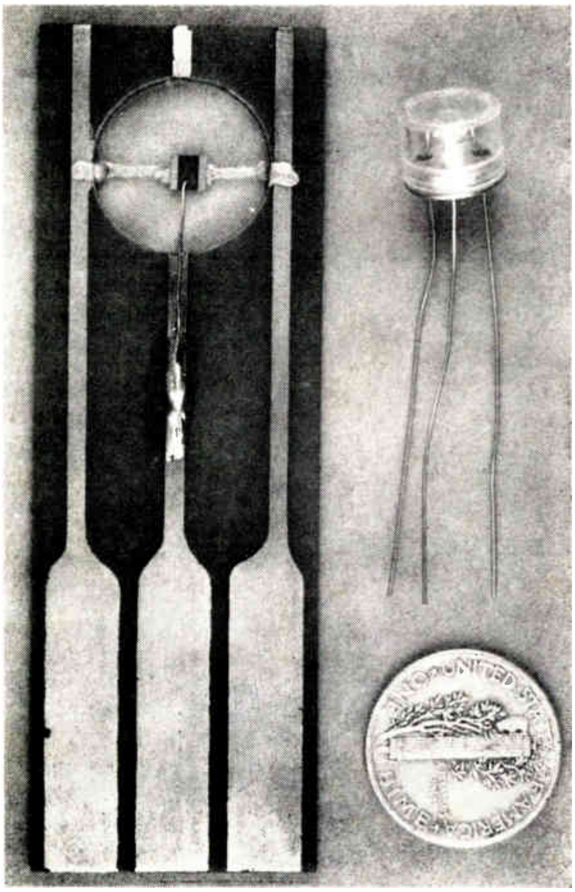



Fig. 1—Field effect phototransistor terminal relationship and common source connection. Source and drain are ohmic; gate is diodic and semitransparent.



(a) (b)

Fig. 2—Cadmium sulfide field effect phototransistors. (a) Mounted for detailed evaluation. (b) Mounted in transparent transistor header.

## Terminal Characteristics

The penetration of the space charge layer into the semiconductor slab, and the resulting decrease in the slab conductance is determined by the magnitude of the reverse bias voltage across the gate junction. Considering the grounded source terminal configuration, Fig. 1, the gate bias voltage is the difference between the potential applied to the gate terminal and the potential in the semiconductor slab. The latter is a function of the drain terminal potential. Thus, the slab conductance is a function of both gate and drain potentials.

The drain terminal voltage-current characteristic at various values of gate voltage (common source) is shown in Fig. 3. A "constant" current region of operation exists when the gate-to-drain potential difference is sufficient to cause the thickness of the space charge layer to approach that of the slab. This bias voltage is designated "pinch-off" voltage $V_p$. An increase in drain voltage above the $V_p$ value alters the space charge distribution in such a manner to keep the pinch-off current essentially constant. The gate potential determines the value of the pinch-off current; thus an active gate-to-drain mutual transconductance $G_m$ exists. The mutual transconductance, together with the high dynamic output impedance of the device, permits a large voltage gain to be realized. Furthermore, the high gate terminal impedance of the device permits useful current and power gains to be realized.

The terminal characteristics of the field effect phototransistor are dependent on the carrier density within the slab, which is determined by the intensity and wavelength of the incident light excitation. Therefore, these characteristics vary greatly with illumination parameters.

Typical characteristics of a unit when illuminated with an incandescent lamp at an intensity of the order of 200 foot-candles are as follows:

Pinch-off current ($V_g=0$): 200 $\mu$a,
Pinch-off voltage: 30 volts,
Mutual transconductance: 20 $\mu$mho,
Short circuit current gain: 400,
Open circuit voltage gain: up to 1000,
Output impedance (resistive): up to 50 meghoms,
Input impedance: 20 to 100 megohms depending on load resistance.

A finite gate-to-drain resistance exists which produces feedback resulting in the dependence of input impedance on load resistance and of output impedance on source resistance.

Several experimental phototransistors were operated in a temperature range from $-50°$F to 150°F with a negligible change in terminal characteristics when illuminated with an incandescent lamp. However, a considerable temperature dependence was observed when illuminated with monochromatic wavelengths greater than 5300 angstroms.

Frequency response varies greatly with operating conditions but extends from dc throughout the audio range.

High-frequency attenuation results from the junction capacity of the gate and from stray capacities in the drain circuit in conjunction with the high dynamic drain impedance.

## Photoelectric Characteristics

The pinch-off current of the cadmium sulfide field effect phototransistor is much more sensitive to illumination intensity and wavelength than are the other electrical parameters of the device. The photoconductivity of cadmium sulfide exhibits a sharp peak between 5100 and 5200 Å.[8] The wavelength dependence of pinch-off current of the transistor, and the photocurrent when connected as a two-terminal photoconductor is shown in Fig. 4. Under certain operating conditions, the pinch-off current has been observed to be proportional to the square of the illumination intensity. Sensitivities of the order of $10^{-8}$ amperes per foot-candle squared have been observed with incandescent illumination.

The pinch-off current is also very sensitive to infrared quenching wavelengths.[9] Certain discrete wavelengths in the 1-micron region, when applied in combination with excitation wavelengths, cause a reduction in the conductivity of cadmium sulfide and produce other effects which sharply reduce the pinch-off current. This wavelength dependence of the pinch-off current and two-terminal photocurrent is shown in Fig. 5. Pinch-off current sensitivities of the order of 1 $\mu a/\mu w/cm^2$ have been observed. The variation of pinch-off current and two-terminal photocurrent with infrared quenching intensity is shown in Fig. 6. The pinch-off current is many times more sensitive to infrared quenching intensity than is the two-terminal photocurrent.

[8] M. Balkanski and R. D. Waldron, "Internal photoeffect and exciton diffusion in cadmium and zinc sulfides," *Phys. Rev.*, vol. 112, pp. 123–125; October 1, 1958.

[9] R. H. Bube, "Infrared quenching and unified description of photoconductivity phenomena in cadmium sulfide and selenide," *Phys. Rev.*, vol. 99, pp. 1105–1116; August, 1955.

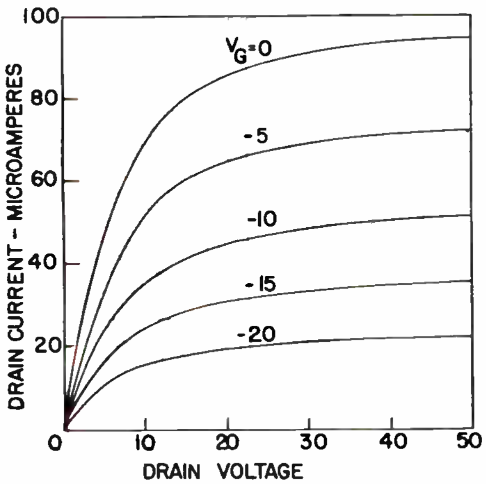



Fig. 3—Typical drain terminal characteristic with common source connection and 200 foot-candle illumination.

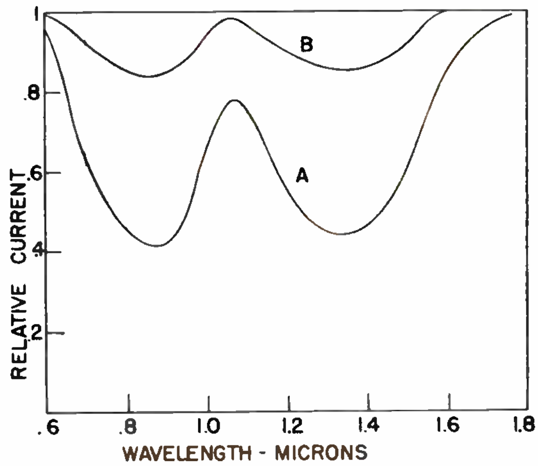



Fig. 5—Infrared quenching vs wavelength with constant excitation illumination from tungsten source; A) pinch-off current, B) two-terminal photocurrent.

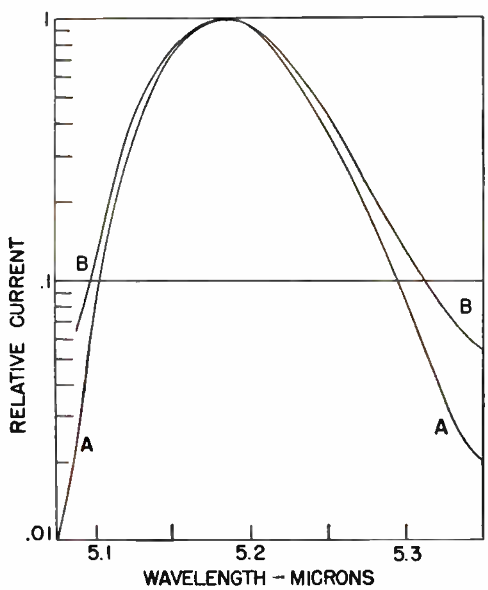



Fig. 4—Pinch-off current A), and two-terminal photocurrent B), as a function of incident wavelength.

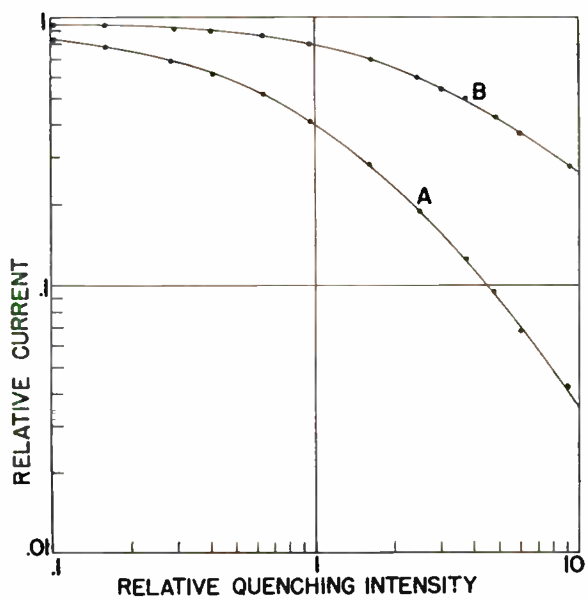



Fig. 6—Infrared quenching vs quenching intensity, A) pinch-off current, B) two-terminal photocurrent. Quenching source: 1200°K black body; excitation source: 2850°K tungsten source with quenching wavelengths filtered out.

### Field Effect Parameters

Field effect theory in a photoconductor differs in detail from that in a doped semiconductor, although generalizations common to both cases can be derived. The parameters used in deriving theoretical relationships are common to both cases but some which are constant in doped semiconductors are variables when photoconductors are considered.

The electrical characteristics of a field effect transistor are dependent on the physical dimensions and the bulk properties of the semiconductor slab. The important dependent and independent parameters are summarized:

$V_p$ = pinch-off potential, volts,
$I_p$ = pinch-off current, amperes,
$a$ = thickness, cm,
$c$ = width, cm,
$L$ = length, cm,
$\rho$ = charge density, coulombs/cm³,
$k$ = dielectric constant, farads/cm,
$\mu$ = carrier mobility, cm²/volt-second.

The following relationships are based on the gradual approximation defined by Shockley.[3] The potential within the semiconductor slab $V(y)$, the field $E_y$ and the charge density $\rho(y)$ are related by Poisson's equation:

$$-d^2V(y)/dy^2 = dE_y/dy = \rho(y)/k, \tag{1}$$

where $(y)$ is the distance from the gate surface. The induced charge is contained in the space charge layer and an increase in junction bias voltage increases the total space charge by extending the boundary of the space charge layer. The relationship between bias voltage and space charge layer thickness is dependent on the manner in which the space charge is distributed in the material. However, considering a general charge density distribution, the pinch-off potential can be derived from (1) in the following form:

$$V_p = (\rho_0 a^2/2k)[D_v], \tag{2}$$

where $[D_v]$ is a function of the charge distribution, and $\rho_0$ is the charge density at $y=0$.

Inasmuch as a potential gradient exists in the direction of current flow $(x)$, the potential in the conducting channel and the resulting space charge boundary are both functions of $(x)$, the distance from the source contact. Therefore the current density in the conducting channel is a function of $(x)$. Furthermore, if free carrier distribution in the conducting channel is a function of $(y)$, the conductivity $\sigma(y)$ and the current density $J$ will be a function of $(y)$:

$$J(x, y) = E_x\sigma(y). \tag{3}$$

Integration of (3) over suitable limits yields pinch-off current,

$$I_p = (a^3c\mu\rho_0^2/6kL)[D_1], \tag{4}$$

when the gate-to-source voltage equals zero.

The bulk conductance of the semiconductor slab with no space charge layer is

$$G_0 = (c/L)\int_0^a \sigma(y)dy = (\rho_0 ac\mu/L)[D_g], \tag{5}$$

where $[D_g]$ is another function of carrier distribution.

The mutual transconductance $G_m$ of a field effect transistor with zero bias between gate and source terminals is theoretically equal to the bulk conductance $G_0$ of the slab.

The portions of (2), (4), (5) which are in parentheses are independent of the charge distribution. The bracketed portions are dependent on charge distribution and are always dimensionless. The distribution functions will generally include the thickness parameter $(a)$. The distribution functions for an exponential charge distribution are derived in the Appendix.

### Field Effect in a Photoconductor

The principal differences encountered in consideration of field effects in a photoconductor and in a doped semiconductor result from the differences in the mechanisms which determine the space charge distribution and the carrier distribution in the material. In the analyses made by Shockley[3] and by Warner, *et al.*,[10] semiconductor materials such as Ge and Si were sufficiently activated with donors or acceptors to permit minority carriers to be neglected. The application of an electric field which removes the majority carriers from a region creates a space charge in that region with polarity opposite to that of the removed carriers. The distribution of the charge density in the space charge region is equal to the difference between donor and acceptor density in that region. Furthermore, the distribution of the carrier density in the conducting channel is equal to that of this activation density in the channel.

In an insulating photoconductor, however, electron-hole pairs are generated photoelectrically. In CdS and other *n*-type photoconductors, free holes produced by pair excitation are captured quickly by imperfection centers.[11] The resulting free hole mobility and lifetime have extremely low values; the holes can be assumed to be immobile in a first-order approximation. Application of an electric field to illuminated CdS, which removes the free electrons from a region, creates a positive space charge in that region in the form of trapped holes.

[10] R. M. Warner, W. H. Jackson, E. I. Doucette, and H. A. Stone, "A semiconductor current limiter," Proc. IRE, vol. 47, pp. 44–56; January, 1959.

[11] R. H. Bube, "Photoconductivity of the sulfide, selenide, and telluride of zinc or cadmium," Proc. IRE, vol. 12, pp. 1836–1850; December, 1955.

Inasmuch as the space charge and carrier distribution in a doped semiconductor correspond directly to the activation distribution, these values can be evaluated and applied to field effect equations. Furthermore, the distribution functions do not have first-order dependence on external parameters. In a photoconductor, however, the space charge and carrier distribution is an interdependent function of illumination intensity and wavelength, crystal inhomogeneities and electric field. The distribution functions are not only difficult to predict but also vary greatly with external parameters.

The carrier density in a photoconductor is equal to the rate at which the free carriers are generated per unit volume (excitation density) times the mean carrier lifetime in the conduction band before recombining with a hole. The carrier density distribution within the photoconductor slab is dependent on the distribution of the excitation density and on the manner in which the carriers may diffuse or drift from their generation sites. The excitation density at a particular point is proportional to the rate at which light is absorbed at that point. The light intensity distribution is a function of the incident light intensity $J_0$ and the absorption coefficient $\alpha$ and is related by Lambert's law:

$$J(y) = J_0 \exp(-\alpha y), \tag{6}$$

where $(y)$ is the distance from the illuminated surface. The excitation density $f(y)$ is proportional to the rate of absorption:

$$f(y) = -dJ(y)dy = J_0\alpha \exp(-\alpha y). \tag{7}$$

The absorption coefficient $\alpha$ is a function of wavelength[8] and may vary over a range from 10 to $10^4$ cm$^{-1}$. Thus illumination wavelength is important in determining the excitation density distribution.

Because of their very short lifetime as a carrier and low mobility, the generated holes do not drift an appreciable distance from their point of generation. The drift may not be entirely negligible at illumination wavelengths which yield a very high absorption coefficient, inasmuch as all of the carriers may be generated in an extremely narrow region near the surface. In addition, exciton diffusion lengths in CdS have been reported to be of the order of one cm and exciton production has been found to exceed pair production at certain wavelengths.[8] Excitons may diffuse into unilluminated regions of the crystal and dissociate into electron-hole pairs, thereby influencing charge distribution.

Carrier lifetime is probably nonuniform throughout the crystal, especially in the presence of infrared quenching radiation. Near-infrared radiation in the 0.89- and 1.35-micron regions cause a reduction of the photoconductivity of CdS, as shown in Fig. 5, by effectively reducing the carrier lifetime. A mechanism has been proposed whereby the infrared shifts the population density of certain recombination centers with a resulting increase in recombination rate.[9] The quenching effect is a function of the ratio of quenching intensity to excitation intensity.[9] Most excitation radiation is absorbed in relatively short distances in the crystal, while the absorption of the infrared quenching radiation is very slight. Thus, the ratio of quenching to excitation wavelengths increases with distance $(y)$ from the illuminated surface, and the free carrier lifetime may be expected to decrease with $(y)$, with a corresponding decrease in free electron and trapped hole density. The influence of quenching radiation on the charge distribution may be great and would account for the significantly greater effect of infrared on the pinch-off current than on the two-terminal photocurrent as shown in Figs. 5 and 6. The two-terminal photocurrent is proportional to the bulk conductance of the semiconductor slab. The bulk conductance (5) is proportional to the area under the charge distribution curve, independent of its shape, while the pinch-off voltage and current are extremely sensitive to the distribution characteristic.

All of the factors discussed so far affect the charge distribution in a perfectly homogeneous semiconductor slab. Additional factors exist in a practical device. For example, the carrier lifetime, mobility and infrared effects may be significantly different at the crystal surface than in the interior of the slab, effecting a charge distribution discontinuity near the surface. Furthermore, inasmuch as the gate is formed by heating a copper contact, the copper is diffused a small but finite distance into the crystal. The excitation density, carrier lifetime, mobility, infrared effects and the resulting charge distribution will be different in this "doped" region than in the bulk of the slab.

## Experimental Correlation

Qualitative correlation of the experimental results with theoretical relationships is possible if an assumption of the charge distribution is made. Quantitative correlation is not possible because of incomplete knowledge relating the many factors which influence the charge distribution. Because of the exponential decrease of light intensity within the crystal, a simple first assumption is that the charge distribution decreases exponentially with distance from the illuminated surface. Then, if the gate surface is illuminated,

$$\rho(y) = \rho_0 \exp(-my), \tag{8}$$

where $m$ is a factor which represents the combined effects of all the mechanisms producing the exponential reduction. With this distribution, the distribution functions in (2), (4), (5) are, as derived in the Appendix,

$$[D_v]_a = (2/m^2a^2)(e^{-ma} + mae^{-ma} - 1), \tag{9}$$

$$[D_I]_a = (3/2m^3a^3)\left[(2ma + 3)e^{-2ma} - 4e^{-ma} + 1\right], \tag{10}$$

$$[D_g] = (1/ma)(1 - e^{-ma}). \tag{11}$$

If the surface opposite the gate junction is illuminated, the charge distribution is reversed:

$$\rho(y) = \rho_0 \exp m(y - a), \tag{12}$$

$$[D_v]_0 = (2/m^2a^2)(ma + e^{-ma} - 1), \tag{13}$$

$$[D_I]_0 = (3/2m^3a^3)[(2ma - 3) + 4e^{-ma} - e^{-2ma}]. \tag{14}$$

Inasmuch as the bulk conductance is proportional to the area under the $\rho(y)$ curve, $[D_g]$ is not dependent on which surface is illuminated.

The ratio of the pinch-off current with opposite surface illuminated to that with the gate surface illuminated is equal to the ratio of the corresponding distribution functions:

$$(I_p)_0/(I_p)_G = [D_I]_0/[D_I]_G. \tag{15}$$

Pinch-off current ratios were obtained experimentally at several illumination wavelengths and quenching intensities. When the illumination was changed from the gate side to the opposite side, the illumination intensity was adjusted to yield a common value of bulk conductance. This partially compensates for the reduction of intensity by the semitransparent copper gate. Pinch-off current ratios in the range from 1 to 4 were observed, indicating a variation in the value of $(ma)$ from 0 to 3.1. Thus, a qualitative variation of the charge distribution with both illumination wavelength and quenching intensity is indicated.

The measured value of pinch-off current ratio is subject to error inasmuch as the semitransparent gate reduces the effective incident illumination on only that portion of the surface beneath the gate. When illuminated from the gate side, the relative intensity is greater on the end portions than beneath the gate. However, when illuminated from the opposite side, the incident intensity is uniform over the entire surface. Inasmuch as the portions of the slab outside of the gate region act as degenerative feedback resistances,[4] the resulting feedback ratio will also change with direction of illumination. For this reason, the measured values of the pinch-off current ratios will be slightly lower than the ratios of their distribution functions.

The distribution functions $[D_I]_G$ and $[D_g]$ from (10) and (12), are plotted as a function of $(ma)$ in Fig. 7. The experimentally obtained relationship between pinch-off current and two-terminal photocurrent as a function of infrared quenching intensity, Fig. 6, is qualitatively similar to the theoretical curves, Fig. 7. The similarity between the experimental and theoretical curves indicates that the assumed exponential distribution may not differ greatly from the actual distribution and that the exponent $(m)$ increases with infrared quenching intensity.

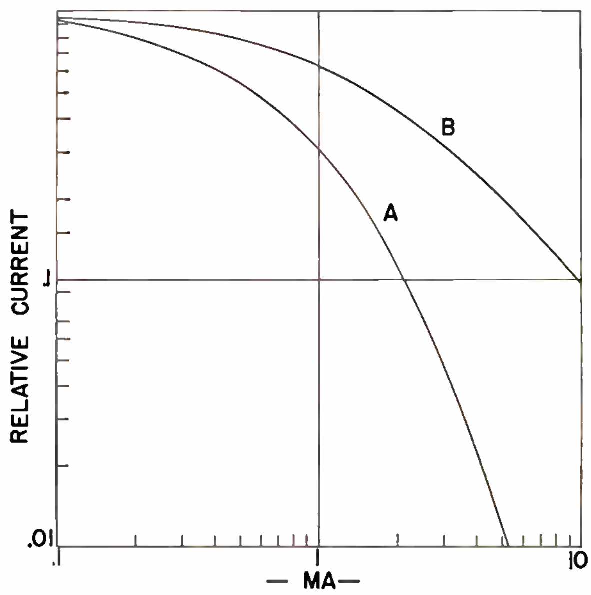



Fig. 7—Theoretical relationship between distribution function and the exponent $(ma)$ with exponential charge distribution, for A) pinch-off current with gate side illuminated, B) two-terminal photocurrent.

## Practical Applications

The unique characteristics of field effect phototransistors allow them to perform new and combined circuit functions which are not practicable with conventional circuit elements. Furthermore, they are solid state devices having the small size, high efficiency and ruggedness common to semiconductor components.

Direct connection of the gate-to-drain terminals yields a two-terminal current limiter similar to that described by Warner, *et al.*,[10] but whose limiting current is a function of light intensity. Because of its high ratio of dynamic-to-dc impedance, the device can be applied to conventional two-terminal photoconductor circuits (*i.e.*, bridges and dividers) and produce a considerably greater output voltage change for a given supply voltage than would a simple two-terminal photoconductor. Furthermore, the dependence of pinch-off current on the square of the light intensity has particular advantage in detecting small changes in relatively large light levels.

When connected in a conventional photocell circuit, application of suitable signals to the gate will perform switching and modulating functions. A reference voltage can be applied to the gate terminal which will determine the light intensity required to produce a particular output current for use in illumination control systems. Furthermore, suitable feedback networks between the gate and drain terminals can be used for frequency or temperature compensation, or for arbitrary shaping of the device characteristics.

Inasmuch as the field effect phototransistor has useful power gain, it can be used as an oscillator or as a signal amplifier. Phase shift oscillators employing one phototransistor have been constructed whose amplitude is a function of light intensity or which will oscillate only within a narrow range of incident light intensity. Signal amplifiers have been made which have light dependent gain, and which can be gated on or off with light intensity. Neon lamp relaxation oscillators using the cadmium sulfide transistor in place of the conventional resistor produce a very linear, constant amplitude sawtooth signal whose repetition rate can be varied with gate voltage and light intensity.

Unusual circuit functions can be performed by the device when signal information is contained in both the light modulation and gate voltage. For example, if the device is connected as a marginal oscillator, a discrete output occurs when the incident light intensity is modulated at the oscillator frequency. Furthermore, if the light modulation frequency is the same as that of the gate signal, synchronous phase discrimination results. Other specialized circuit functions can be performed by circuits which include two or more field effect phototransistors or by combining with other active circuit elements. The combination of this amplifying photoconductive device with electroluminescent devices may extend the utility of photoelectric circuits.[12]

## Practical Limitations

The CdS field effect transistor does not compete with conventional junction transistors or vacuum tubes for general amplification applications. The major difficulties encountered in design of practical circuits using the device result from the relatively low mutual transconductance and high output impedance.

The mutual transconductance with zero gate voltage is approximately equal to the bulk conductance of the semiconductor slab, (5), and is a function of the carrier charge density, mobility and slab dimensions. Carrier density is the only parameter sufficiently flexible to permit a significant increase in transconductance. Increasing carrier density by a factor of 10 will increase $G_m$ by that factor but will also increase pinch-off voltage by 10, pinch-off current by 100 and quiescent power dissipation by 1000. This results in impractical values for pinch-off current and voltage, and the power dissipation and electric field in the semiconductor slab may reach destructive limits of the material. Thus, $G_m$ is limited to values of the order of 10 $\mu$mho in a CdS field effect transistor.

Both the output and input resistances of the CdS transistor are higher than are normally encountered with junction transistors and vacuum tubes. Efficient coupling to other active circuit elements is difficult and its advantageous use as an amplifying element is limited to low-frequency applications requiring high impedance levels (*i.e.*, photomultiplier or ion chamber signal amplification).

Improvement of the practical amplification characteristics can be achieved by increasing the carrier mobility of the slab material. This requires selection of a different material and would ultimately lead to an elemental or a group III-V compound semiconductor. However, CdS is very likely the best material for phototransistor application.

## Appendix

A more general mathematical formulation is required to derive field effect equations for exponential charge distribution than is necessary for uniform[3] or linear graded[10] distributions. If the charge distribution is known, a relationship $V_g = f(h)$ can be derived from the gate potential as a function of the thickness of the space charge layer. Subsequent operations are simplified if the relation $h = g(V_g)$ can be found. This can be done for the uniform or linear graded case but is not possible for the exponential charge distribution case.

With exponential charge distribution of the form,

$$\rho(y) = \rho_0 \exp(-my), \tag{16}$$

the field in the $y$ direction is assumed to be zero in the conducting channel ($h \le y \le a$) using Shockley's gradual approximation.[3]

$$\begin{aligned} E_y &= (I/K)\int \rho(y)dy = 0 \quad \text{at} \quad y = h \\ &= -(\rho_0/mk)(e^{-my} - e^{-mh}). \end{aligned} \tag{17}$$

The maximum field $E_p$ required to pinch-off the conducting channel ($h = a$) exists at $y = 0$:

$$E_p = (-\rho_0/mk)(1 - e^{-ma}). \tag{18}$$

The potential in the space charge region $V(y)$ is equal to the gate voltage $V_g$ at $y = 0$:

$$\begin{aligned} V(y) &= -\int E_y dy = V_g \quad \text{at} \quad y = 0 \\ &= (\rho_0/m^2K)(1 - e^{my} - mye^{-mh}) + V_g. \end{aligned} \tag{19}$$

With finite channel current, the potential in the conducting channel is a function of $x$, the distance from the source. The potential $V(x)$ cannot be derived directly for the exponential case but can be solved for $V(h)$ where $h$ is a function of $x$:

$$\begin{aligned} V(h) &= V(y) \quad \text{at} \quad y = h \\ &= (\rho_0/m^2K)(1 - e^{-mh} - mhe^{-mh}) + V_g. \end{aligned} \tag{20}$$

With a gate-to-source potential $V_g$, a finite space charge layer thickness $H_s$ will exist at $x = 0$. Furthermore, $V(h) = 0$ at $x = 0$, so from (20),

$$V_g = (\rho_0/m^2K)(e^{-mH_s} + mH_se^{-mH_s} - 1). \tag{21}$$

[12] S. K. Ghandhi, "Photoelectronic circuit applications," Proc. IRE, vol. 47, pp. 4–11; January, 1959.

The space charge layer thickness $H_D$ at the drain end of the channel ($x=L$) is related to the gate voltage and the drain voltage $V_D$:

$$V_g - V_D = (-\rho_0/m^2K)(1 - e^{-mH_D} - mH_De^{-mH_D}). \quad (22)$$

The potential $V_p$ required to pinch off the conducting channel is equal to $V_g - V_D$ at $H_D = a$:

$$V_p = (\rho_0/m^2K)(1 - e^{-ma} - mae^{-ma}). \quad (23)$$

The current in the conducting channel is constant at all values of $x$. The charge density represented by the free electrons in the conducting channel is assumed to be equal to $-\rho(y)$ in that region. The immobile holes generated in that region do not contribute to the channel conductivity. Additional free electrons forced into the conducting channel by the transverse field are rapidly distributed throughout the conducting system of the circuit and do not contribute significantly to the steady state channel current. Although the channel current is not a function of $x$, the current density $J$ in the channel is a function of both $x$ and $y$ because of its dependence on $h(x)$ and $\rho(y)$:

$$J(x, y) = -E_x\mu\rho(y). \quad (24)$$

The channel current is obtained by integrating (24) and inserting the slab width $c$ and the relationship $E_x = -dV(x)/dx$:

$$I = c\mu(dV/dx)\int_h^a \rho(y)dy$$
$$= (c\mu\rho_0/m)(e^{-mh} - e^{-ma})(dV/dx). \quad (25)$$

Then, by substituting $dV(x)/dx = (dV/dh)(dh/dx)$ where $(dV/dh) = (\rho_0k/h)\exp(-mh)$ from (20),

$$I\int_0^L dx = \frac{c\mu\rho_0^2}{mK}\int_{H^s}^{H_D}(he^{-2mh} - he^{-m(a+h)})dh. \quad (26)$$

At pinch-off, $H_D = a$ and with zero gate voltage, $H_S = 0$. The current $I_p$ existing with these conditions is

$$I_p = (c\mu\rho_0^2/4m^3KL)[(2ma+3)e^{-2ma} - 4e^{-ma} + 1]. \quad (27)$$

The mutual transconductance from gate to drain is

$$G_m = (\partial|/\partial V_g) = (\partial|/\partial H_S)(\partial V_g/\partial H_S)^{-1}$$
$$+ (\partial|/\partial H_D)(\partial V_g/\partial H_D)^{-1}. \quad (28)$$

The partial derivatives are obtained from (21), (22), (26):

$$G_m = (c\mu\rho_0/mL)(e^{-mH_S} - e^{-mH_D}). \quad (29)$$

The bulk conductance of the slab is

$$G_0 = (\mu c/L)\int_0^a \rho(y)dy = (c\mu\rho_0/mL)(1 - e^{-ma}). \quad (30)$$

Note that with zero gate voltage, ($H_S = 0$), and with $V_D = V_p$, ($H_D = a$), then $G_m = G_0$.

## Acknowledgment

The cadmium sulfide field effect transistor program was initiated and coordinated by E. F. Weller. Additional appreciation is extended to Y. T. Sihvonen who supplied the CdS crystals and prepared the contacts on the first successful units, to J. W. Bergstrom and F. D. Bosco who further developed fabrication techniques, and to A. J. Gioia who assisted in parameter evaluation.

# The Optimum Formula for the Gain of a Flow Graph or a Simple Derivation of Coates' Formula*

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*Summary*—**Starting from the definition of a determinant and using a few of its elementary properties, this paper gives an independent derivation of the optimum formula for the gain of a flow graph. Thus, a simpler path is shown to Coates' important result. This paper is self-contained, so that no previous knowledge of flow graphs is required. For motivation, the reader is referred to some well known papers and books.**

## I. Introduction

Mason's signal flow graphs[1,2] constitute a very useful tool for analysis of engineering problems, linear problems especially. The reason for their popularity and usefulness is that they display in a very intuitive manner the causal relationships between the several variables of the system under study. Many people have successfully used flow graph ideas in various fields.[1–9] Therefore, the publication of Mason's second paper[2] giving a systematic method for writing down almost by inspection the gain of a linear system was an important addition to the flow graph literature. Presently the state has been reached where a great many engineering schools include signal flow graphs in one of their senior courses.[5]

More recently, C. L. Coates[3] has shown that Mason's general gain formula is not the simplest expansion and has given a rigorous and lucid derivation of a new gain formula that is optimum in the sense that, *in general*, 1) no cancellations can occur between common factors of the numerator and denominator, and, 2) no cancellation can occur among the terms of the algebraic sums of the numerator and of the denominator.

The purpose of this paper is to present an independent derivation of Coates' formula. The author's hope is that this derivation is so simple that even seniors can grasp it![10] The only required background is the definition of a determinant. For the reader's convenience, this definition and the properties of determinants used in the derivation are listed in the Appendix.

For further background, motivation and examples, the reader is referred to the literature.[1–3,5] The present paper is self-contained in that it can be read independently of Mason's and Coates' papers.[1–3]

A word about the organization of the paper: There is a difference between Mason's and Coates' procedure for drawing the flow graph of a linear system. The difference, however, is very slight. The first five sections constitute an independent derivation of Coates' formula; they use exclusively Coates' procedure for associating a flow graph to a system of equations. Section VII discusses the difference between Mason's signal-flow graphs and Coates' flow graphs; it shows how, given one of them, the other may easily be obtained.

## II. The Set of Equations and its Associated Flow Graph

Our purpose is to solve by topological methods the set of linear algebraic equations

$$\sum_{j=1}^{n} a_{kj}x_j - b_k = 0 \qquad (k = 1, 2, \cdots, n). \qquad (1)$$

To this set of equations we shall associate a *flow graph* which is defined as follows:

> Definition 1—A *flow graph* is a set of weighted oriented branches which connect at nodes. That is, each branch has a positive direction and a weight, the branch gain.

The flow graph associated with (1) has $n$ nodes and one source node. The case $n=2$ is illustrated in Fig. 1. The process of associating a flow graph to a set of equations is as follows:

1) To the source node is associated an input variable that is taken to be unity.
2) To each of the other nodes is associated one of the variables $x_1, x_2, \cdots, x_n$ of the set.

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10 Some school will insist that the word "seniors" be replaced by "sophomores." More power to them!

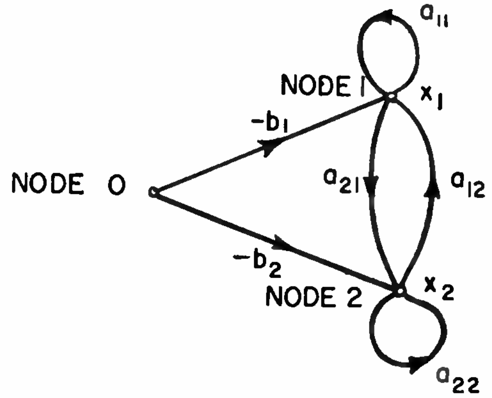


Fig. 1—Flow graph for the case of 2 equations with 2 unknowns.

3) Each node is labelled by one of the integers from 1 to $n$ such that the node labelled $k$ is associated with $x_k$. The source node is labelled 0.
4) If $a_{jk} \neq 0$, there is a branch directed from node $k$ to node $j$ with gain $a_{jk}$.
5) If $b_k \neq 0$, there is a branch connecting the source node 0 to node $k$. This branch is directed from 0 to $k$ and its branch gain is $-b_k$.

This process describes how one goes from the equations to the graph. The reverse process, to obtain the equations from the graph, is very simple.

Consider Fig. 1 and concentrate on node 1. In order to write the equation associated with node 1, first consider all the branches coming into node 1; they are $a_{11}$, $a_{12}$ and $-b_1$. The equation is obtained by equating to zero the sum of the products of their branch gains times the variables these branches originate from, viz:

$$a_{11} x_1 + a_{12} x_2 - b_1 \cdot 1 = 0.$$

Physically, we may think of these nodes as high gain operational amplifiers whose feedback loop is open. Because, in that case, if the output voltage is in the linear range of the amplifier, the sum of the currents into the input node must be very nearly zero.

At this stage an important point should be brought up. It is clear that to every set of equations such as (1) corresponds a flow graph and conversely. If, however, the order in which the equations appear in (1) is changed, the corresponding flow graph changes in a nontrivial manner. For example, to the set of equations

$$\begin{cases} \alpha x_2 + \beta x_3 = 0 \\ \gamma x_1 + \delta x_3 = b_1 \\ \epsilon x_1 + \eta x_2 = b_2 \end{cases}$$

corresponds the flow graph of Fig. 2.

Rearranging them as follows, we get a new set of equations

$$\begin{cases} \gamma x_1 + \delta x_3 = b_1 \\ \epsilon x_1 + \eta x_2 = b_2 \\ \alpha x_2 + \beta x_3 = 0 \end{cases}$$

and the flow graph of Fig. 3.

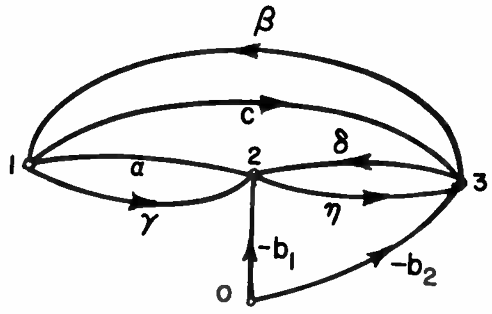


Fig. 2—Flow graph of the system (2).

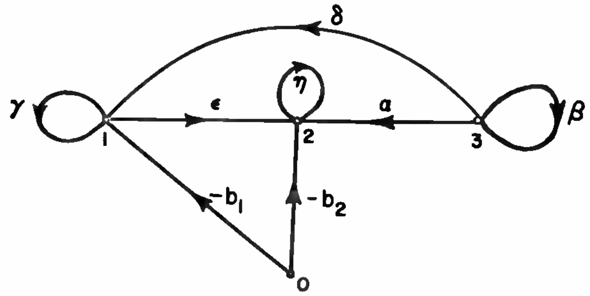


Fig. 3—Flow graph of the system (3).

Thus, once a system of linear homogeneous algebraic equations, such as (1), has been ordered in a fixed way, there is a one-to-one correspondence between the equations and the flow graph.

## III. Algebraic Solution of (1)

If the matrix of the coefficients of the $x_j$'s in (1) is nonsingular, the solution is given by

$$x_l = \frac{\sum_{k=1}^{n} \Delta_{kl} b_k}{\Delta} \qquad (l = 1, 2, \cdots, n) \tag{2}$$

where

$\Delta$ is the determinant of the coefficient matrix $(a_{ij})$.
$\Delta_{kl}$ is the cofactor of the element of the $k$th row and $l$th column.

In the following we shall devise a topological method for evaluating $\Delta$ and products of the form $b_k \Delta_{kl}$.

## IV. Topological Evaluation of $\Delta$

In order to evaluate $\Delta$ by topological means, we require a few topological ideas; hence we define:

$G$ to be the flow graph of the system (1), where the equations are taken in the order in which they appear;
$G_0$ to be the flow graph obtained from $G$ by deleting the source node 0.

Definition 2—A *connection* of the flow graph $G$ is a subgraph of $G$ such that

1) each node of $G$ is included,

2) each node has only one branch terminating to it and one branch originating from it.

Definition 3—*A directed loop* is a connected subgraph whose branches $b_1, b_2, \cdots, b_l$ can be ordered in such a way that

1) The tip of $b_k$ is the origin of $b_{k+1}$ ($k=1, 2, \cdots, l-1$).
2) The origin of $b_1$ is the tip of $b_l$.
3) Each node along the directed loop is encountered only once.

Thus, a directed loop is precisely what is meant by a loop in the ordinary language. Fig. 4 illustrates the concept. Fig. 5(a) shows a flow graph $G$ and Fig. 5(b) its five connections. It is clear that a connection is either a directed loop or a collection of nontouching directed loops (they are nontouching because of 2) in definition 2). In addition, we shall need this definition:

Definition 4—*The connection-gain* of a connection of $G$ is the product of the branch gains of the branches of that connection. It is denoted by $C(G)$.

The first link between the determinant $\Delta$ and the flow graph $G$ is obtained by referring to the definition of a determinant:[4]

$$\Delta = \sum_P (\text{sgn } P) a_{1i_1} a_{2i_2} \cdots a_{ni_n} \tag{3}$$

where the summation is taken over all the $n!$ permutations $P=(i_1, i_2, \cdots, i_n)$ of the integers, $1, 2, \cdots, n$ and (sgn $P$) is $+1$ or $-1$ depending on whether the permutation $P$ is even or odd.[11]

*Lemma 1: A product appears in (3) if and only if it is a connection-gain $C(G_0)$ of the flow graph $G_0$.*

*Proof:* Recall that $G_0$ is the graph $G$ with the source node 0 deleted. Consider a particular product $\prod$ in the sum (3). Let $\prod'$ be the set of all branches whose gain appear in the product $\prod$. Since $\prod$ is a product of factors $a_{ki_k}$, with $k$ running from 1 to $n$, there is one and only one branch of $\prod'$ that terminates at each of the $n$ nodes of $G_0$. Since $i_1, i_2, \cdots, i_n$ is a permutation of $1, 2, \cdots, n$, there is one and only one branch of $\prod'$ originating from each node of $G_0$. Hence $\prod'$ is a connection of $G_0$.

Conversely, given an arbitrary connection of $G_0$, since it contains by definition one branch terminating in each of the nodes of $G_0$ and one branch leaving each one of the same nodes, then its connection-gain can be written as

$$a_{1j_1} a_{2j_2} \cdots a_{nj_n}$$

where $i_1, i_2 \cdots, i_n$ is a permutation of the numbers $1, 2, \cdots, n$. Hence, it will appear as one of the products of the expansion (3).

[11] The Appendix lists the three properties of determinants that will be used later.

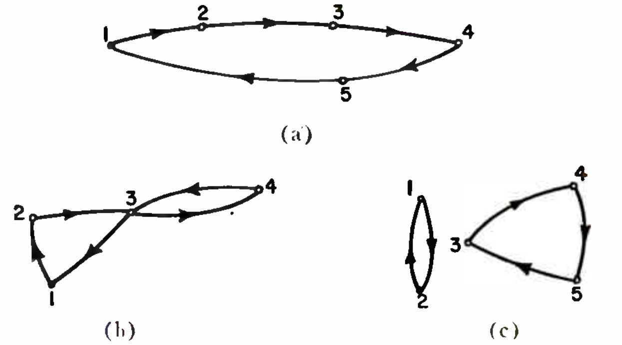

Fig. 4—(a) Example of a directed loop. (b) This is not a directed loop; when traversing the loop in the positive direction, node 3 is encountered more than once. (c) This is not a directed loop because it is not a connected subgraph.

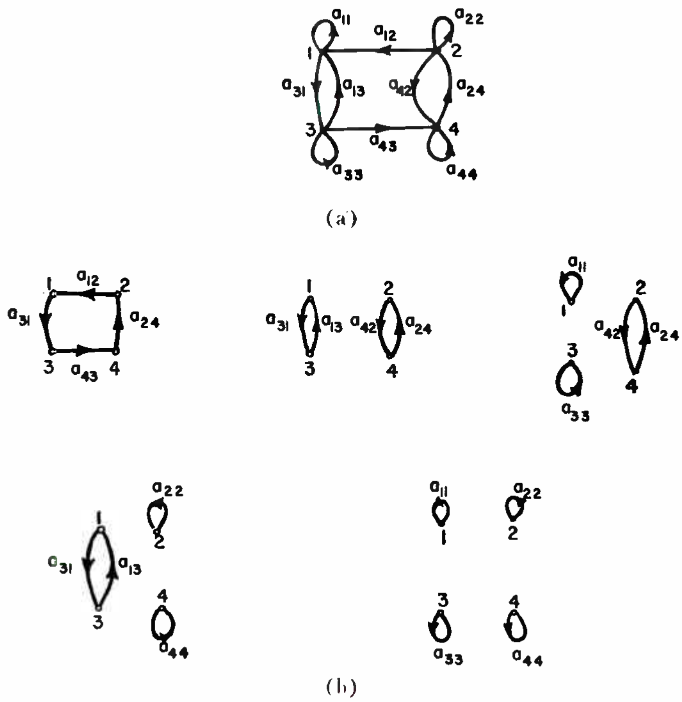

Fig. 5—(a) Flow graph associated with the matrix $A$. (b) The five connections of the flow graph shown in Fig. 5(a).

Thus by simply listing all the connections of $G_0$, as is done on Fig. 5, one obtains all the terms of the sum (3). The question of the signs remains. First let us make two rather obvious statements:

Statement 1—If, in a determinant, such as the one of the matrix $A$, any two rows are interchanged *and* the corresponding columns are also interchanged, the value of the determinant is not affected. (See Appendix, Property 3.)

Statement 2—Consider the system of equations (1) and its associated flow graph $G$. Suppose any two equations, say the $i$th and the $k$th, are interchanged and also the two variables located in the corresponding columns (*i.e.*, $x_i$ and $x_k$): then to the resulting set of equations (1′) corresponds a new flow graph $G'$. A little thought will show that $G$ and $G'$ are identical except for an interchange of the labels of the $i$th and $k$th node.

The method required for specifying the sign of each term of (3) is obtained by the following reasoning:

Consider again a particular product $\prod$ of the sum (3) and its associated connection $\prod'$ of the graph $G_0$. $\prod'$ is a collection of directed loops; for simplicity let us assume that $\prod'$ consists of three nontouching directed loops having respectively $n_1$, $n_2$, $n_3$ nodes. Clearly, $n_1+n_2+n_3=n$, since all nodes of $G_0$ are included.

As a consequence of Statements 1 and 2 we can, without affecting any of the terms of the determinant expansion (3), relabel the nodes of $\prod'$ so that along the first directed loop of $\prod'$ as it is traversed in the positive direction one traverses the nodes 1, 2, $\cdots$, $n_1$ in that order; and similarly for the other two directed loops. The branch gain product of the first directed loop is then

$$a_{1n_1}a_{21}a_{32}\cdots a_{n_1,n_1-1}.$$

Note that the factors of this product are ordered so that their row subscripts occur in their natural order as required by (3). Hence, the sign assigned to $\prod$ is that assigned to the permutation, defined by the column subscripts:

$$n_1, 1, 2, 3, \cdots, n_1-1; n_1+n_2, n_1+1, \cdots (n_1+n_2-1);$$
$$(n_1+n_2+n_3), (n_1+n_2+1), \cdots (n_1+n_2+n_3-1).$$

To rearrange this permutation in the natural order, $(n_1-1)+(n_2-1)+(n_3-1)=n-3$ interchanges between adjacent symbols are required. Hence, the sign of the permutation is $(-1)^{n-3}=(-1)^n(-1)^{+3}$. Note that there are three directed loops in the product $\prod$. It is clear that if the connection $\prod'$ had $L$ directed loops the sign would have been $(-1)^{n+L}$.

Thus, we obtain the general

*Theorem 1: The determinant $\Delta$ of the system (1) can be evaluated from its flow graph $G$ by the formula*

$$\Delta = (-1)^n \sum_p (-1)^{L_p} C(G_0)_p \tag{4}$$

where

$L_p$ is the number of directed loops in the $p$th connection.

$C(G_0)_p$ is the connection gain of the $p$th connection.

$G_0$ is the flow graph $G$ with the source node 0 deleted.

The summation of the connection gains $C(G_0)$ is taken over all connections of $G_0$.

*Example:* The determinant of the matrix associated with the graph of Fig. 5. From the graph $G$ of Fig. 5, we obtain the matrix

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & 0 \\ 0 & a_{22} & 0 & a_{24} \\ a_{31} & 0 & a_{33} & 0 \\ 0 & a_{42} & a_{43} & a_{44} \end{bmatrix}.$$

From the five connections of $G$ shown on the figure,

$$\det A = -a_{12}a_{24}a_{43}a_{31} + a_{13}a_{31}a_{42}a_{24} - a_{11}a_{33}a_{42}a_{24} - a_{22}a_{44}a_{13}a_{31} + a_{11}a_{22}a_{33}a_{44}.$$

This expansion can also be obtained by Mason's method, but his general formula will give 25 terms which will eventually reduce to the five listed above.

## V. Evaluation of the Numerator of (2)

The numerator of (2) is a sum of terms all having the same form. Consider one of them in particular; say, $\Delta_{kl}b_k$. In other words, we are going to evaluate the numerator of (2) assuming that there is only one branch, with gain $-b_k$, connecting the source node 0 to the rest of the graph, as shown on Fig. 6(a). Since we know how to evaluate an $n\times n$ determinant by topological means, let us note that $\Delta_{kl}b_k$ is equal to the determinant obtained by replacing the $l$th column of $\Delta$ by a column of zero except for the element of the $k$th row, which is $b_k$.

$$\begin{vmatrix} & 0 & \\ & 0 & \\ & b_k & \\ & 0 & \\ & \vdots & \\ & 0 & \\ & 0 & \end{vmatrix} \leftarrow k\text{th row}$$

$\uparrow$ $l$th column

This determinant will not change if all the elements of the $k$th row, with the single exception of $b_k$, are replaced by zero. The result is the determinant $\Delta'$.

$$\Delta' = \begin{vmatrix} & & 0 & & \\ & & \vdots & & \\ & & 0 & & \\ 0\ 0\ \cdots & & 0\ b_k & 0 \cdots & 0 \\ & & \vdots & & \\ & & 0 & & \\ & & 0 & & \end{vmatrix} \leftarrow k\text{th row}$$

$\uparrow$ $l$th column

In order to evaluate $\Delta'$ by topological means, let us note that the flow graph $G'$ associated with $\Delta'$ is obtained from $G_0$ by: 1) deleting all branches leaving node $l$ (the node with which the variable $x_l$, being sought, is associated); 2) deleting all branches coming into node $k$; and 3) adding the branch $b_k$ oriented from node $l$ to node $k$. This operation is illustrated on Figs. 6(a) and

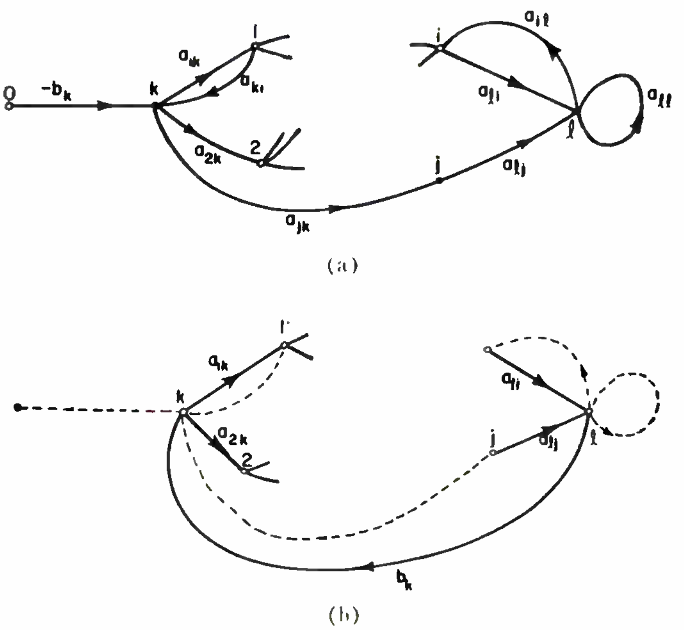


Fig. 6—(a) Flow graph $G$. (b) Flow graph $G'$ obtained from $G$ by deleting all branches leaving node $l$, deleting all branches coming into node $k$ and adding branch $b_k$ oriented from node $l$ to node $k$.

6(b). From (4),

$$b_k\Delta_{kl} = \Delta' = (-1)^n \sum_\tau (-1)^{L_\tau} C(G')_\tau$$

where

$C(G')_\tau$ is the connection gain of the $\tau$th connection of $G'$.

$L_\tau$ is the number of directed loops of the $\tau$th connection.

The summation is taken over all connections of $G'$.

In order to interpret this result in terms of the graph $G$, let us define as follows:

Definition 5—*A one-connection* from $p$ to $q$ of a flow graph $G$ is a subgraph of $G$ which includes all the nodes of $G$, and such that

1) no branch terminates at $p$ and only one branch of the subgraph originates from $p$, thus:

o———→——
$p$

2) no branch originates from $q$ and only one branch of the subgraph terminates at $q$, thus:

———→——o
$q$

3) all other included nodes have exactly one incoming and one outgoing branch.

An example of a set of one-connections is shown on Figs. 7 and 8. It is apparent from Fig. 8 that, in general, a one-connection is a forward path together with some directed loops.

Consider Fig. 6(b). Each one of the connections of $G'$

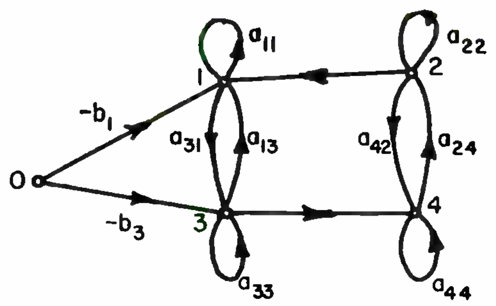

Fig. 7—Flow graph associated with the set of equations (6).

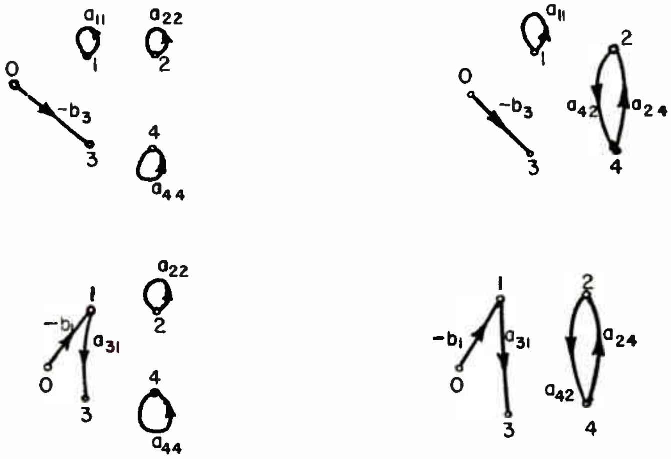

Fig. 8—The one-connections from 0 to 3 of the flow graph of Fig. 7.

includes the branch $b_k$ because it is the only branch that leaves the $l$th node. In each one of these connections let us remove the origin of branch $b_k$ from node $l$ and place it at the source node 0 where it was originally in graph $G$. Finally, let us change the branch gain from $b_k$ to $-b_k$. In each case the resulting configuration is a *one-connection* from 0 to $l$ of flow graph $G$. Since by displacing the branch $b_k$ one directed loop has been "opened," the number of directed loops in the one-connections of $G$ is one less than that of the original connections of $G'$; this will result in a change of sign which will cancel the one caused by the change of sign of the branch gain $b_k$. Consequently,

$$b_k\Delta_{kl} = \Delta' = (-1)^n \sum_\sigma (-1)^{L_\sigma} C(G;0-l)_\sigma$$

where

$C(G;0-l)_\sigma$ is the one-connection gain (*i.e.*, the product of the branch gains) of the $\sigma$th one-connection from 0 to $l$ of the flow graph $G$.

$L_\sigma$ is the number of directed loops in the $\sigma$th one-connection.

The summation is taken over all one-connections from 0 to $l$ of $G$.

## VI. General Formula

In general, there is more than one branch connecting the source node to the rest of the graph; obviously, in such cases the individual contributions of each such branch must be summed and the result takes this form:

*Theorem 2: In order to solve for the variable $x_l$ defined by the set of equations*

$$\sum_{j=1}^{n} a_{kj}x_j = b_k \qquad (k = 1, 2, \cdots, n) \tag{1}$$

1) Set up the associated flow graph $G$ as specified in Section II.
2) Draw all the connections of the flow graph $G_0$ (=graph $G$ with source node 0 deleted) and list their connection gains: $C(G_0)_1$, $C(G_0)_2, \cdots$
3) Draw all the one-connections from the source node 0 to the node $l$ of the graph $G$ and list their one-connection gains: $C(G; 0-l)_1$, $C(G; 0-l)_2, \cdots$
4)

$$x_l = \frac{\sum_{\sigma} (-1)^{L_\sigma} C(G; 0 - l)_\sigma}{\sum_{\rho} (-1)^{L_\rho} C(G_0)_\rho} \tag{5}$$

where

$L_\sigma$ = number of directed loops in the $\sigma$th one-connection from 0 to $l$ of the flow graph $G$.
$L_\rho$ = number of directed loops in the $\rho$th connection of $G_0$.
the summations are taken over all connections and one-connections from 0 to $l$ of graphs $G_0$ and $G$ respectively.

*Example:* Consider the system of equations,

$$\begin{cases} a_{11}x_1 + a_{12}x_2 + a_{13}x_3 = b_1 \\ a_{22}x_2 + a_{24}x_4 = 0 \\ a_{31}x_1 + a_{33}x_3 = b_3 \\ a_{42}x_2 = a_{43}x_3 + a_{44}x_4 = 0. \end{cases} \tag{6}$$

Let us solve for $x_3$. The graph $G$ is shown on Fig. 7. All the connections of $G$ are listed in Fig. 5(b). The one-connections from 0 to 3 of $G$ are shown on Fig. 8 Then, by (5), we have

$$x_3 = \frac{b_3a_{11}a_{22}a_{44} - b_3a_{11}a_{42}a_{24} - b_1a_{31}a_{22}a_{44} + b_1a_{31}a_{24}a_{42}}{\Delta}$$

where

$$\Delta = a_{11}a_{22}a_{33}a_{44} - a_{12}a_{24}a_{43}a_{31} + a_{13}a_{31}a_{42}a_{24} - a_{11}a_{33}a_{42}a_{24} - a_{22}a_{44}a_{13}a_{31}.$$

The general expression (5) calls for two important comments.

Comment 1—*In general,* there can be no cancellation of terms in the algebraic sums of either the numerator or the denominator of (5).

The reason for this is quite obvious: Since each term is a connection gain (a one-connection gain) of a connection (one-connection) distinct from all the other connections (one-connections) there can, in general, be no cancellations; for it would imply the existence of special relationships between the gains of various branches.

There is, however, one simplification that any engineer worth his salt would instinctively take advantage of. Suppose $x_1$ is to be computed and suppose there are some node variables $x_{k_1}, x_{k_2}, \cdots, x_{k_m}$ that have no effect on $x_1$, then these nodes may be deleted from the graph when $x_1$ is computed.

This idea can be expressed precisely if the following definition is introduced:

Definition 6—*A forward path* from $p$ to $q$ of the flow graph $G$ is a connected subgraph whose branches $b_1$, $b_2, \cdots, b_l$ can be ordered such that

1) the tip of $b_k$ is the origin of $b_{k+1}$ $(k=1, 2, \cdots, l-1)$
2) each node of the forward path has only one branch terminating to it and one branch originating from it, with the exception of $p$ and $q$ which, respectively, have only one branch originating and terminating to them.

A forward path from $p$ to $q$ can be obtained from each one-connection from $p$ to $q$ by deleting from the one-connections all the directed loops.

The second comment takes the form

Comment 2—When solving for $x_1$, delete from the graph $G$ all the nodes $x_{k_1}, x_{k_2}, \cdots, x_{k_m}$ which have the property that there is no forward path that connects each one of them to $x_1$.

*Example:* Consider the system

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 &= 0 \\ a_{21}x_1 + a_{22}x_2 &= +b_2 \\ a_{32}x_2 + a_{33}x_3 + a_{34}x_4 &= 0 \\ a_{43}x_3 + a_{44}x_4 &= 0. \end{aligned}$$

The corresponding flow graph is shown in Fig. 9. It is obvious in this simple example, from the graph and from the equations, that the variables $x_3$ and $x_4$ may be disregarded in solving for $x_1$; also, there is no forward path from 3 to 1 and from 4 to 1.

A straightforward analysis shows that if the nodes $x_{k_1} \cdots x_{k_m}$ are not deleted, all the connection gains and the one-connection gains of (5) will have a common factor which will cancel from numerator and denominator. This leads to the very important conclusion that, provided the precaution of Comment 2 is taken into ac-

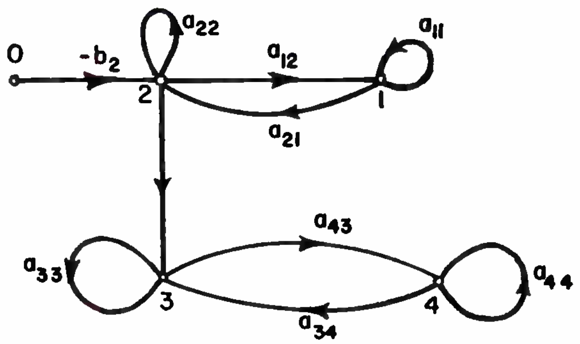


Fig. 9—Illustration of a flow graph that has no forward path from nodes 3 and 4 to node 1.

count, Theorem 2 gives the optimum gain formula for a flow graph.

Thus, the following important conclusion is reached: Given the problem of solving (1) by topological methods then, provided the Comment 2 is taken into account, the expression given in Theorem 2 is the simplest expression for the solution in terms of the $b_k$'s and $a_{ij}$'s.

## VII. The Relationship Between Signal-Flow Graphs (Mason) and Flow Graphs (Coates)

The process of association of a flow graph (Coates) to a set of equations has been described in detail in Section II. For reference let us note that the equations are written

$$\sum_{j=1}^{n} a_{kj}x_j = b_k \qquad (k = 1, 2, \cdots, n) \tag{1}$$

where

$a_{kj}$ is the gain of the branch, directed from $j$ to $k$, connecting node $j$ to node $k$, and

$-b_k$ is the gain of the branch connecting the source node to node $k$.

Mason,[2] on the other hand, writes his equations thus:

$$\sum g_{kj}x_j = x_k + b_k \qquad (k = 1, 2, \cdots, n) \tag{7}$$

where

$g_{kj}$ is the gain of the branch, directed from $j$ to $k$, connecting node $j$ to node $k$, and

$-b_k$ is the gain of the branch connecting the source node to node $k$.

Simply by looking at the equations we can see clearly that (1) and (7) will be identical if and only if

$$g_{kj} = a_{kj} \text{ if } k \neq j \quad \text{and} \quad g_{kk} - 1 = a_{kk}.$$

This gives the following rules:

1) To obtain a flow graph (Coates) from a given signal-flow graph (Mason), simply subtract one from the gain of each existing self loop and to each node of the signal-flow graph devoid of self loop, insert one with gain $-1$.

2) To obtain a signal-flow graph (Mason) from a flow graph (Coates), add unity to the gain of each existing self loop and to each node of the flow graph devoid of self loop, insert a self loop of gain $+1$.

Physically, we can interpret both graphs in terms of analog computer concepts:

### A. Signal-Flow Graphs

Node variables $x_j$: potential of node $j$ with respect to ground.

Gain $g_{kj}$: admittance of the branch connecting $j$ to $k$, thus $g_{kj}x_j$ is a current entering node $k$.

Node: electronic summing amplifier: its output voltage is equal to the sum of the input currents:

$$x_k = \sum_{j=1}^{n} g_{kj}x_j - b_k \cdot 1.$$

Note that this summing amplifier does not invert the sign as is usually the case with analog computer amplifiers.

### B. Flow Graphs

Node variables $x_j$: potential of node $j$ with respect to ground.

Gain $a_{kj}$: admittance of the branch connecting $j$ to $k$.

Node: operational amplifier with its feedback loop open; thus if the output voltage $x_k$ is in the linear range, the sum of the input currents is negligibly small in view of the high gain of the amplifier; hence

$$\sum a_{kj}x_j - b_k \cdot 1 = 0.$$

## Appendix

By definition, the determinant[4] of a matrix $A$ is

$$\det A = \Delta = \sum_P (\text{sgn } P) a_{1i_1} a_{2i_2} \cdots a_{ni_n}$$

where $\Sigma/P$ denotes that the summation is taken only over the $n!$ permutations $i_1, i_2, \cdots, i_n$ of $1, 2, \cdots, n$ and (sgn $P$) is $+1$ or $-1$ depending on whether the permutation $i_1, i_2, \cdots, i_n$ is even or odd.

The key properties that are used in the paper are the following:

1) The interchange of any two adjacent symbols of a permutation changes the permutation into one of the opposite parity.

2) Exactly one element from each row and one element from each column appears in each term of the expansion of $\Delta$.

3) If any two parallel lines (rows or columns) of $A$ are interchanged, the determinant of the resulting matrix is $-\det A$.

# A Broad-Band Cyclotron Resonance RF Detector Tube*

FRANKLIN M. TURNER†, MEMBER, IRE

*Summary*—**A tube is described which utilizes the cyclotron motion of electrons to provide a resonant system which is tuned by variation of the magnetic flux density. The amplitude of the cyclotron motion depends upon the relationship of the applied signal frequency and the electron cyclotron frequency; at resonance, the amplitude is maximum. Resonance is detected by shooting the spiraling electrons through a honey-comb type mesh grid; the current intercepted by the grid is greatest at resonance and is proportional to the RF signal power.**

**The tube is a complete TRF receiver (less video amplifier) within one vacuum envelope. The resonant frequency is a linear function of solenoid current; the tube can be tuned over a wide frequency range (at least 10:1) with a single control. The characteristics of the device have been investigated for resonant frequencies from 65 to 650 mc; the sensitivity and 3-db RF bandwidth can be varied within limits; typical signal sensitivity is −45 dbm (500-kc video bandwidth) with a 4-mc 3-db RF bandwidth.**

**The measured characteristics and the theoretical predictions are in reasonable agreement.**

## Introduction

An electron beam, a static magnetic field parallel to the beam, and a perpendicular RF electric field may be combined to form a resonant system which can be tuned electronically over a wide frequency range. The application of this resonant system to the detection and frequency determination of RF signals had been explored by several investigators[1–3] and some tubes were constructed at Stanford University[4,5] prior to 1950. The sensitivity of these tubes was extremely poor, but it was nevertheless encouraging enough to support further efforts. From 1950 to 1954, tubes with much improved sensitivity were developed. Until recently, information concerning these tubes could not be widely disseminated due to security restrictions.

The cyclotron resonance detector tube, or cyclon detector tube, as it is sometimes designated, is essentially a nonamplifying resonant system followed by a detector; the resonant frequency of the system is the "cyclotron frequency"; the detector is a grid through which an electron beam is shot.

The cyclotron frequency is determined by the magnitude of the static magnetic field in which the electron beam is immersed. In one type of cyclotron resonance tube (the Spanatron) developed at Stanford,[6–10] the magnitude of the static magnetic field is made to vary spatially, in a known manner, across a sheet electron beam so that electrons in different sections of the beam have different resonant frequencies. The other, historically more recent, type consists of a pencil electron beam immersed in a uniform static magnetic field. Both types utilize the same basic phenomena. In the Spanatron, however, the frequency of an unknown signal is obtained by determining (with a detector grid) the section of the sheet beam that is in resonance with the unknown signal. Signal frequency is determined in the pencil beam tube by adjusting the magnitude of the uniform static magnetic field until resonance is indicated. This paper is concerned with the latter type of tube.

A photograph and a functional schematic representation of the cyclotron resonance detector tube to be described is shown in Figs. 1 and 2. A pencil electron beam is directed between the inner and outer conductors of a 50-ohm coaxial line. When an RF signal is applied to the coaxial line, an alternating electric field perpendicular to the beam is excited. If the RF frequency and the cyclotron frequency are nearly equal, the mutually perpendicular RF electric field and the uniform static magnetic field will cause individual electrons to spiral about axes parallel to the beam. The path radius of the spiralling electrons will be greatest when the RF fre-

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† Stanford Elect. Labs., Stanford University, Stanford, Calif.

1 J. Weber, "Some Notes on Indicators for Non-Scanning Radio Receivers," Internal Memorandum, Navy Dept., Bureau of Ships, Washington, D. C., September 6, 1946.

2 S. F. Kaisel, "Analysis of a Proposal for a Non-Scanning Radio-Frequency Spectrum Analyzer," Electronics Res. Lab., Stanford University, Stanford, Calif., N6onr 25107; September 1, 1947.

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8 W. H. Kohl, "Construction of a Sealed-Off, All-Metal Cyclotron Resonance Tube," Electronics Res. Lab., Stanford University, Stanford, Calif., Tech. Rept. No. 23, Nonr 22510; August 15, 1954.

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quency, as viewed by an observer moving at the axial velocity of the electrons, is equal to the cyclotron frequency. To detect the spiral motion of the electrons, the beam is passed through a grid which is composed of many honeycomb-like cells (Fig. 3); some electrons are captured by the grid. If the path radii of the spiralling electrons are relatively small, most of the beam will pass through the detecting grid to the collector. If the path radii of the electrons are increased, fewer of the electrons in the beam will reach the collector. Thus, a current whose amplitude is sensitive to the path radii of the electrons may be obtained either from the detecting grid or from the collector.

The characteristics of a detecting grid were first investigated by Roberts[9] and Worcester;[10,11] Stewart subsequently completed a statistical theory of detector grid behavior. Stewart[12–15] also proposed and built cyclotron resonance detector tubes utilizing a coaxial line interaction structure. The tubes described here are refinements of Stewart's early models.

In the following portions of this paper a simplified analysis of the energy transfer from the RF electric field to the spiralling electrons will be presented, the mechanical details of the tube will be outlined, and the electrical characteristics, both predicted and measured, will be discussed. The theory of the detecting grid is presented elsewhere; only the observed characteristics of one particular grid are reported here.

Fig. 1—Cyclotron resonance detector tube. Overall dimensions, $14\frac{3}{4} \times 1\frac{11}{32}$ inches.

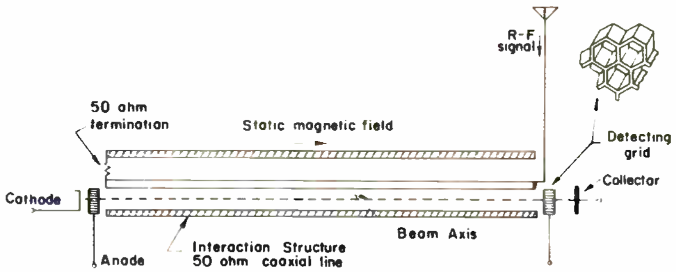



Fig. 2—Cyclotron resonance detector tube, functional schematic.

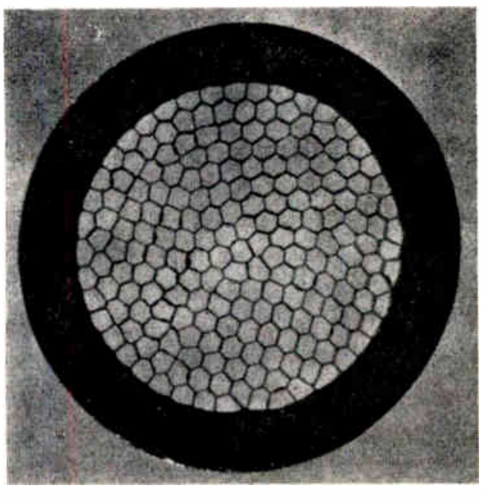


Fig. 3—Honey-comb detecting grid. Hexagonal cell diameter and depth, approximately 10 mils.

## Description of Cyclotron Resonance Detector Tube

This section describes the mechanical details of a cyclotron resonance detector tube and typical operational procedures.

Construction of the tube is not difficult; many of the parts can be purchased commercially and those requiring fabrication are not complex. The tube is rugged, reliable, and simple to operate.

A major component of the tube is the 10-inch coaxial-line interaction structure. It is nonmagnetic stainless steel tubing; the inside diameter of the larger tubing is 0.36 inch, while the outside diameter of the smaller tubing is 0.15 inch. The outer coaxial cylinder is supported within the glass envelope by two support rings. Each support ring contains three synthetic sapphire balls (one of which is spring-loaded) which bear against the glass envelope. The tubing forming the inner coaxial conductor is supported at the gun end of the tube by an Aquadag coated glass bead. The glass bead, visible in Fig. 1, serves not only as a mechanical support, but also as the 50-ohm termination for the coaxial line.

The external RF connection to the tube is made at a coaxial Kovar seal near the collector. A short section of internal coaxial transmission line connects the interaction structure to the Kovar seal. RF is brought in at the collector end of the tube, not only to reduce the overall diameter of the tube, but also to keep the magnetic Kovar as far from the beam as possible.

A standard RCA cathode-heater assembly with a flat 0.12-inch oxide-coated cathode button provides the electron source. Both the anode and the detecting grid, which are mounted perpendicular to the beam, are of the type shown in Fig. 3. These grids, made available

[11] Subsequent to his work at Stanford, Worcester and his associates at the Engrg. Exp. Sta., University of Colorado, Boulder, have continued the study of cyclotron resonance, with particular emphasis on the Spanatron. Tech. Repts. 1–7, Nonr-1147-01, describe their work during the 1953–1958 period.

[12] J. L. Stewart, "The Analytical Theory of Cyclotron Resonance Video Detectors and Mixers with Examples," Electronics Res. Lab., Stanford Unversity, Stanford, Calif., Tech. Rept. No. 17, N6onr 25123; September 25, 1952. This was also a Ph.D. dissertation under the same title.

[13] J. L. Stewart, "The Theory of Cyclon Detectors and Mixers," Electronics Res. Lab., Stanford University, Stanford, Calif., Tech. Rept. No. 19, N6onr 25132; April 10, 1953.

[14] J. L. Stewart, "New Cyclon Detectors," Electronics Res. Lab., Stanford University, Stanford, Calif., Tech. Rept. No. 23, N6onr 25132; June 26, 1953.

[15] J. L. Stewart, "Electron flow through small tubes with magnetic focusing," *J. Appl. Phys.*, vol. 24, pp. 1236–1240; September, 1953.

through the courtesy of Varian Associates, have a cell diameter and depth of approximately 0.010 inch.

Typical applied potentials and resulting currents are: coaxial interaction structure, zero volts dc (outer conductor grounded); useful cathode voltage range, $-3$ to $-15$ volts; cathode current, 50–60 $\mu$a; collector current (in the absence of RF), 5–15 $\mu$a; dc collector potential, a few volts above ground (not critical); detecting grid, ground potential.

The beam voltage at which the tube is to be operated is chosen on the basis of RF bandwidth and sensitivity considerations (see Figs. 8 and 9); the anode potential is set one volt positive with respect to the cathode, and the tube's position in the magnetic field is adjusted to secure maximum collector current in the absence of a signal. A slight spatial re-alignment of the tube in the magnetic field, and adjustment of the anode potential, may be required to obtain maximum sensitivity when a test signal is applied.

The required magnetic field was generated by a wire-wound solenoid $16\frac{1}{2}$ inches in length and $4\frac{1}{2}$ inches in outside diameter. A reasonable amount of care must be exercised during construction of the solenoid to obtain winding uniformity. At a cyclotron frequency of 650 mc (232 gauss), the solenoid dissipated approximately 40 watts; a 1-ma change in the solenoid current varied the cyclotron frequency 3 mc.

## Detection of Spiralling Electrons

The most satisfactory method discovered so far for detecting spiralling electrons is a honey-comb grid of the type shown in Fig. 3. It appears from geometrical considerations that, as a first approximation, the probability of electron interception by the detecting grid would be directly proportional to the radius of the electron's helical path. Observations indicated that this was not true; grid detection is more complicated than one might suspect. Consideration of the random phenomena created by the electrostatic field near the grid, and by thermal factors, suggested that a statistical approach to the problem might be fruitful. Both Worcester[10] and, more recently, Stewart[12,13,15] have analyzed detecting of grid behavior from a statistical viewpoint. Both these analyses correctly indicate that the change in intercepted current will be nearly proportional to the square of the signal-induced radius under small-signal conditions. That this is so may be inferred from Fig. 6 and (9). The actual sensitivity realized by the detecting grids is within a few db of that which is theoretically possible according to Stewart's analysis. For more details on the theoretical behavior of the honey-comb grids, the reader is referred to the references cited.

Theoretically the signal is negative at the detector grid (grid intercepts electrons) and positive at the collector; thus, it would seem, one would have a choice of video signal polarity. In practice, however, some detection occurs in the interaction structure; *i.e.*, some electrons spiral into the conductors of the RF transmission line. Near the lower frequency limit of the tube described, the detected signal at the grid may change polarity—due to interception of electrons in the interaction structure. Since the polarity of the signal at the collector is always the same, it was used rather than the grid signal.

## Energy Transfer Mechanism

An electron entering the coaxial interaction structure with only an axial velocity would, in the absence of an RF signal, follow a straight-line trajectory parallel to the beam axis. However, should the electron acquire a velocity component transverse to the axial magnetic field, due to thermal emission effects, the RF field, or from any cause whatsoever, the electron trajectory will not be a straight line. The electron will instead spiral about a line parallel to the beam axis; in addition to its axial velocity, it will have acquired an angular velocity. Thus, the electron trajectory may be visualized as a helix of constant pitch with an axis parallel to the static axial magnetic field. The number of revolutions the spiralling electron completes each second (the cyclotron frequency) is uniquely determined by the magnetic flux density.

If the frequency of the RF field, as viewed by an observer moving at the axial velocity of the electron, is equal to the cyclotron frequency and if the phase relationship of the spiralling electron and the RF field is optimum, the electron will continuously gain energy from the transverse electric field. The radius of the spiralling electron will continuously increase as the electron moves through the interaction structure. If the observed RF frequency differs from the cyclotron frequency, the electron gains less energy, its path radius is less, and the current intercepted by the detector grid is less. Hence, the spiralling electrons form a resonant system. It is the purpose of the ensuing analysis to determine the characteristics of this resonant system.

In order to simplify the analysis, the terminated coaxial line structure used in the actual tube is replaced by a lossless, terminated parallel-plate transmission line in which all fringing fields are neglected. The parallel-plate structure and assumed coordinate system are shown in Fig. 4. The RF electric field is entirely in the $y$ direction and independent of the $x$ coordinate; the uniform static magnetic field is in the $+z$ direction only. A partial list of the symbols used follows (mks units are used unless otherwise noted).

$B$ = axial magnetic flux density,
$e$ = electronic charge,
$E_y$ = instantaneous RF electric field $= E_0 \cos(\omega t + \beta z + \phi)$,
$E_0$ = maximum value of RF electric field,
$m$ = electron mass,
$u_0$ = $z$-directed electron velocity,
$v$ = RF phase velocity,
$\beta$ = RF phase constant,

- $\phi$ = phase angle relating value of RF electric field and angular position of electron at $t=0$, *i.e.*, $-E_0e\cos\phi$ is force acting on electron at $t=0$,
- $\omega$ = angular frequency of RF input ($\omega=2\pi f$),
- $\omega_c$ = cyclotron angular frequency ($\omega_c=2\pi f_c$),
- $\omega_k$ = angular frequency of RF input viewed by moving electron, and
- $\tau$ = electron transit time through interaction space.

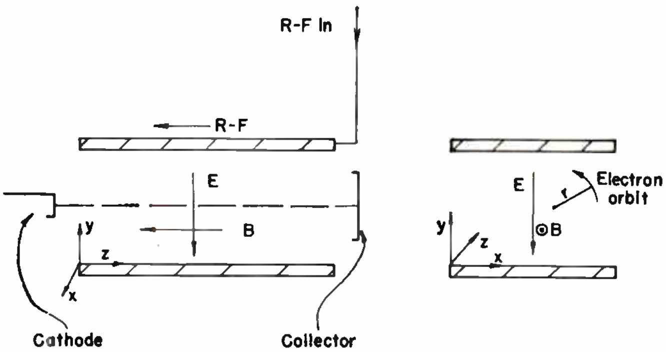
Neglecting the effects of other electrons, *i.e.*, space charge, it is well known that an electron having a velocity component perpendicular to a static magnetic field will, under equilibrium conditions, perform a circular motion having an angular velocity:

$$\omega_c = 2\pi f_c = \left|\frac{e}{m}B\right|,$$

where $f_c$ = cyclotron frequency in cps.

The incremental energy gained by the orbiting electron from the RF electric field (see Figs. 4 and 5) is:

$$dW = \boldsymbol{F}\cdot\boldsymbol{ds} = -E_y e r\omega_c \cos\omega_c t\, dt. \qquad (1)$$




(a) (b)

Fig. 4—Parallel-plate interaction structure, side and end views.

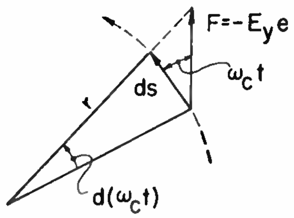



Fig. 5—Electron force diagram.

Since the energy of a spiralling electron is

$$W = \tfrac{1}{2}mr^2\omega_c^2, \qquad (2)$$

then

$$dW = mr\omega_c^2 dr.$$

Eliminating $dW$ from (1) and (2),

$$dr = \frac{E_y}{B}\cos\omega_c t\, dt = \frac{E_0}{B}\cos(\omega t + \beta z + \phi)\cos\omega_c t\, dt. \quad (3)$$

The electron enters the interaction structure at $z=t=0$. The $z$ coordinate of the electron is $z=u_0t$, so that $\beta z=\omega/v(u_0t)$. Eq. (3) may be written

$$dr = \frac{E_0}{B}\cos(\omega_k t + \phi)\cos\omega_c t\, dt, \qquad (4)$$

where

$$\omega_k \triangleq \omega\left(1 + \frac{u_0}{v}\right).$$

If the amount of energy absorbed by the electron is small, $E_0$ can be assumed constant. Integrating (4) over the time interval 0 to $\tau$, where $\tau$ is the electron transit time, one obtains

$$r = \left|\frac{E_0\tau}{2B}\left(\frac{\sin(\omega_c\tau - \omega_k\tau - \phi) + \sin\phi}{(\omega_c - \omega_k)\tau} + \frac{\sin(\omega_c\tau + \omega_k\tau + \phi) - \sin\phi}{(\omega_c + \omega_k)\tau}\right) + r_0\right| = |r_s + r_0|. \qquad (5)$$

In this equation,

- $r$ = total electron path radius at $t=\tau$,
- $r_0$ = initial electron path radius prior to electronic interaction, and
- $r_s$ = component of electron path radius due to electronic interaction with RF field.

The absolute magnitude of (5) is taken since a negative value of $r$ has no physical significance.

If the assumption is made that $(\omega_c+\omega_k) \gg |\omega_c-\omega_k|$, (5) can be written

$$r = \left|\frac{E_0\tau}{2B}\,\frac{\sin\frac{\Delta\omega\tau}{2}}{\frac{\Delta\omega\tau}{2}}\cos\left(\phi - \frac{\Delta\omega\tau}{2} \pm 2n\pi\right) + r_0\right|,$$

$$n = 0, 1, 2, \cdots, \quad \text{and} \quad \Delta\omega = \omega_c - \omega_k. \qquad (6)$$

Application of the assumption noted invalidates (6) near the zeros of the $(\sin\Delta\omega\tau/2)/(\Delta\omega\tau/2)$ term. The equation can be used, however, to describe the maximum value of $|r|$ as a function of the pertinent variables.

Presumably all values of $\phi$ are possible in an actual tube so that the maximum possible electron path radius as a function of $\Delta\omega\tau$ is observed by the detecting grid. This radius is

$$r = \left|\frac{E_0\tau}{2B}\left|\frac{\sin\frac{\Delta\omega\tau}{2}}{\frac{\Delta\omega\tau}{2}}\right| + r_0\right|. \qquad (7)$$

Maximum radius is obtained at $\Delta\omega=0$; resonance, therefore, occurs when $\omega_c=\omega_k$, *i.e.*, when

$$f_c = f\left(1+\frac{u_0}{v}\right). \tag{8}$$

The factor $(1+u_0/v)$ represents the increase in the signal frequency ($f$) as "seen" by the electron due to the Doppler effect. If the RF wave on the parallel-plate transmission line were a standing-wave rather than a traveling-wave, resonance would occur at $f=f_c$.

The electron path radius at resonance is

$$r_m = \left|\frac{E_0\tau}{2B} + r_0\right|. \tag{9}$$

Taking the ratio of (7) and (9) gives the relative electron-path radius with respect to the resonant radius. Assuming that the initial radius $r_0$ is small compared to the signal induced radius, this ratio becomes

$$\frac{r}{r_m} = \left|\frac{\sin\frac{\Delta\omega\tau}{2}}{\frac{\Delta\omega\tau}{2}}\right|. \tag{10}$$

Both experimental and theoretical considerations indicate that the detecting grid output varies as the square of the electron path radius. Squaring (10), therefore, gives the relative response curve of the device as the signal frequency varies. If the signal frequency is held constant, and the magnetic field (cyclotron frequency) is varied, the response curve is given by the square of (10) provided $\Delta\omega$/resonant angular frequency $\ll 1$.

Eq. (10) has decreased to 0.707 of its maximum value when $\Delta\omega\tau/2=1.39$; the 3-db bandwidth is, therefore,

$$\Delta f_{3db} = \frac{\Delta\omega}{\pi} = \frac{2.78}{\pi\tau}. \tag{11}$$

Since the energy transferred to a resonant electron is given by $\frac{1}{2}m(E_0\tau/2B)^2\omega_c^2$, the power transferred to a beam is

$$P_c = \frac{e}{m} I \frac{(E_0\tau)^2}{8}, \tag{12}$$

where $I$ = beam current, and $P_c$ = power transferred to the beam.

It will be noted from the preceding analysis that the resonant electron path radius is proportional to the product of the peak value of RF field and electron transit time [see (9)]. Once one has decided upon an interaction structure, the peak value of the transverse electric field is fixed for a given signal power input. Transit time, however, can be controlled by adjustment of the beam voltage.

Increasing the electron transit time (decreasing the beam voltage) decreases the signal power required to attain a given resonant radius, and at the same time, decreases the 3-db bandwidth [see (11)]. As one might suspect, there is a practical limit as to how far the transit time may be increased. Experimentally, the minimum useful beam voltage has been determined to be approximately 3.5 volts for the 10-inch coaxial-tube line. This corresponds to a minimum 3-db bandwidth of about 4 mc. The 3-db bandwidth, as indicated by (11), has been found to be essentially independent of the resonant frequency, at least over the 10:1 frequency range investigated. Similarly, the power coupled to the beam at resonance is independent of frequency. Eq. (12) also indicates that the frequency range over which power can be satisfactorily coupled to the beam is determined only by the frequency characteristics of the interaction structure.

In arriving at (10), which describes the relative electron path radius, it was assumed that all values of $\phi$ are possible because the time-relationship of electron entry and the peak RF field is random. Some electrons will, therefore, always acquire the maximum possible energy as the signal frequency varies about the cyclotron frequency. The response for off-resonance frequencies would, under these conditions, decrease in relative amplitude at the slowest possible rate; *i.e.*, the response given by (10) has the worst possible selectivity for this resonant system.

One is therefore led to inquire as to the possibility of obtaining a more selective response characteristic. Such a possibility exists; for $\phi=0$, (10) becomes:

$$\frac{r}{r_m} = \left|\frac{\sin\Delta\omega\tau}{\Delta\omega\tau}\right|, \tag{13}$$

where $r_m$ is given by (9). The 3-db bandwidth obtained for $\phi=0$ is exactly one-half of that given by (11).

## Characteristics of the Cyclotron Resonance Detector Tube

The tube responds to CW, AM, and FM signals; for convenience, however, pulsed signals were generally used in determining the characteristics described in this section.

The relative amplitude of detected RF pulses as a function of the peak RF power input is shown in Fig. 6. The detection is square law over the region where the slope of the curve is one, *i.e.*, over a power input range of 20 db. Saturation occurs at approximately 1/10 of a milliwatt; the input RF power dynamic range is approximately 35 db. The data for Fig. 6 were taken at resonance with a beam voltage of 4.0 volts at an RF input frequency of 230 mc. The detector characteristic observed at other frequencies (100 and 500 mc) is not significantly different from that shown in Fig. 6.

The relative response curve for the tube is shown in Fig. 7; the solid curve represents the actual response, while the dashed curves are the envelopes of the two the-

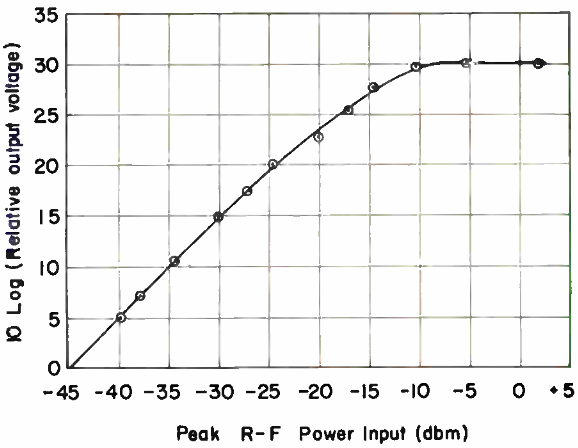



Fig. 6—Grid detector characteristic.

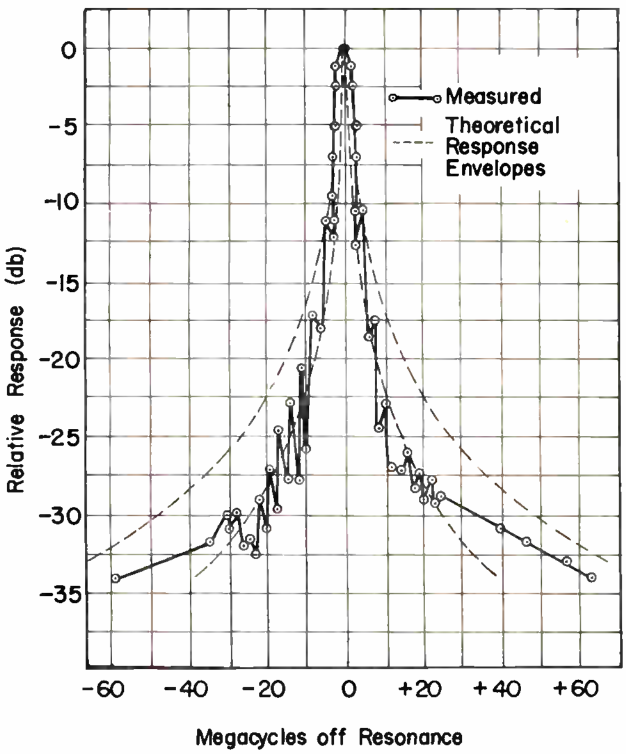



Fig. 7—Cyclotron resonance relative response curve.

oretical response characteristics obtained from (10) and (13), assuming the detector grid responds to the square of the relative electron path radius. Due to the assumption noted in connection with (6), only the envelope of the theoretical responses (curve through maximum values of $|r/r_m|^2$) is shown in Fig. 7. The outer dashed curve is (10) squared and represents the envelope of the response one would expect to obtain; the inner, more sharply resonant, dashed curve is shown merely to indicate a more desirable response which is, at least theoretically, obtainable. Inspection of Fig. 7 shows that the agreement between experiment and theory is reasonable, but by no means perfect. Assumptions involved in the analysis and the experimental error probably account for the discrepancy.

The characteristic shown in Fig. 7 is typical of the response curves observed for resonant frequencies greater than 100 mc. In the region of 100 mc and below, the response becomes noticeably asymmetric for reasons not clearly understood.

The selectivity of the resonant system is not particularly impressive: the 30-db/3-db bandwidth ratio is only about 14. One obvious means of improving the selectivity is to provide RF pre-selection ahead of the tube. For operation over an extensive frequency range, as well as for ease in tracking, the pre-selector also probably should be a device which utilizes the cyclotron resonance phenomena. Perhaps a device patterned after the Cuccia electron coupler[16,17]—but with wide-band transmission line input and output interaction-structures—would be an effective pre-selector.

The 3-db RF bandwidth as a function of beam voltage is shown in Fig. 8. The solid curve is plotted from measured data; the dashed curve is calculated from (11). The electron transit-time required for substitution in (11) was calculated on the basis of a 10-inch interaction length and an average axial velocity, $u_0$, given by the relation $\frac{1}{2}mu_0^2 = eV$, where $V$ is the cathode voltage. The predicted and measured curves are nearly parallel for beam voltages greater than 3.5 volts, thus, at least qualitatively, providing verification of (11) in this region.

The abrupt change in the general trend of the solid curve in Fig. 8 at beam voltages of 3.5 volts and less is correlated with a similar change in the sensitivity-beam voltage characteristic (see Fig. 9).

Since the electron path radius at resonance is proportional to the transit time [see (9)], it is to be expected that sensitivity will decrease with an increase in beam voltage. In Fig. 9 the tangential signal sensitivity for a 1-$\mu$sec pulse (500-kc video bandwidth[18]) is plotted as a function of beam voltage. At beam voltages of 3.5 volts and less, the general trend of the curve is reversed: in this region the tube also becomes acutely sensitive to minor changes in operating conditions. It is customary, therefore, to operate the tube at a beam voltage of four or even five volts when maximum sensitivity is desired.

The sensitivity-beam voltage characteristic is essentially independent of frequency, at least over the 65–650-mc range examined. The ordinate (sensitivity) will change with resonant frequency. The shape of the curve and of the abscissa, however, remain intrinsically unchanged.

[16] C. L. Cuccia, "The electron coupler—a developmental tube for amplitude modulation and power control at ultra-high frequencies—Part I," *RCA Rev.*, vol. 10, pp. 270–303; June, 1949.

[17] C. L. Cuccia, "The electron coupler—a developmental tube for amplitude modulation and power control at ultra-high frequencies—Part II," *RCA Rev.*, vol. 14, pp. 72–99; March, 1953.

[18] The post-detection (video) amplifier bandwidth must be chosen so as to amplify the detected modulation with satisfactory fidelity. This bandwidth will in turn affect the video amplifier noise and thereby the minimum detectable RF signal.

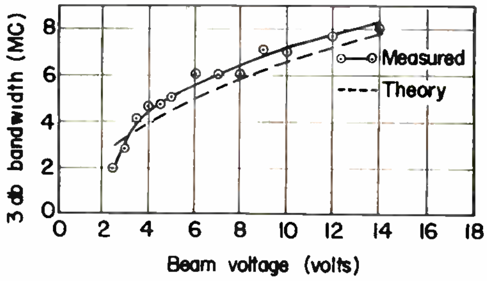



Fig. 8—3-db RF bandwidth vs beam voltage.

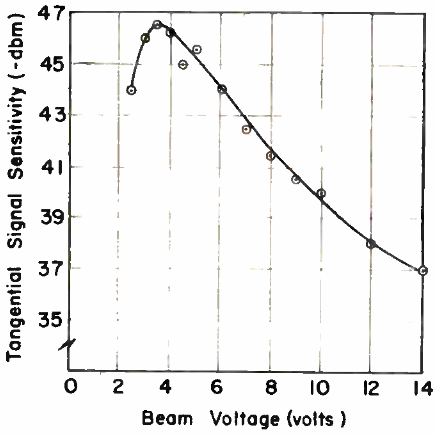



Fig. 9—Tangential signal sensitivity vs beam voltage, 500-kc video bandwidth.

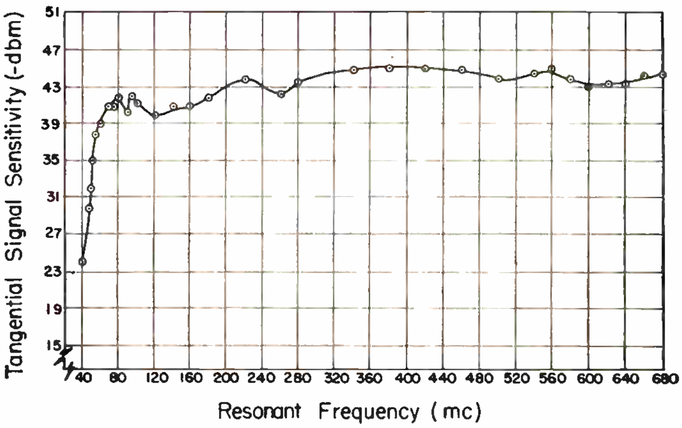



Fig. 10—Tangential signal sensitivity vs resonant frequency, 500-kc video bandwidth and 5-mc RF bandwidth.

The wide frequency range over which the cyclotron resonance detector tube can be operated is indicated in Fig. 10. The resonant frequency was varied by changing the current in the solenoid windings; no other adjustment was made. The sensitivity gave no sign of decreasing above 680 mc; data were not taken at higher frequencies because of solenoid dissipation. The sensitivity shown in Fig. 10 is for an RF bandwidth of 5 mc (5-volt beam) and for a 1-μsec pulse (500-kc video bandwidth).

The poor sensitivity of the tube at the lower frequencies appears to be due primarily to beam transmission difficulties. At 56 mc, for example, the axial magnetic flux density required for resonance is only about 20 gauss. The useful low-frequency limit for these tubes would appear to be about 65 mc; operation near this low frequency limit requires that the solenoid be carefully shielded from the earth's magnetic field.

RF pre-amplification can be used to improve upon the basic sensitivity of the cyclotron resonance tubes. Low-noise, wide-band distributed amplifiers have been employed to obtain tangential signal sensitivities of −90 to −95 dbm over wide frequency ranges.

One of the unusual features of these tubes, possibly unique, is the electronically variable RF 3-db bandwidth. Fig. 8 would indicate that one need only vary the beam voltage to attain a desired 3-db bandwidth. It is true that the beam voltage controls the bandwidth, but usually a slight adjustment of anode voltage (and possibly of the tube's spatial alignment) is required to obtain maximum sensitivity following a change in the beam voltage. At most, the adjustments would take a few minutes; it might, however, be useful if one were able to change the bandwidth rapidly. This can be accomplished by distorting the axial magnetic field so as to achieve an effect analogous to staggered tuning.

The interaction structure of the cyclotron resonance tube and the magnetic field in which the tube is immersed are analogous to a resonant circuit which is tuned by varying the magnetic flux density. If the magnetic flux density over one-half the length of the interaction structure is different from that of the other half, the situation is analogous to that of two tuned circuits of different resonant frequencies connected in series. (In bandpass-amplifier theory, this combination would be called a "staggered pair.") Perhaps the simplest way to achieve a staggered magnetic field is to add a second winding to the solenoid which is wound clockwise for half the length of the solenoid and counter-clockwise for the remaining half. A current flowing in this winding will produce, ideally, an axial magnetic field which adds to the main field over one-half the length of the solenoid and subtracts from the main field over the other half. Since the added winding need only produce a magnetic field on the order of one or two gauss, the additional power required is negligible.

With the proper current flowing in the additional solenoid winding, a response curve with three peaks is obtained (see insert of Fig. 11). This response is nearly independent of the resonant frequency, as long as the beam voltage and the current in the additional winding remain unchanged. To change from the response of Fig. 7 to the three-peaked response of Fig. 11, one need only throw a switch to send a predetermined current through the additional winding. If the beam voltage is changed by more than 10 per cent, it is necessary to adjust the value of this current to obtain maximum results.

In Fig. 11 the 3-db bandwidths for the uniform and staggered magnetic fields are compared. The bandwidth is increased by a factor of approximately 3 (theoreti-

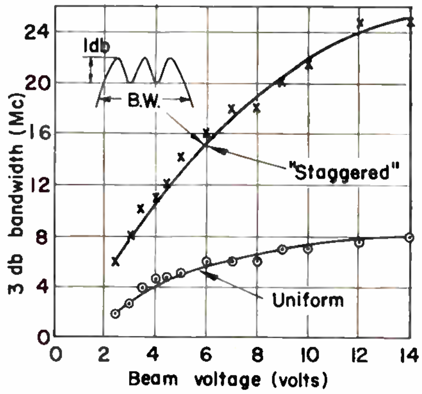



Fig. 11—3-db RF bandwidth vs beam voltage, uniform and "staggered" magnetic field.

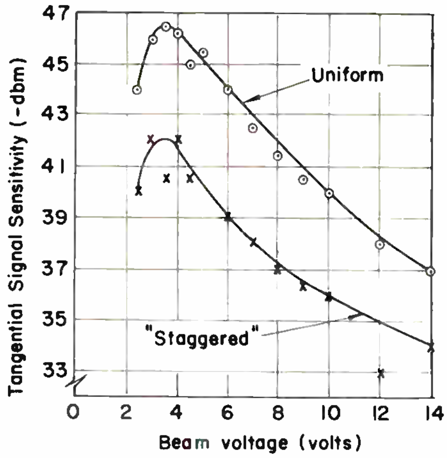



Fig. 12—Tangential signal sensitivity vs beam voltage, uniform and "staggered" magnetic field.

cally, 2.8) when the magnetic field is staggered. The increased bandwidth is acquired at the expense of sensitivity; the reduction of sensitivity (see Fig. 12) varies between 3 and 5 db depending upon the beam voltage.

The cyclotron resonance tubes are relatively immune to damage by high RF powers. Permanent damage is most likely to occur first at the terminating resistance. A small change in the value of the coaxial line termination is not detrimental. However, a large VSWR on the coaxial line would narrow the frequency range over which satisfactory sensitivity could be obtained. RF power of a magnitude far less than that which could cause any possible physical damage does, however, produce undesirable spurious responses.

If the RF input is sufficient to saturate the tube, that is, if it is greater than −10 dbm, spurious responses—which have no apparent relationship to the applied signal frequency—appear over a wide frequency range. These responses are at least 30 db below the peak of the main response and are easily identifiable. A second type of spurious response—which may have more serious consequences—is observed when the input power exceeds approximately −20 dbm. This response occurs when the cyclotron frequency is approximately half of the signal frequency: its amplitude is also at least 30 db below the main response, but the shape of its response-curve appears to be very similar to that of the main response (Fig. 7); hence, it can be mistaken for a weak legitimate signal.

## Conclusions

The idealized and simplified theory of energy transfer presented in this paper—along with the results from an analysis of detecting grid behavior[13]—is sufficient to predict many of the characteristics of a cyclotron resonance detector tube.

The cyclotron resonance tubes are characterized by an extremely broad frequency range (at least 10:1) over which operation is possible. Resonance may be electronically varied; tuning is linear and may be accomplished either with a single manual control, or by periodic variation of the solenoid current (automatic frequency scanning). The sensitivity, RF bandwidth, dynamic range, and selectivity of this device should prove adequate for many purposes.

## Acknowledgment

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The Stanford-developed cyclotron resonance tubes could not have been brought to their present state without the contributions of many people. In particular, the work of S. F. Kaisel, L. A. Roberts, W. G. Worcester, and J. L. Stewart was indispensable.

# Anomalies in the Absorption of Radio Waves by Atmospheric Gases*

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***Summary*—This paper summarizes recent measurements of the attenuation of radio waves by atmospheric gases and compares the measured losses with those predicted by Van Vleck. Reasonably good agreement has been noted between the predicted and measured losses for oxygen, but the measured loss for water vapor is considerably in excess of that predicted. Various factors which may influence this discrepancy are discussed.**

## Introduction

In two classic papers in 1947, Van Vleck[1,2] evaluated the experimental evidence available on the absorption characteristics of atmospheric gases and predicted the magnitude of the attenuation of radio waves due to oxygen and water vapor. These papers have served as the starting point for most subsequent work in the field and the numerical predictions have been used frequently to estimate propagation losses.

The absorption of energy from a radio wave by atmospheric gases is due to the transition from one molecular rotation energy level to another caused by the electromagnetic wave. For gases at very low pressures, this energy change is associated with a very narrow band of frequencies. For increased pressures, the energy is absorbed over a wider range. The frequency dependence of microwave absorption was given by Van Vleck and Weisskopf[3] and the Van Vleck-Weisskopf equation as given in the Appendix has been the most commonly used means of predicting atmospheric losses.

Two critical constants are involved in each energy level transition. The first of these is the frequency associated with the energy transition. This may be determined from a knowledge of the energy levels or from direct measurement. Since the energy differences are very small for absorption lines in the microwave spectrum, the error involved in taking the difference of two nearly equal values is large. For this reason, direct measurement of resonant frequency is preferable where possible.

The second critical number is the line breadth constant associated with the frequency spread of the absorption. This value should be determined by direct measurement for the most reliable results.

## Van Vleck's Choice of Line Breadth Constant

At the time of Van Vleck's papers, no propagation test had been made through the actual atmosphere in the millimeter wavelength region, and only a very few quantitative data were available in the centimeter region. On the basis of infrared studies, it had been possible to establish the molecular energy levels and the frequencies associated with their differences.

Oxygen losses in the millimeter spectrum result from the interaction of the magnetic moment of the $O_2$ molecule with the electromagnetic field. Transitions to the ground state occur with corresponding wavelengths grouped around 0.5 cm, and with one transition wavelength at 0.25 cm. In addition, nonresonant or Debye absorption provides a continuous spectrum of loss.

For line breadth constants of 0.05 or greater, the lines in the 5-mm wavelength band blend together to form a single line. On the basis of measurement of oxygen losses near 5 mm in waveguides by Berringer,[4] Van Vleck concludes that the appropriate line breadth constant should be 0.02 $cm^{-1}$ at one atmosphere. The losses calculated, using this constant, were plotted in Fig. 1. The attenuation curve is somewhat irregular at the first peak but the details are masked by the log-log scale.

Measurements by Lamont[5] of oxygen losses around 5 mm through the actual atmosphere were found to be adequately explained by the use of the line breadth of 0.02 $cm^{-1}$. Laboratory measurements by Strandberg, *et al.*,[6] on pure oxygen and oxygen-nitrogen mixtures agreed with a line breadth constant between 0.015 and 0.02 $cm^{-1}$.

For water vapor, one line occurs near 1.35 cm and one at 1.63 mm. In addition, there are a vast array of lines in the near millimeter region. Ghosh and Edwards[7] have listed 588 of these absorption lines. Of these, 149 with significant line strength have wavelengths between 0.05 and 1.0 mm. The direct measurement of the line breadth constant has been possible only for the 1.35-cm line. Van Vleck concluded, on the basis of resonant cavity measurements by Becker and Autler[8] at Columbia Uni-

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† Electrical Engineering Research Lab., University of Texas, Austin.

[1] J. H. Van Vleck, "The absorption of microwaves by oxygen," *Phys. Rev.*, vol. 71, pp. 413–424; April 1, 1947.

[2] J. H. Van Vleck, "The absorption of microwaves by uncondensed water vapor," *Phys. Rev.*, vol. 71, pp. 425–433; April 1, 1947.

[3] J. H. Van Vleck and V. F. Weisskopf, "On the shape of collision-broadened lines," *Rev. Mod. Phys.*, vol. 17, pp. 227–236; April–July, 1945.

[4] E. R. Beringer, "The absorption of one-half centimeter electromagnetic waves in oxygen, *Phys. Rev.*, vol. 70, pp. 53–57; July, 1946.

[5] H. R. L. Lamont, "Atmospheric absorption of microwaves," *Phys. Rev.*, vol. 74, p. 353; August, 1948.

[6] M. W. P. Strandberg, C. Y. Meng, and I. G. Ingersoll, "The microwave spectrum of oxygen," *Phys. Rev.*, vol. 75, pp. 1525–1528; May, 1949.

[7] S. N. Ghosh and H. D. Edwards, "Rotation Frequencies and Absorption Coefficients of Atmospheric Gas," Geophys. Res. Directorate, AF Cambridge Res. Ctr., Bedford, Mass., Rept. No. 82; March, 1956.

[8] G. E. Becker and L. H. Autler, "Water vapor absorption of electromagnetic radiation in the centimeter wave-length range," *Phys. Rev.*, vol. 70, pp. 300–307; September 1 and 15, 1946.

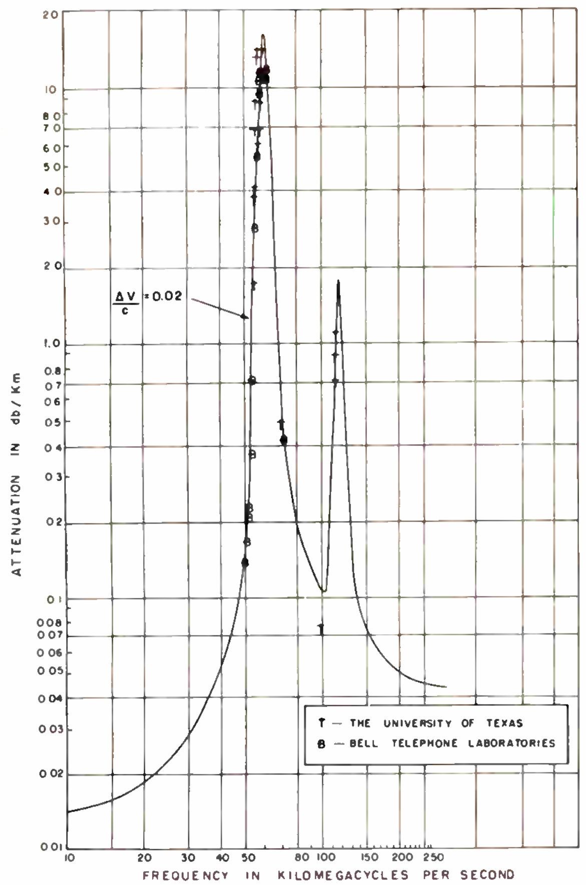


Fig. 1—Attenuation due to oxygen at one atmosphere.

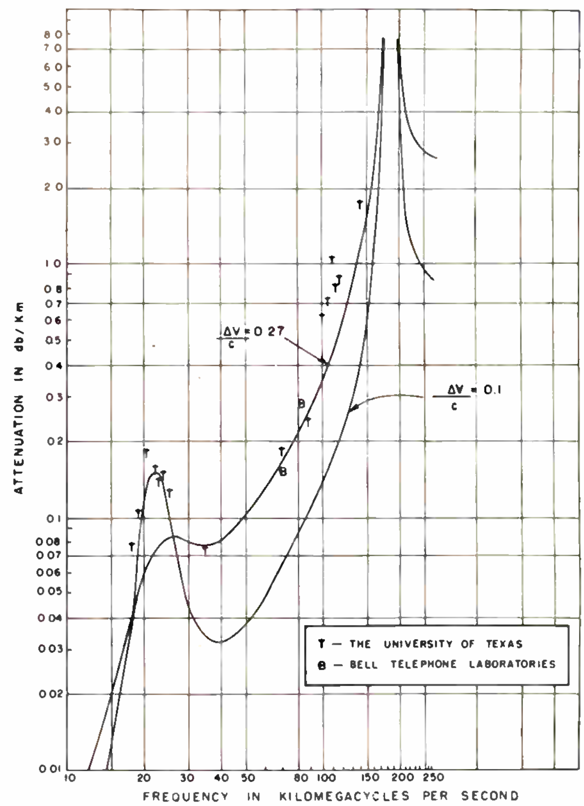


Fig. 2—Water vapor attenuation for 7.5 g/m³.

versity, that this line breadth constant should be approximately 0.1 $cm^{-1}$. The assumption was made that this line breadth constant was the same for all water vapor lines and the spectral distribution of the water vapor losses was calculated. This theoretical attenuation as a function of frequency is shown in Fig. 2 for the line breadth constant of 0.1 $cm^{-1}$ and also for a line breadth constant of 0.27 $cm^{-1}$.

## Difficulties in Direct Transmission Loss Measurements

It is rather surprising that there are very few reports in the technical literature of quantitative measurements of absorption by atmospheric gases on actual transmission paths. Dicke's[9] radiometric measurement of the sun at 1, 1.25 and 1.50 cm provided estimates of the water vapor loss, but required a knowledge of the water vapor distribution with height which can only be approximated.

The problem in millimeter measurements has been the lack of generators of sufficient power to make actual transmission tests. In recent years, however, improvements in millimeter techniques have extended the range over which propagation measurements could be made, and data are available at a good many frequencies.

In addition to the equipment problems, there are a number of difficulties encountered in the propagation tests that require them to be made with a great deal of care.

The general procedure for making the tests is to observe the signal level on a number of days and to plot this signal strength as a function of water vapor content in the atmosphere. The slope of this line provides the water vapor losses and the ordinate or *y*-axis intercept provides the oxygen loss.

Inhomogeneity in the water vapor content is known to exist both on small and large scales. In practice, the water vapor concentration is measured at both ends of the path and compared to data available from the U. S. Weather Bureau. The process of time averaging of the measurements and the use of many samples gives a measure of the variation of loss with water vapor concentration which is felt to be quite reliable.

Another annoyance in the measurement is the fact that considerable scintillation in the signal level may occur. The magnitude of these fluctuations is greater than can be explained by variations in the mean water vapor density and therefore must be attributed to refraction effects. The signal chosen as representative of a given sampling period is the mean level.

A third problem in propagation measurements is the presence of precipitation along the path. Care must be taken that the absorption measurements are made at a time when the atmosphere is free of rain or solid particulate matter.

[9] R. H. Dicke, R. Beringer, R. L. Kyhl, and A. B. Vane, "Atmospheric absorption measurements with a microwave radiometer," *Phys. Rev.*, vol. 70, pp. 340–348; September 1 and 15, 1946.

### Summary of Recent Measurements

During recent years, improvements in generators and components have made possible a number of absorption measurements through the actual atmosphere. Such measurements have been made by Bell Telephone Laboratories[10] at wavelengths in the 5- to 6-mm region and at 4.3 and 3.7 mm. Similar measurements have been made by The University of Texas Electrical Engineering Research Laboratory at wavelengths in the range from 1.2 to 1.7 cm, at 8.6 mm, 4.3 mm, 3.35 mm, 2.15 mm, and at a number of wavelengths in the region from 2.5 to 3 mm.[11] The results of all these measurements have been plotted on Figs. 1 and 2 for comparison with the Van Vleck curves.

The points plotted on the log-log curves tend to give the impression of a closer agreement between the measured and theoretical values than actually exists. Some details of the spectrum will be considered later.

From Fig. 1, it is seen that the agreement between the measured and calculated values of absorption for oxygen are reasonably good, but for reasons pointed out later, care should be exercised in extrapolating the data to points very far from the frequencies at which they were measured.

From Fig. 2, it is seen that the water vapor losses are consistently larger than those predicted by Van Vleck for a line breadth constant of 0.1 cm$^{-1}$. These deviations will be discussed in greater detail in the following sections.

### Residual Effect of Submillimeter Water Vapor Lines

In those sections of the microwave spectrum far removed from a water vapor absorption line, the attenuation is primarily controlled by the skirts of the submillimeter lines. This effect is shown in Fig. 3.[12] The line numbers are in the order of increasing frequency. It is noted in the frequency range from 50 to 130 kmc that the first 12 lines make a relatively small contribution to the total absorption and that line numbers 21 through 76 make approximately the same contribution as the first 20 lines.

The curves of Fig. 3 are based on the assumption that the line breadth constant is 0.1 cm$^{-1}$ for all of the lines. Recent evidence has indicated that the line breadth may vary from line to line. Such variations could cause the attenuation curve to rise much more rapidly with frequency than is shown in Fig. 3.

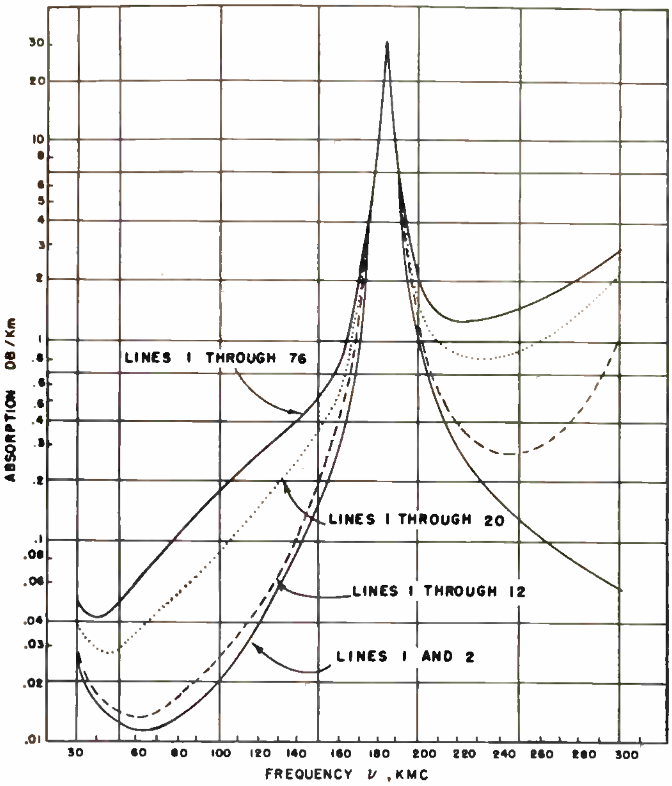


Fig. 3—Calculated water vapor absorption for 7.5 g/m³ for $\Delta\nu/c = 0.1$.

All of the water vapor loss measurements made prior to September 1958 could be approximately accounted for by the expediency of increasing the line breadth constant for the infrared residual lines from 0.1 to 0.27 cm$^{-1}$.

Recent measurements at The University of Texas, however, have uncovered several anomalies which have thrown out this simple panacea. These newer measurements are described in the following sections.

### Measurements Around the 1.35-cm Line

In spite of the fact that the frequency of the 1.35-cm line has been known with precision for some time, quantitative measurements of the magnitude of its absorption through the actual atmosphere are very scarce. For this reason, data were recently taken by the Electrical Engineering Research Laboratory at a number of wavelengths in this region.[13]

These recent data are plotted in Fig. 4 together with the three points reported by Dicke, *et al.*[9] The curve is plotted on a linear basis for one gram of water vapor per cubic meter instead of for the standard atmosphere condition of 7.5 grams. Neither the Van Vleck-Weisskopf curve for the 0.1 cm$^{-1}$ nor for the 0.27 cm$^{-1}$ line breadth constant adequately represents the measured data even in the vicinity of the absorption line.

[10] "Millimeter Wave Research—Final Report," Bell Telephone Laboratories, New York, N. Y., ONR Contract 687(00), Rept. No. 24261-15; May, 1955.

[11] C. W. Tolbert, A. W. Straiton, and J. H. Douglas, "Studies of 2.15 MM Propagation at an Elevation of 4 KM and the Millimeter Spectrum," Elec. Engrg. Res. Lab., The University of Texas, Austin, Rept. No. 104; November 1, 1958.

[12] W. E. Patterson, "Absorption of Microwaves of Millimeter Wavelength by Atmospheric Water Vapor," Master's Thesis, The University of Texas, Austin; June, 1957.

[13] C. W. Tolbert, A. W. Straiton, and C. O. Britt, "Propagation Studies Between 18.0 and 25.5 KMCS," Elec. Engrg. Res. Lab., The University of Texas, Austin, Rept. No. 110; July 10, 1959.

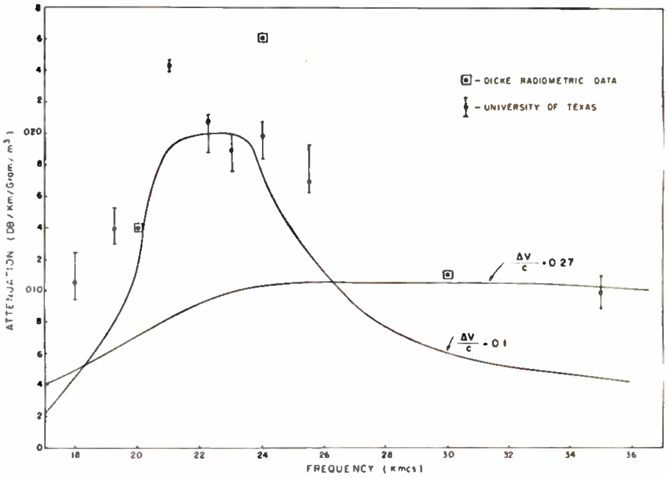


Fig. 4—Water vapor losses in 18.0- to 25.5-kmc spectrum.

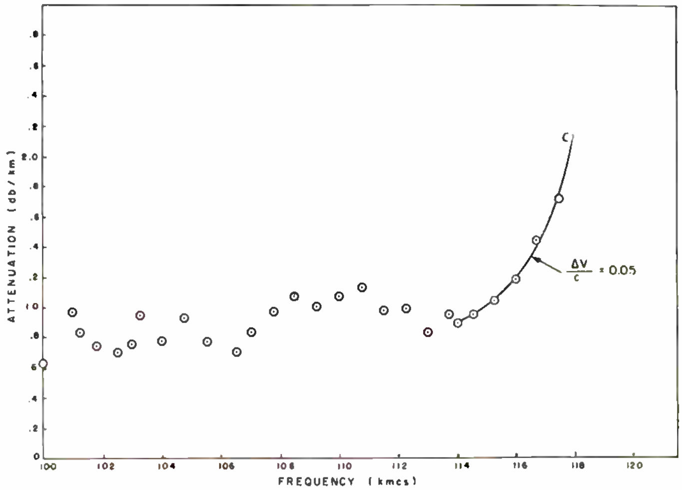


Fig. 5—Attenuation adjusted to standard atmosphere.

## Measurements in the 2.5 to 3.0-mm Region

### *Water Vapor Losses*

The University of Texas has recently completed a series of measurements in the wavelength region from 2.5 to 3.0 mm.[14] Sufficient data were taken to obtain the slope of the water vapor line at frequencies of 100, 104.75, 110, 113 and 117.5 kmc, and these five points are shown in Fig. 2. Two anomalies are seen from these data. In the first place, the level of the attenuation is approximately 50 per cent higher than would be indicated by the Van Vleck-Weisskopf equation even for a line breadth constant of 0.27 $cm^{-1}$. In the second place, the loss at 110 kmc is greater than the loss at the other four frequencies. Although no water vapor line has been predicted at 110 kmc, the increased attenuation at this frequency indicates that such a line may exist.

In addition to the five frequencies at which sufficient data were taken to obtain the water vapor slope, one or more soundings were made at 23 other frequencies in this region. The data were adjusted to the 7.5-grams-per-cubic-meter atmosphere by using a water vapor line slope obtained by interpolating between the values measured at the five frequencies. This may be done with some confidence since the correction applied was a function of the deviation from the standard atmosphere condition. The attenuation adjusted to the standard atmosphere is then shown in Fig. 5.

### *Oxygen Losses*

From the shape of the smooth curve drawn through the higher frequency points, an oxygen absorption line may be fitted. It was found that a line with a resonant frequency of 118.75, a maximum attenuation of 1.7 db/km and a line breadth constant of 0.05 $cm^{-1}$ would give the measured shape.

The line breadth constant at this frequency had been found by Anderson, *et al.*,[15] to be 0.12 $cm^{-1}$ at one atmosphere by laboratory methods. These measurements were made at a temperature of 190° K. A temperature correction to 300° K may be made using the line breadth as inversely proportional to temperature as measured by Hill and Gordy,[16] but the corrected value is still considerably greater than that determined by the propagation measurements.

A similar discrepancy exists around the 5-mm lines. Artman and Gordon[17] determined a line breadth of 0.049 $cm^{-1}$ from laboratory measurements on pure $O_2$ and $O_2$-$N_2$ mixtures. Propagation measurements by Bell Telephone Laboratories and The University of Texas have indicated that the line breadth constant should be nearer 0.02 $cm^{-1}$.[10,18]

### *Losses Due to Rare Gases*

The data in the region from 100 to 106 kmc were found to be erratic with day-to-day variations which did not correlate with the water vapor density changes. It was therefore felt that these losses were due to some of the rarer gases in the atmosphere such as $N_2O$, $NO_2$, $SO_2$, and $O_3$, which have resonant frequencies in this general area. These irregular losses were about 0.2 db/km during the measurement period.

[14] C. W. Tolbert, C. O. Britt, and J. H. Douglas, "Radio Propagation Measurements in the 110 to 118 KMCS Spectrum," Elec. Engrg. Res. Lab., The University of Texas, Austin, Rept. No. 107; April 15, 1959.

[15] R. S. Anderson, C. M. Johnson, and W. Gordy, "Resonant absorption of oxygen at 2.5 millimeters wavelength," *Phys. Rev.*, vol. 83, pp. 1061–1062; 1951.

[16] R. M. Hill and W. Gordy, "Temperature dependence of the line breadth of oxygen," *Phys. Rev.*, vol. 91, p. 222; July 1, 1953.

[17] J. O. Artman and J. P. Gordon, "Absorption of microwaves by oxygen in the millimeter region," *Phys. Rev.*, vol. 96, pp. 1237–1245; December 1, 1954.

[18] C. W. Tolbert, J. H. Douglas, and C. O. Britt, "Measured Absorption of Millimeter Wavelengths by Oxygen at Partial Atmospheric Pressures," Elec. Engrg. Res. Lab., The University of Texas, Austin, Rept. No. 100; May 15, 1958.

### Change in Attenuation with Pressure

High elevation measurements have been made by The University of Texas at wavelengths of 8.6,[19] 4.3[20] and 2.15[11] mm. These data were taken over paths between mountain peaks in Colorado with elevations from 12,000 to 14,000 feet. Losses due to water vapor were measured at all three wavelengths and the loss due to oxygen was measured at 4.3 mm. The oxygen losses at 8.6 and 2.15 were too small to measure with accuracy. The results of these measurements are shown in Table I.

TABLE I

| Wavelength (mm) | Attenuation in db/km | |
|---|---|---|
| | Water Vapor (1g/m³) | Oxygen |
| 8.6 | 0.03 | |
| 4.3 | 0.10 | 0.22 |
| 2.15 | 0.12 | |

It is generally assumed that at the resonant frequency the loss for the same concentration of the absorbing gas will be the same regardless of the total pressure of the atmosphere. It is also assumed that the line breadth constant is proportional to the total pressure.

The losses for the higher altitude may be calculated from the Van Vleck-Weisskopf equation by adjusting the line breadth constant for the pressure change starting with line breadth constants at one atmosphere of 0.27 $cm^{-1}$ for water vapor, and 0.02 $cm^{-1}$ for oxygen. Losses calculated on this basis were found to agree reasonably well with the measurements.

In the light of recent anomalies at 1.35 cm and 2.6 mm, however, it would be expected that additional anomalies may be found at high altitudes for other wavelengths. The use of the Van Vleck-Weisskopf equation for higher altitudes should then be limited to the part of the spectrum in which the measurements were made.

### Discussion of Deviation of Measured and Predicted Absorption Values

In trying to fit the measured points with the Van Vleck-Weisskopf line broadening equation, we find that the use of a single line breadth constant is inadequate. The data may be approximately fitted by introducing a number of line strength and line width constants. In so doing, however, the equation loses much of its simplicity and utility. Some of the relationships that account for the anomalies will be discussed in this section.

[19] C. W. Tolbert and A. W. Straiton, "Radio Propagation Measurements Between Pike's Peak and Mount Evans at a Wavelength of 8.6 Millimeters," Elec. Engrg. Res. Lab., The University of Texas, Austin, Rept. No. 77; September 30, 1955.

[20] C. W. Tolbert and A. W. Straiton, "Radio Propagation Measurements Between Pike's Peak and Mount Evans at a Wavelength of 4.3 Millimeters," Elec. Engrg. Res. Lab., The University of Texas, Austin, Rept. No. 88; November 22, 1956.

#### *Variation of Line Breadth Constant from Line to Line*

Benedict and Kaplan[21] point out that there is considerable theoretical and experimental evidence that the line width for the various water vapor lines is different depending on the rotational states involved. With the imposing array of lines which influence millimeter absorption, the absorption-frequency curve could take on a wide variety of shapes. The general effect would be that of having a greater increase in absorption with frequency as the shorter millimeter wavelengths are approached. This has been the general trend in the measured water vapor loss since the ratio of the measured losses to those predicted by Van Vleck vary from three to ten as the frequency goes from 35 to 140 kmc.

#### *Possibility of Unpredicted Lines*

The measurements in the 100- to 118-kmc range indicated that a water vapor line occurs at 110 kmc. Although no line has been predicted at this frequency, it would not be surprising if one did occur because of the very complex nature of the water vapor transitions.

An alternate explanation of the water sensitive loss at 110 kmc is that an isotope of $H_2O$ or another of the rarer gases in the atmosphere would vary in concentration in proportion to the water vapor density. There is, however, little theoretical justification of the increased attenuation on this basis.

The effect of some of the rarer gases was observed in the 100- to 106-kmc region where erratic losses of approximately 0.2 db/km were noted. These losses did not vary in proportion to the water vapor concentration, but changed inconsistently from day to day. This is the only region where these effects could be noted, although they might be expected at other frequencies to a lesser amount.

#### *Nonlinearity of Water Vapor Absorption*

Water vapor absorption curves as a function of water vapor concentration as measured by The University of Texas and by Bell Telephone Laboratories have shown a tendency to increase faster with water vapor concentration than at a straight line rate. The range of water vapor concentration and the variability of the result have made it difficult to determine the exact deviation from a straight line.

If such nonlinearity does exist, it must be due to the fact that $H_2O$-$H_2O$ molecular collisions have a much greater effect on line broadening than do $H_2O$-Air collisions. Becker and Autler estimate a ratio of 5 in the cross section of the $H_2O$-$H_2O$ collision as compared to the $H_2O$-Air collision.

[21] W. S. Benedict and L. D. Kaplan, "Calculation of line width in $H_2O$-$N_2$ collisions," *J. Chem. Phys.*, vol. 30, pp. 388–399; February, 1959.

*Limitation on Van Vleck-Weisskopf Equation*

As pointed out by Van Vleck,[2] an explanation of the deviation of theoretical and experimental determinations of atmospheric absorption could result from limitations of the Van Vleck-Weisskopf equation in the far wings. The validity of this equation when the line widths are in the same order of magnitude as the resonant frequency has been questioned.

On the high-frequency side of the absorption lines, the Van Vleck-Weisskopf equation predicts that the loss will approach a constant. This is known to break down in the infrared region, but the extent of its validity is difficult to predict.

The Van Vleck-Weisskopf equation is based entirely on the broadening of the absorption lines by collisions of the molecules. Other factors which affect line broadening include Doppler broadening, saturation broadening, and radiation broadening. Each of these effects has been discussed by Rogers.[22] Although these other broadening factors are generally considered to be negligible, the possibility of their making a significant contribution should not be overlooked.

## Conclusions

Measurements of the absorption of microwaves by the atmosphere have indicated that theoretical predictions of the losses are not entirely satisfactory. Oxygen losses in the vicinity of the absorption lines may be explained satisfactorily by the proper choices of the line breadth constants. The line breadth constants are, however, lower than those predicted on the basis of nonpropagation-type laboratory measurements.

The measured water vapor losses are consistently higher than predicted. No single line breadth constant will satisfactorily explain the experimental data.

It is felt, therefore, that the extension of experimental absorption data to frequencies, pressures, or mixture ratios considerably different from those used in the measurement programs should be avoided.

## Appendix

### Van Vleck-Weisskopf Equation

If a single spectral line, remote from all others, is considered, the attenuation in decibels per kilometer of an incoming electromagnetic wave is given by

$$\gamma = \frac{[10^6 \log_{10} e] 8\pi^2 N p \nu^2 |\mu_{JJ'}|^2 e^{-W_J/kT} S}{3ckTGP}$$

where

$\gamma$ = absorption coefficient, in decibels per kilometer

$c$ = speed of light $= 2.9979 \times 10^{10}$ cm per second

$k$ = Boltzmann's constant $= 1.3802565 \times 10^{-16}$ erg per degree Kelvin

$p$ = partial vapor pressure of the absorbing gas, in mm of Hg

$P$ = total pressure of the atmosphere, in mm of Hg

$T$ = temperature of the atmosphere, in degrees Kelvin

$G$ = rotational partition function of the absorbing gas (dimensionless)

$N$ = number of molecules per cubic centimeter in the atmosphere $= 9.66 \times 10^{18} \times P/T$

$\nu$ = frequency of the incoming electromagnetic wave, in cycles per second

$W_J$ = the energy of the absorbent lower rotational state $J$, in cm$^{-1}$

$|\mu_{JJ'}|^2$ = square of the dipole moment matrix element associated with the absorbent rotational transition $J \rightarrow J'$, inclusive of the static dipole moment and weighting factors (dimensionless)

$S$ = the modified structure factor

$$= \frac{\Delta\nu}{(\nu_{JJ'} - \nu)^2 + (\Delta\nu)^2} + \frac{\Delta\nu}{(\nu_{JJ'} + \nu)^2 + (\Delta\nu)^2}$$

where

$\Delta\nu$ = absorption line half-intensity half-width, in cycles per second

$\nu_{JJ'}$ = the center or resonant frequency of the absorbent rotational transition $J \rightarrow J'$, in cycles per second.

As used throughout this paper, the line breadth constant is taken as $\Delta\nu/c$ with the unit of cm$^{-1}$.

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# Interaction Impedance Measurements by Propagation Constant Perturbation*

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*Summary*—**The perturbation in the complex propagation constant of a lossy, nonreciprocal, periodic waveguide produced by the insertion of a rod, which may be cylindrical or periodic, parallel to the waveguide axis is developed. The application to the experimental determination of the interaction impedance and electromagnetic field distribution of waveguides is presented, together with the approximations which are applicable. The perturbation formulas for three particular classes of circuit—lossless, reciprocal, cylindrical circuits; lossy, nonreciprocal, cylindrical circuits; and lossy, nonreciprocal, periodic circuits—of interest for traveling wave tubes and other extended interaction microwave tubes, are derived and the limitations discussed. Explicit interaction impedance relations for these circuits in terms of the phase constant perturbation, caused by a cylindrical or periodic rod, are given.**

## I. Introduction

PERTURBATION techniques have proved to be useful for determining experimentally the electromagnetic field distributions both in resonant microwave structures, such as klystron cavities, and propagating structures, such as slow wave circuits for traveling wave tubes. In particular, the determination of the interaction impedance $Z = E^2/2\beta^2 S$ of traveling wave tube circuits is readily accomplished using perturbation measurements ($S$ is the total power on the circuit, $\beta$ is the propagation constant, and $E$ is the peak longitudinal electric field strength at the position where the electron beam will be located). The techniques for using a resonated section of the circuit (resonated using shorting plates) and obtaining the interaction impedance from a measurement of the change in resonant frequency of the section caused by the insertion of a small dielectric or metallic bead are well known.[1,2] One formulation of the relationship between the perturbing bead parameters, the change in the resonant frequency, and the electromagnetic fields in the resonant section which has a close relation to the treatment presented here has been given by Casimir.[3] There have been many others as well.[4–7] Of course, the converse procedure of using the change in resonant frequency and $Q$ of a standard cavity to investigate the dielectric and magnetic parameters of small samples of material introduced into the cavity is also well known.

For stability reasons, most traveling wave tube circuits are intentionally made somewhat lossy. These lossy circuits are not amenable to the resonant section technique because of their low $Q$ and the resulting difficulty in measuring the resonant frequency accurately. In addition, there has been some interest in recent years in using ferrite loaded circuits to obtain nonreciprocal attenuation properties, and these circuits are not readily adapted to conventional resonant section perturbation techniques because of the nonreciprocity. Therefore, measurement techniques which are applicable to propagating circuits and use the perturbation of the propagation constant by a bead or rod to determine the electromagnetic field pattern and the interaction impedance are necessary. Of course, the propagation constant perturbation and the resonant frequency perturbation measurements are complementary and closely related. For example, measurements on a propagating circuit might be made by determining the change in applied frequency necessary to hold the propagation constant unchanged when a perturbing object is inserted. However, attention will be confined here to constant frequency measurements in which the propagation constant is perturbed.

Measurements of the interaction impedance of slow wave circuits using the technique of the perturbation of the propagation constant are, of course, not new.[2] Kino[8] has given a derivation of the propagation constant perturbation caused by a dielectric or metallic rod in a lossy, periodic, reciprocal system using normal mode techniques. Lagerstrom[9] has considered lossless, peri-

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odic, reciprocal systems and analyzed in some detail the effects of perturbing rod size as well as periodic rods. The treatment here will be applicable to lossy, periodic, nonreciprocal structures and is based on a field theory approach which gives a direct derivation of an exact relationship and facilitates the evaluation of approximations convenient for measurements. The derivation is basically analogous to Casimir's[3] treatment of lossless resonant cavities, but is a generalization and adaptation applicable to lossy, periodic, nonreciprocal, propagating structures. Several related treatments are also of interest. Goubau[10] has discussed the perturbation of the input impedance of an electromagnetic system caused by the insertion of a test body, while Redfield[11] has considered the perturbation of the admittance matrix of an electrodynamic system. Auld[12] has developed a related perturbation theorem for the scattering matrix at a junction.

## II. Derivation of Basic Equations

Consider a waveguide of arbitrary cross section which is periodic with period $L$ in the direction of propagation $z$ and which has a single frequency wave propagating in the $z$ direction. It is assumed that only one of the possible modes of the structure is excited. By Floquet's theorem, the fields in the waveguide may be written as

$$\begin{aligned} \boldsymbol{E}_i(x, y, z, t) &= \boldsymbol{E}_0(x, y, z)e^{j\omega t-\Gamma_0 z} \\ &= \sum_n \boldsymbol{E}_{0n}(x, y)e^{j\omega t-(\Gamma_0+j2\pi n/L)z}, \quad (1a) \end{aligned}$$

$$\begin{aligned} \boldsymbol{H}_i(x, y, z, t) &= \boldsymbol{H}_0(x, y, z)e^{j\omega t-\Gamma_0 z} \\ &= \sum_n \boldsymbol{H}_{0n}(x, y)e^{j\omega t-(\Gamma_0+j2\pi n/L)z}, \quad (1b) \end{aligned}$$

where the propagation constant $\Gamma_0=\alpha_0+j\beta_0$ is complex for a lossy waveguide. Note that $\boldsymbol{E}_0$ and $\boldsymbol{H}_0$ are periodic in $z$ with period $L$, while the space harmonic field amplitudes $\boldsymbol{E}_{0n}$ and $\boldsymbol{H}_{0n}$ are independent of $z$. If the waveguide is cylindrical rather than periodic, all the $\boldsymbol{E}_{0n}$ and $\boldsymbol{H}_{0n}$ for $n\neq 0$ are zero.

Now let a rod be inserted into the waveguide parallel to, but not necessarily coinciding with, the $z$ axis. The "rod" may be either uniform in cross section, or be periodic in $z$ with period $L$, *e.g.*, a series of beads spaced at intervals equal to $L$. Hereafter, the term "rod" will refer to either of these configurations unless explicitly stated to the contrary. The final fields after the insertion of the rod will be

$$\begin{aligned} \boldsymbol{E}_f(x, y, z, t) &= [\boldsymbol{E}_0(x, y, z) + \boldsymbol{E}_1(x, y, z)]e^{j\omega t-(\Gamma_0+\Gamma_1)z} \\ &= \sum_n [\boldsymbol{E}_{0n}(x, y) + \boldsymbol{E}_{1n}(x, y)]e^{j\omega t-(\Gamma_0+\Gamma_1+j2\pi n/L)z} \quad (2a) \end{aligned}$$

$$\begin{aligned} \boldsymbol{H}_f(x, y, z, t) &= [\boldsymbol{H}_0(x, y, z) + \boldsymbol{H}_1(x, y, z)]e^{j\omega t-(\Gamma_0+\Gamma_1)z} \\ &= \sum_n [\boldsymbol{H}_{0n}(x, y) + \boldsymbol{H}_{1n}(x, y)]e^{j\omega t-(\Gamma_0+\Gamma_1+j2\pi n/L)z}. \quad (2b) \end{aligned}$$

It is assumed that only a single mode of the perturbed system has been excited, with a propagation constant $\Gamma_0+\Gamma_1=\alpha_0+\alpha_1+j(\beta_0+\beta_1)$, and that this mode has a field distribution which is roughly similar to that of the original mode.

From Maxwell's curl equations,

$$\nabla \times \boldsymbol{E}_0 - \Gamma_0(\boldsymbol{k} \times \boldsymbol{E}_0) = -j\omega \boldsymbol{B}_0, \quad (3a)$$

$$\nabla \times \boldsymbol{H}_0 - \Gamma_0(\boldsymbol{k} \times \boldsymbol{H}_0) = j\omega \boldsymbol{D}_0, \quad (3b)$$

$$\nabla \times \boldsymbol{E}_1 - (\Gamma_0 + \Gamma_1)(\boldsymbol{k} + \boldsymbol{E}_1) - \Gamma_1(\boldsymbol{k} \times \boldsymbol{E}_0) = -j\omega \boldsymbol{B}_1, \quad (3c)$$

$$\nabla \times \boldsymbol{H}_1 - (\Gamma_0 + \Gamma_1)(\boldsymbol{k} \times \boldsymbol{H}_1) - \Gamma_1(\boldsymbol{k} \times \boldsymbol{H}_0) = j\omega \boldsymbol{D}_1, \quad (3d)$$

where $\boldsymbol{k}$ is a unit vector in the $z$ direction. By multiplying (3c) and (3d), respectively, by $\boldsymbol{H}_0^*$ and $\boldsymbol{E}_0^*$ (* denotes complex conjugate), combining, and using a vector identity,

$$\begin{aligned} \boldsymbol{E}_0^*\cdot\nabla\times\boldsymbol{H}_1 - \boldsymbol{H}_0^*\cdot\nabla\times\boldsymbol{E}_1 &= -\nabla\cdot(\boldsymbol{E}_0^*\times\boldsymbol{H}_1 + \boldsymbol{E}_1\times\boldsymbol{H}_0^*) \\ &\quad -\boldsymbol{E}_1\cdot\nabla\times\boldsymbol{H}_0^* + \boldsymbol{H}_1\cdot\nabla\times\boldsymbol{E}_0^* \\ &= -\Gamma_1\boldsymbol{k}\cdot(\boldsymbol{E}_0\times\boldsymbol{H}_0^* + \boldsymbol{E}_0^*\times\boldsymbol{H}_0) - (\Gamma_0+\Gamma_1)\boldsymbol{k} \\ &\quad \cdot(\boldsymbol{E}_1\times\boldsymbol{H}_0^* + \boldsymbol{E}_0^*\times\boldsymbol{H}_1) + j\omega(\boldsymbol{E}_0^*\cdot\boldsymbol{D}_1 + \boldsymbol{H}_0^*\cdot\boldsymbol{B}_1). \quad (4) \end{aligned}$$

After multiplication by $\exp(-2\alpha_0 z)$ and utilization of a vector identity, integration over one period of the waveguide, and the application of Gauss' theorem, there results

$$\begin{aligned} &\Gamma_1 \iiint_V \boldsymbol{k}\cdot(\boldsymbol{E}_0\times\boldsymbol{H}_0^* + \boldsymbol{E}_0^*\times\boldsymbol{H}_0)e^{-2\alpha_0 z}dv \\ &+ \Gamma_1 \iiint_V \boldsymbol{k}\cdot(\boldsymbol{E}_0^*\times\boldsymbol{H}_1 + \boldsymbol{E}_1\times\boldsymbol{H}_0^*)e^{-2\alpha_0 z}dv \\ &= j\omega \iiint_V (\boldsymbol{E}_0^*\cdot\boldsymbol{D}_1 - \boldsymbol{D}_0^*\cdot\boldsymbol{E}_1 + \boldsymbol{H}_0^* \\ &\qquad \cdot\boldsymbol{B}_1 - \boldsymbol{B}_0^*\cdot\boldsymbol{H}_1)e^{-2\alpha_0 z}dv \\ &+ \iint_A \boldsymbol{n}\cdot(\boldsymbol{E}_0^*\times\boldsymbol{H}_1 + \boldsymbol{E}_1\times\boldsymbol{H}_0^*)e^{-2\alpha_0 z}da. \quad (5) \end{aligned}$$

Here $V$ denotes a volume corresponding to one period of the waveguide, $A$ denotes the surface area enclosing this volume, and $\boldsymbol{n}$ is a unit vector normal to this surface, directed outward. Any currents present in materials with finite conductivity are included in the electric displacement vectors $\boldsymbol{D}_0$ and $\boldsymbol{D}_1$ by having the imaginary part of the dielectric constant include the conductivity as well as the dielectric loss term.

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We note that $D_0 = \hat{\epsilon}_i \cdot \hat{E}_0$ and $B_0 = \hat{\mu}_i \cdot H_0$, where $\hat{\epsilon}_i$ and $\hat{\mu}_i$ are the dielectric constant and permeability of the material in the waveguide prior to the insertion of the perturbing rod. These, in general, will be functions of position within the waveguide and complex to account for losses. The circumflex indicates that these may be tensor quantities, as is, for example, the permeability of a ferrite material. Also, in all regions external to the perturbing rod, $D_1 = \hat{\epsilon}_i \cdot E_1$ and $B_1 = \hat{\mu}_i \cdot H_1$. Since it is assumed that the rod is inserted only into regions which were previously empty, (5) may be rewritten as

$$\begin{aligned}
\Gamma_1 \iiint_V & k\cdot(E_0 \times H_0^* + E_0^* \times H_0)e^{-2\alpha_0 z}dv \\
&+ \Gamma_1 \iiint_V k\cdot(E_0^* \times H_1 + E_1 \times H_0^*)e^{-2\alpha_0 z}dv \\
&= j\omega \iiint_{\delta V} (\epsilon_0 E_0^*\cdot P + \mu_0 H_0^*\cdot M)e^{-2\alpha_0 z}dv \\
&+ j\omega \iiint_{V-\delta V} \left[E_0^*\cdot(\hat{\epsilon}_i E_1) - E_1\cdot(\hat{\epsilon}_i\cdot E_0)^* + H_0^* \right. \\
&\qquad \left. \cdot(\hat{\mu}_i\cdot H_1) - H_1\cdot(\hat{\mu}_i\cdot H_0)^*\right]e^{-2\alpha_0 z}dv \\
&+ \iint_A n\cdot(E_0^* \times H_1 + E_1 \times H_0^*)e^{-2\alpha_0 z}da, \qquad (6)
\end{aligned}$$

where $P = D_1/\epsilon_0 - E_1$ and $M = B_1/\mu_0 - H_1$ are the polarization and magnetization of the rod. $\delta V$ denotes the volume of one period of the rod and $V - \delta V$ denotes the volume of one period of the waveguide exclusive of the rod volume. Eq. (6) is an exact expression relating the change in the propagation constant to the fields and the rod parameters. The first integral on the left is recognized to be four times the time average power in the $z$ direction of the original unperturbed circuit integrated over a length in the $z$ direction equal to one period of the structure. Thus, the first term on the left can be put in the form,

$$\Gamma_1 \iiint_V k\cdot(E_0 \times H_0^* + E_0^* \times H_0)e^{-2\alpha_0 z}dv = 4\Gamma_1 \int_z^{z+L} S_0(z)dz, \qquad (7)$$

where $S_0(z)$ represents the time average power in the $z$ direction. $S_0(z)$ is, of course, real so that by taking the real and imaginary parts of (6), expressions for $\alpha_1$ and $\beta_1$ can be obtained.

The integrals in (6) are taken over one complete period of the structure; this is precisely defined for the $z$ direction, but is somewhat vague for the transverse directions. For structures with enclosing, perfectly conducting walls, it suffices to integrate over the volume enclosed by the walls. In this case, of course, all the fields external to the region enclosed by the walls are zero. For open boundary structures, *e.g.*, an unshielded helix, the fields exist out to infinity, and one must integrate out to infinity in the transverse directions. For structures with imperfectly conducting walls, the fields will again extend out to infinity in the transverse directions. Those fields external to the walls are clearly negligible when the waveguide walls are made of the usual metals. However, to cover all possible cases here, we will integrate out to infinity in the transverse directions, but we recognize that for many important cases the contribution from the fields external to the waveguide walls will be completely negligible. By integrating out to infinity, the surface integral of (6) may be simplified because the fields will go to zero at infinity for structures that propagate a mode carrying finite power in the $z$ direction. Thus, in all cases there will be a contribution to the surface integral possible only over planes that are normal to the $z$ axis.

Using this simplification, (6) may be written as

$$\begin{aligned}
4\Gamma_1 & \int_z^{z+L} S_0(z)dz \\
&+ \Gamma_1 \iiint_V k\cdot(E_0^* \times H_1 + E_1 \times H_0^*)e^{-2\alpha_0 z}dv \\
&= j\omega \iiint_{\delta V} (\epsilon_0 E_0^*\cdot P + \mu_0 H_0^*\cdot M)e^{-2\alpha_0 z}dv \\
&+ j\omega \iiint_{V-\delta V} \left[E_0^*\cdot(\hat{\epsilon}_i\cdot E_1) - E_1(\hat{\epsilon}_1\cdot E_0)^* + H_0^* \right. \\
&\qquad \left. \cdot(\hat{\mu}_i\cdot H_1) - H_1\cdot(\hat{\mu}_i\cdot H_0)^*\right]e^{-2\alpha_0 z}dv \\
&- (1 - e^{-2\alpha_0 L})e^{-2\alpha_0 z} \iint_{A_c} k \\
&\qquad \cdot(E_0^* \times H_1 + E_1 \times H_0^*)da. \qquad (8)
\end{aligned}$$

Here $A_c$ represents the waveguide cross section at $z = z$ or $z = z + L$ (the cross section at these two points is the same because of the periodicity). As noted above, $A_c$ may extend out to infinity. It should be observed that the equality in (8) is independent of the value of $z$ chosen.

## III. Application to Interaction Impedance Measurements

Eq. (8) is the basic equation with which we will deal. As it stands, it is too cumbersome to be useful in practice, but in many cases of interest, approximations can be made which render it useful for the experimental measurement of the interaction impedance. In order to determine what approximations are valid and their implications, several special cases will be examined in some detail.

### A. Lossless, Reciprocal, Cylindrical Waveguides

In this case $\alpha_0 = 0$, the dielectric constant and permeability are real scalars, and since only the fundamental space harmonic fields exist, each of the integrands in (8) has the same $z$ dependence, exp $(-2\alpha_0 z)$, and the integration over $z$ may be omitted. $\beta_1$ is found by adding (8) to its complex conjugate.

$$\beta_1 = \omega \frac{\iint_{\delta A} [\epsilon_0(E_0^* \cdot P + E_0 \cdot P^*) + \mu_0(H_0^* \cdot M + H_0 \cdot M^*)]da}{8S_0 + \iint_{A_c} k \cdot (E_0^* \times H_1 + E_0 \times H_1^* + E_1 \times H_0^* + E_1^* \times H_0)da}. \tag{9}$$

$\delta A$ denotes the cross section of the perturbing rod which is cylindrical.

It will be observed that, so far, no restrictions have been placed on the constancy of the power before and after the rod insertion. Naturally, $\beta_1$ is independent of the power level, but the individual integrals in (9) will vary with the power. For convenience, we will arbitrarily demand that the power level be kept constant throughout the measurements. That is,

$$S_0 = S_0 + S_1, \tag{10a}$$

$$S_1 = 0, \tag{10b}$$

where $S_1$ is the change in power,

$$S_1 = \frac{1}{4} \iint_{A_c} k \cdot (E_0 \times H_1^* + E_0^* \times H_1 + E_1 \times H_0^* + E_1^* \times H_0 + E_1 \times H_1^* + E_1^* \times H_1)e^{-2\alpha_0 z}da. \tag{11}$$

Therefore,

$$\iint_{A_c} k \cdot (E_1 \times H_1^* + E_1^* \times H_1)e^{-2\alpha_0 z}da = -\iint_{A_c} k \cdot (E_0 \times H_1^* + E_0^* \times H_1 + E_1 \times H_0^* + E_1^* \times H_0)e^{-2\alpha_0 z}da. \tag{12}$$

It should be noted that (12) is general and holds for lossy, nonreciprocal, periodic waveguides as long as the power is held constant.

$$\beta_1 = \omega \frac{\iint_{\delta A} [\epsilon_0(E_0^* \cdot P + E_0 \cdot P^*) + \mu_0(H_0^* \cdot M + H_0 \cdot M^*)]da}{8S_0 - \iint_{A_c} k \cdot (E_1 \times H_1^* + E_1^* \times H_1)da}. \tag{13}$$

This expression, which is exact, can be simplified by making two assumptions about the perturbing rod's parameters. 1) The rod's cross-sectional dimensions are small compared to the waveguide dimensions and the wavelength of the propagating wave. 2) The combined effect of the perturbing rod's dielectric constant, permeability, and cross-sectional area is such that, external to the rod, the perturbation of the fields is small. These assumptions imply that $|\beta_1| \ll \beta_0$.

As a consequence of these assumptions, we can relate the components of the polarization and magnetization in the rod to the components of the initial electric and magnetic fields at the rod location through the use of the effective electric and magnetic susceptibilities $\chi_e$ and $\chi_m$ of the rod material and the effective depolarizing and demagnetizing factors for the rod geometry. This use of geometrical factors implies that the rod cross section is at least elliptical. The polarization and magnetization components are given by $P_x = \chi_e E_{0x}/(1 + N_{ex}\chi_e)$, $M_x = \chi_m H_{0x}/(1 + N_{mx}\chi_m)$, etc., where $N_{ex}$, $N_{mx}$ are the effective depolarizing and demagnetizing factors for fields in the $x$ direction. With the assumptions above, $N_e$ and $N_m$ are given by the static values for an elliptic body. When several field components are simultaneously present, then each will separately produce a perturbation whose magnitude depends on the $N$ value for the particular direction. The geometry of the rod may be adjusted to emphasize or minimize the perturbation caused by the field in any particular direction by controlling the $N$ values.

The assumption that the fields in the rod are essentially uniform over the cross section means that the integrand in the numerator of (13) is independent of position in the rod. Finally, by assumption 2), it is seen that the second term in the denominator will be small compared to $4S_0$. Letting the subscript $r$ refer to the value of the fields at the rod location, the change in the propagation constant is approximately given by

$$\beta_1 \cong \omega \delta A \frac{\left[\frac{\epsilon_0 \chi_e}{1 + N_e \chi_e} |E_0|_r^2 + \frac{\mu_0 \chi_m}{1 + N_m \chi_m} |H_0|_r^2\right]}{4S_0}, \tag{14}$$

which is the customary expression.

It has also been tacitly assumed that the rod itself is lossless. If the rod were lossy, then one or both of $\chi_e$, $\chi_m$ would be complex and (14) would change slightly. Also, $\alpha_1$ could be written down by subtracting (8) from its complex conjugate. For cases where the fields are not uniform over the rod cross section so that using the static values of $N_e$ and $N_m$ is not justified, correction factors may be obtained by examining the integral in the numerator of (9) for particular cases (Lagerstrom[9] has discussed correction factors in some detail).

Eq. (14) indicates that, by using dielectric rods for which $\chi_m = 0$, or metallic rods so shaped as to emphasize the effective $\chi_e$ relative to the effective $\chi_m$, the interaction impedance can be obtained by measuring $\beta_0$, $\beta_1$, and the rod parameters.

$$Z = \frac{|E_0|_r^2}{2\beta_0^2 S_0} \cong \frac{2\beta_1}{\omega\beta_0^2 \delta A \dfrac{\epsilon_0 \chi_e}{1 + N_e \chi_e}}. \qquad (15)$$

Eq. (15) also holds for lossless, reciprocal, periodic waveguides if the rod is cylindrical and inserted at a location where only one of the space harmonic fields has an appreciable magnitude. In this case, the impedance is that of the particular space harmonic, and $E_0$ should be replaced by $E_{0n}$ in (15).

### B. Lossy, Nonreciprocal, Cylindrical Waveguides

Again, since only the fundamental space harmonic can exist, all of the integrands of (8) have the same $z$ dependence so that integration over $z$ may be omitted. Eq. (8) now reduces to

$$4\Gamma_1 S_0(z) + \Gamma_1 \iint_{A_c} k\cdot(E_0^* \times H_1 + E_1 \times H_0^*)e^{-2\alpha_0 z}da$$
$$= j\omega \iint_{\delta A} (\epsilon_0 E_0^* \cdot P + \mu_0 H_0^* \cdot M)e^{-2\alpha_0 z}da$$
$$+ j\omega \iint_{A_c - \delta A} [E_0^* \cdot (\hat{\epsilon}_i \cdot E_1) - E_1 \cdot (\hat{\epsilon}_i \cdot E_0)^*$$
$$+ H_0^* \cdot (\hat{\mu}_i \cdot H_1) - H_1 \cdot (\hat{\mu}_i \cdot H_0)^* ]e^{-2\alpha_0 z}da. \qquad (16)$$

Inasmuch as the most important sources of nonreciprocal effects at microwave frequencies are ferrite materials, $\hat{\mu}_i$ will be taken as a tensor but $\hat{\epsilon}_i$ will be regarded as a scalar. Therefore, in the last integral of (16),

$$E_0^* \cdot (\hat{\epsilon}_i \cdot E_1) - E_1 \cdot (\hat{\epsilon}_i \cdot E_0)^* = E_0^* \cdot E_1 (\epsilon_i - \epsilon_i^*). \qquad (17)$$

$E_0^* \cdot E_1$ will be real in the lossless case and not far different for the usual range of traveling wave tube attenuation. $(\epsilon_i - \epsilon_i^*)$ will be nonzero only in regions where there is lossy dielectric material or material with finite conductivity. Since $(\epsilon_i - \epsilon_i^*)$ is pure imaginary, (17) will be nearly pure imaginary. Therefore, its contribution to $\beta_1$ will be negligible, although the contribution to $\alpha_1$ may be significant.

The situation regarding the magnetic field terms of the last integral in (16) is somewhat more complex. In general, there can be a contribution to $\beta_1$ from these terms even in the lossless case because of the off-diagonal elements of the permeability tensor. Thus, it is not clear in the general case what the relative magnitude of the contribution to $\beta_1$ from these terms will be. However, there is one important class of ferrite loaded waveguide structures about which more may be said. If the magnetic fields within the ferrite are circularly polarized in a plane perpendicular to the direction of the applied dc magnetic field, then the effective permeability tensor becomes diagonal.[13] If we assume that the perturbing rod is so located that the perturbed field is also circularly polarized in the ferrite, then

$$H_0^* \cdot (\hat{\mu}_i \cdot H_1) - H_1 \cdot (\hat{\mu}_i \cdot H_0)^* = H_0^* \cdot H_1(\mu_{cp} - \mu_{cp}^*), \qquad (18)$$

where $\mu_{cp}$ represents the effective permeability in this case. This is the same form that occurred in (17) so that the remarks made there apply here as well. It is reasonable to assume that, in the more practical cases where the fields are not exactly circularly polarized but are nearly so in the ferrite, the contribution to $\beta_1$ of the term in (18) will still be negligible. This case, where the ferrite is located in a circularly polarized microwave field, is the one of most practical importance and most widespread use in traveling wave tubes.

In the more general situation of arbitrary polarization of the fields in the ferrite, the contribution to $\beta_1$ of the tensor permeability terms will be small if the perturbation is such that the change in the field energy stored within the ferrite associated with the off-diagonal permeability elements is small compared to the total change in field energy stored in the whole structure.

Assuming, then, that the above discussion is applicable, and introducing the two assumptions made in Section III, A,

$$\beta_1 \cong \frac{\omega\delta A e^{-2\alpha_0 z}}{4S_0(z)}\left\{\frac{\epsilon_0}{2}\left[\left(\frac{\chi_e}{1+N_e\chi_e}\right) + \left(\frac{\chi_e}{1+N_e\chi_e}\right)^*\right]|E_0|_r^2 + \frac{\mu_0}{2}\left[\left(\frac{\chi_m}{1+N_m\chi_m}\right) + \left(\frac{\chi_m}{1+N_m\chi_m}\right)^*\right]|H_0|_r^2\right\}, \qquad (19a)$$

$$\alpha_1 \cong \frac{\omega\delta A e^{-2\alpha_0 z}}{4S_0(z)}\left\{\frac{\epsilon_0}{2}\left[\left(\frac{\chi_e}{1+N_e\chi_e}\right) - \left(\frac{\chi_e}{1+N_e\chi_e}\right)^*\right]|E_0|_r^2 + \frac{\mu_0}{2}\left[\left(\frac{\chi_m}{1+N_m\chi_m}\right) - \left(\frac{\chi_m}{1+N_m\chi_m}\right)^*\right]|H_0|_r^2\right\}$$
$$+ \frac{j\omega e^{-2\alpha_0 z}}{8S_0(z)} \iint_{A_c - \delta A} [(\epsilon_i - \epsilon_i^*)(E_0^* \cdot E_1 + E_0 \cdot E_1^*) + (\mu_{cp} - \mu_{cp}^*)(H_0^* \cdot H_1 + H_0 \cdot H_1^*)]da. \qquad (19b)$$

The expression for $\beta_1$ is in a form similar to (14) so that the remarks made there about the application to interaction impedance measurements apply here as well.

[13] D. Polder, "On the theory of ferromagnetic resonance," *Phil. Mag.*, vol. 40, pp. 99–115; January, 1949.

$$Z \cong \frac{4\beta_1}{\omega\beta_0^2\delta A\epsilon_0\left[\left(\frac{\chi_e}{1+N_e\chi_e}\right)+\left(\frac{\chi_e}{1+N_e\chi_e}\right)^*\right]}. \quad (20)$$

The expression for $\alpha_1$ reveals several interesting points. Under certain circumstances, a lossy rod may be used to make interaction impedance measurements by noting the change in attenuation of the structure when the rod is inserted. For this to be possible, the effective value of

$$\left(\frac{\chi_e}{1+N_e\chi_e}\right)-\left(\frac{\chi_e}{1+N_e\chi_e}\right)^*$$

relative to

$$\left(\frac{\chi_m}{1+N_m\chi_m}\right)-\left(\frac{\chi_m}{1+N_m\chi_m}\right)^*$$

must be large and the structure must either be originally low-loss and reciprocal, or the rod geometry and placement be such that the contribution to $\alpha_1$ from the last integral of (19b) be negligible. Under these conditions,

$$Z \cong \frac{4\alpha_1}{j\omega\delta A\beta_0^2\epsilon_0\left[\left(\frac{\chi_e}{1+N_e\chi_e}\right)-\left(\frac{\chi_e}{1+N_e\chi_e}\right)^*\right]}. \quad (21)$$

$\alpha_1$ may be either positive or negative in general, depending on the field distribution relative to the lossy regions before and after inserting the rod. For example, if a lossless, high dielectric constant rod is inserted along the center of a waveguide with lossy walls, then $\alpha_1$ will be negative because the rod causes an increased percentage of the total field energy to be concentrated in the lossless region. If this same rod were inserted along one of the waveguide walls, then $\alpha_1$ might be positive since the percentage of the total field energy in the lossy region might increase.

### C. Lossy, Nonreciprocal, Periodic Waveguides

For periodic structures it is necessary to retain the integration in $z$ over a complete period of the waveguide since $\boldsymbol{E}_0$, $\boldsymbol{E}_1$, $\boldsymbol{H}_0$, $\boldsymbol{H}_1$, etc., are periodic functions of $z$. $S_0(z)$ will no longer vary as $\exp(-2\alpha_0 z)$ although it is still true that $S_0(z+L)$ differs from $S_0(z)$ by $\exp(-2\alpha_0 L)$. The $z$ dependence of $S_0(z)$ will depend on the distribution of the lossy material in the waveguide. The discussion in Section III, $B$ relative to the contribution of the dielectric loss terms and the tensor permeability to $\beta_1$ and $\alpha_1$ applies to the periodic structure as well. Therefore, utilizing this and the assumptions made in Section III, $A$, (8) may be reduced to the following pair of equations for $\beta_1$ and $\alpha_1$,

$$\beta_1 \cong \frac{\omega\delta A\int_z^{z+L}\left\{\frac{\epsilon_0}{2}\left[\left(\frac{\chi_e}{1+N_e\chi_e}\right)+\left(\frac{\chi_e}{1+N_e\chi_e}\right)^*\right]\boldsymbol{E}_0\cdot\boldsymbol{E}_0^*+\frac{\mu_0}{2}\left[\left(\frac{\chi_m}{1+N_m\chi_m}\right)+\left(\frac{\chi_m}{1+N_m\chi_m}\right)^*\right]\boldsymbol{H}_0\cdot\boldsymbol{H}_0^*\right\}e^{-2\alpha_0 z}dz}{4\int_z^{z+L}S_0(z)dz}, \quad (22a)$$

$$\alpha_1 \cong -\frac{j\omega\delta A\int_z^{z+L}\left\{\frac{\epsilon_0}{2}\left[\left(\frac{\chi_e}{1+N_e\chi_e}\right)-\left(\frac{\chi_e}{1+N_e\chi_e}\right)^*\right]\boldsymbol{E}_0\cdot\boldsymbol{E}_0^*+\frac{\mu_0}{2}\left[\left(\frac{\chi_m}{1+N_m\chi_m}\right)-\left(\frac{\chi_m}{1+N_m\chi_m}\right)^*\right]\boldsymbol{H}_0\cdot\boldsymbol{H}_0^*\right\}e^{-2\alpha_0 z}dz}{4\int_z^{z+L}S_0(z)dz}$$

$$+\frac{j\omega\int_z^{z+L}\iint_{A_c-\delta A}\left[(\epsilon_i-\epsilon_i^*)(\boldsymbol{E}_0\cdot\boldsymbol{E}_1^*+\boldsymbol{E}_1\cdot\boldsymbol{E}_0^*)+(\mu_{cp}-\mu_{cp}^*)(\boldsymbol{H}_0\cdot\boldsymbol{H}_1^*+\boldsymbol{H}_1\cdot\boldsymbol{H}_0^*)\right]e^{-2\alpha_0 z}da\,dz}{8\int_z^{z+L}S_0(z)dz}. \quad (22b)$$

Each of the fields $\boldsymbol{E}_0$, $\boldsymbol{H}_0$, is made up of an infinite set of space harmonics. Because of the attenuation factor, $\exp(-2\alpha_0 z)$, the space harmonic fields are not orthogonal over the interval $L$ so that cross-product terms of the space harmonics will appear in the integrals if $\boldsymbol{E}_0$ and $\boldsymbol{H}_0$ are replaced by $\boldsymbol{E}_{0n}\exp(-j2\pi nz/L)$ and $\boldsymbol{H}_{0n}\exp(-j2\pi nz/L)$, respectively. Therefore, the propagation constant perturbation $\beta_1$ will be, in general, a measure of an averaged field in the rod.

If only one space harmonic field has an appreciable amplitude at the rod location, then a cylindrical rod that perturbs primarily the electric field

$$\frac{\chi_e}{1+N_e\chi_e} \gg \frac{\chi_m}{1+N_m\chi_m}$$

may be used. This leads to

$$\beta_1 \cong \omega\delta A \frac{(1 - e^{-2\alpha_0 L})e^{-2\alpha_0 z}}{8\alpha_0 \int_z^{z+L} S_0(z)dz} \frac{\epsilon_0}{2} \cdot \left[\left(\frac{\chi_e}{1 + N_e\chi_e}\right) + \left(\frac{\chi_e}{1 + N_e\chi_e}\right)^*\right] |E_{0n}|_r^2. \quad (23)$$

It is easily seen that if $\alpha_0$ approaches zero, (23) approaches (14) (with $\chi_m = 0$). If only a single space harmonic field is assumed to be present everywhere in the structure, then (23) approaches (19a) (with $\chi_m = 0$).

In some periodic circuits, $S_0(z)$ will still vary as $\exp(-2\alpha_0 z)$ so that (23) will simplify to (19a) in these cases. This is true, for example, for a helix inside a glass envelope with the lossy material distributed uniformly around the circumference. It would not be precisely true for a helix supported by lossy rods, but the discrepancy is probably not large. However, for the normal range of traveling wave tube attentuation, $\alpha_0 L$ will be small enough that

$$\frac{1 - e^{-2\alpha_0 L}}{2\alpha_0} \cong L \quad (24)$$

to a good approximation. Then (23) becomes

$$\beta_1 \cong \frac{\omega\delta A}{4}\left[\frac{e^{-2\alpha_0 z}}{\frac{1}{L}\int_z^{z+L} S_0(z)dz}\right]\frac{\epsilon_0}{2} \cdot \left[\left(\frac{\chi_e}{1 + N_e\chi_e}\right) + \left(\frac{\chi_e}{1 + N_e\chi_e}\right)^*\right] |E_{0n}|_r^2. \quad (25)$$

This relates $\beta_1$ to the average power in one period of the structure. For lossy, periodic circuits, the quantity

$$\frac{1}{Le^{-\alpha_0 2}} \int_z^{z+L} S_0(z)dz / Le^{-2\alpha_0 z}$$

is the proper average value of power to insert into the interaction impedance formula, so that

$$Z_n \cong \frac{4\beta_1}{\omega\delta A \beta_n^2 \epsilon_0 \left[\left(\frac{\chi_e}{1 + N_e\chi_e}\right) + \left(\frac{\chi_e}{1 + N_e\chi_e}\right)^*\right]}, \quad (26)$$

where $Z_n$ is the interaction impedance of the $n$th space harmonic, recalling that only the $n$th space harmonic has an appreciable amplitude at the rod location, and $\beta_n = \beta_0 + 2\pi n/L$. Thus, a cylindrical rod is an adequate perturbation for a lossy glass enclosed helix as well as a lossy rod supported helix if the measurements are made on the helix axis where only the fundamental space harmonic field exists.

In regions where several space harmonics have appreciable amplitudes, a periodic array of beads may be used to determine $Z_n$. It will probably be necessary to use beads whose geometry is such as to cause an anisotropic perturbation in order to determine the field along a particular direction of interest. One effective arrangement is to use an array of needle shaped beads. For large length-to-diameter ratios, these will cause a perturbation when there is a component of field parallel to the long dimension but relatively little perturbation for components perpendicular to this direction. If the bead length as well as the cross section is small compared to a wavelength, then the field inside each bead is uniform and (22a) becomes

$$\beta_1 \cong \frac{\omega\delta V_b e^{-2\alpha_0 z'} \frac{\epsilon_0}{2}\left[\left(\frac{\chi_e}{1 + N_e\chi_e}\right) + \left(\frac{\chi_e}{1 + N_e\chi_e}\right)^*\right](E_0 \cdot E_0^*)_{z'}}{4\int_z^{z+L} S_0(z)dz}, \quad (27)$$

where $z'$ denotes the position of the bead in the period of the structure under consideration. $\delta V_b$ is the volume of one bead. $(E_0^* \cdot E_0)_{z'}$ may be written as

$$(E_0 \cdot E_0^*)_{z'} = \sum_n \sum_m E_{0n} \cdot E_{0m}^* e^{-j2\pi(n-m)z'/L} \quad (28)$$

which displays the periodic nature of this term. If $\beta_1$ is measured as a function of bead position, $z'$, as the periodic array of beads is moved through one complete period of the structure, then $Z_n$ can be determined. The plot of $\beta_1$ vs $z'$ is seen from (27) and (28) to be given by a product of an exponential function $\exp(-2\alpha_0 z')$ and a periodic function $(E_0 \cdot E_0^*)_{z'}$. After extracting the exponential portion, the remaining periodic curve can be Fourier analyzed to determine the amplitudes of the space harmonic fields. From this, of course, the interaction impedance can be calculated.

## IV. Conclusions

General relations for the perturbation of the real and imaginary parts of the propagation constant of lossy, nonreciprocal, periodic waveguides by a perturbing rod placed parallel to the axis have been developed. The rod may be either cylindrical or periodic, and lossless or lossy. Approximate formulas valid when the perturbation is small are readily obtained if the rod cross section is small compared to the wavelength so that the fields may be considered uniform, or nearly so, inside the rod.

The application of the propagation constant perturbation formulas to the measurement of the interaction impedance of propagating structures can be made, and