FEBRUARY · 1955

Proceedings of the I·R·E

A Journal of Communications and Electronic Engineering

THE SIGNAL CORPS' NEW HOME

Signal Corps Engineering Laboratory

The Signal Corps Engineering Laboratory at Fort Monmouth, N.J., formerly housed in more than four hundred separated structures, is now moving into the new building shown here. When the hexagonal-shaped structure is completed, it will be one of the largest buildings devoted to research and development in the United States.

Volume 43 Number 2

IN THIS ISSUE

TABLE OF CONTENTS INDICATED BY BLACK-AND-WHITE MARGIN, FOLLOWS PAGE 80A

IRE Standards on Radio Aids to Navigation: Definitions of Terms appear in this issue.

The Institute of Radio Engineers

OUR 10 MILLIONTH MILITARY UNIT SHIPPED THIS YEAR

Military Components
FOR EVERY APPLICATION

A HUNDRED STOCK UNITS in our catalog B . . . 30,000 special designs

POWER COMPONENTS

The scope of military power components produced at UTC ranges from 500 lb. plate transformers to miniaturized 2 oz. units . . . hermetically sealed and encapsulated . . . molded types.

FILTERS

UTC filters, equalizers and discriminators are produced in designs from .1 cycles to 400 mc. Carrier, aircraft, and telemetering types available in standard designs.

ENCAPSULATED UNITS

8 years of encapsulation experience assure maximum reliability in this class of UTC material.

MOLDED UNITS

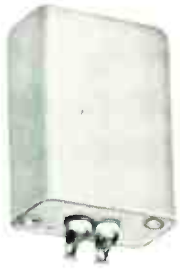
UTC molded units range from ⅓ oz. miniatures to the 100 lb. 3 phase unit illustrated.

PULSE TRANSFORMERS

UTC pulse transformers cover the range from molded structures weighing a fraction of an ounce to high power modulator applications.

AUDIO COMPONENTS

UTC military audio units range from 1 ounce subminiatures to high power modulation transformers. Standard, high fidelity, sub-audio, and supersonic types.



HIGH Q COILS

Unequalled stability is effected in UTC high Q coils thru special processes and materials. Toroid, mu-core, and variable inductors are available to military standards.

MINIATURIZED COMPONENTS

UTC H-30 series audios are the smallest hermetic types made. Class A, B, and H power components of maximum miniaturization are regular production at UTC.

MAGNETIC AMPLIFIERS

In addition to a stock line of servo motor magnetic amplifiers, UTC manufactures a wide variety to customer specifications. Saturable reactors are supplied for frequencies from 1 cycle to 40 mc.

WRITE FOR UTC CATALOG B

. . . includes complete line of hermetic audios, reactors, magnetic amplifiers, filters, high Q coils, pulse transformers, etc.

UNITED TRANSFORMER CO.

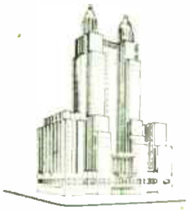
150 Varick Street, New York 13, N. Y. EXPORT DIVISION: 13 E. 40th St., New York 16, N. Y. CABLES: "ARLAB"

March 21-24

The Radio-Electronic
SPECTACULAR
of 1955!

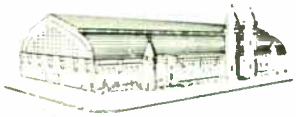
See! Hear!

IRE
National Convention



At both the Waldorf-Astoria (convention headquarters) and Kingsbridge Armory, you'll attend what actually amounts to 22 conventions fused into one. Hundreds of scientific and engineering papers will be presented during the many technical sessions, a large number of which are organized by I R E professional groups. You'll meet with the industry's leaders—enjoy the finest meeting and recreational facilities in New York.

and
Radio
Engineering Show



At the Kingsbridge Armory and Kingsbridge Palace, you'll walk through a vast panorama of over 700 exhibits, displaying the latest and the newest in radio-electronics. You'll talk shop with the industry's top manufacturers—enjoy the conveniences provided for you in the world's finest exhibition halls, easily reached by subway and special bus service.

Admission by registration only. $1.00 for I R E members, $3.00 for non-members. Social events priced extra.

The Institute of Radio Engineers
1 East 79 Street, New York

7 out of 704*
good reasons why you should attend the Radio Engineering Show

Hear...
vital research and engineering papers on computers, transistors, color TV, etc., subject-organized in 55 sessions.

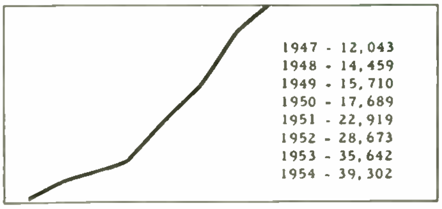
Watch...
a computer balance a cane, making 20 corrective moves a second—at the IRE Show.

See...
the exhibits of 69 components vital to successful Automation. Or compare 21 different types of Transistors—and other subminiature components.

Check-up on...
"1955 Instrumentation" shown on Instruments Avenue. Exhibit grouping helps you see more on the Avenues named.

Audio • Broadcast • Radar
Transistor • Television
Radio • Components • Microwave
Airborne • Production
Circuits • Computer • Electronics

Meet...
all your friends. 39,302 attended IRE in 1954.



Enjoy...
The Convention's Social Events. It is good to mingle with your industry friends at IRE.

Get the facts...
faster and easier at exhibits and sessions than you could from weeks of your own "digging."

**Send for the 1954 Directory of 604 Exhibitors and list of 100 new exhibitors.*

PROCEEDINGS OF THE I.R.E. February, 1955, Vol. 43. No. 2. Published monthly by the Institute of Radio Engineers, Inc., at 1 East 79 Street, New York 21, N.Y. Price per copy: members of the Institute of Radio Engineers $1.00; non-members $2.25. Yearly subscription price: to members $9.00; to non-members in United States, Canada and U.S. Possessions $18.00; to non-members in foreign countries $19.00. Entered as second class matter, October 26, 1927, at the post office 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.

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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

March 1-3, 1955

Western Joint Computer Conference and Exhibition, Hotel Statler, Los Angeles, Calif.

Exhibits: Mr. William L. Martin, 5230 Norwich Ave., Van Nuys, Calif.

March 21-24, 1955

Radio Engineering Show and I.R.E. National Convention, Kingsbridge Armory and Kingsbridge Palace, N.Y.C.

Exhibits: Mr. William C. Copp, Institute of Radio Engineers, 1475 Broadway, New York 36, N.Y.

April 27-29, 1955

Seventh Regional Technical Conference & Trade Show, Hotel Westward Ho, Phoenix, Ariz.

Exhibits: Mr. George McClarathan, 509 East San Juan Cove, Phoenix, Ariz.

May 9-11, 1955

National Conference on Aeronautical Electronics, Biltmore Hotel, Dayton, Ohio.

Exhibits: Mr. William Klein, 1472 Earlham Drive, Dayton, Ohio

May 18-20, 1955

National Telemetering Conference, Morrison Hotel, Chicago, Ill.

Exhibits: Mr. Kipling Adams, General Radio Company, 920 S. Michigan Ave., Chicago, Ill.

May 19-21, 1955

Armed Forces Communication Association Global Communications Conference, Hotel Commodore, New York, N.Y.

Exhibits: Mr. William C. Copp, 1475 Broadway, New York 36, N.Y.

Aug. 24-26, 1955

Western Electronic Show & Convention, Civic Auditorium, San Francisco, Calif.

Exhibits: Mr. Mal Mobley, 344 N. La-Brea, Los Angeles 36, Calif.

Sept. 12-16, 1955

Tenth Annual Instrument Conference & Exhibit, Shrine Exposition Hall & Auditorium, Los Angeles, Calif.

Exhibits: Mr. Fred J. Tabery, 3443 So. Hill St., Los Angeles 7, Calif.

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.

THIS IS IT!

NEW 3-WATT Blue Jacket®

miniaturized axial-lead wire wound resistor

This power-type wire wound axial-lead Blue Jacket is hardly larger than a match head *but it performs like a giant!* It's a rugged vitreous-enamel coated job—and like the entire Blue Jacket family, it is built to withstand severest humidity performance requirements.

Blue Jackets are ideal for dip-soldered sub-assemblies . . . for point-to-point wiring . . . for terminal board mounting and processed wiring boards. They're low in cost, eliminate extra hardware, save time and labor in mounting!

Axial-lead Blue Jackets in 3, 5 and 10 watt ratings are available without delay in any quantity you require. ★ ★ ★

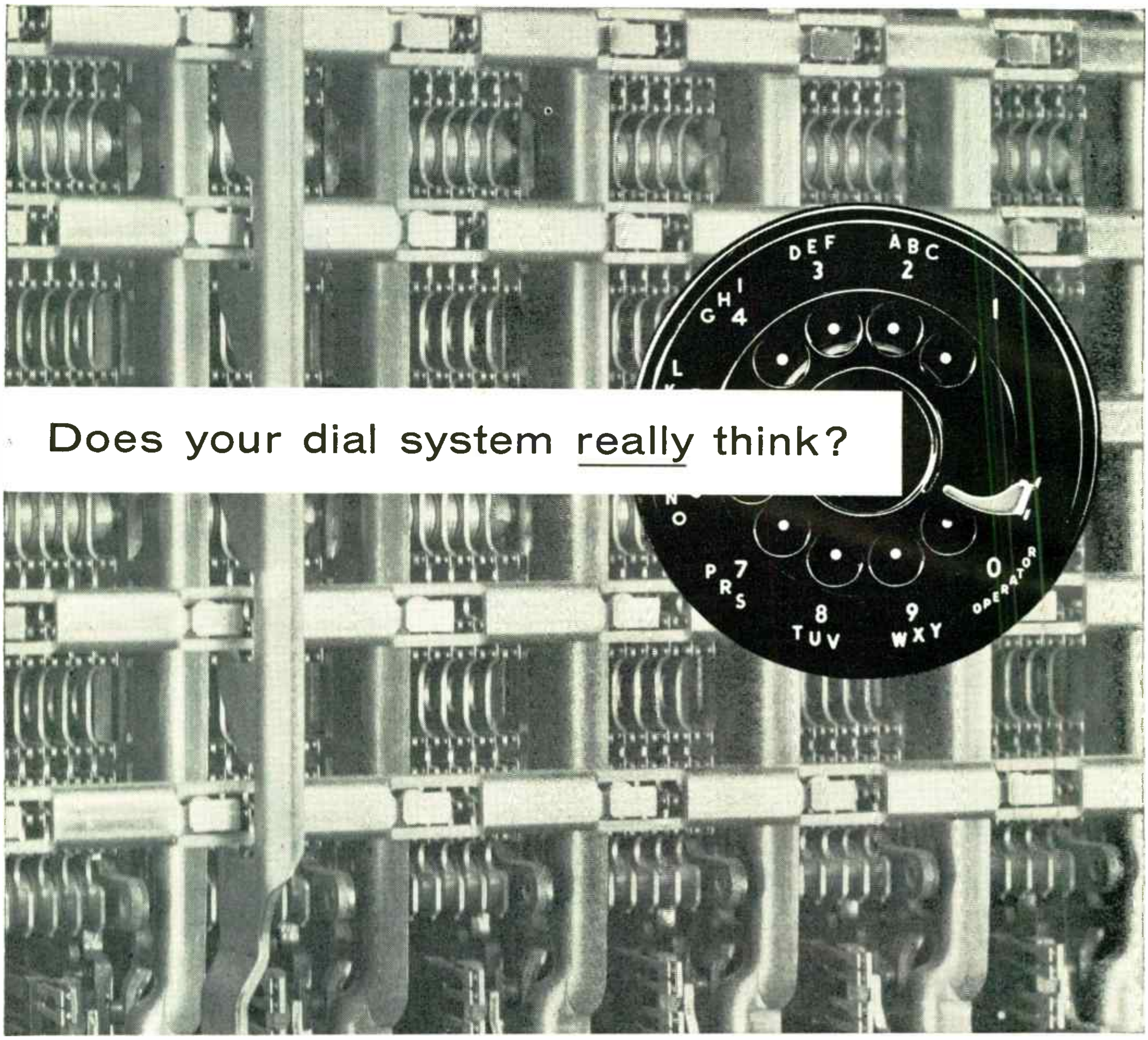
SPRAGUE TYPE NO.	WATTAGE RATING	DIMENSIONS L (inches)	D	MAXIMUM RESISTANCE
151E	3	17/32	13/64	10,000 Ω
27E	5	1 1/8	5/16	30,000 Ω
28E	10	1 7/8	5/16	50,000 Ω

Standard Resistance Tolerance: ±5%

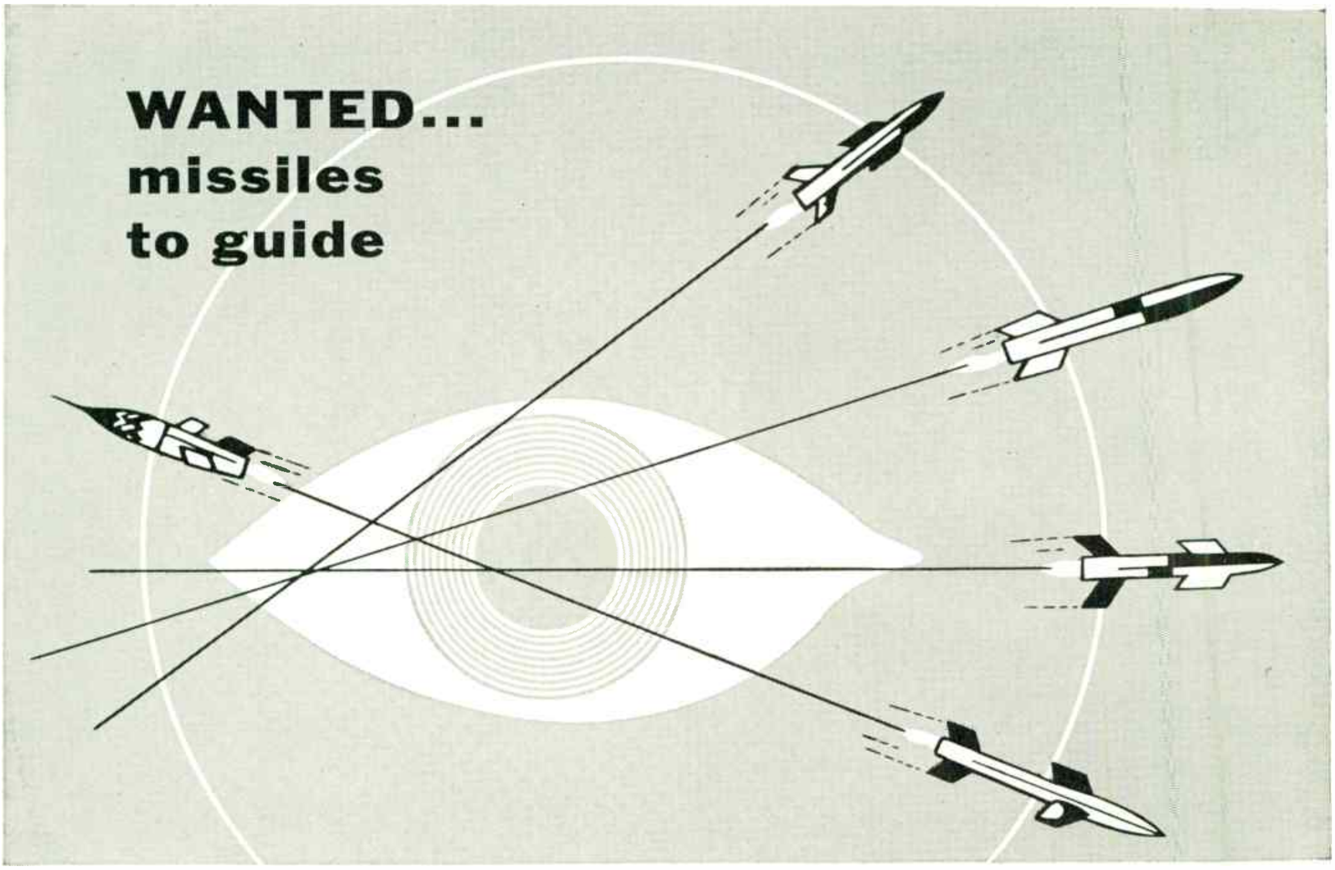
SPRAGUE

WRITE FOR ENGINEERING BULLETIN NO. 111B

SPRAGUE ELECTRIC COMPANY • 235 MARSHALL ST. • NORTH ADAMS, MASS.


DEF 3
ABC 2
1
GHI 4
L
O
PRS 7
8 TUV
9 WXY
0 OPERATOR


MIDLAND
3579.545 kc



Transmitters and Monitors of proven accuracy and reliability

SYNCHROTEL TRANSMITTERS

for the remote electrical transmission of data such as true airspeed, indicated airspeed, absolute pressure, log absolute pressure, differential pressure, log differential pressure, altitude and Mach number.

PRESSURE MONITORS

to provide control signals which are functions of altitude, absolute pressure, differential pressure, etc.

To control a guided missile effectively and absolutely is a challenging problem with which hundreds of engineers are grappling every day.

The solution depends upon the efficiency and the reliability of the controlling parts.

For over 25 years Kollsman has been making precision aircraft instruments and equipment used on military and commercial aircraft throughout the world. The talents and skills needed for success in this special and challenging field are equally necessary in the design and manufacture of precision controls for missiles.

Kollsman is presently making Transmitters and Monitors of proven accuracy and reliability for missile control.

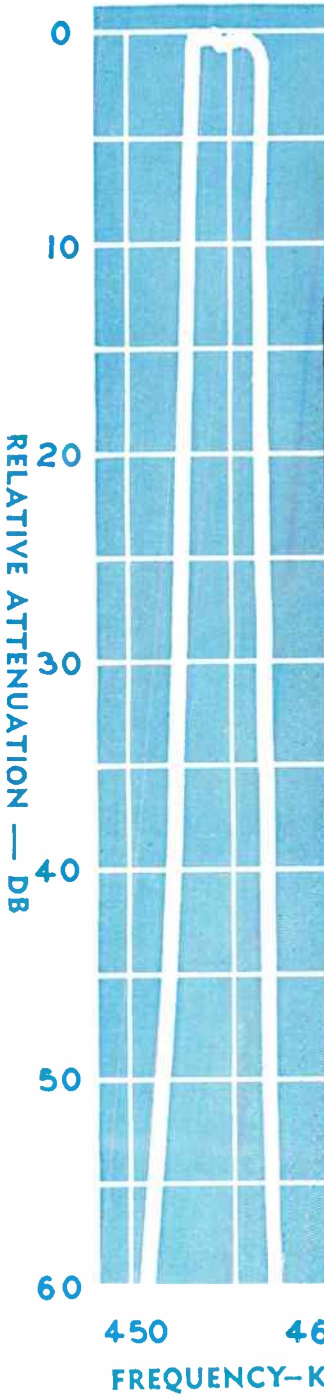
Brochures are available on the above two products.

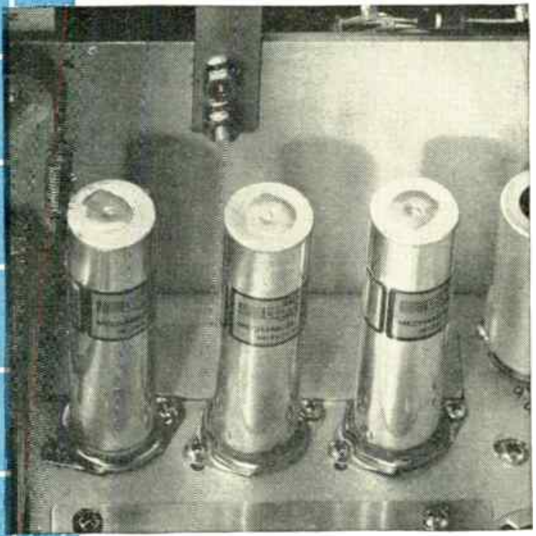
Please write us regarding your specific problems or requirements in the field of missile control.

kollsman INSTRUMENT CORP.

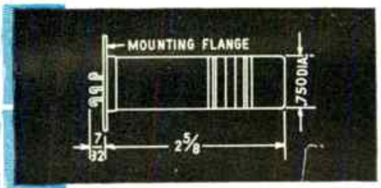
80-16 45th AVE., ELMHURST, NEW YORK • GLENDALE, CALIFORNIA • SUBSIDIARY OF *Standard* COIL PRODUCTS CO. INC.

new MECHANICAL FILTER designs by Collins

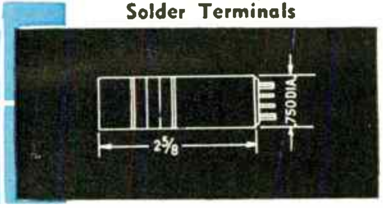




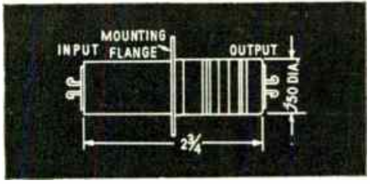
- new low insertion loss
- temperature compensated
- new compact tubular design



F455H-Series, Single-Ended Solder Terminals



F455J-Series, 9-Pin Miniature Plug-In



F455K-Series, Double-Ended Solder Terminals

Sharp selectivity characteristics, compactness of tubular design and choice of terminal style illustrated above are among top features of the new designs.

COLLINS Mechanical Filters have become the byword to electronics people looking for superior selectivity characteristics, compact design, simplified circuitry and maintenance-free service in IF passband filters. Utilizing magnetostrictive principles of mechanical resonance to provide high attenuation of unwanted signals, Collins has established a wide margin of leadership maintained by an intensive research program. The important developments of this research are now available to the electronic industry.

Most significant of these new developments are the lowering of transmission loss to 10 db or less, and temperature compensation of the Filter for operation over a range of -40°C to +85°C. Shape factors are now nearer to the ideal "square" curve than ever before thought possible. And a new tubular style case, permitting greater conservation of space in new equipment designs, has been developed with three options in terminal style.

In addition to producing a comprehensive line of standard Filters ranging from 250 kc to 500 kc, Collins welcomes your special filtering problems. Filters can be designed for IF frequencies from 100 kc to 500 kc, and with bandwidths from 500 cps to 15 kc.

To apply our experience to your particular problems or for further information on existing designs, contact the nearest Collins office.

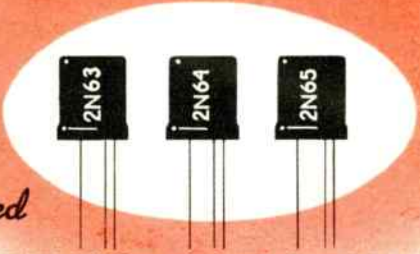
COLLINS RADIO COMPANY
Cedar Rapids, Iowa

261 Madison Ave., NEW YORK 16
1930 Hi-Line Dr., DALLAS 2
2700 W. Olive Ave., BURBANK
Collins Radio Company of Canada, Ltd., 74 Sparks Street, OTTAWA, ONTARIO

COLLINS

LOOKING FOR GERMANIUM TRANSISTORS THAT CAN DO THE JOB UP TO 85°C

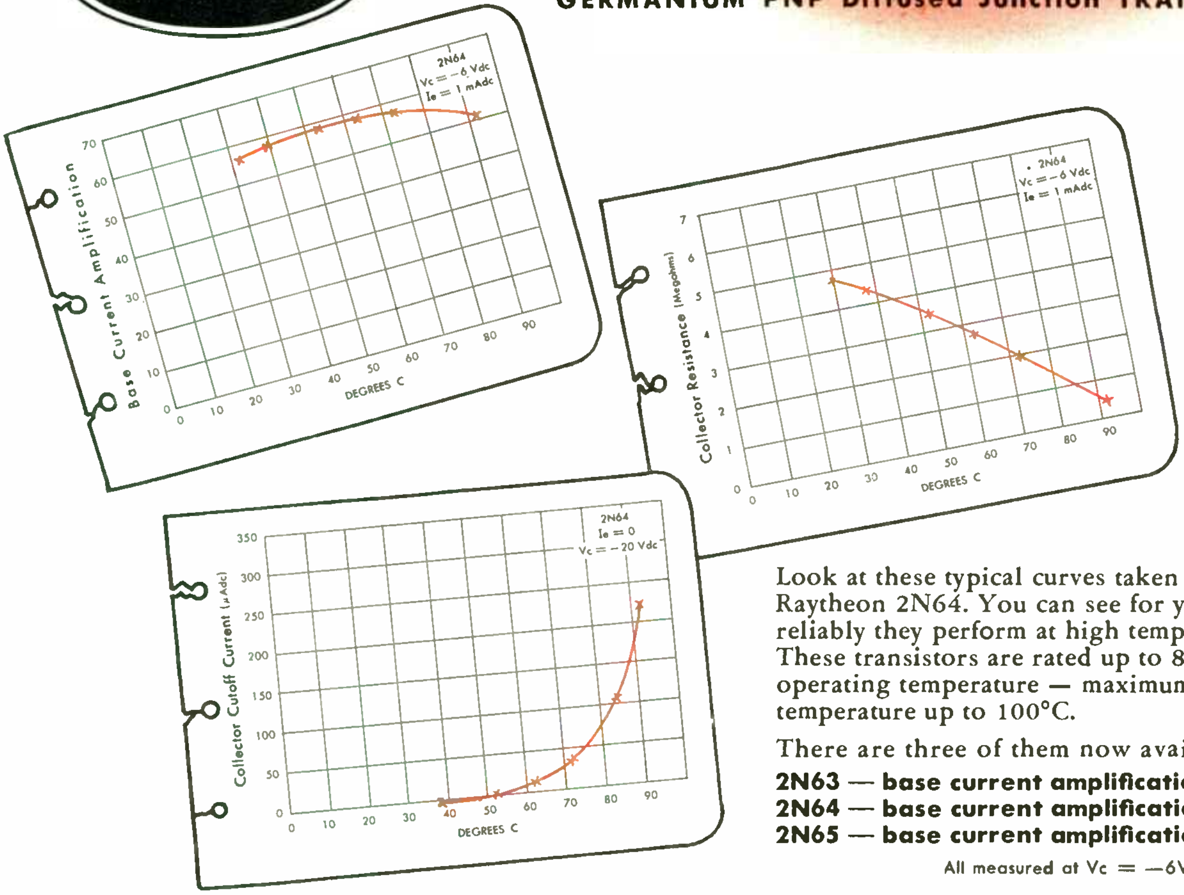
HERE THEY ARE!



RAYTHEON

Hermetically sealed

GERMANIUM PNP Diffused Junction TRANSISTORS



Look at these typical curves taken on a Raytheon 2N64. You can see for yourself how reliably they perform at high temperature. These transistors are rated up to 85°C operating temperature — maximum storage temperature up to 100°C.

There are three of them now available:

2N63 — base current amplification factor 22
2N64 — base current amplification factor 45
2N65 — base current amplification factor 90

All measured at Vc = —6Vdc, Ie = 1mAdc

There are several times as many

RAYTHEON TRANSISTORS

in use as all other makes combined!

DYNAMIC QUALITY CONTROL *with* MICROSCOPIC INSPECTION

ON ALL

RAYTHEON RELIABLE SUBMINIATURE TUBES

Assures Dependable Guided Missile Performance

All these Raytheon Reliable Subminiature Tubes must pass microscopic inspection

TYPE	DESCRIPTION
CK5639	Output Pentode
CK5702WA	RF Amplifier Pentode
CK5703WA	High Frequency Triode
CK5744WA	High Mu Triode
CK5783WB	Voltage Reference
CK5784WA	RF Mixer Pentode
CK5787WA	Voltage Regulator
CK5829WA	Dual Diode
CK5995	Rectifier Diode
CK6021	Medium Mu Dual Triode
CK6110	Dual Diode
CK6111	Medium Mu Dual Triode
CK6112	High Mu Dual Triode
CK6152	Low Mu Triode
CK6247	Low Microphonic Triode
CK6533	Low Microphonic Triode

RAYTHEON, pioneer in microscopic inspection of reliable tubes for missiles, applies this inspection technique as the tubes are made. Employed as an integral part of Raytheon's quality control system, microscopic inspection controls the quality of manufacture of parts and sub-assemblies as well as that of the completed tubes, thus permitting continuous feed back to the production line. This provides positive corrective action during production, in addition to segregation of defective units.

Raytheon microscopic inspection assures continuous quality improvement. The resulting higher quality provides increased insurance against catastrophic tube failures.

FLAT PRESS SUBMINIATURE TUBES • THE SEAL OF RELIABILITY

The long flat press glass to metal seal is a Raytheon development that eliminates button cracking, reduces glass strain and lead burning, and prevents lead corrosion because leads can be tinned right up to the glass. Its in-line lead arrangement permits easier socketing and easier wiring, and is ideal with printed circuitry.

RAYTHEON

Excellence in Electronics

RAYTHEON MANUFACTURING COMPANY

Receiving Tube Division — Home Office: 55 Chapel St., Newton 58, Mass. Bigelow 4-7500
For application information write or call the Home Office or: 4935 West Fullerton Avenue, Chicago 39, Illinois, NAtional 2-2770
589 Fifth Avenue, New York 17, New York, PLaza 9-3900 • 622 South La Brea Ave., Los Angeles 36, California, WEbster 8-2851

RAYTHEON MAKES ALL THESE:

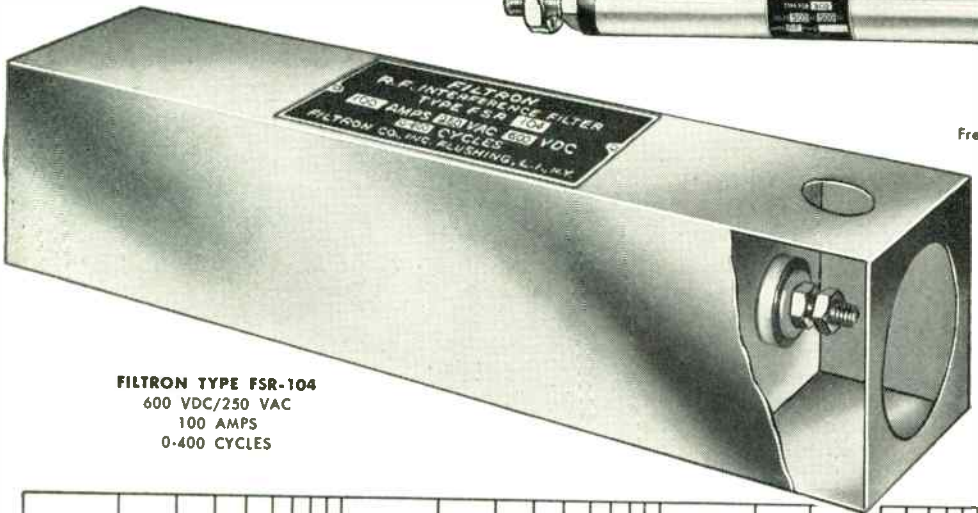
RELIABLE SUBMINIATURE AND MINIATURE TUBES • SEMICONDUCTOR DIODES AND TRANSISTORS • NUCLEONIC TUBES • MICROWAVE TUBES • RECEIVING AND PICTURE TUBES

HIGH ATTENUATION • CONTINUOUS DUTY • HERMETICALLY SEALED

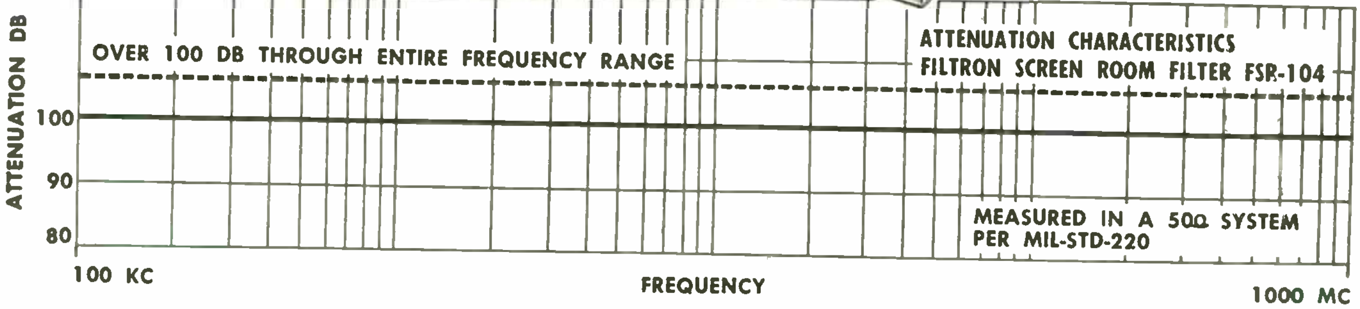
FILTRON

SCREEN ROOM FILTERS

FILTRON TYPE FSR-502
500 VAC/DC
100 AMPS
Frequency Range 1000 to 15,000 MC



FILTRON TYPE FSR-104
600 VDC/250 VAC
100 AMPS
0-400 CYCLES



JUST OFF THE PRESS—Write for your copy

RADIO INTERFERENCE FILTER CATALOG

This 20 page catalog contains valuable data on FILTRON RADIO INTERFERENCE FILTERS for SCREEN ROOMS, INDUCTION HEATING EQUIPMENT, DIATHERMY SETS, X-RAY UNITS and other electrical interference-producing equipment. Included are illustrated installation recommendations, essential information on applications, attenuation characteristics and mechanical dimensions . . . Your copy gladly sent free upon request.

FILTRON
RADIO INTERFERENCE FILTERS
for
• SCREEN ROOMS
• INDUCTION HEATING EQUIPMENT
• DIATHERMY SETS
• X-RAY UNITS

Screen room manufacturers specify and install FILTRON Screen Room Filters as standard equipment.

FILTRON Screen Room Filters are used in the majority of industrial, government and military screen rooms, to meet the requirements of specification MIL-S-4957, and wherever critical RF measurements are required.

FILTRON has over 40 types of Screen Room Filters available, ranging from 1 Amp to 1000 Amps, 28 VDC to 500 Volt AC/DC, 0 to 1000 cycles. Complete technical information available.

FILTRON RF Interference Filters are also specified in the latest types of Radar, Radio Transmitters, Receivers, Motor Generator Sets, Inverters, Aircraft, Electronic Systems, and numerous other "restricted" equipments.

When you have an RF Interference Filter problem, consult FILTRON—the most dependable name in RF Interference Filters.

SALES REPRESENTATIVES

G. S. Marshall Co., Pasadena, Cal.
Roy J. Magnuson, Chicago, Ill.
Massey Associates, Inc., Narbeth, Pa., Washington, D. C.

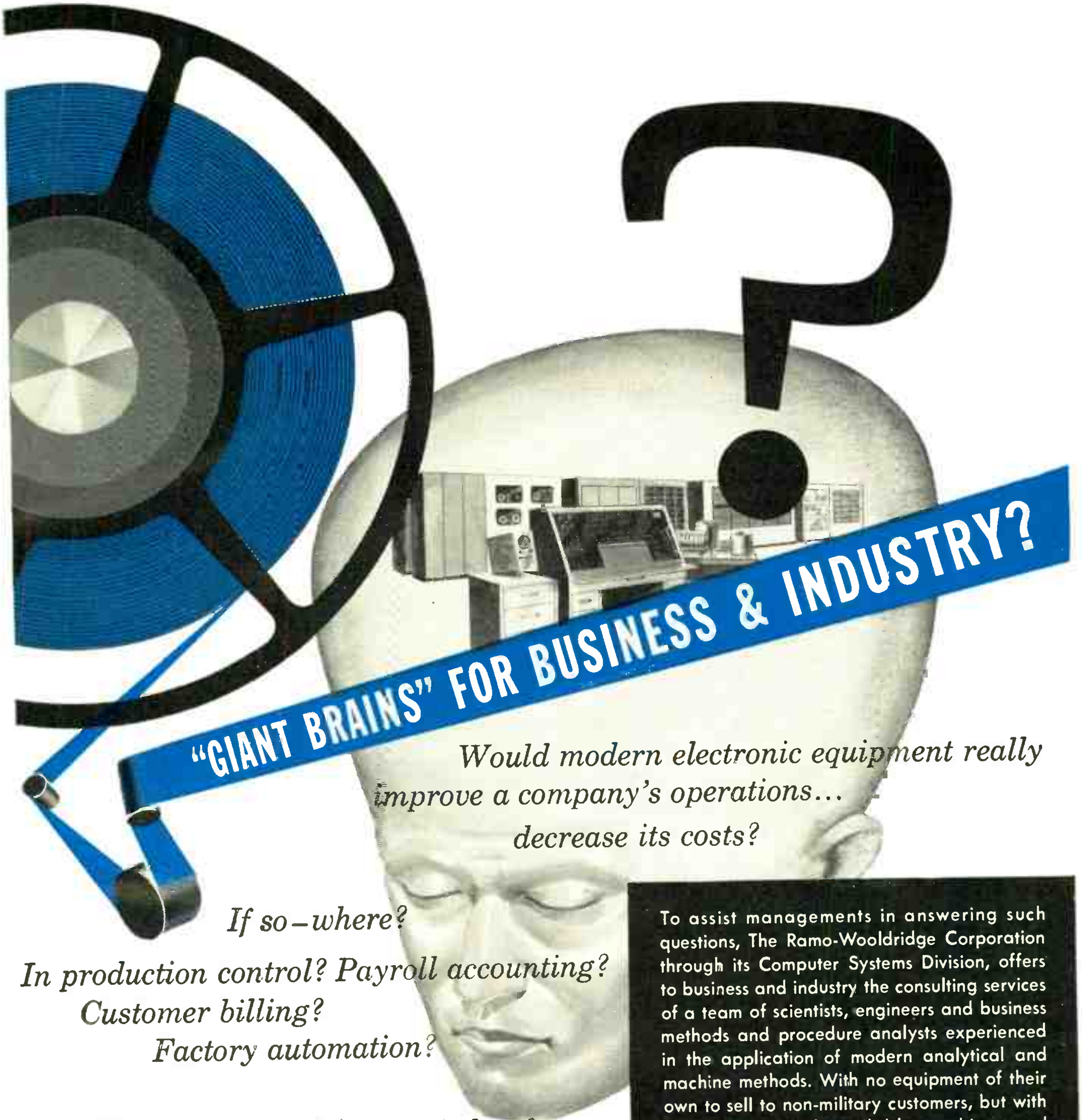
Holliday-Hathaway, Cambridge, Mass., Canaan, Conn.
Sales Offices at: New York, N. Y., Great Neck, N. Y.
Rochester, N. Y., Binghamton, N. Y.
Wood-Ridge, N. J.

INTERFERENCE FREE means FILTERED by

An inquiry on your company letterhead will receive prompt attention.

FILTRON CO., INC. • FLUSHING, LONG ISLAND, NEW YORK

LARGEST EXCLUSIVE MANUFACTURERS OF RF INTERFERENCE FILTERS



*Would modern electronic equipment really improve a company's operations…
decrease its costs?*

If so—where?

*In production control? Payroll accounting?
Customer billing?
Factory automation?*

*What make of equipment is best?
What changes in company methods and
procedures would be required?*

To assist managements in answering such questions, The Ramo-Wooldridge Corporation through its Computer Systems Division, offers to business and industry the consulting services of a team of scientists, engineers and business methods and procedure analysts experienced in the application of modern analytical and machine methods. With no equipment of their own to sell to non-military customers, but with understanding of available machines and techniques, this group is in a position to be objective in its recommendations.

Other activities of the Computer Systems Division include a program of development of an advanced type of digital computer for military applications and operation of the company's own computing center, consisting of extensive, general-purpose computing equipment.

These activities comprise a part of the program whereby The Ramo-Wooldridge Corporation seeks to maintain broad coverage of the important field of automation, computation and control.

The Ramo-Wooldridge Corporation

DEPT. P-7, 8820 BELLANCA AVENUE, LOS ANGELES 45, CALIFORNIA

NEWS and NEW PRODUCTS

February 1955

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

Encapsulated Resistor

The Daven Co., Dept. RD, 191 Central Ave., Newark 4, N. J., announces the production of a new sub-miniature encapsulated resistor. Designated as Type 1273, this unit is $\frac{1}{4}$ inch in diameter by 5/16 inch long and can be supplied with up to 400,000 ohms maximum resistance. Mounting is by radial leads and power rating is 0.1 watt.

This resistor is made in accordance with MIL-R-93A specifications, meets all humidity requirements and can be used from −55° to +125°C. It is available in accuracies to ±0.05 per cent and can be supplied with any type resistance wire depending upon the temperature coefficient required. Further information may be obtained from the company.

UHF-TV Marker Generator

The Ultra-Marker, a new development of **Kay Electric Co.,** 14 Maple Ave., Pine Brook, N. J., is a crystal-positioned uhf-TV marker generator. Designed for use with a sweeping oscillator, the Ultra-Marker develops an oscilloscope display marker signal at all uhf sound and picture frequencies covered by an associated sweeping oscillator.

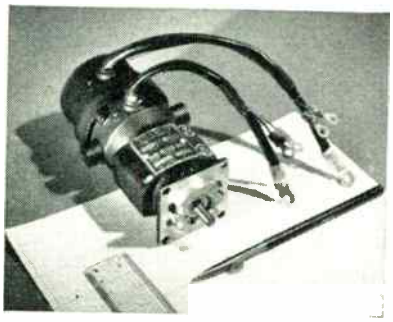
The generator, together with a suitable sweeping oscillator and an oscilloscope, form suitable uhf-TV production test and alignment setup.

A switching system which eliminates all but every fourth set of channel markers permits the instrument to be used with less accurately calibrated sweep generators. Additional features are: Calibrated rf output attenuator to make marker levels independent of sweeping oscillator output settings, narrow pip type markers fed directly to the oscilloscope, not through the receiver under test, and a sweeping signal input requirement of 10 millivolts into its 70 ohm input circuit.

The generator is enclosed, complete with regulated power supply, in a steel cabinet.

Quick-Stopping Motor

A new permanent-magnet motor for 28-volt dc operation is available from **Dalmotor Co.,** 1360 Clay St., Santa Clara, Calif. It has an integral brake separately actuated from 28 volts dc, and is capable of bringing the armature to a stop from the rated operating speed of 4,500 rpm within one shaft revolution. Designed for continuous-duty applications requiring good speed regulation, the unit supplies a high starting torque of 50 ounce/inches at 10 amperes.



Standard ratings include a total input current, including the 0.25-ampere brake current, of 2.5 ampere with 40-watt load. The dynamic brake torque is 100 ounce/inches minimum. Weighing 2.4 pounds, the unit has reversible rotation and is designated as Type PM-4.

Ferrite Cores With Adjustable Inductance

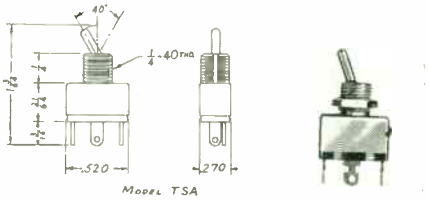
Two new ferrite pot core assemblies, with a method for adjusting coils to exact inductance values, are now available from **the Ferroxcube Corp. of America,** 235 E. Bridge St., Saugerties, N. Y. Pot core D-36/22 and pot core D-25/16 are provided with slots into which to slide inductance trimming strips consisting of Ferroxcube powder bonded to a plastic strip. The ferrite powder on the tape gradually increases in thickness as the strip is pulled through the air gap, therefore decreasing the effective gap length. An inductance adjustment of from 5 to 10 per cent is possible by this means. After final adjustment, the strip trimmer is cemented into place and the unused ends are cut off.

Coils using these new ferrite cores will have a very high Q and yet be small and light in weight. Since the copper windings are completely surrounded by high permeability Ferroxcube, coils may be placed close together with negligible intercoupling.

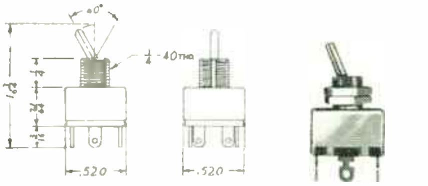
Complete dimensions and design information for both core assemblies are shown in engineering bulletin FC-5110, available on letterhead request.

Subminiature Toggle Switches

Miniature Switch Corp., 147 Ocean Ave., Lynbrook, L. I., N. Y., is a new company in the field of subminiature switching devices intended for use in transistorized and printed circuits. This company is an affiliate of LIECO, INC.



Model TSA



Model TSB

The subminiature toggle switches are available in two models: Single-pole double-throw (Model TSA) and double-pole double-throw (Model TSB). These switches have electrical ratings of 2 amperes at 115 volts ac, or 24 volts dc and 1 ampere at 50 volts dc. Approximate size of body is $\frac{1}{4} \times \frac{1}{2} \times \frac{1}{4}$ inch for spdt and $\frac{1}{4} \times \frac{1}{2} \times \frac{1}{2}$ inch for dpdt models. These switches are designed to comply with military requirements for salt spray, vibration, shock, endurance, etc. Available with a silicone rubber boot for panel sealing to withstand pressures in excess of 14 psi.

Additional information will be supplied upon request. Switches are available for immediate delivery.

Frequency Standard

The Industrial Test Equipment Co., 55 E. 11 St., New York 3, N. Y., has introduced Frequency Standard Model 620. This instrument can deliver up to 5 volts at a precise frequency of 60 or 120 cps

(Continued on page 14A)

POWER AND IMPEDANCE MEASUREMENTS

DAVEN OUTPUT POWER METERS

of unexcelled accuracy and reliability have many applications

The DAVEN Output Power Meters are designed to measure the actual power delivered by an audio signal system to a given load. However, because of the characteristics of the circuit, they are admirably suited to other applications, namely:

1. **Determination of Characteristic Impedance of an A.C. Source.**
2. **Effects of Load Variation on a Signal System.**
3. **Transmission Line Equalisation Measurements.**
4. **Measurement of Insertion Loss in Multi-channel Mixer and other complex circuits.**
5. **Filter and Transformer Measurements.**
6. **Radio Receiver Measurements.**

The equipment shown on this page is built to DAVEN'S well-known standards of precision. Please write for more detailed data. Let our engineering department help you on specific problems.

TYPE OP-182

Impedance Range: 2.5 ohms to 20,000 ohms. Remains essentially resistive over frequency range of 30 to 10,000 cps. Accuracy ±5%.

Power Range: 0.1 mw. to 5 watts in steps of 0.1 mw.

Indicating Meter: Calibrated from 0 to 50 milliwatts and from 0 to 17 db.—Zero level: 1mw.

Meter Multiplier: Will change reading of indicating meter by ratios of 0.1:1, 1:1, 10:1, 100:1, or decibel reading by −10, 0, +10, +20.

TYPE OP-961

Impedance Range: 2.5 ohms to 20,000 ohms. Remains essentially resistive over frequency range of 30 to 10,000 cps. Accuracy ±2%.

Power Range: 0.1 milliwatts to 50 watts in steps of 0.1 milliwatts.

Indicating Meter: Calibrated from 1 to 50 milliwatts and 0 to 17 decibels. Zero level: 1mw.

Meter Multiplier: Extends the power reading of the indicating meter from 0.1x to 1,000x scale value, or the db. reading from −10 to +30 db. in steps of 2 db.

TYPE OP-962

Characteristics similar to OP-961, except that it can measure up to 100 watts.

Impedance Range: 40 selected impedances between 2.5 and 20,000 ohms. Accuracy ±2% over frequency range 30 to 10,000 cycles.

Power Range: 0.1 mw to 100 watts in 0.1 mw steps. Range may be extended below 0.1 mw by use of external amplifier.

Indicating Meter: Calibrated from .01 watt to 1 watt and from −10 to +10 db. Zero level: 1mw.

Meter Multiplier: Extends range of meter from 0.01 to 100 times scale reading.

THE DAVEN CO.

195 CENTRAL AVENUE • NEWARK 4, NEW JERSEY

News-New Products

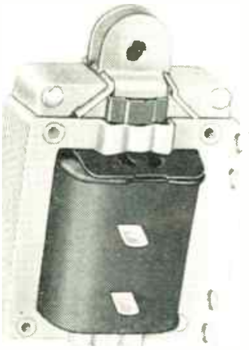
These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(*Continued from page 12A*)

(factor set to within ±0.01 per cent.) Other frequencies precisely set can also be supplied upon request. Frequency stability is such that temperature variations from −40°C to +85°C or line voltage variations from 105–125 volts will affect frequency of oscillation by less than ±0.01 per cent. Output distortion is less than 1 per cent. The output amplifier is transformer coupled which presents the option of either isolated output or grounding one of output terminals. Dimensions are height 9 inches, width 15 inches, depth 8 inches. Weight is 17 pounds. This instrument should be useful in accurate low frequency timing applications.

Solenoid

Dormeyer Industries, Dept. PIN, 3418 N. Milwaukee Ave., Chicago 41, Ill., recently developed a small and compact solenoid which is now available in quantity for small equipment and components. Incorporating a new positioning of double shading coil for high seated pull, the solenoid is a lightweight unit adapted to rugged duty.



The new solenoid is said to be engineered to outlast the product in which it is installed. It will operate in any position and is regularly furnished for both constant and intermittent duty, 115 v, 60 cps ac. Blade terminals are standard, with flexible leads optional.

(*Continued on page 98A*)

Raytheon – World's Largest Manufacturer of Magnetrons and Klystrons

Arthur W. Richardson, Chief Engineer, Station WGBH-TV, Boston, Mass., at station's Raytheon KTR-100 microwave relay which transmits picture and sound simultaneously.

More than 75 TV stations using this equipment for STL, remotes, and network intercommunication have proved the performance of the 5976 Klystron.

Color TV relay uses Raytheon 5976 Klystrons

The new, compact Raytheon KTR-100 microwave relay is a good example of the use of the long-life Raytheon 5976 in regular and color TV relay equipment. This reliable Klystron has also been selected for additional applications by other leading manufacturers—for these five reasons:

Over 22,000 hours of life—many users report more than 22,000 hours (over 2½ years) of continuous service.

Low temperature coefficient—temperature need not be held to close tolerance. No forced air cooling.

Low power requirements—only 300 volts at 25 mA. Easy to install.

Low initial cost—lowest cost Klystron in its class. Immediate delivery in any quantity.

Low maintenance cost—long life means absolute maximum of trouble-free operation . . . ideal for isolated installations.

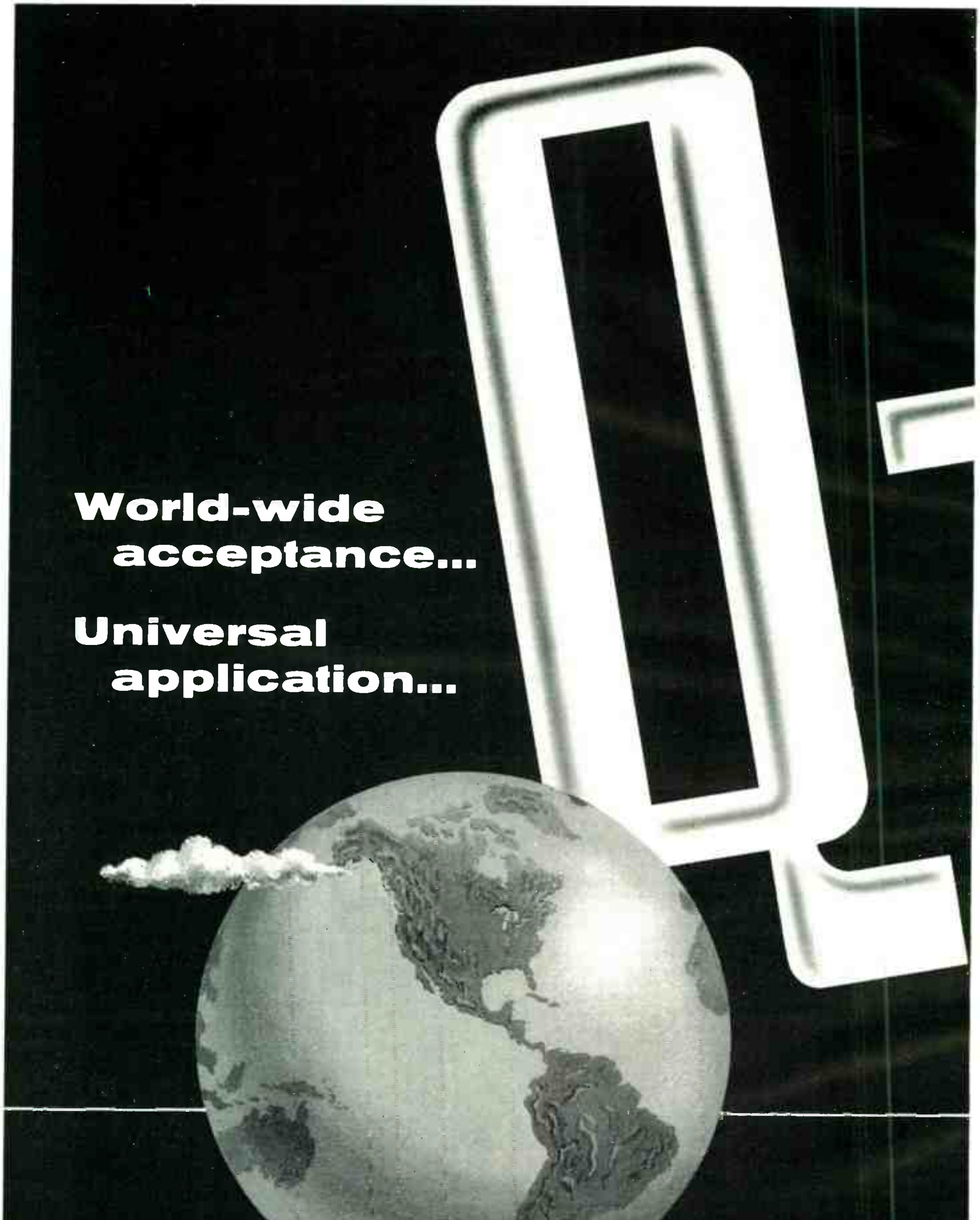
Condensed Operating Data—5976 Klystron

	3¾ Mode	2¾ Mode
Power output	110 mW av. (6750 Mc)	150 mW av. (6750 Mc)
Frequency range	6200-7425 Mc	6200-7425 Mc
Reflector voltage	—78 to —158 Vdc	—200 to —285 Vdc
Resonator voltage	300 Vdc	300 Vdc
Current	25 mA	25 mA
Modulation sensitivity	1.0 Mc/v	0.5 Mc/v
Temp. coefficient	—.10 to +.10 Mc/C°	—.10 to +.10 Mc/C°
Pulling figure	0.2% of operating freq.	0.1% of operating freq.

Write for valuable Data Booklets on Raytheon Magnetrons and Klystrons, including the stable, reliable 5976. Our Application Engineer Consultation Service is also available to you without cost or obligation. Call us when you have a microwave tube problem.

RAYTHEON

RAYTHEON MANUFACTURING COMPANY
Microwave and Power Tube Operations, Section PL-13
WALTHAM 54, MASSACHUSETTS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Universal
application...

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*REGISTERED TRADE NAME

A-27 *RF* LACQUER

Wherever coil lacquer is used, Q-max is the recognized name for quality. Q-max promotes rigidity and electrical stability. This clear, practically loss-free coating penetrates deeply, seals out moisture and adheres to practically all materials. Easily applied and fast drying, Q-max is recommended for both VHF and UHF service. The new Q-max Bulletin is available, now. Write today!

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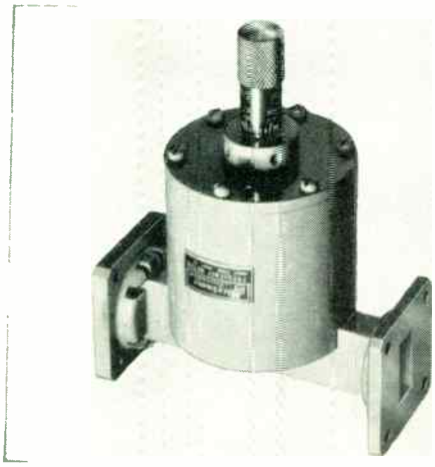
New Microwave Components for 12.5 to 18.0 Kmc/s



New Frequency Meter

Designed for insertion in RG-91/U waveguide transmission systems, a new frequency meter designated MA-582 is a precision adjustable cavity operating in the TE_{01} mode.

The frequency of the applied signal is indicated by a reduction of transmitted power as observed by a separate detector such as the MA-595.

The tuning plunger is micrometer driven and made of polished invar. This construction tends to minimize the errors resulting from the differences between calibration temperature and ambient operating temperatures. In addition, individual calibration curves are supplied with each meter to insure calibrating accuracy of one tenth of one percent or better.

Meter mounting is on a short section of RG-91/U waveguide. Input and output terminals are standard UG-541/U and UG-419/U connectors. The unit is precision-machined of brass and invar and internal conducting surfaces are silver plated. External finish is zinc chromate primer coated with gray baked enamel.

MODEL	MA-582
CONNECTOR	UG-541/U; UG-419/U
FREQUENCY RANGE Kmc/s	12.4–18.0
NOMINAL DIP	20%
APPROXIMATE LOADED Q	6000

Send for Data Sheet MA-582

New IN78 Crystal Holder

A new crystal holder designed for use with the IN78 crystal over the frequency range 12.5–17.0 Kmc/s is now available from Microwave Associates under the designation MA-595.

The unit's VSWR is less than 1.50 over the specified frequency range when terminated with a matched dummy crystal such as the MA-594.

IF output is available at a standard BNC type connector (UG-89/U). The input is a standard UG-541/U choke flange. Other type input connectors are available on special order. The holder is mounted on a short section of RG-91/U rectangular waveguide for easy incorporation into these systems. Material is brass. All conducting surfaces are silver plated. Exterior is zinc chromate primed and finished with baked-on gray enamel.

MODEL	MA-595
CONNECTORS	UG-541/U; UG-89/U
FREQUENCY RANGE Kmc/s	12.5–17.0
VSWR max.	1.50
OUTPUT CAPACITY $\mu\mu f$	5

Send for Data Sheet MA-595

Send for more information

Complete specifications, mounting dimensions, prices, etc. are available for our silicon diodes, TR and ATR tubes, magnetrons and waveguide components including these new elements:

MA-568	*Waveguide choke plunger*
MA-569	*Rat race power divider*
MA-578	*Power set attenuator*
MA-596	*Balanced mixer*

In addition to the above, complete specifications and drawings for more than 60 other components in the 3 to 75 K mc/s range are described in our Waveguide Component Catalog #55W

ATR · TR · AND MAGNETRON TUBES
WAVEGUIDE COMPONENTS AND
TEST EQUIPMENT · SILICON DIODES

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Associates INCORPORATED

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BOSTON 15, MASSACHUSETTS
COPLEY 7-7577

Industrial Engineering Notes*

FEDERAL PERSONNEL

Dr. Ralph D. Bennett, Senior Scientist and Technical Director of the Naval Ordnance Laboratory, has resigned to accept the position of Manager of the Technical Department of the Knolls Atomic Power Laboratory. . . .

FCC ACTIONS

The Federal Communications Commission has issued a Notice of Proposed Rule Making looking toward the establishment of bandwidth definitions and spurious emission limitations for AM and FM stations. To accomplish this, the Commission proposes to amend part 3 of the Rules and the Standards of Good Engineering Practice as defined in Docket No. 11,233 which is FCC Memeo 13,175. The Notice of Proposed Rule Making pointed out that at present the rules and standards do not define the bandwidth utilized by AM and FM stations nor do they set forth any definite limit on spurious emissions from such stations. Rules for other services, however, do contain such limitations. "Numerous complaints have been received," the Commission said, "that second harmonic radiations from FM broadcast stations falling within the upper portion of the VHF television band are of sufficient intensity to cause interference in areas of fringe television reception. Also, harmonics of standard broadcast stations cause interference to government stations." The definitions of bandwidth for AM and FM stations are the same as those set forth in the Final Acts of the International Telecommunications and Radio Conferences, Atlantic City, 1947, for "bandwidth occupied by an emission."

INDUSTRY STATISTICS

Television set production during October declined slightly from the level of September, a five-week reporting period, but set a new October output record. Despite the shorter reporting period, unit production of radios increased in October from September, it was reported. For the month of October, 921,476 TV receivers were manufactured compared with 947,796 in September and 680,433 sets turned out in October, 1953. The TV set output for the first 10 months of this year was reported to have been 5,654,791 units compared with 6,204,803 TV sets manufactured in the same 1953 period. Radio production in October was reported as 997,788 sets. In September, 932,323 radios had been manufactured while 1,052,493 sets were produced in October 1953. During the first 10 months of this year, radio production was reported as 8,040,230 units compared with 11,201,656 sets manufactured in the like 1953 pe-

(Continued on page 41A)

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* The data on which these NOTES are based were selected by permission from *Industry Reports*, issues of November 29, December 6 and 13, published by the Radio-Electronics-Television Manufacturers Association, whose helpfulness is gratefully acknowledged.

New, wide band thermistor and bolometer mounts require no tuning, speed microwave measuring

-hp- 420A Crystal Detector

Employs a silicon crystal to detect rf signals in a coaxial line employing Type N fittings. Covers frequencies 10 mc to 12.5 kmc. Frequency response flat within ±3 db full range, excellent conversion efficiency. No tuning. Uses modified 1N21 crystal. $50.00.

-hp- X421A Crystal Detector

X-Band Crystal Detector for use in waveguide systems at frequencies 8.2 to 12.4 kmc. Frequency response is flat within ±2 db. No tuning. Detector has square law characteristic within ±1 db over a 40 db dynamic range. $75.00.

-hp- 477A Thermistor Mount

For coaxial measurements. Provides complete coverage of all frequencies 10 mc to 10 kmc. SWR is less than 1.5. Operates with -hp- 430B/C Power Meter for direct power readings. No tuning. Not subject to burnout. Input connector is Type N; output is Type BNC. $75.00.

-hp- 487A Thermistor Mount

For fast, accurate waveguide measurements. Each mount covers full range of its waveguide frequency. Available for all frequencies 3.95 through 12.4 kmc. No tuning required, SWR less than 1.5. Not subject to burnout. Operates with -hp- 430B/C Power Meter for direct power readings. $75.00 to $95.00.

Here are four new wide band thermistor and bolometer mounts for use with coaxial or waveguide equipment at frequencies between 10 mc and 12.5 kmc. These new instruments are extremely simple to use, require no tuning, have low SWR, and may be used with a power meter such as *-hp-* 430B/C to provide direct reading measurements.

Brief descriptions of new *-hp-* 420A and X421A Detector Mounts and *-hp-* 477A and 487A Fixed Tuned Thermistor Mounts appear at left. The broad complete coverage *-hp-* line of detectors and mounts is listed below. For details, see your local *-hp-* sales engineer, or write direct for Technical Bulletin, specifying instrument model number.

Complete Coverage—All Frequencies!

Model	Instrument	Frequency	Element	Price
420A	Detector Mount	10 mc to 12.5 kmc	1N21 Crystal	$ 50.00
X421A	Detector Mount	8.2 kmc to 12.4 kmc	1N26 Crystal, mod.	75.00
440A	Detector Mount	2.4 kmc to 12.4 kmc	Crystal, Bolometer	85.00*
442B	Broad Band Probe	2.4 kmc to 18.0 kmc	—	35.00
444A	Broad Band Probe	2.6 kmc to 18.0 kmc	—	50.00
475B	Tunable Bolometer Mount	1.0 kmc to 4.0 kmc	Barretter, Thermistor, Fuse	200.00
476A	Universal Bolometer Mount	10 mc to 1.0 kmc	1/100 amp. fuses	85.00
477A	Thermistor Mount	10 mc to 10 kmc	Thermistor	75.00
S485A	Detector Mount	2.6 kmc to 3.95 kmc	Bolometer	125.00*
G485B	Detector Mount	3.95 kmc to 5.85 kmc	Bolometer, Crystal	95.00*
J485B	Detector Mount	5.85 kmc to 8.2 kmc	Bolometer, Crystal	90.00*
H485B	Detector Mount	7.05 kmc to 10.0 kmc	Bolometer, Crystal	85.00*
X485B	Detector Mount	8.2 kmc to 12.4 kmc	Bolometer, Crystal	75.00*
P485C	Detector Mount	12.4 kmc to 18.0 kmc	Thermistor	110.00
G487A	Thermistor Mount	3.95 kmc to 5.85 kmc	Thermistor	95.00
J487A	Thermistor Mount	5.85 kmc to 8.2 kmc	Thermistor	90.00
H487A	Thermistor Mount	7.05 kmc to 10.0 kmc	Thermistor	80.00
X487A	Thermistor Mount	8.2 kmc to 12.4 kmc	Thermistor	75.00

All mounts contain element unless marked (*).

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

INSTRUMENTS FOR COMPLETE COVERAGE

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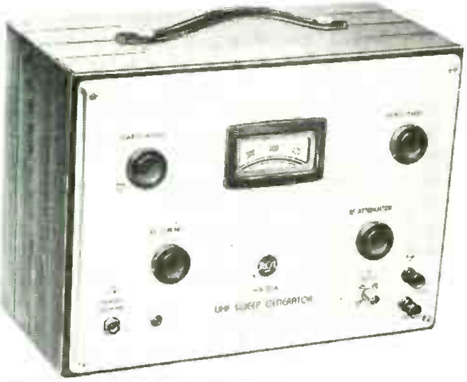
RCA DATA FOR

***NEW*—RCA-6BQ6-GTB/6CU6, 12BQ6-GTB/12CU6, and 25BQ6-GTB/25CU6** are directly interchangeable with similar types in the 6BQ6 family. In comparison with previous versions, these types retain the same desirable characteristics, but feature a modified mount design to provide higher perveance and to permit higher ratings.

RCA OSCILLOGRAPH TUBES—RCA-5ABP1, 5ABP7 and 5ABP11 flat-faced cathode-ray tubes feature electrostatic focus, electrostatic deflection, and post-deflection acceleration. These 5-inch oscillograph tubes differ only in spectral-energy emission and persistence characteristics of their respective phosphors. Outstanding features: very high deflection sensitivity, high spot intensity, and high grid-modulation sensitivity. The exceptionally high deflection sensitivity and low capacitance of the pair of deflecting electrodes provided for vertical-deflection, make this pair of electrodes especially suited for operation from wide-band amplifiers. The small size and high brilliance of the fluorescent spot gives finer detail in oscillographic traces . . . even with high-speed phenomena.

***NEW*—RCA-5U4-GB** is the "heavy duty" version of the 5U4-G. The improved design permits operation at higher peak and average currents, especially desirable when used in power supplies of TV receivers and radio equipment having high dc requirements. Additional important features of the RCA-5U4-GB include: double-wing plate design (for more plate area and increased heat conduction) . . . increased plate thickness (for more uniform heating) . . . double mica spacers (which provide better support, more resistance to shock, vibration) . . . flared base which engages button stem (eliminates need for cementing, reduces possible loose bases) . . . button stem (reduces electrolysis and leakage).

RCA WG-298A UHF DEMODULATOR—connects between the output of the WR-86A sweep generator and a 300-ohm termination for use in measuring the approximate standing-wave ratio of a 300-ohm-transmission line throughout the UHF range of 300-950 Mc. The WG-298A may also be used with other instruments such as the WR-40A, WR-41B or any UHF sweep generators using a 50-ohm BNC type output connector.



RCA WR-86A UHF SWEEP GENERATOR—recommended for continuous production line testing and general service applications on color and black-and white TV. This instrument is also useful for checking converters, tuners, filters and other equipment operating in the 300 to 950 Mc range. The WR-86A provides wide sweep range continuously adjustable to 10% of indicated dial frequency up to 850 Mc; up to 85 Mc for frequencies from 850-950 Mc, flat output with a max. voltage amplitude variation of 0.1 db per megacycle over the swept range; high output voltage at least 0.6 v across 50 or 300 ohms, and wide range attenuation continuously adjustable over a range of 60 db.

For technical data, write RCA, Commercial Engineering, Section B35R, Harrison, N.J.

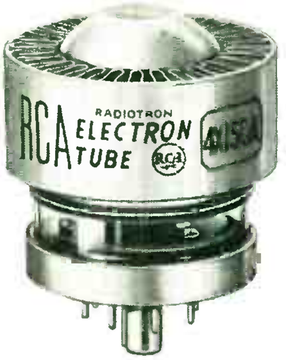
ELECTRON TUBES—SEMICONDUCTOR DEVICES—BATTERIES—TEST EQUIPMENT—ELECTRONIC COMPONENTS

DESIGNERS

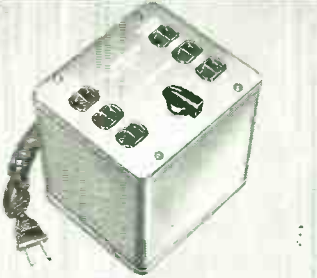
RCA-2D21—a sensitive, four-electrode thyratron, of the indirectly heated cathode type for use in relay applications. It has a high control ratio (essentially independent of ambient temperature over a wide range), extremely small pre-conduction or gas-leakage currents right up to the beginning of conduction, very low grid-anode capacitance and grid current. The 2D21 is not affected appreciably by line-voltage surges and, in a high-sensitivity circuit, can be operated directly from a vacuum phototube.

RCA-5879—is a sharp-cutoff pentode of the 9-pin miniature type intended for use as an audio amplifier in applications requiring reduced microphonics, leakage, noise, and hum. It is especially well-suited for input stages of medium-gain public address systems, home sound recorders, and general-purpose audio systems.

RCA MULTIPLIER PHOTOTUBES—RCA-6342, 5819 and 6199 multiplier phototubes are "head-on" types for use in applications involving low-level, large area light sources. Coupled with suitable phosphors, these tubes are especially useful in scintillation counters for detecting and measuring nuclear particle radiation. Spectral response of these types covers the range from 3000 to 6200 angstroms with maximum response at about 4000 angstroms. Types 6199 and 5819 have luminous sensitivity values of 24 and 25 amperes per lumen respectively when operated with a supply voltage of 1000 volts. Type 6342 has a luminous sensitivity value of 7.5 amperes per lumen with a supply voltage of 1250 volts, or 35 amperes per lumen with 1500 volts.



RCA-4X150-A—a very small and compact forced-air-cooled beam power tube for use in power amplifier or oscillator service at frequencies up to 500 megacycles and also as a wideband amplifier in video applications. The 4X150-A has a maximum plate dissipation of 150 watts. Terminal arrangements of this power tube facilitate its use with tank circuits of the coaxial type. Additional features: unipotential cathode . . . integral radiator . . . coaxial-electrode structure. Max. length: 2.468", max. diameter: 1.645".



RCA WP-25A TV ISOTAP—designed for use as either an adjustable isolation transformer or as an adjustable autotransformer to facilitate testing and trouble-shooting of series string circuits in radio and TV receivers, and other electronic equipment. Seven-position selector switch permits adjustment of primary voltage in 5-volt steps for operation from any supply-line voltage from 105 to 130 v. Output voltages of approximately 105, 115, and 130 v are provided throughout the supply-line voltage range.

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TUBE DIVISION HARRISON, N. J.

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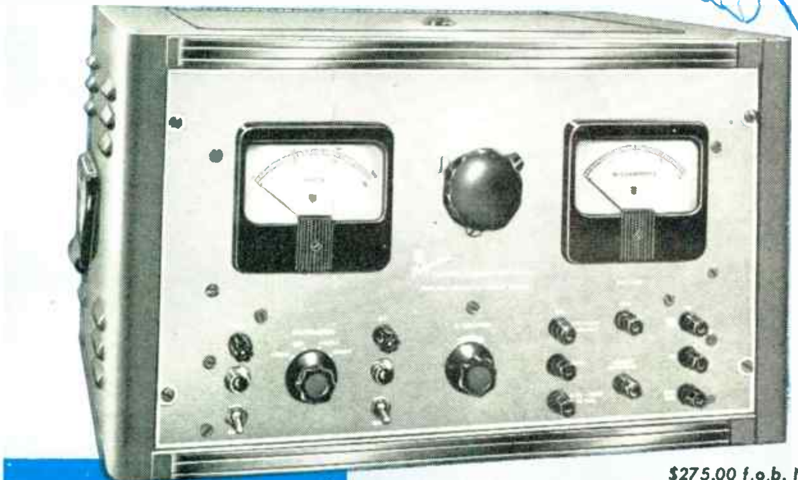
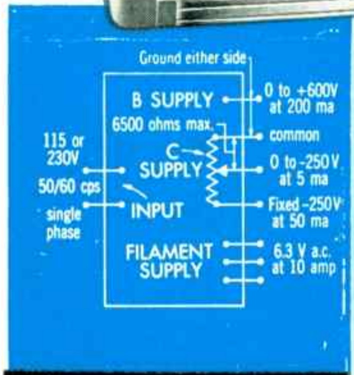
A New Voltage Regulated
DC POWER SUPPLY

- **for general laboratory and production line use**
- **power supply for many low voltage klystrons**



$275.00 f.o.b. N. Y.



Flexible ground permits stacking of supplies to provide up to —600V. cathode voltage and an additional 0 to —250V. for the reflector of low voltage klystrons.

Features:

- Wider than usual output range:
  "B" supply 0 to ±600V. at 200 ma.
  "C" supply 0 to —250V. at 5 ma.
- Additional fixed supply —250V. at 50 ma.
- Unregulated 6.3V., 10A. C.T. filament supply
- Excellent voltage regulation (only ±.25V.)
- Low ripple (less than 4 mv.)
- Input 115 or 230 Volts ac, 50/60 cps, single phase

The PRD Type 807 is a general purpose, constant voltage power supply, competitively priced to fit any instrument budget. It is conservatively rated for continuous service. Panel voltmeter monitors either supply voltage; milliameter indicates "B" supply current. Write for bulletin.

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MODEL WWVR

A receiver of the instrument class which is setting a new standard for the reception and presentation of the world's finest standards of time and frequency as broadcast by the National Bureau of Standards from WWV and WWVH.

The fundamental use of this receiver is in the calibration of local equipment to the accuracy of these primary time and frequency standards.

This time saving instrument incorporates all the latest techniques for clear reception. A glance at the front panel will at once show the ease of operation and instant availability of the desired Radio and Audio frequencies.

Model WWVR allows the operator full use of the world's finest primary standards of frequency and time. All frequencies broadcast from WWV (or WWVH) are accurate to one part in fifty million. This instrument in your laboratory will truly give you a . . .

PRIVATE PIPELINE TO PRECISION

—Specifications—

SENSITIVITY—Better than 1 microvolt on all frequencies.

SELECTIVITY—Less than 18 KC for —60db, 2.5 KC for —3db.

FREQUENCIES—Choice of three RF front ends delivered with receiver, 2.5, 5, 10, 15, 20 or 25 mc.

SMALL IN SIZE—Standard 5¼" relay rack panel.

DOUBLE CONVERSION—First IF amplifier at 2 MC, crystal converter to 60 KC second IF amplifier.

FRONT END—Four tuned circuits at the signal frequency for maximum sensitivity and image rejection.

AGC and AVC—AGC system provides constant RF input to second detector. AVC system independently controls audio resulting in constant output on tones.

INDIVIDUAL INPUTS—Three individual inputs for tuned antennas plus one common input for broad-band antenna. Balanced 300 ohm or unbalanced 72 ohm input.

Send for complete specifications, prices and delivery schedule.

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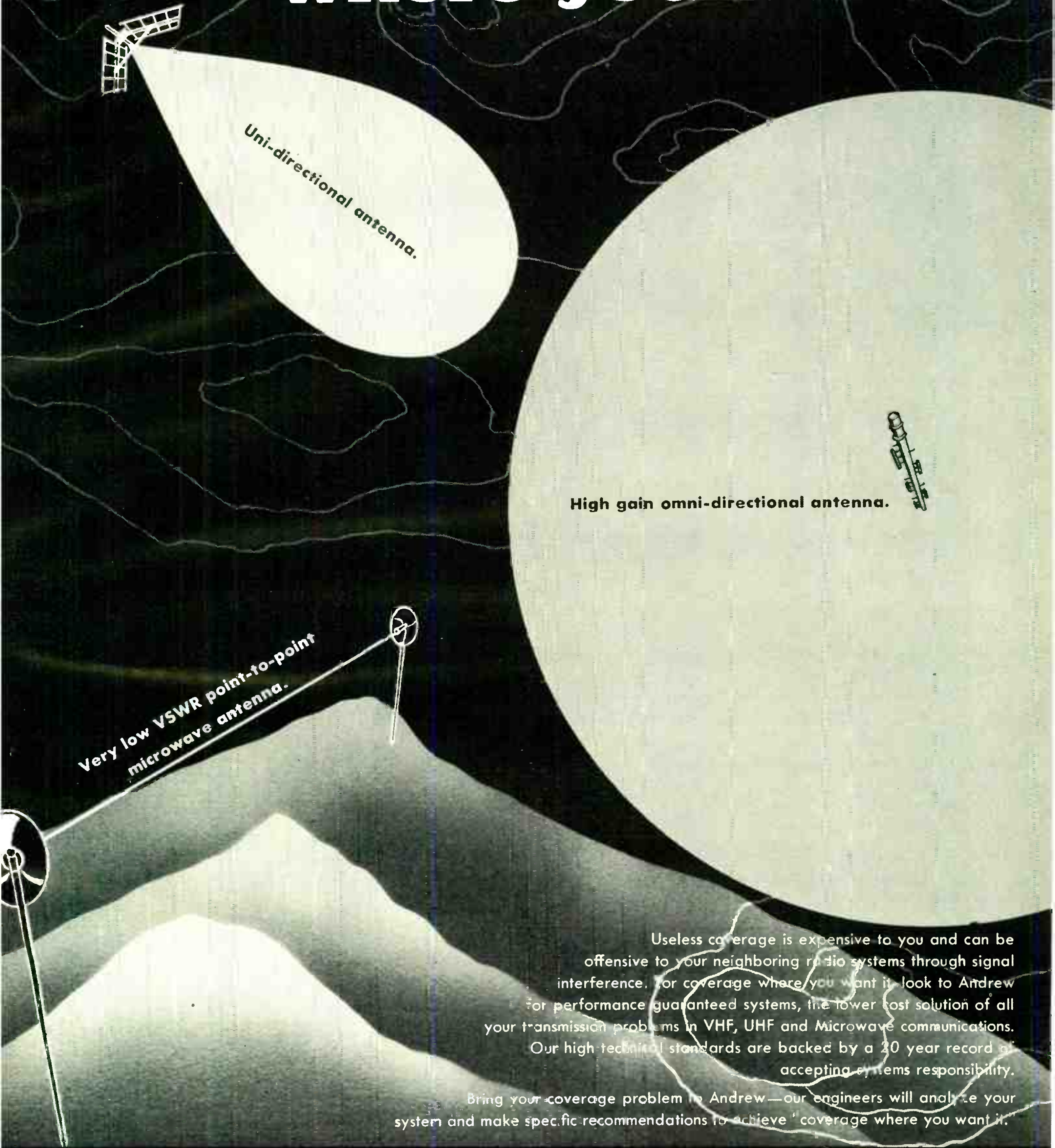

Useless coverage is expensive to you and can be offensive to your neighboring radio systems through signal interference. For coverage where you want it, look to Andrew for performance guaranteed systems, the lower cost solution of all your transmission problems in VHF, UHF and Microwave communications. Our high technical standards are backed by a 20 year record of accepting systems responsibility.

Bring your coverage problem to Andrew—our engineers will analyze your system and make specific recommendations to achieve "coverage where you want it."

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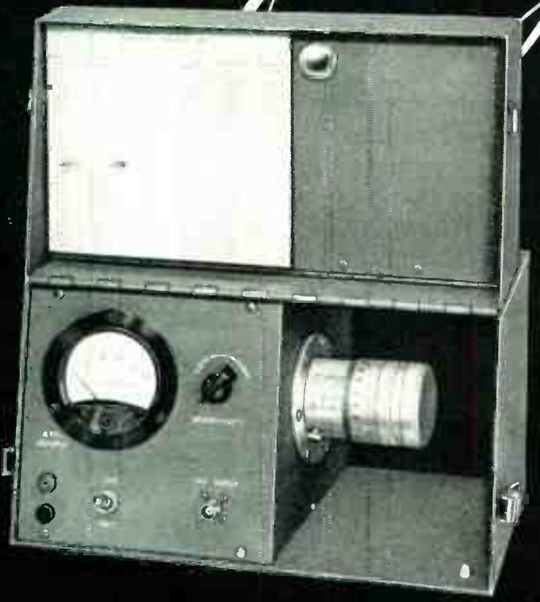
Frequency Meters



COMPLETELY SELF-CONTAINED FIELD TEST INSTRUMENTS

by

FREQUENCY STANDARDS

These precision-built field test instruments were designed by Frequency Standards to provide rapid and accurate means of frequency measurement in the field. Frequency is determined by means of a micrometer dial. This reading is translated to frequency by accurate individual calibration charts or curves. Transducers, fittings, and cables can be supplied to meet the requirements of customers and convenient storage space for these items is provided in the lid of the instruments.

MODEL	FREQUENCY RANGE	ACCURACY
912-4	900-1200 MC	.01%
1217-4	1200-1700 MC	.02%
1723-4	1700-2300 MC	.02%
2335-4	2300-3500 MC	.02%
3545-4	3500-4500 MC	.01%
4458-4	4400-5800 MC	.01%
5882-4	5800-8200 MC	.01%

SPECIAL CAVITY DESIGNS

Frequency Standards maintains complete facilities for the design and manufacture of Reference Cavities, Preselector Cavities, and Filters to customers' specifications or blueprints. Our facilities also permit quantity production of complex waveguide assemblies.

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of Variable Resistors • Founded 1896

THE ONLY COMPLETE LINE FOR ALL COLOR TV APPLICATIONS

1. SIZES—"dime size" to 2 1/2" diameter.
2. WATTAGES—2/10 watt to 4 watt.
3. TYPES—carbon and wirewound with and without attached switch.
4. MOUNTINGS—conventional bushing, twist ear and snap-in bracket for printed circuits.
5. TERMINAL STYLES—for conventional soldering, printed circuits and wire wrap.
6. COMBINATIONS—an endless variety of tandems, both single and dual shaft.

A CTS control can be tailored to your specific requirement.

FURTHER DETAILS ON OTHER SIDE

High voltage control for focus applications. Rated up to 5,000 volts DC across end terminals and 2 1/2 watts depending on total resistance. Will operate up to 15,000 volts DC above ground when mounted on insulated panel. CTS type 85.

Miniature 3/4″ "dime size" composition control. Conserves panel space at price comparable to larger size bushing mounted controls. CTS type 70.

1 1/8″ diameter composition control for applications where ratings up to 3/4 watt required. CTS type 35.

Concentric shaft tandem control with conventional bushing mounting. Designed for front panel dual knob applications, such as contrast and volume. Available in various combinations of composition or wirewound front and rear sections with or without on-off switch attached to rear section. CTS type GC-C252-45 with wirewound front section, composition rear section and on-off switch illustrated.

Ear mounted composition control. Simply twist two ears for rigid mounting. Eliminates bushing and mounting hardware. Available with shafts for knob operation or for preset applications with insulated or metal shaft. CTS type P45 with metal shaft illustrated.

Ear mounted two watt wirewound available with or without center tap. CTS type P-254 with tap illustrated.

Four watt wirewound control available with or without center tap. CTS type 27 with tap illustrated.

Higher Wattage Carbon Controls With Exceptional Stability Available

- **ONE WATT:** Entire 45 series 15/16″ diameter line available with 90 series special one watt military resistance elements.
- **TWO WATT:** Entire 35 series 1 1/8″ diameter line available with 95 series special two watt military resistance elements.

Ear mounted tandem for preset applications. Combines panel space saving features of a concentric tandem with the economy of an ear mounted unit. Available in various combinations of composition or wirewound front and rear sections. CTS type P-C2-45 with composition front and rear sections illustrated.

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CTS also makes a complete line of controls for military, black and white TV, radio and other commercial applications. Consultation without obligation available for **all** your control applications. Write for complete catalog TODAY.

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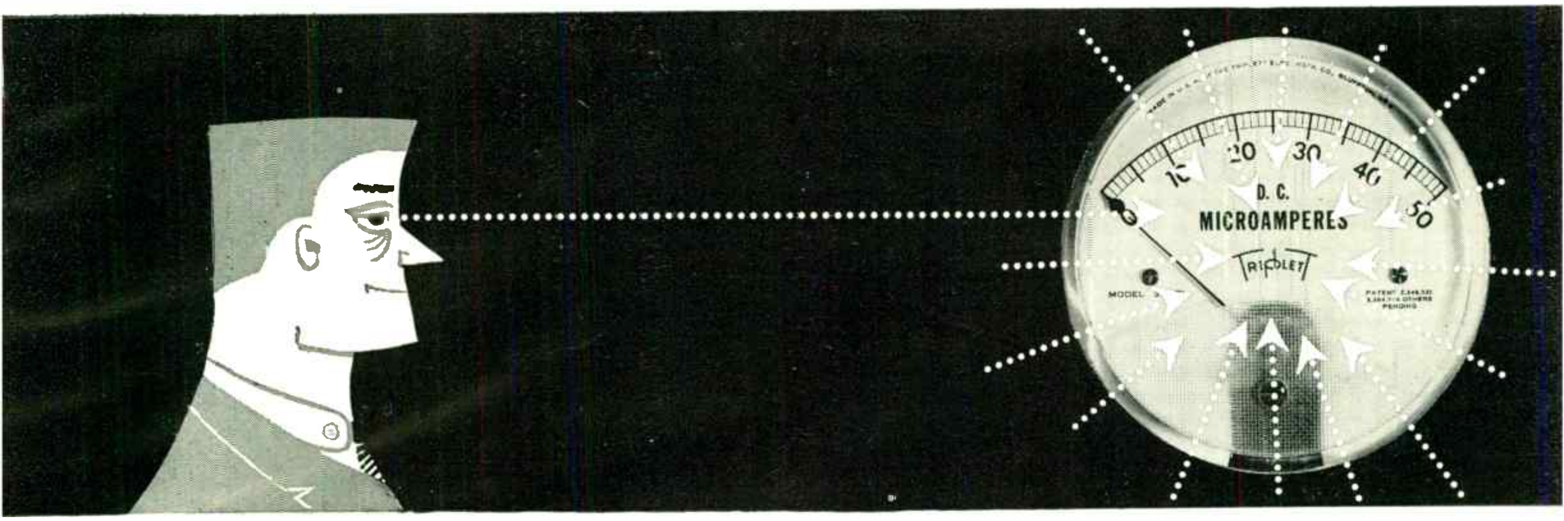
Specialists in Precision Mass Production of Variable Resistors • Founded 1896

LOOK AGAIN at PANEL METERS



for 5 Exclusive features to improve efficiency and appearance in your equipment

1 longer scale length

Full open face on round meters allows much longer scale than conventional types for quicker, easier readings from much greater distances.

2 visibility unlimited

Entire dial face encased in transparent non-breakable plastic. Entire dial is exposed to viewing.

3 light unobstructed

Full natural lighting from top, sides and bottom. No bezel or case rim interrupts the light from any angle.

4 interchangeability—universal

Longer scale length, yet the mounting makes it readily interchangeable with all conventional round meters of the same size. The panel space occupied is exactly the same.

5 appearance revolutionized

These handsome modern streamlined Triplett PL Panel Meters with clear plastic fronts will make an amazing improvement in the appearance of equipment panels in addition to contributing greatly to reading accuracy. An additional advantage is the unbreakable crystal.

Your Triplett representative will appreciate the opportunity to have you examine samples of the PL line. Triplett PL panel meters are being stocked by leading distributors.

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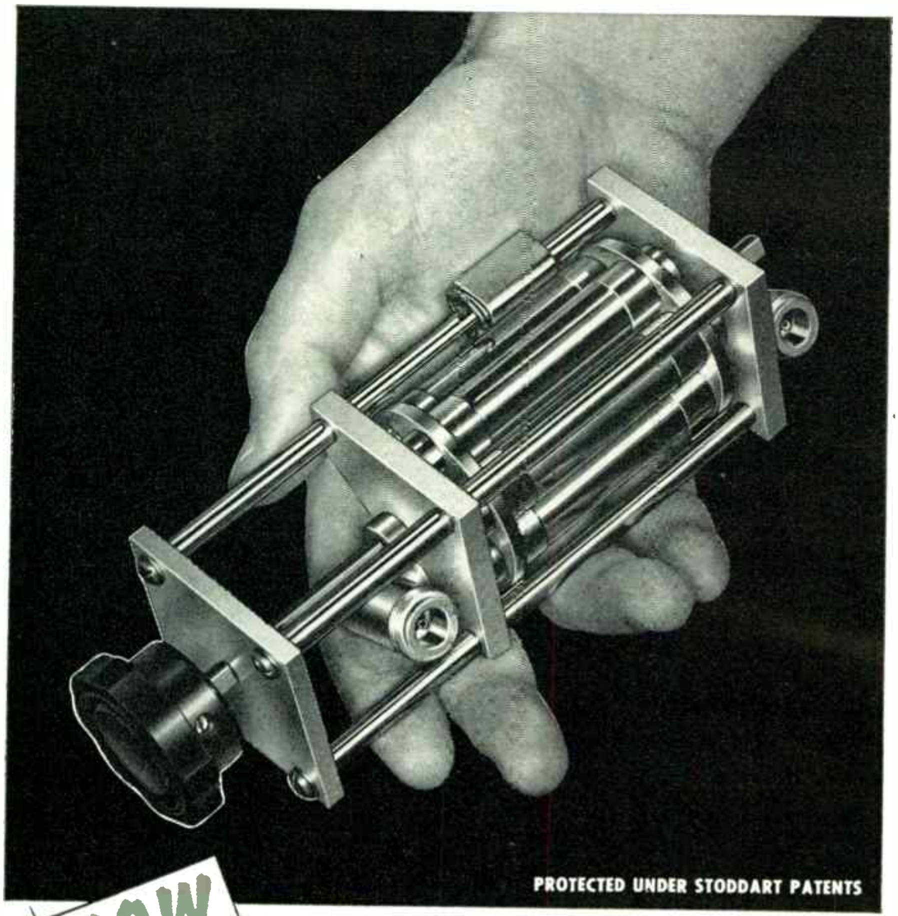
RAY L. TRIPLETT
FOR HALF A CENTURY

TRIPLETT ELECTRICAL INSTRUMENT CO., Bluffton, Ohio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Precision Attenuation to 3000 mc!

TURRET ATTENUATOR featuring "PULL-TURN-PUSH" action

SINGLE "IN-THE-LINE" ATTENUATOR PADS and 50 ohm COAXIAL TERMINATION

FREQUENCY RANGE:
dc to 3000 mc.
CHARACTERISTIC IMPEDANCE:
50 ohms
CONNECTORS:
Type "N" Coaxial female fittings each end
AVAILABLE ATTENUATION:
Any value from .1 db to 60 db
VSWR:
<1.2, dc to 3000 mc., for all values from 10 to 60 db
<1.5, dc to 3000 mc., for values from .1 to 9 db
ACCURACY:
±0.5 db
POWER RATING:
One watt sine wave power dissipation

Send for free bulletin entitled "Measurement of RF Attenuation"

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Inquiries invited concerning pads or turrets with different connector styles

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MODEL 543

Designed for convenient measurement of circuit capacitances from 0 to 150 MMF. Minimum resistance across measured capacitance 1500 ohm. Accuracy better than 3% or .5 MMF.

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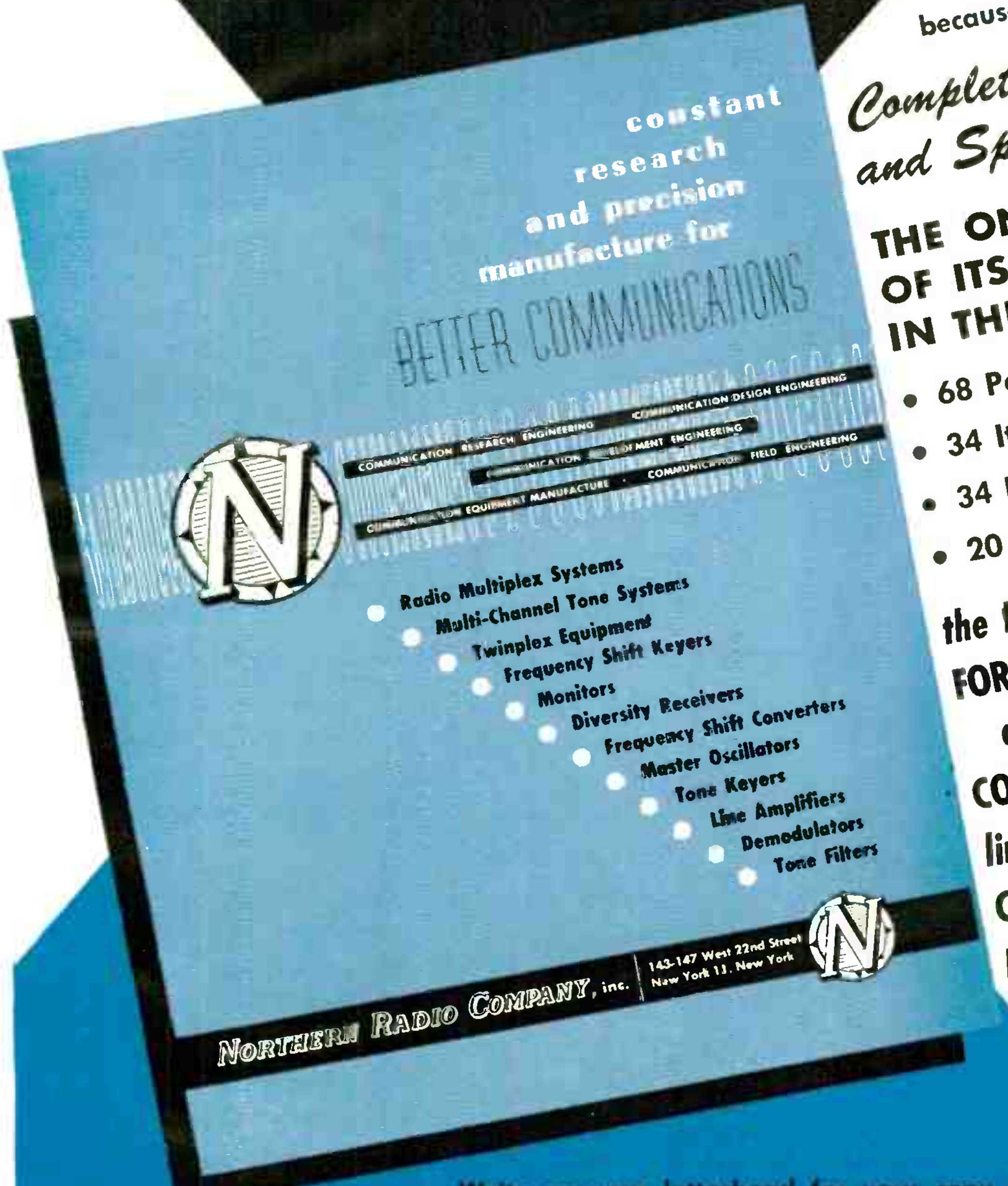

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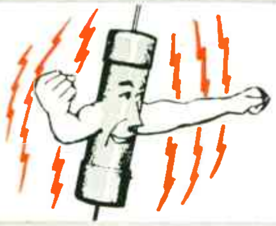

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TYPE DC DEPOSITED CARBON RESISTORS

Manufactured under rigid quality controls to deliver matchless performance and economy. Pure carbon in crystalline form is bonded to a selected ceramic core and then sealed against moisture with a special silicone coating having high di-electric strength, excellent thermal conductivity, and high resistance to abrasion.

Five wattage ranges and seven basic sizes: DC-⅛, ⅛ watt; DC-¼, ¼ watt; DCS-½, ½ watt; DCM-½, ½ watt; DC-½, ½ watt; DC-1, 1 watt; DC-2, 2 watts.

- From 1 ohm to 200 megohms, depending on type
- Temperature coefficient varies slightly from 140 PPM to 500 PPM per degree C
- 1% accuracy. (Other tolerances available)

Meet MIL-R-10509-A Specifications

WRITE FOR BULLETIN No. R-24

DALE PRODUCTS, Inc.

1302 28th AVE., PHONE 2139 COLUMBUS, NEBRASKA, U.S.A.
Export Dept., Pan-Mar Corp., 1270 Broadway, New York 1, N.Y.

UHF Standard Signal Generator with Low Hum Level

MODEL 84-TV

FEATURES:

- DC operation of oscillator tube filament.
- Wide continuous frequency coverage.
- Frequency calibration accurate to ± 0.5%.
- Output dial calibrated in microvolts.
- Negligible stray field and leakage.
- Special design mutual inductance type attenuator.
- Low harmonic content.
- Low residual hum modulation.

USES:

The versatility of this instrument makes it adaptable to many applications within its frequency range; for driving slotted lines and other impedance measuring devices; for measuring the characteristics of UHF filters, traps, antennas, matching networks and other devices.

SPECIFICATIONS:

Frequency Range: 300 to 1000 Mc.
Frequency accuracy ± 0.5%.

Output: 0.1 uv to 1.0 v across a 50-ohm load.

Modulation: 0 to 30% from an internal 1000-cycle oscillator. External modulation from 50 to 20,000 cys. Residual hum modulation less than 0.5%.

Power Supply: 105 to 125 volts, 60 cycles, 120 watts.

Leakage: Negligible.

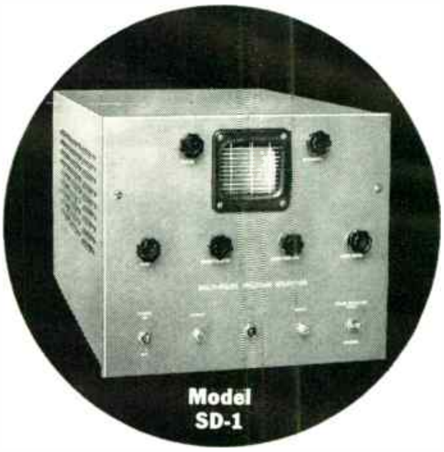
Laboratory Standards

MEASUREMENTS CORPORATION
BOONTON · NEW JERSEY

MICROWAVE MULTI-PULSE SPECTRUM SELECTOR

for use with Polarad Spectrum Analyzers

The Polarad Multi-Pulse Spectrum Selector increases the versatility of Polarad Spectrum Analyzers by displaying and allowing selection for analysis a specific train of microwave pulses as well as any one pulse in the train.



Model SD-1

It will select and gate a group of pulses up to 100 μsec. in length; is designed to work with fast, narrow pulses; and can be adjusted to gate any pulse including the first at zero time. Special circuitry discriminates automatically once pulses have been selected. The Model SD-1 has been designed to operate with all Polarad Spectrum Analyzers at any of the frequencies they will accept.

- Completely self-powered portable unit.
- High intensity, flat-face CRT for accurate display with:
  - Continuously variable sweep widths; 10 to 100 μsec.
  - Continuously variable gate widths for pulse selection; 0.2 to 10 μsec.
  - Continuously variable gate delays for pulse selection; 0 to 100 μsec.
  - Automatic gating of spectrum analyzer during time of pulse consideration.
  - Intensified gates (brightening) to facilitate manual pulse selection.
  - Triggered sweep on first pulse in any train. No sweep in absence of signal.

SPECIFICATIONS:

Maximum Pulse Train Time..............100 μsec.
Pulse Rise Time....................05 μsec. or Less
Minimum Pulse Separation.................1 μsec.
Repetition Rate....................10 –10,000 pps.
Minimum Pulse Width...........................1 μsec.
Input Power....................95 to 130 volts, 50/60 cps., 350 watts

Input Impedance . . . 50 ohms
Output Impedance . . . 50 ohms
(to match TSA Spectrum Analyzer)

AVAILABLE ON EQUIPMENT LEASE PLAN

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43-20 34th STREET
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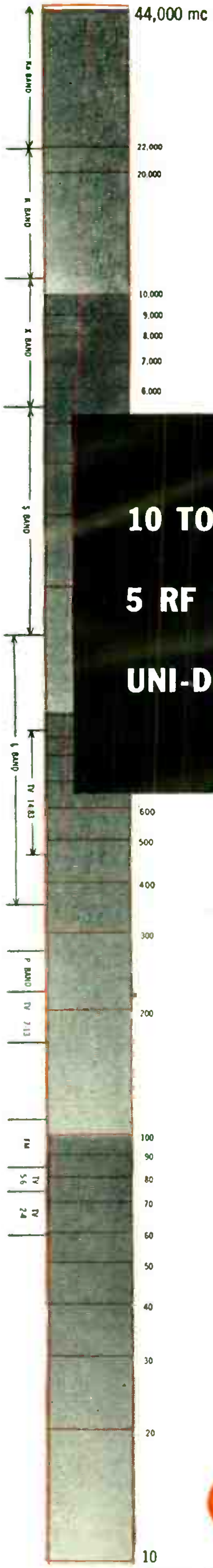

PORTABLE DIRECT READING SPECTRUM ANALYZER

10 TO 44,000 mcs

5 RF HEADS

UNI-DIAL TUNING

MODEL TSA

Now, a new Polarad spectrum analyzer only 21 inches high that covers the entire frequency range 10 to 44,000 mcs with 5 interchangeable RF tuning heads. The model TSA operates simply—single dial frequency control—with utmost frequency stability. It provides highest accuracy, and reliability for observation and true evaluation of performance over the entire RF spectrum—saving engineering manhours.

This instrument is designed for maximum utility and versatility in the laboratory and on the production line providing an easy-to-read 5 inch CRT display of the RF spectrum.

Model No.	Equipment
Model OSA	Spectrum Oisplay and Power Unit
Model STU-1	RF Tuning Unit 10-1,000 mc.
Model STU-2A	RF Tuning Unit 910-4, 560 mc.
Model STU-3A	RF Tuning Unit 4,370-22,000 mc.
Model STU-4	RF Tuning Unit 21,800-33,000 mc.
Model STU-5	RF Tuning Unit 33,000-44,000 mc.

SPECIFICATIONS:

Frequency Range: 10 kc to 44,000 mc.

Frequency Accuracy: 1%

Resolution: 25 kc.

Frequency Oispersion: Electronically controlled, continually adjustable from 400 kc to 28 mc per one screen diameter (horizontal expansion to 20 kc per inch)

Input Impedance: 50 ohms—nominal

*Sensitivity:
STU-1 10-400 mcs —89 dbm
400-1000 mcs —84 dbm

STU-2A 910-2,200 mcs —87 dbm
1,980-4,560 mcs —77 dbm

STU-3A 4,370-10,920 mcs —75 dbm
8 900-22,000 mcs —60 dbm

STU-4 21,800-33,000 mcs —55 dbm

STU-5 33,000-44,000 mcs —45 dbm

Overall Gain: 120 db

Attenuation:
**RF Internal 100 db continuously variable IF 60 db continuously variable

Input Power: 400 Watts

*Minimum Discernible Signal
**STU-1, STU-2A, STU-3A

The model TSA Spectrum Analyzer has these exclusive Polarad design and operating features:

- Single frequency control with direct reading dial. No klystron modes to set. Tuning dial accuracy 1%.
- Five interchangeable RF tuning units for the entire frequency range 10 to 44,000 mcs.
- Temperature compensation of Klystron Oscillator.
- Swept IF provides 400 kc to 25 mc display independent of RF frequency setting.
- Internal RF attenuator.*
- Frequency marker for measuring frequency differences from 100 kc to 25 mc.

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EIMAC Vacuum Switches

for high voltage, airborne service

Compact, fast action Eimac vacuum switches are custom designed for high voltage application. Single pole, double throw action contacts are precision spaced in high vacuum, permitting reliable performance regardless of ambient atmospheric conditions. In antenna switching service, RF peak potentials as high as 20kv may be applied between the switch terminals. Eimac vacuum switches are not limited to this service, however, as they will handle 1.5 amps at 5kv in DC switching. Efficient operation in severe airborne conditions, small size and instant response give these switches a distinct advantage over conventional relays. Now available are four Eimac switch types, including one for pulse service.

For further information contact our Application Engineering department

Eimac

EITEL-McCULLOUGH, INC.
SAN BRUNO, CALIFORNIA
The World's Largest Manufacturer of Transmitting Tubes

simplify custom installation

The 4200 Sound Effects Filter and 4201 Program Equalizer are now available in component form, as illustrated, for the custom builder.

In addition to the flexibility of installation, all the features and characteristics of the standard models are retained.

The high and low sections of either model may be obtained separately. Complete wiring instructions included.

Send for Bulletin TB-4

Model 4200 Sound Effects Filter
(Send for Bulletin S)

Model 4201, Program Equalizer
(Send for Bulletin E)

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SEALED—RUGGEDIZED INSTRUMENTS
BY ROLLER-SMITH HAVE THAT
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Perfect Readability: New shrouds designed by leading industrial designers focus attention to the large dial, assuring "one look" readability and enhanced appearance.

Greater Accuracy: New zero adjuster permits "split-second" adjustment from the front. No danger of leaks.

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Roller-Smith sealed and ruggedized instruments feature these three outstanding engineering and design improvements in all sizes from 1½ to 4½ inches to make them the most advanced on the market. Available in all practical ranges of AC and DC for accurate measurements under extreme environmental conditions.

Consult our engineering staff with over 50 years experience to solve your specific research and development problems.

Designed to comply fully with MIL-M-6A and MIL-M-10304 (Signal Corp.)

An extra feature—new "wrap around" shroud with gasket seal makes these meters as modern in appearance as they are in performance. Precisely built, their neat functional form expresses the forward thinking of our engineers.

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Instrument Division
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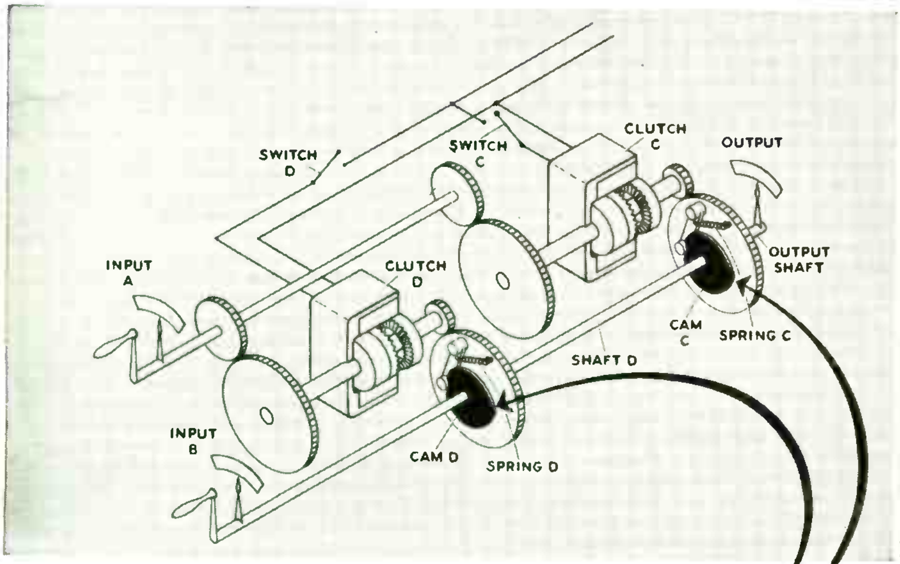
Precision Products Since 1908

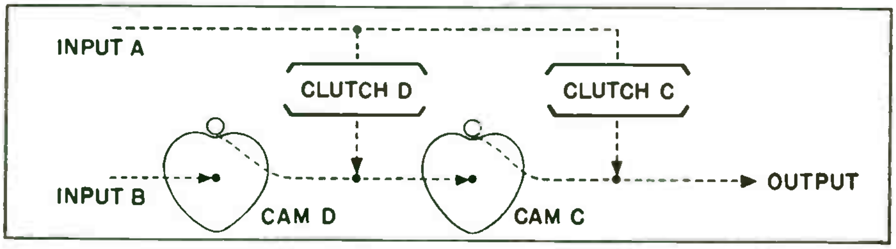
See these and other outstanding Roller-Smith products featuring the "new-look" at Booth 702 I. R. E. Show, Kingsbridge Armory, New York City, March 21-24, 1955.

SINCE 1915 LEADERS IN AUTOMATIC CONTROL



MECHANICAL MEMORY
with a heart

Ford Instrument Company engineers draw on the entire scope of scientific knowledge to solve each problem. In a recent project, Ford found good use for components it developed a score of years ago to produce a mechanical memory system whose accuracy is independent of the time interval, and which meets a military requirement of absolute reliability.



In an instrument in which the input quantities may vary with time, it is desired to produce an output equal to the change in one quantity A since the time t_1, added to the value that a second quantity B had at time t_1. At the same time it is desired to store another output equal to the change in quantity A since a second time t_2, added to the value that the quantity B had at that time t_2. It is further desired at any subsequent time to be able to read the first output or alternately the second output.

The storing of this information is accomplished by closing clutch C at instant 1 and clutch D at instant 2. The first output is then read directly at any subsequent time and the alternate output by opening clutch C. To recycle — clutch D is then opened.

Whatever problems must be solved in designing and manufacturing computers and controls, skills in electronics, magnetics, hydraulics and mechanical and electrical techniques are called upon by Ford engineers to develop the best instruments for the purpose.

If you have a problem in control engineering, Ford Instrument Company's forty years of experience in high precision design and production will help you find the answer.

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FORD INSTRUMENT COMPANY
DIVISION OF THE SPERRY CORPORATION
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of unusual abilities can find a future at FORD INSTRUMENT COMPANY. Write for information.

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UNEQUALED
PERFORMANCE
in

- TELEMETERING
- GUIDED-MISSILE MONITORING
- RADIOSONDE RECEPTION

Frequency coverage of 55 to 260 megacycles, AM and FM, without band changing. The 167 series of Special Purpose Receivers are designed for optimum performance in telemetering, guided-missile monitoring, radiosonde reception, television sound rebroadcasting and many other applications calling for superior performance. The superheterodyne circuit assures lowest noise figure possible with an input tube of reasonable cost, ready availability, and reliable performance. Particular care has been exercised to provide for extreme sensitivity and linearity of response, and the 500 ohm impedance of the output circuit permits bridging of many high-impedance devices. Only the finest components are used in their construction. All meters, transformers and chokes are hermetically sealed; all components are operated well within their safe design limits; and the entire assembly is treated to reduce the effect of moisture and fungus. Rigidly inspected and aligned, the Model 167 Receivers reflect the high standards characteristic of the products of this company which for 45 years has been engaged in manufacturing radio-communications equipment and electronic instruments for the rigid requirements of military service.

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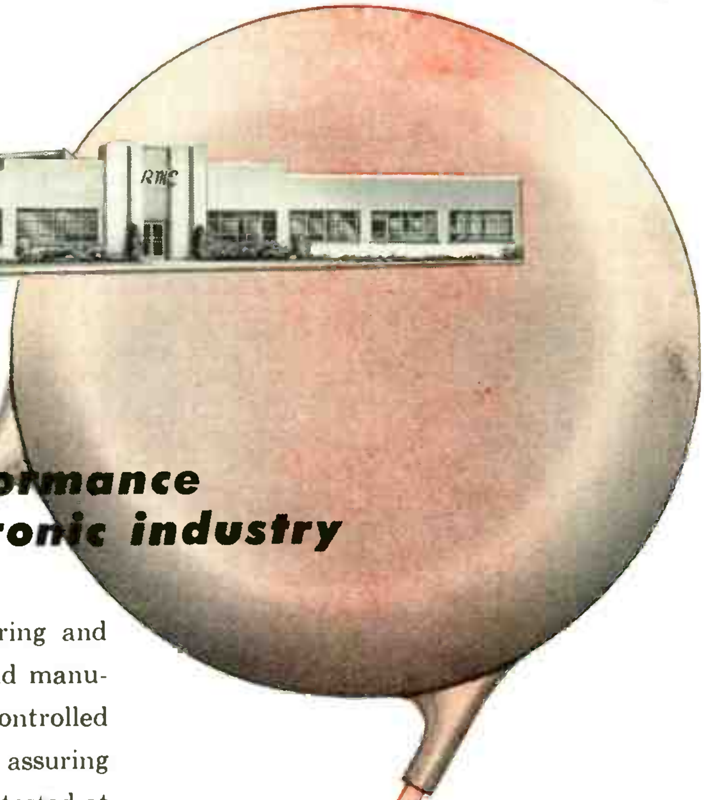
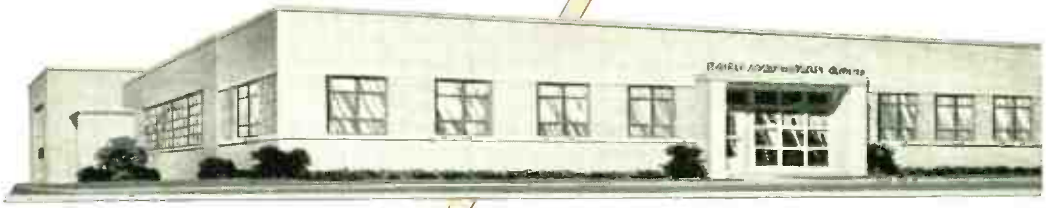
RMC Plant at Attica, Indiana

RMC DISCAPS

the standard of performance throughout the electronic industry



RMC devotes its entire research, engineering and production facilities to the development and manufacture of ceramic capacitors. Production is controlled from basic powders to completed capacitor assuring absolute quality control. Every DISCAP is tested at twice its rated voltage before shipment. DISCAPS are available in temperature compensating, by-pass, stable capacity, high voltage and AC line types in addition to the exclusive new "Wedg-loc" types for printed wire circuits.


RMC Plant and General Office at Chicago, Illinois


RMC Research Division at Chicago, Illinois

3 RMC Plants to Serve You

RMC operates centrally located production plants at Chicago, Illinois and Attica, Indiana. The Research Division in Chicago houses development and engineering personnel continuously at work improving ceramic dielectrics. For standard or special types of ceramic capacitors specify RMC DISCAPS.

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CERAMIC
CAPACITORS

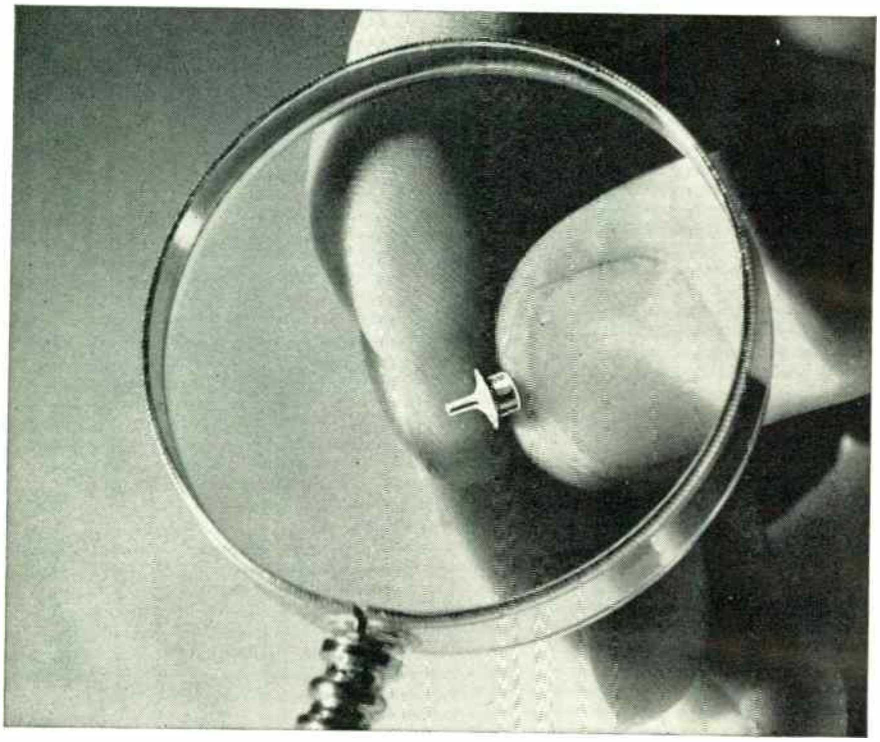
RMC

RADIO MATERIALS CORPORATION
GENERAL OFFICE: 3325 N. California Ave., Chicago 18, Ill.

FACTORIES AT CHICAGO, ILL. AND ATTICA, IND.
Two RMC Plants Devoted Exclusively to Ceramic Capacitors

Stupakoff

Kovar HARD GLASS Seals



No "Leakers" in 52 million!

Over 52 million of the seals illustrated above are in use; and not a single "leaker" has been discovered!

In their manufacture, Kovar metal and *hard borosilicate glass* (Pyrex) are permanently bonded together, forming a fused-oxide seal that is vacuum- and pressure-tight, and corrosion-proof at the interfaces.

Borosilicate glass, matching perfectly the thermal expansion of Kovar, gives to Stupakoff seals thermal endurance, weather resistance, and high electrical insulating properties over the full temperature range of the glass.


Stupakoff
KOVAR GLASS
Seals

Complete data of hundreds of sizes, styles and ratings of standard Stupakoff Kovar HARD GLASS hermetic seals is given in this catalog. Send for a free copy of Bulletin 453A.

Stupakoff

CERAMIC & MANUFACTURING COMPANY • LATROBE, PA.

DIVISION OF *The* **CARBORUNDUM** *Company*

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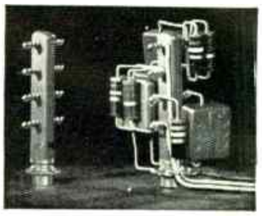
for that short grid lead use the Sangamo

Tote-m-pole

First used in Navy electronic gear, Tote-m-poles are invaluable for "bug-resistant" wiring of models and production units. Advantages: Short leads; high component density; improved ventilation.



Tote-m-pole supporting "T" network of 5 resistors and 4 capacitors.

Actual Size

CUSTOM COMPONENTS DEPT.*
SANGAMO ELECTRIC COMPANY
SPRINGFIELD, ILLINOIS

*H. V. Power Supplies • Inductive Components
Servo Instruments • Low-X Resistors

FOIL

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ADHESIVE-BACKED

park "thinplates"

are .003-inch aluminum foil ANODIZED, and backed by pressure sensitive adhesive. These plates conform to JAN specifications.

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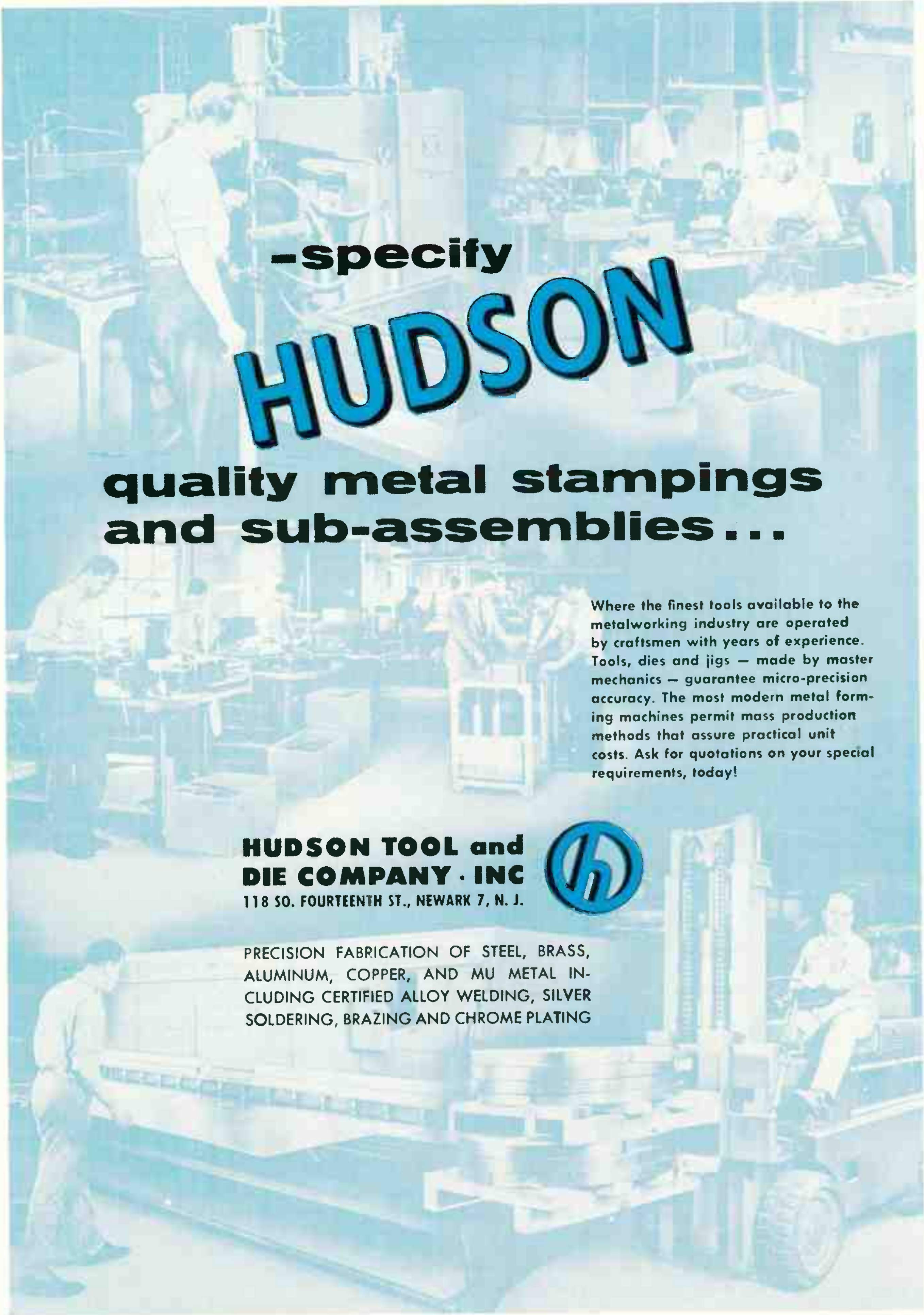

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quality metal stampings and sub-assemblies...

Where the finest tools available to the metalworking industry are operated by craftsmen with years of experience. Tools, dies and jigs — made by master mechanics — guarantee micro-precision accuracy. The most modern metal forming machines permit mass production methods that assure practical unit costs. Ask for quotations on your special requirements, today!

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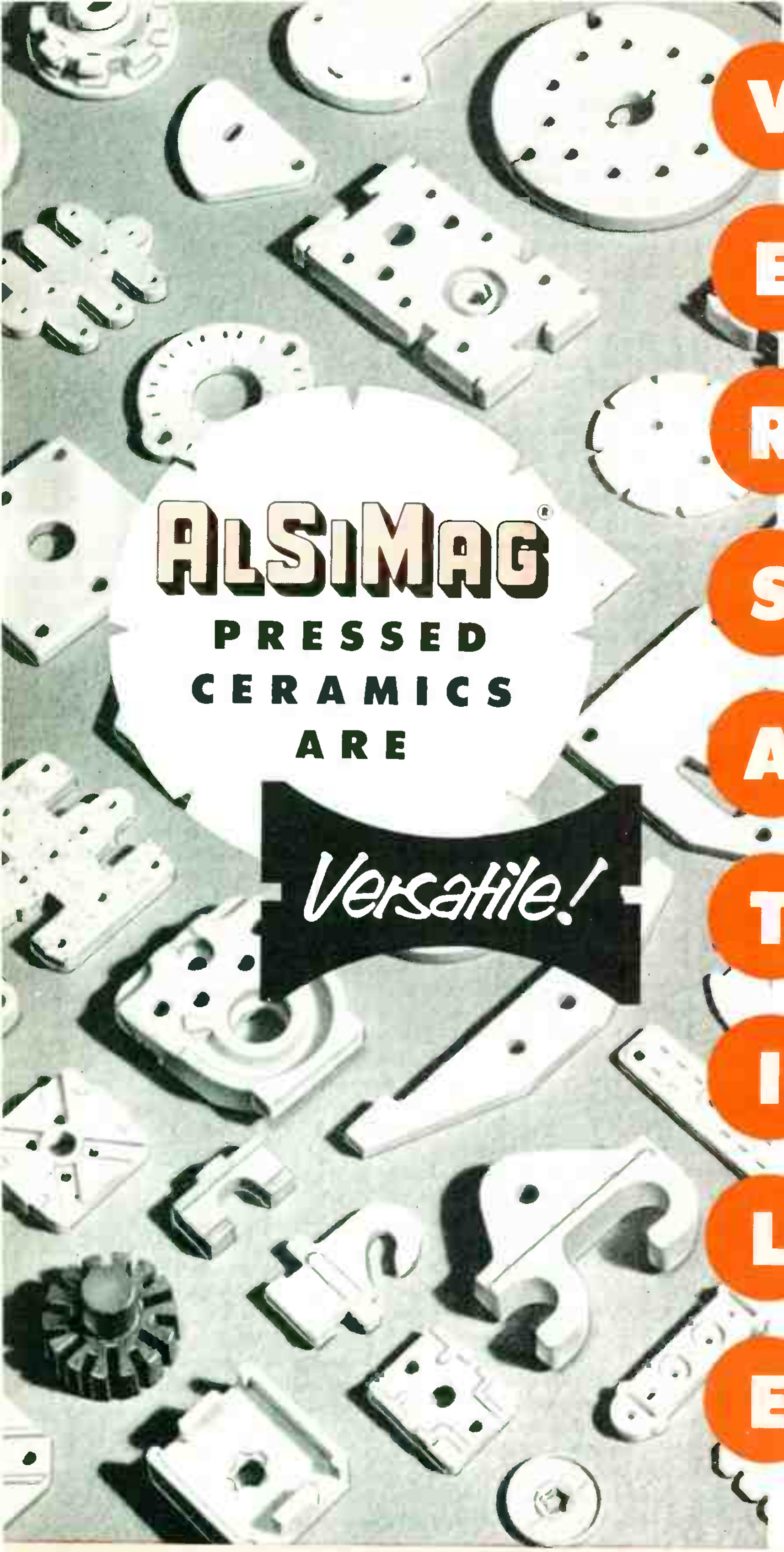

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Experience. Methods which have been perfected from 54 years of specialized experience.

Redesign service. Available without charge. Every effort made to find the best design . . . performance-wise and economy-wise.

Selection of materials. Widest in the industry. Careful matching with requirements. New bodies being developed constantly for unusual operating conditions.

Applications determine the material. You may choose from Lava, Silicon Carbide, Alumina (vitrified or porous), Cordierite, Steatite, Zircon, Zirconium Oxide, Magnesium Silicate, Aluminum Silicate, Forsterite, Titanium Dioxide. All available from this one source.

Tooling. No problem with AlSiMag. Well equipped die shops. Expert machinists. Tooling at actual estimated cost.

Intricate Designs. AlSiMag's over-all delivery record is unsurpassed . . . complicated shapes, precision tolerances, intricate miniatures.

Low Cost. Superior quality. Achieved through the right equipment . . . right materials . . . all-important "know-how."

Efficient production methods. Quality controlled manufacture. Well experienced, versatile personnel.

- AlSiMag may offer improvements for your application. Send in blueprint or sample today for price and delivery information.

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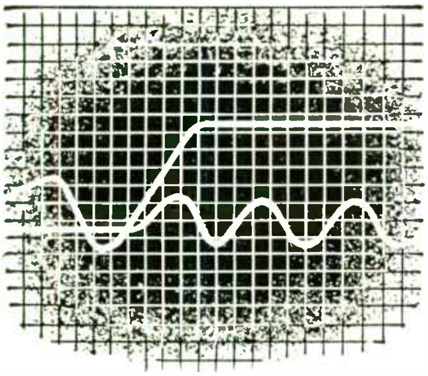
AMERICAN LAVA CORPORATION

A SUBSIDIARY OF MINNESOTA MINING AND MANUFACTURING COMPANY

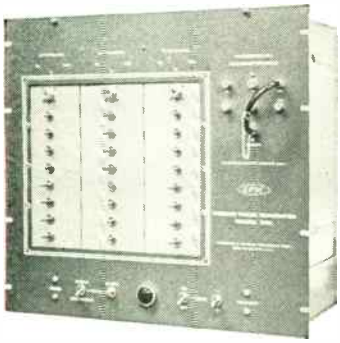
CHATTANOOGA 5, TENNESSEE

Branch offices in these cities (see your local telephone directory): Cambridge, Mass. • Chicago, Ill. • Cleveland, Ohio • Dallas-Houston, Texas • Indianapolis, Ind. • Los Angeles, Calif. • Newark, N. J. • Philadelphia-Pittsburgh, Pa. • St. Louis, Mo. • South San Francisco, Calif. • Syracuse, N. Y. • Tulsa, Okla.



EPIC

EPIC FAST PULSE AND COUNTING EQUIPMENT



Proved Dependability In A Versatile Range Of Assemblies

0.001 MICROSECOND RISE TIME SQUARE PULSE GENERATORS for the millimicrosecond to microsecond range.

0-10 MC DECADE AND BINARY SCALERS

FULLY AUTOMATIC 0-10 MC NUCLEAR SCALERS with predetermined count, predetermined time operation, precision high voltage power supplies, preamplifiers and discriminators.

- **PLUG IN COUNTING STRIPS**
- **0.1 MICROSECOND COUNTER CHRONOGRAPHS**
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- **WIDE BAND AMPLIFIERS**

ALSO CUSTOM DESIGNED EQUIPMENT TO MEET YOUR INDIVIDUAL REQUIREMENTS!

Write for detailed engineering bulletin No. 404

EPIC

ELECTRICAL AND PHYSICAL INSTRUMENT CORPORATION
Engineering Division
42-19 27th Street, Long Island City 1, N. Y.

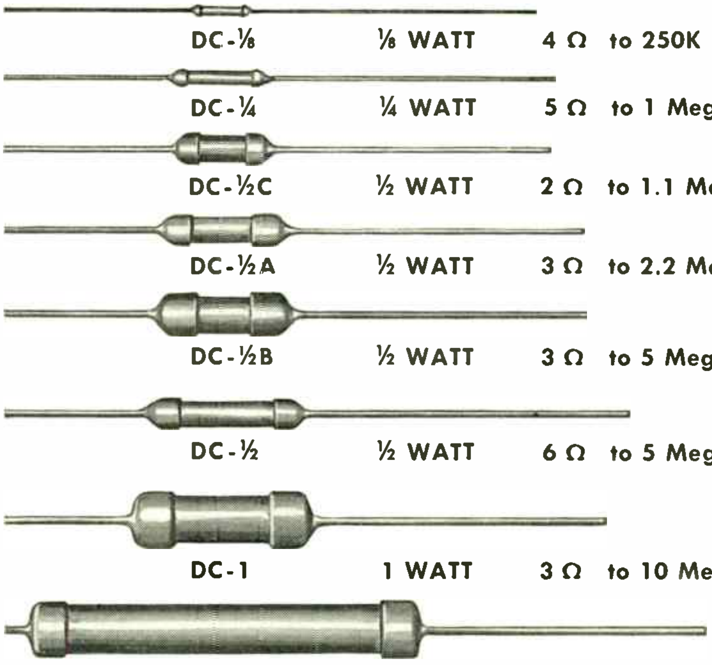
If this is what YOU NEED in RESISTORS . . . .

- **STABILITY**
- **PRECISION***
- **LOW TEMPERATURE COEFFICIENT**
- **LOW NOISE LEVEL**
- **WIDE RANGE OF VALUES**
- **SMALL PHYSICAL SIZE**
- **LOW COST**

CHOOSE FROM THESE 8 SIZES OF

Electra DEPOSITED CARBON RESISTORS

SHOWN IN ACTUAL SIZE



DC-⅛	⅛ WATT	4 Ω	to 250K
DC-¼	¼ WATT	5 Ω	to 1 Megohm
DC-½C	½ WATT	2 Ω	to 1.1 Megohms
DC-½A	½ WATT	3 Ω	to 2.2 Megohms
DC-½B	½ WATT	3 Ω	to 5 Megohms
DC-½	½ WATT	6 Ω	to 5 Megohms
DC-1	1 WATT	3 Ω	to 10 Megohms
DC-2	2 WATTS	10 Ω	to 50 Megohms

* Standard Resistance tolerance is ± 1% but all Electra resistors are available in ± 2%, ± 5%, and ± 10%. Electra quality is unsurpassed in the industry as several hundred leading manufacturers, our customers, will testify. You will find our services to your liking . . . deliveries are prompt and special requirements completely followed.

MAIL FOR COMPLETE SPECIFICATIONS

Electra carbon-coat PRECISION RESISTORS

ELECTRA MANUFACTURING CO.
RESISTOR DIV. 2537 MADISON KANSAS CITY, MO.

Please send bulletin E-4 giving complete specifications and characteristics of Electra Carbon Coat Resistors.

Name____________________

Company____________________

Address____________________

City____________ State______

Where dependability, long life and uniform performance are all-important . . . select

Bendix Red Bank

HARD GLASS Miniature Beam Power Amplifier

Here's another advance in the Bendix Red Bank "Reliable" Vacuum Tube program. Featuring a hard glass bulb and stem with gold-plated pins . . . plus a conservative design center of cathode temperature . . . the Bendix Red Bank RETMA 6094 can operate at temperatures up to 300° C. compared to an average of only 175° C. for soft glass bulbs. Thus, this new tube ideally meets aircraft, military and industrial applications where freedom from early failure, long service life, and uniform performance are essential.

The Bendix 6094 uses pressed ceramic spacers, instead of mica, for element separation. In other tubes, deterioration of mica in contact with the hot cathode causes loss of emission which is greatly accelerated under shock and vibration. Ceramic eliminates this problem and greatly reduces damage caused by fatigue failure of parts.

For complete details on our special-purpose tubes, write today.

ELECTRICAL RATINGS*

Heater voltage (AC or DC)**	6.3 volts
Heater current	0.6 amps.
Plate voltage (maximum DC)	275 volts
Screen voltage (maximum DC)	275 volts
Peak plate voltage (max. instantaneous)	550 volts
Plate dissipation (absolute max.)	12.5 watts
Screen dissipation (absolute max.)	2.0 watts
Cathode current (max. instantaneous peak value)	100.0 ma
Heater-cathode voltage (max.)	±450 volts
Grid resistance (max.)	0.1 megohm
Grid voltage (max.)	+5.0 volts
(min.)	−200.0 volts
Cathode warm-up time	45 seconds

(Plate and heater voltage may be applied simultaneously.)

*To obtain greatest life expectancy from tube, avoid designs where the tube is subjected to all maximum ratings simultaneously.

**Voltage should not fluctuate more than ±5%.

MECHANICAL DATA

Base	9 pin miniature hard glass—gold plated tungsten pins
Bulb	Hard glass—T6½
Max. over-all length	2⅞"
Max. seated height	2⅝"
Max. diameter	⅞"
Mounting position	any
Max. altitude	80,000 feet
Max. bulb temperature	300°C.
Max. impact shock	500g
Max. vibrational acceleration	50g

(100-hour shock excited fatigue test, sample basis.)

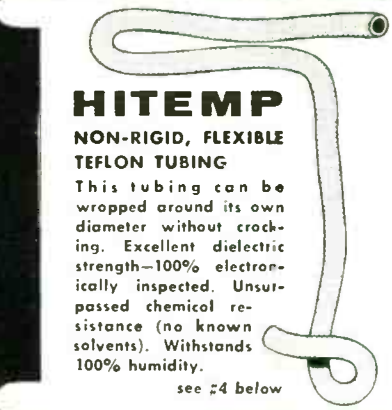
Bendix Red Bank

Manufacturers of Special-Purpose Electron Tubes, Inverters, Dynamotors, Voltage Regulators, Fractional D.C. Motors and A.C. and D.C. Generators.

EATONTOWN, N. J.

DIVISION OF Bendix AVIATION CORPORATION — THE NAME MILLIONS TRUST

West Coast Sales and Service: 117 E. Providencia Ave., Burbank, Calif.
Export Sales: Bendix International Division, 205 E. 42nd St., New York 17, N. Y.
Canadian Distributor: Aviation Electric Ltd., P.O. Box 6102, Montreal, P.Q.



HITEMP

NON-RIGID, FLEXIBLE TEFLON TUBING

This tubing can be wrapped around its own diameter without cracking. Excellent dielectric strength—100% electronically inspected. Unsurpassed chemical resistance (no known solvents). Withstands 100% humidity.

see #4 below

From the list below select the wire which meets your needs:

1. **TEMPRITE TEFLON MAGNET WIRE**—Sizes from 14—50 AWG incl. Withstands temperatures from −90C°+260°C. Single, heavy, triple or quad thickness.
2. **TEMPRITE-X SPECIAL TEFLON MAGNET WIRE**—Same characteristics and sizes as regular Temprite magnet wire, but specially processed for severe applications.
3. **THERMALON SILICONE MAGNET WIRE**—Sizes from 14—50 AWG incl. Used for temperatures from −54°C-+180°C. Made in single or heavy thickness.
4. **NON-RIGID, FLEXIBLE TEFLON TUBING**—Sizes 26—10 inclusive. Used for temperatures from −90°-+260°C. 10 solid colors or spiral striped in over 200 combinations. Conforms to MIL Std. 104.
5. **TEMPRENE TEFLON HOOK-UP WIRE**—Sizes from 30—10 AWG incl. Unaffected by temperatures from −90°C-+260°C. Excellent dielectric, impervious to all commercial solvents. Solid colors or spiral striped in 55 different color combinations. Made to meet MIL-W-16878A.
6. **TEMPREX TEFLON EXTRUDED HOOK-UP WIRE**—Sizes from 30—10 AWG incl. Types E and EE of MIL-W-16878A in 14 solid colors. Same characteristics as Temprene.
7. **TEMPCLAD TEFLON-FIBERGLAS LEAD WIRE**—Sizes from 30—8 AWG incl. Made to MIL-W-7139, for temperatures from −90°-+260°C. Suitable where maximum abrasion protection or resistance to mechanical stress is required.
8. **RETEP TEFLON SATURATED GLASS BRAID LEAD WIRE**—Low cost, low voltage push-back type for the range—90°C-+260°C. Retains flexibility after impregnation.
9. **NEBROC TEFLON-FIBERGLAS LACING CORD**—Developed especially for wiring harnesses or coil tying. Made in sizes from .009"—.076" and in tape form.
10. **TEMPTUBE TEFLON-FIBERGLAS TUBING**—Sizes up to 1¼" ID. Fully saturated for high dielectric and maximum abrasion resistance. Colors on request.

For complete engineering specifications write

HITEMP WIRES

26 WINDSOR AVENUE
MINEOLA, LONG ISLAND
SPECIALISTS IN HIGH-TEMPERATURE INSULATION

Now Available at E-I

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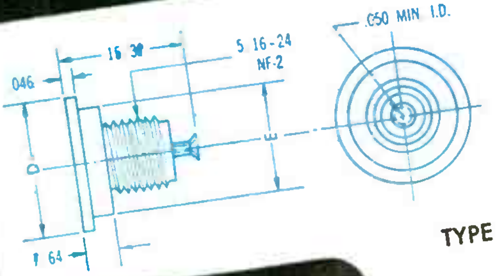
THREADED END SEALS*

FOR TUBULAR COMPONENTS

E-I compression seals offer super rugged construction that withstands pressure changes, shock and vibration. No special skill is required to apply the seal, and assembly is rapid as all metal parts are tin dipped for easy soldering. In addition to standard types, special constructions and diameters can be supplied quickly, on order. Check your hermetically-sealed terminal requirements with E-I.

Threaded Barrel Flared Tubing Types

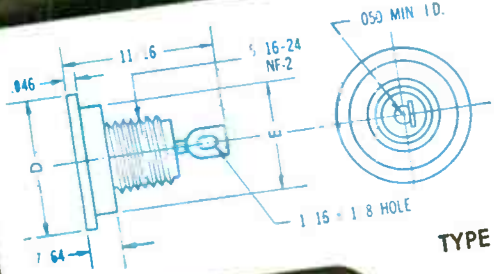


TYPE 535S-5/16-24R-.075/F

TYPE 643S-5/16-24R-.075/F

TYPE 723S-5/16-24R-.075/F

Threaded Barrel Lug Types



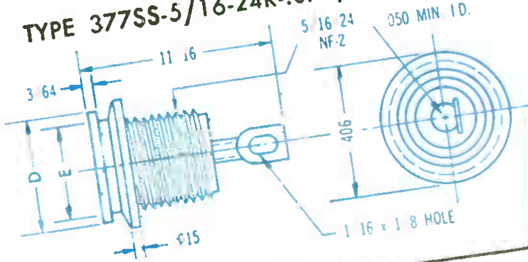
TYPE 535S-5/16-24R-.075/PT

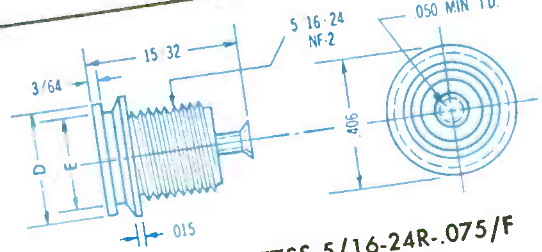
TYPE 643S-5/16-24R-.075/PT

TYPE 723S-5/16-24R-.075/PT

Grooved Flange Threaded Barrel Lug Types

TYPE 377SS-5/16-24R-.075/PT





TYPE 377SS-5/16-24R-.075/F

TYPE NUMBER	DIMENSION D	DIMENSION E
535S -5/16-24R-.075/F	.535	.437
643S -5/16-24R-.075/F	.643	.500
723S -5/16-24R-.075/F	.723	.562
535S -5/16-24R-.075/PT	.535	.437
643S -5/16-24R-.075/PT	.643	.500
723S -5/16-24R-.075/PT	.723	.562
377SS-5/16-24R-.075/PT	.377	.323
377SS-5/16-24R-.075/F	.377	.323

STANDARD COMPRESSION END SEALS both lug and flared tubing types available for resistors, condensers, capacitors and other tubular components. Diameters supplied to match threaded barrel terminals.

ELECTRICAL INDUSTRIES

DIVISION OF AMPEREX ELECTRONIC CORP.

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NEWARK 4, NEW JERSEY

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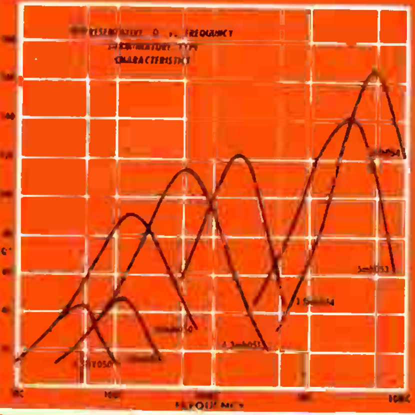
MOLDED PLASTIC TOROIDS

(M. P. Series) STOCKED UNITS FOR IMMEDIATE DELIVERY TO MIL. SPECS - SHOCK, MOISTURE, TEMPERATURE . . .

C-A-C®

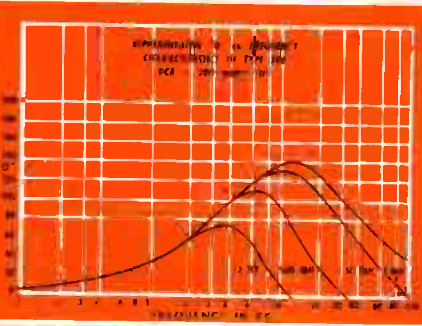
COMMUNICATION ACCESSORIES COMPANY Hickman Mills, Missouri

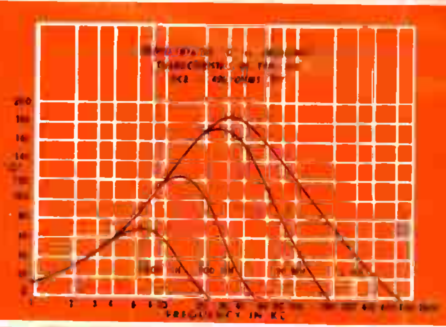
SIZE	TYPES
.688 OD	MP 050
.375 THICK	MP 051
.738 H	MP 053
	MP 054



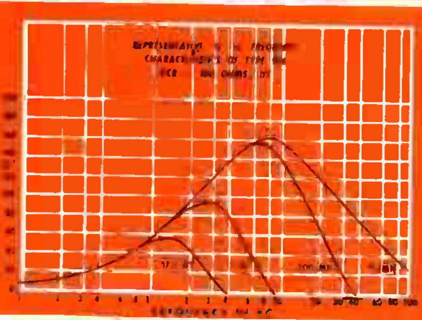
Other Subminiature molded plastic toroids—designs for all requirements—for chassis mount or printed circuits—see your CAC man or write us direct.

SIZE	TYPES
1-1/16 OD	MP 206
1/2 H	MP 848
6-32 MTG.	





SIZE	TYPE
1-5/16 OD	MP 930
23/32 H	
6-32 MTG	

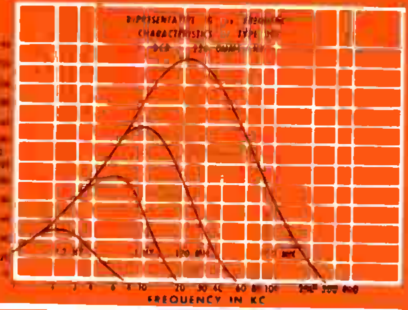


LIST OF STOCKED UNITS

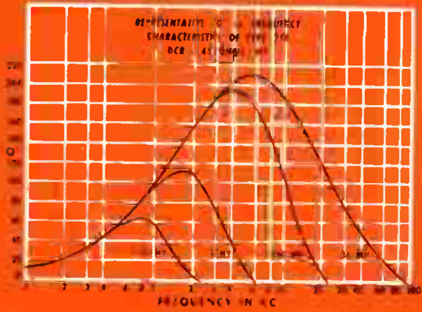
All Other Values and Types on Special Order

Suffix Number	MP 206—	MP 930—	MP 254—
—1	5.0 MH	5.0 MH	20 MH
—2	6.0 MH	6.0 MH	24 MH
—3	7.2 MH	7.2 MH	30 MH
—4	8.6 MH	8.6 MH	36 MH
—5	10 MH	10 MH	43 MH
—6	12 MH	12 MH	50 MH
—7	15 MH	15 MH	60 MH
—8	17.5 MH	17.5 MH	72 MH
—9	20 MH	20 MH	86 MH
—10	24 MH	24 MH	100 MH
—11	30 MH	30 MH	120 MH
—12	36 MH	36 MH	150 MH
—13	43 MH	43 MH	175 MH
—14	50 MH	50 MH	200 MH
—15	60 MH	60 MH	240 MH
—16	72 MH	72 MH	300 MH
—17	86 MH	86 MH	360 MH
—18	100 MH	100 MH	430 MH
—19	120 MH	120 MH	500 MH
—20	150 MH	150 MH	600 MH
—21	175 MH	175 MH	720 MH
—22	200 MH	200 MH	860 MH
—23	240 MH	240 MH	1.00 HY
—24	300 MH	300 MH	1.20 HY
—25	360 MH	360 MH	1.50 HY
—26	430 MH	430 MH	1.75 HY
—27	500 MH	500 MH	2.00 HY
—28	600 MH	600 MH	2.40 HY
—29	720 MH	720 MH	3.00 HY
—30	860 MH	860 MH	3.60 HY
—31	1.00 HY	1.00 HY	4.30 HY
—32	1.20 HY	1.20 HY	5.00 HY
—33	1.50 HY	1.50 HY	6.00 HY
—34	1.75 HY	1.75 HY	7.20 HY
—35	2.00 HY	2.00 HY	8.60 HY
—36	2.40 HY	2.40 HY	10.0 HY
—37	3.00 HY	3.00 HY	12.0 HY
—38		3.60 HY	15.0 HY
—39		4.30 HY	17.5 HY
—40		5.00 HY	20.0 HY
—41		6.00 HY	24.0 HY
—42		7.20 HY	30.0 HY
—43		8.60 HY	36.0 HY
—44		10.0 HY	
—45		12.0 HY	
—46		15.0 HY	
—47		17.5 HY	

SIZE	TYPE
1-5/16 OD	MP 395
23/32 H	
6-32 MTG.	



SIZE	TYPE
2 OD	MP 254
1 H	
8-32 MTG.	



COMMUNICATION ACCESSORIES COMPANY Hickman Mills, Missouri

Industrial Engineering Notes

(Continued from page 18A)

riod. Of the October TV set production, 161,431 receivers were manufactured with UHF tuning facilities, bringing the 10 month total to 1,085,742. 2,907 color TV receivers were manufactured in October. For the first 10 months, color set production totaled 17,445 receivers. Of the October radio production, 12,151 sets contained FM tuning facilities and an additional 2,846 TV receivers were equipped to receive FM signals.

TECHNICAL

A vital new use of radar in ground combat to detect and track down the source of enemy mortar fire was disclosed by the Department of the Army recently. Known as counter-mortar radar AN/MPQ-10, the device was jointly developed and designed by the Army Signal Corps and the Sperry Gyroscope Co. With the aid of the new electronic locator, reportedly far advanced from the experimental stage, front line forces can detect and "lock on" the path of enemy mortar shells, automatically track their trajectory and obtain computer range data which reveal the enemy position. These coordinates then are relayed to an Artillery Fire Direction Center, which can respond with precisely aimed fire to eliminate enemy mortars within moments after they open fire. The equipment is compact and mobile and can be towed by a light Army truck for quick movement in battle. The system consists of a large automatic radar tracker with dish-shaped antenna, a gasoline powered motor generator of Signal Corps lightweight design, a portable tracker mount resembling a 40 mm gun carriage for rapid movement to new positions, and a separate remote control console with radarscopes and all controls used during operation of the radar set. . . . **The Navy Department has announced the successful completion of the first contract involving use of the automatic production system developed by the National Bureau of Standards.** The contract was for the manufacture of several thousand "highly complicated electronic subassemblies" for sonobuoys. Preliminary field tests of the mechanically assembled equipment indicate higher performance and reliability than similar equipment built by conventional methods, the Navy announced. The Bureau of Aeronautics, which let the production contract to the Willys Motors Corporation, recently announced that mechanized production has sufficiently advanced to warrant its more extensive use in producing field equipment for the fleet. The automatic production line, which uses automatic fabrication and assembly equipment, has offered the Bureau of Aeronautics an opportunity for evaluating the technical and economic aspects of a mechanized production line for electronic products.

(Continued on page 42A)

Industrial Engineering Notes

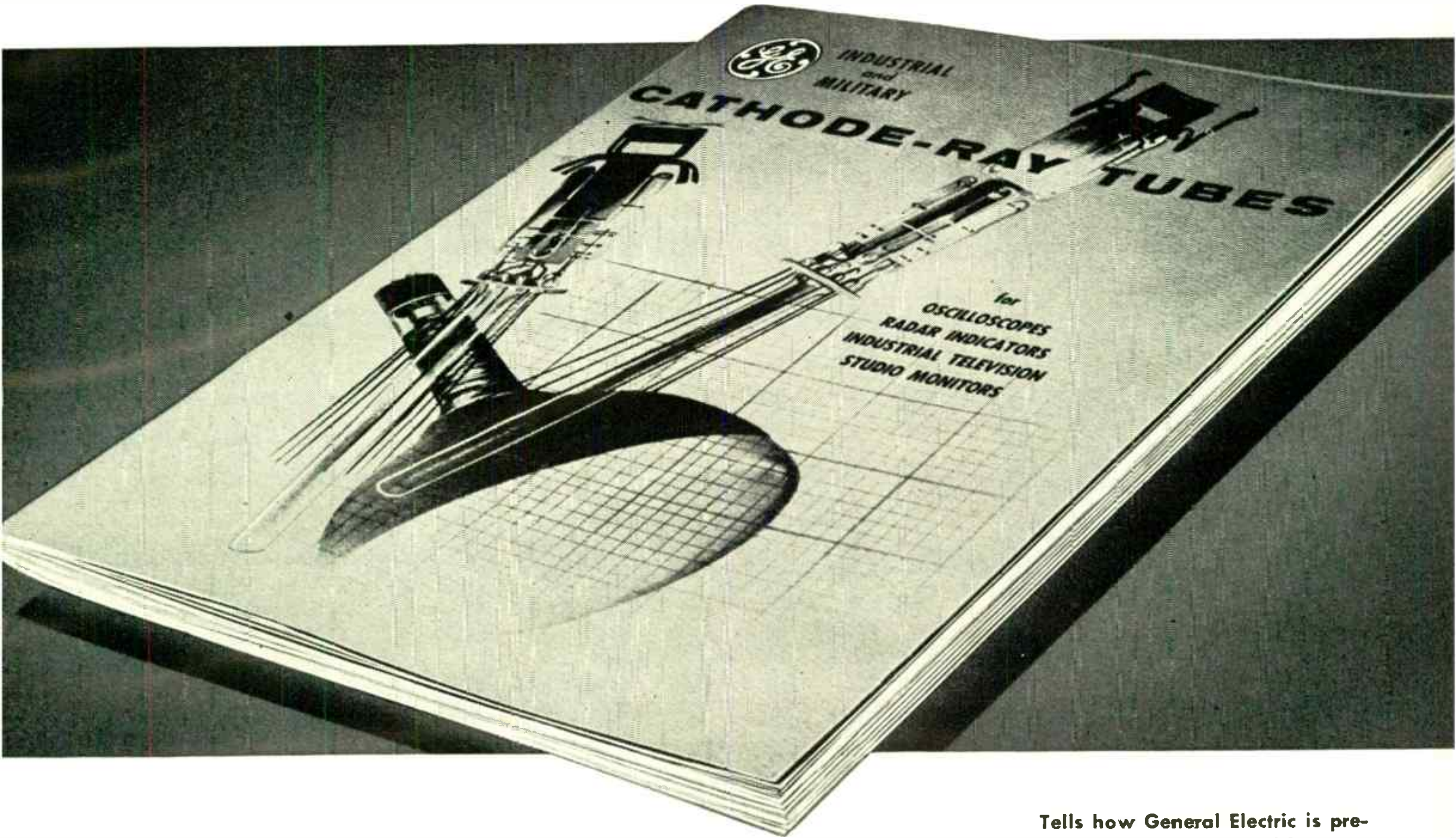
(Continued from page 41A)

The Navy also reported that additional uses for automatically produced electronic components are under study. A series of five volumes, including drawings, have been prepared on the automatic production technique and will be available for purchase from the Office of Technical Services at the Commerce Department. The volume that is now at the printers is entitled "Conversion from Conventional to Automatic Manufacturing." . . . **The Office of Technical Services, Commerce Department, has listed studies in the field of electronics in its November issue of the "Bibliography of Technical Reports."** The following government-sponsored research reports can be purchased from the Photoduplication Section, Library of Congress, Washington 25, D. C., for the reported price: "Crystal Units, Low Frequency, Services for Research and Development. Final Report," PB 115057, microfilm, $7.75; photocopy, $26.50. "Diffraction by a Strip," PB 114771, microfilm, $2; photocopy, $2.75. "Examination of Thermal Characteristics of Some Cast Electronic Equipment Structures with a Collateral Investigation of Bulb Temperatures," PB 115207, microfilm, $5; photocopy, $15.25. "Maximum-Minimum Shift Method for Measuring Complex Dielectric Constants and Permeabilities," PB 115165, microfilm $2.50; photocopy, $5.25. "Radar, a Report on Science at War, Released by the Joint Board on Scientific Information Policy for Office of Scientific Research and Development, War Department, Navy Department," PB 114957, microfilm, $3; photocopy, $7.75. "Research in Physical Electronics. Quarterly Progress Report No. 6," PB 115048, microfilm, $5; photocopy, $15.25. "Research Services and Investigations on Subminiature Multielement Diodes and Bistable Elements for Microtronic Circuits. First Summary Report," PB 115054, microfilm, $3; photocopy, $7.75. "Study of Certain Problems in the Field of Absorption of Microwave Energy in the Atmosphere. Quarterly Progress Report III," PB 115001, microfilm, $2; photocopy, $2.75. "Accuracy of a Self-Balancing Bridge in the Measurement of Microwave Power," PB 115162, microfilm, $2.75; photocopy, $6.50. "Design of Metallized-Glass-Dissipative-Wall Variable Waveguide Attenuator," PB 115157, microfilm, $3; photocopy, $7.75. "New Magnetic Servo Amplifier," PB 111442. Available from the Office of Technical Services, Department of Commerce, Washington 25, D. C., for $1.

TELEVISION

The Federal Communications Commission recently, by Report and Order, withdrew its proposed rule making of March 11, 1954, to require UHF television stations to employ transmitters with a rated power of at least 5 kw and terminated this proceeding (Docket 10952).

Pinpoint your C-R tube design needs with G.E.'s new catalog of Industrial and Military types!



Here is your working guide to cathode-ray tubes for industrial and military applications! General Electric, a pioneer in basic cathode-ray research—leader in C-R tube development—now offers to equipment designers and builders a comprehensive catalog that takes the guesswork out of tube selection.

Ask for your copy . . . and keep it for constant reference! Problems arising from your special circuit needs, on which you may need further and more detailed information, will be handled promptly by letter or by a visit from a G-E tube engineer, as you prefer. The Tube Application Requirement Forms included in the catalog, make inquiry easy and systematic.

Wire or write for Catalog ETD-985-A to *General Electric Company, Tube Department, Schenectady 5, New York.*

Tells how General Electric is prepared to meet your need for new, special C-R types . . . by combining bulbs, guns, and phosphors; or by custom-designing a tube "from the ground up" should volume warrant. Catalog includes forms for transmitting your tube requirements in detail.

●

24 standard G-E industrial and military cathode-ray tubes are illustrated, rated, fully described. Basing diagrams are included.

●

18 phosphors most in demand are described as to color, persistence, and field of application . . . also, spectral-energy emission and persistence curves are plotted for each phosphor.

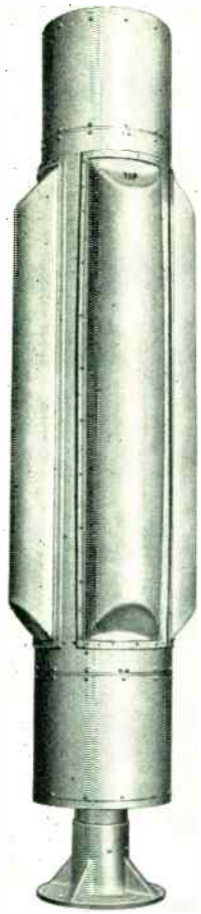
●

9-page section is devoted exclusively to tube, gun, and phosphor research . . . design . . . manufacture . . . testing. Includes many photographs of C-R products and processes.

Progress Is Our Most Important Product

GENERAL ELECTRIC

162-1B1



The Type 2602-E

VOR *antenna**

has these important advantages

- no moving parts
- can be installed in a few hours
- no field adjustments
- used successfully both in the U.S.A. and in other countries
- frequency range — 108 mc to 118 mc
- shipped completely assembled, and tuned when frequency is specified
- can be readily retuned to any frequency within its range
- net weight — approximately 140 lbs.

Write for Bulletin R-255

*Original model was developed for the Air Navigation Development Board.

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ALFORD *Manufacturing Co. Inc*
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NEW, LOW PRICE!

SHAVE IN THE COMFORT OF YOUR CAR, Boat or Plane!

Specially Designed for Operating Standard A.C. Electric Shavers in Automobiles, Buses, Trucks, Boats, and Planes.

Plugs into
Cigarette Lighter
Receptacle on Dash

$9.95 LIST PRICE

TYPE	INPUT D.C. VOLTS	A.C. OUTPUT 60 CYCLES	OUTPUT WATTAGE	LIST PRICE
6-SPB	6	115 volts	15	995
12-SPB	12	115	15	995

Introducing
ATR MIGHTY MIDGET *portable* **INVERTER**
WITH GREATER OUTPUT

DICTATE REPORTS ACCURATELY-PROMPTLY!

make your car, boat or plane a "rolling office" with ATR INVERTERS for changing your storage battery current to A. C. *Household* ELECTRICITY *Anywhere* in your own car!

Plugs into
Cigarette Lighter
Receptacle on Dash

$19.95 AND UP
LIST PRICE

ATR INVERTERS . . .
especially designed for operating standard 110 volt A. C. .

- DICTATING MACHINES
- ELECTRIC RAZORS
- TAPE RECORDER
- WIRE RECORDERS

TYPE	INPUT D.C. VOLTS	A.C. OUTPUT 60 CYCLES	OUTPUT WATTAGE	LIST PRICE
6-DME	6	115 volts	30-40	19.95
6H-DME	6	115 volts	60-75	29.95

Above Inverters also available for 12-volt operation.

See your jobber or write factory today for complete information

ATR **AMERICAN TELEVISION & RADIO CO.**
Quality Products Since 1931
SAINT PAUL 1, MINNESOTA—U. S. A.

LORD FACTS ON VIBRATION

ANYONE CAN MAKE VIBRATION CONTROLS

Practically every mechanism is subjected to either destructive wear or impaired performance because of vibration or shock . . . and practically anyone could make a unit to "solve" these problems to some degree. It is important, however, that the vibration control units contribute to improved operation and efficiency of the mechanism—and at reasonable cost.

The use of makeshift or incorrectly applied units usually makes the condition worse instead of better.

LORD has devoted over 30 years to the successful solution of thousands of vibration and shock problems. LORD research, engineering, and production facilities have produced over 27,000 types of highly effective control units for all kinds of applications.

Exceptional engineering and manufacturing skills plus the use of only the best materials provide users of LORD products with several outstanding advantages:

EFFECTIVE VIBRATION ISOLATION—LORD units reduce operating vibration, shock, and noise to the lowest practical level—over a long, service-free operating life.

LOWER MAINTENANCE COSTS—Effective isolation provided by LORD systems reduces destructive vibration—lowering maintenance adjustment and parts replacement costs.

FLEXIBILITY IN USE—LORD extensive design and production facilities have developed a group of standard mountings of several types. These are adaptable to many standard vibration control applications and provide effective and economical solutions to a wide range of problems.

The extensive facilities at LORD are available on request for solution of your problems, whether they are simple or complex. Simply call or write the Home Office, Erie, Pa. or the LORD Field Engineer nearest you.

LORD MANUFACTURING COMPANY • ERIE, PENNSYLVANIA

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PLATE FORM MOUNTINGS


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CHAN-L-MOUNTS


TEMPROOF MOUNTINGS

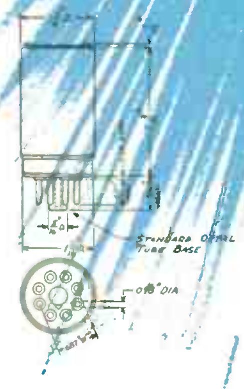

FLEXIBLE COUPLINGS

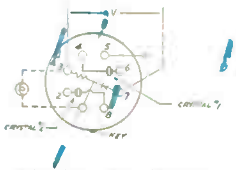
LORD
BONDED RUBBER

DESIGNERS AND PRODUCERS OF BONDED RUBBER PRODUCTS SINCE 1924

NEW HIGH STABILITY PACKAGE WITH 100kc AND 1000kc CRYSTALS

The
BLILEY TCO-2L
TEMPERATURE
CONTROLLED OVEN
(75°C) WITH TYPE
BH6A CRYSTAL AT
1000kc AND TYPE
BH9A CRYSTAL AT
100kc





BOTTOM VIEW OF BASE

Another masterpiece in crystal craftsmanship

This compact temperature controlled package provides a high stability reference source at both 100kc and 1000kc. Recommended for general laboratory use and the precision calibration of signal generators or other test instrumentation.

TECHNICAL DATA

CRYSTAL UNITS IN TCO-2L OVEN	FREQUENCY	STABILITY (Over Ambient Range) −40°C to +70°C
BLILEY TYPE BH6A	1000kc	±.0001%
BLILEY TYPE BH9A	100kc	±.0003%
ACCURACY AT 75°C—ADJUSTABLE TO ZERO BEAT IN RECOMMENDED CIRCUIT		
HEATER RATING: 7.9 watts; 6.3 volts—1.26 amperes		
Octal Base (See Diagram)	Crystals Hermetically Sealed	

Bliley CRYSTALS

Bliley ELECTRIC COMPANY
UNION STATION BUILDING
ERIE, PENNSYLVANIA

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201M U-47M

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Over 85% of the torque wrenches used in industry are

STURTEVANT TORQUE WRENCHES

Read by Sight, Sound or Feel.

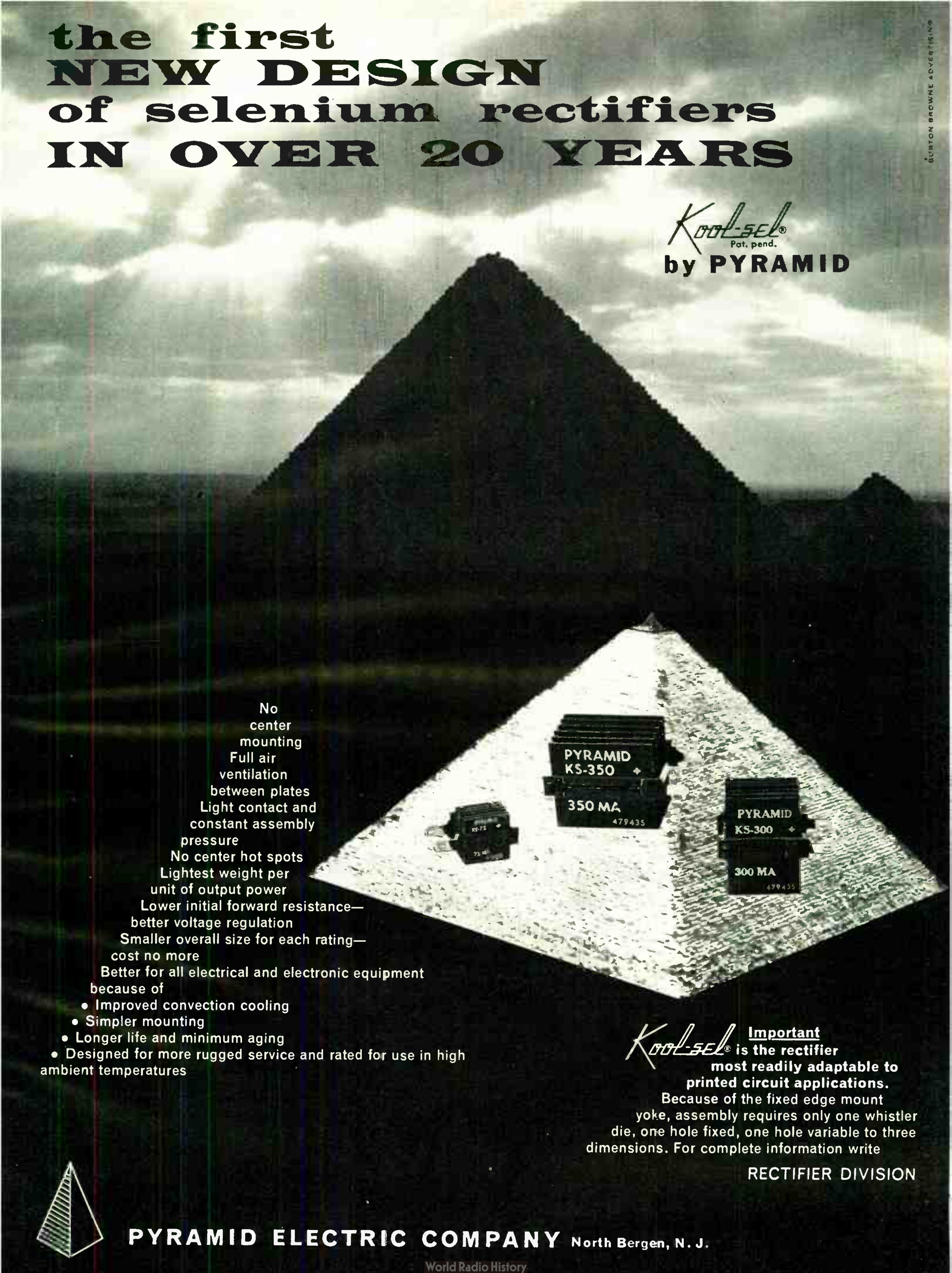
- **Permanently Accurate**
- **Practically Indestructible**
- **Faster—Easier to use**
- **Automatic Release**
- **All Capacities**

in inch grams...inch ounces,...inch pounds ...foot pounds (All sizes from 0-6000 ft. lbs.)

Every manufacturer, design and production man should have this valuable data. Sent upon request.

P.A. STURTEVANT CO
ADDISON QUALITY ILLINOIS

the first NEW DESIGN of selenium rectifiers IN OVER 20 YEARS



Kool-sel®
Pat. pend.
by PYRAMID

No center mounting
Full air ventilation between plates
Light contact and constant assembly pressure
No center hot spots
Lightest weight per unit of output power
Lower initial forward resistance—better voltage regulation
Smaller overall size for each rating—cost no more
Better for all electrical and electronic equipment because of

- Improved convection cooling
- Simpler mounting
- Longer life and minimum aging
- Designed for more rugged service and rated for use in high ambient temperatures

Important
Kool-sel® is the rectifier most readily adaptable to printed circuit applications. Because of the fixed edge mount yoke, assembly requires only one whistler die, one hole fixed, one hole variable to three dimensions. For complete information write

RECTIFIER DIVISION

PYRAMID ELECTRIC COMPANY North Bergen, N. J.

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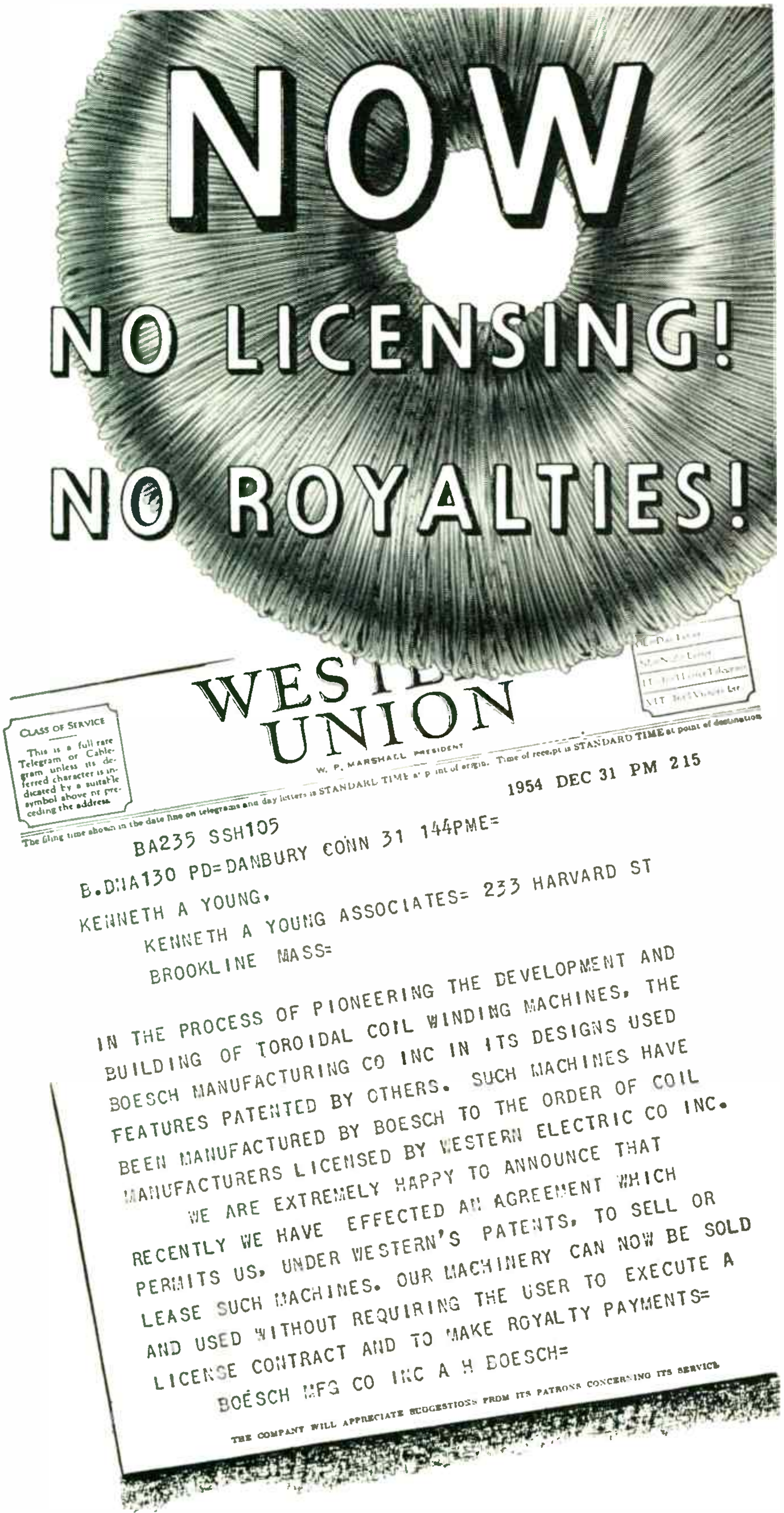

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IN THE PROCESS OF PIONEERING THE DEVELOPMENT AND
BUILDING OF TOROIDAL COIL WINDING MACHINES, THE
BOESCH MANUFACTURING CO INC IN ITS DESIGNS USED
FEATURES PATENTED BY OTHERS. SUCH MACHINES HAVE
BEEN MANUFACTURED BY BOESCH TO THE ORDER OF COIL
MANUFACTURERS LICENSED BY WESTERN ELECTRIC CO INC.
WE ARE EXTREMELY HAPPY TO ANNOUNCE THAT
RECENTLY WE HAVE EFFECTED AN AGREEMENT WHICH
PERMITS US, UNDER WESTERN'S PATENTS, TO SELL OR
LEASE SUCH MACHINES. OUR MACHINERY CAN NOW BE SOLD
AND USED WITHOUT REQUIRING THE USER TO EXECUTE A
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THE COMPANY WILL APPRECIATE SUGGESTIONS FROM ITS PATRONS CONCERNING ITS SERVICE

MAKERS OF THE WORLD'S MOST VERSATILE WINDING MACHINES

BOESCH
MANUFACTURING CO., INC.
DANBURY, CONN.

52-ohm LINE STRETCHERS

Coaxial, constant impedance type, has low VSWR

Rugged, reliable and handles substantial RF power.

Model 3701 extends 8 inches.

Model 3702 extends 14 inches.

Both can be fitted with Types N, HN, or other connectors.

Write for Bulletin R-454

ANTENNA SYSTEMS—COMPONENTS
AIR NAVIGATION AIDS—INSTRUMENTS

AMCI **ALFORD** *Manufacturing Co., Inc.*
299 ATLANTIC AVE., BOSTON, MASS.

SORENSEN

the FIRST line of electronic & tubeless Power Regulation Equipment

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- AC Line Voltage Regulators
- DC Power Sources (Nobatrons)
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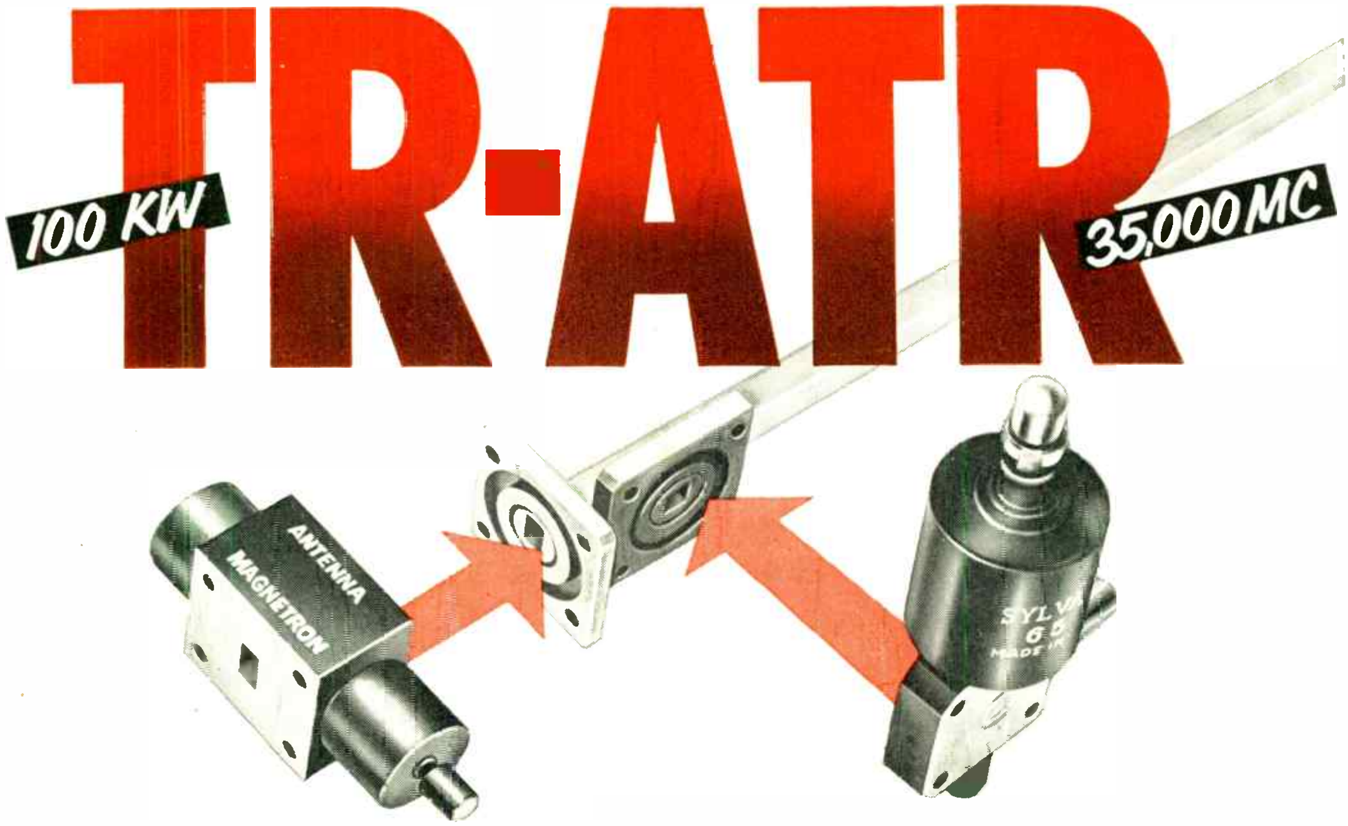
* * *

Be sure to visit our booth at the I.R.E. Show next month. Booth 646—Circuits Avenue and Radio Road.

SORENSEN & CO., Fairfield Avenue, Stamford, Conn.

Another important SYLVANIA First
for your microwave equipment . . .

TR-ATR



These high-power microwave components incorporate "ceramic-windows" for peak performance at 100 KW power levels—mounting is simplified

ATR Type 6546

featuring . . .

- ✓ new unitized construction —dual ATR and mount in one package — eliminate "castle" mounts

TR Type 6545

featuring . . .

- ✓ metal reservoir—extends tube life
- ✓ doubly loaded Q of 50—eliminates critical tuning at any setting

ELECTRICAL SPECIFICATIONS

Center frequency	34,860 Mc.
Transmitter peak power (min)	20 kw.

LOW LEVEL CHARACTERISTICS

Equivalent conductance (max)	0.15
Tuning susceptance	±0.07

HIGH LEVEL CHARACTERISTICS

Arc loss (max)	0.9 db
Firing time (max)	10 secs.

ELECTRICAL SPECIFICATIONS

Tuning range	33,814—35,906 Mc.
Transmitter peak power	100 kw.
Leakage power (max)	30 mw.
Insertion loss (max)	2.5 db
Ignitor Interaction (max)	0.2 db
Recovery time (max)	4 usec.

For all your TR-ATR needs Sylvania offers a complete line. Write for complete data.
"Another reason why it pays to specify Sylvania"

SYLVANIA

Sylvania Electric Products Inc.
1740 Broadway, New York 19, N.Y.

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LIGHTING • RADIO • ELECTRONICS • TELEVISION • ATOMIC ENERGY

No. 2 *in a series*

design progress through inter-company co-operation

. . . coordinated by Airtron inc.

NEW . . . DOUBLE-RIDGE WAVEGUIDE *for both* X-band and C-band operation!

Recently, Airtron was confronted with a difficult problem—how to develop a waveguide that would perform satisfactorily for both "X" and "C"-Band operation.

Due to differences of opinion concerning the optimum frequency for airborne weather radar systems, equipment manufacturers have selected two different operating frequencies for their designs . . . 5.6 cm ("C"-band) and 3.2 cm ("X"-band). As a result, two different waveguide sizes were required. This meant that should it become advisable to switch from one frequency band to the other it would necessitate the installation of an entirely new waveguide system . . . as well as the replacement of the radar equipment.

This was highly impractical and, accordingly, a coordinated effort was set up among the airlines technical advisory organization (ARINC), leading manufacturers of radar equipment, and the engineering staff of Airtron.

Working as a team the theoretical and practical difficulties were overcome and the solution evolved in a new double ridge waveguide. The new design not only permits handling of both bands, but also results in a considerable reduction in size and weight for "C"-band and improved electrical properties for "X"-band.

This is just another concrete example of how Airtron's creative engineering . . . and their close association with leading manufacturers in all phases of electronics . . . can be of assistance to you . . . whether the components you need are new in design or so-called "standard" plumbing.

***FREE CATALOG** on Ridge Waveguide for Airborne Weather Radar . . . contains a complete description of the new ridge waveguide series. Write on your letterhead c/o Dept. C for your copy today!*

Airtron inc. Linden, New Jersey

Designers & Manufacturers of Rigid and Flexible Waveguide Components and Aircraft Accessories

Branch Offices: Albuquerque • Boston • Chicago • Dallas • Dayton • Kansas City
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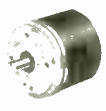
Precision AND *Accuracy* GIANNINI *Potentiometers*

SOME OUTSTANDING EXAMPLES:



SPIRALPOT

Models 85175A
85171A
85172A
85173A

Slide-wire, infinite resolution, low noise. Resistances 2 to 2500 ohms. Linearities 0.1% to 0.025%. 1 to 40 turns.

MICROTORQUE

Model 85111

Extremely low torque (.003 oz. in.). Resolution to .06%, 1" dia. x 1.31"; shaft 0.031", dia. 1.63 watts (average). Resistance: 250 to 25,000 ohms; 12 wiring types. Linearity: ±0.5% or ±0.25%.

MINIGANG

Model 85193

Rugged—small; resolution to .06%, 1.125" dia. up to six sections; 2 watts per section. Resistances: 130 to 70,000 ohms. Linearities: ±0.5% or ±0.25%.

RECTIPOT

Model 8620

Linear motion, rigid metal case; 1" dia. one or two elements; strokes from 0." to 6.0". Resistances from 400 ohms/in. to 15,000 ohms/in.; taps available.

UNIVERSAL GANGPOT

Model 85197

1 to 12 sections; 2" dia. Resistances 360 to 200,000 ohms per section. Linearities: ±0.3% to ±0.15%; sleeve or ball bearings; sections phaseable 3600; solid shaft, anodized aluminum case; log or sine-cosine outputs.

Giannini

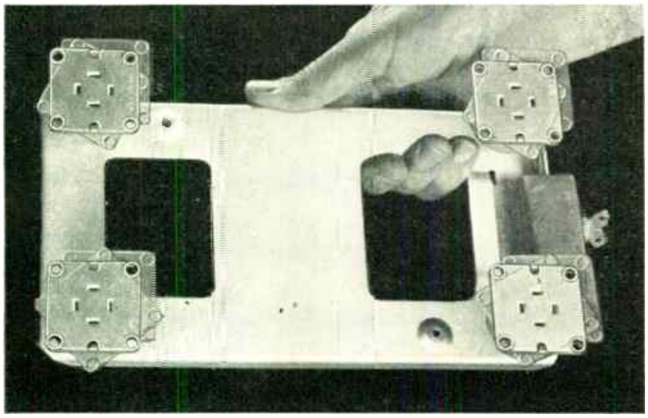
Product of Electromechanical Division
EAST ORANGE, NEW JERSEY

for information write

G. M. GIANNINI & CO., INC.
PASADENA 1, CALIFORNIA

PLAIN FACTS ABOUT VIBRATION AND SHOCK MOUNTINGS

FOR AIRBORNE ELECTRONIC EQUIPMENT

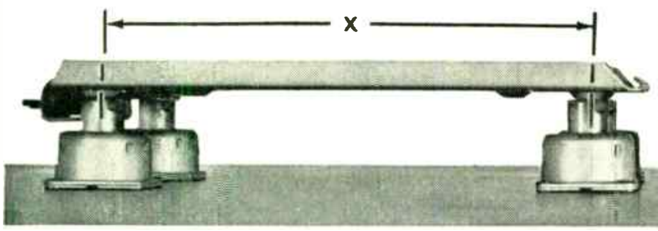


OUT-DATED UNIT MOUNT BASE

16 mounting holes and 16 bolts required.

Unit mountings may be improperly attached to the rack, and are very likely to be seriously misaligned during attachment to aircraft or missile structure.

Even minor discrepancies in spacing and attachment of unit mounts can defeat the whole purpose of the mounting base, and result in poor performance and deterioration of equipment.



Excessive height required. Unit mount bulk imposes reduced spacing (X) between support centers, resulting in impaired stability (critical in lateral direction). Greater sway space required.

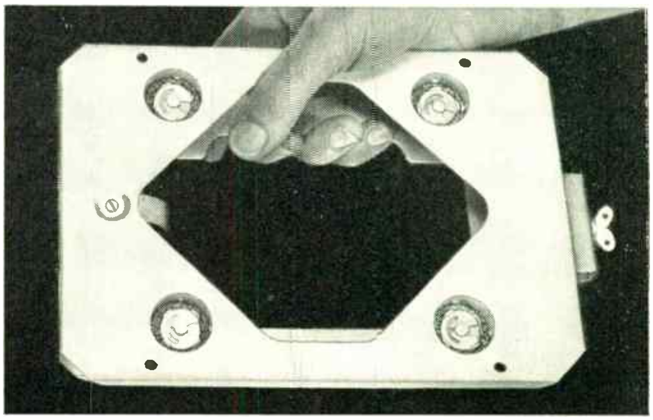
Well Designed Electronic Equipment, *If Poorly Mounted,* Too Often Operates Inefficiently and Unreliably

Failure also can result from use of inadequate mountings which are not engineered for the particular equipment and purpose. Conventional shock mounts or so called "isolators", reasonably effective when installed under ideal laboratory conditions, become dangerous trouble makers when installed by usual production line methods.

Attachment of a base plate to unit mounts to achieve spacing control is a makeshift arrangement resulting in excessive weight with no height reduction.

Failure also can result from obsolescent unit mounts employing internal rubber, organic or synthetic materials which deteriorate rapidly and are susceptible to temperature and environmental changes.

The importance of today's electronic equipment surely justifies the use of integrated mounting systems designed to meet specific problems rather than the unreliable application of assembled "catalogue" mounts.

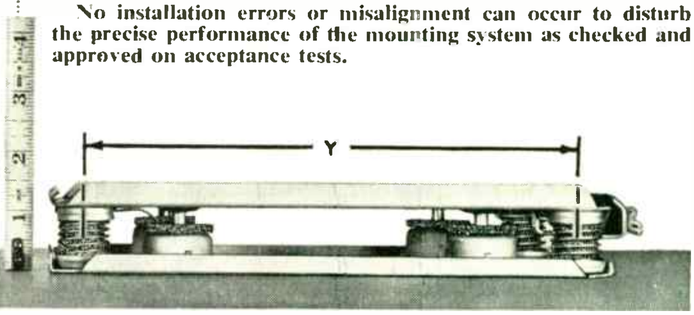


TODAY'S ENGINEERED MOUNTING SYSTEM

Only 4 mounting holes required.

Prespaced holes in a one piece base plate assure quick, accurate attachment. Relationship of all 4 holes is definitely fixed (holes spaced for interchangeability with unit mounts).

No installation errors or misalignment can occur to disturb the precise performance of the mounting system as checked and approved on acceptance tests.



Note reduction in mounting height. Important space saved. Maximum spacing (Y) of resilient elements at extreme corners provides stability. Less sway space required.

Robinson All-Metal Engineered Mounting Systems Assure Outstanding Performance and Reliability of Equipment

The Robinson concept of vibration and shock control is the design and application of 100% all-metal mounting systems. Engineered with careful understanding of the equipment to be protected and performance expected, Robinson mounting systems come to you completely manufactured, ready to receive the electronic equipment or instrument.

The integration of these mounting systems into the electronic equipment of aircraft and missiles results in reduction of elapsed design time and basic development cost.

Robinson Mountings utilize, as main resilient elements, metal wire cushions (MET-L-FLEX), exclusive with Robinson. This construction has been thoroughly proven by years of use in nearly all military and commercial aircraft.

Some other important characteristics of Robinson Mountings: inherent high damping, non-linear spring rate, performance unaffected by grease, oil, water, dust, extreme temperatures or environmental changes.

USE OF ROBINSON ENGINEERED MOUNTING SYSTEMS results in:

A. Reliable and uniform performance in every installation under all types of environmental conditions.

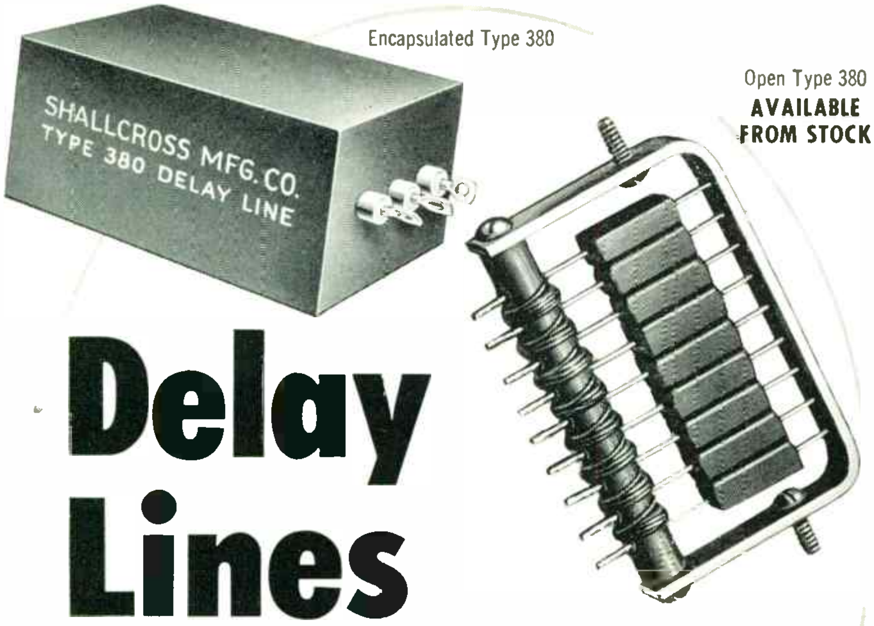
B. Reduced cost through "de"ruggedization of equipment — substantial reduction of size and weight is possible by simplified and compact design.

C. Simplified installation — only four attachment holes required—pre-spaced to save time and assure accuracy.

For full information about this new concept of vibration and shock control, write or wire today.

ROBINSON AVIATION INC.
TETERBORO, NEW JERSEY
Vibration Control Engineers

West Coast Engineering Office:
3006 Wilshire Boulevard, Santa Monica, California



Delay Lines

...STOCK TYPES FOR QUICK DELIVERIES
...SAMPLES AND "SPECIALS" TO EXACT SPECIFICATIONS

As engineering specialists in both wire winding and electronic equipment assemblies, Shallcross offers complete facilities for the design and large-scale production of delay lines in a variety of open and encapsulated styles for both highly critical as well as commercial uses.

Typical applications include use as compensating delays for color television, in signal delays for TV synchronizing signal generators, and in wideband distributed-type amplifiers.

Now available for prompt delivery is the Shallcross open-type 380 described below. This is a typical lumped parameter delay line using silvered mica capacitors conforming to JAN Style CM-15, Characteristic E. Many other types can be readily designed for specific applications. Quick delivery of prototypes! Send your specifications for prompt consideration by Shallcross engineers. SHALLCROSS MFG. CO., 524 Pusey Avenue, Collingdale, Pa.

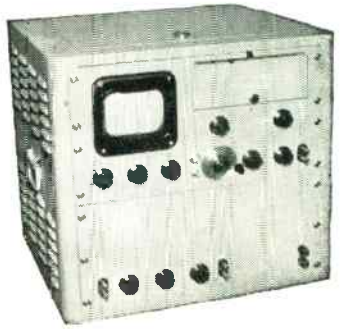
SHALLCROSS TYPE 380 DELAY LINE

SIZE:
Open Type: 2¼″ x 1½″ x 5/16″
Encapsulated Type: 2¼″ x 1″ x 1″

ELECTRICAL CHARACTERISTICS:
Maximum pulse voltage: ± 100 volts
Rise time: 0.04 microseconds
Total delay: 0.3 ± 0.03 microseconds
Impedance: 500 ohms
Cut-off frequency: 8.5 megacycles

Shallcross

SPEED UP



AUDIO WAVE FORM ANALYSIS

PANORAMIC SONIC ANALYZER LP-1

Many engineers find that Panoramic's LP-1 expedites their entire measurements program. LP-1 analyzes sound vibrations and electrical waveforms quickly, conveniently, accurately. Designed to eliminate the tedious problems commonly associated with audio wave form analysis, the Panoramic technique provides valuable visual information *in seconds!*

- Visualizes frequency and amplitude of waveform components between 40 and 20,000 cps; magnifies small portions of spectrum for detailed analysis; displays easily photographed; scans spectrum in 1-second; analyzes changing and static phenomena.

It will pay you to investigate the many unique advantages of LP-1.

- **SPECIAL APPLICATIONS**
- Investigations of closely spaced sound and vibration frequencies. Harmonic analysis of waveforms having low frequency fundamentals. Spectrum analysis requiring constant band width.
- Panoramic's LP-1 offers scores of unique advantages; it will pay you to check their application to your problems.

WRITE TODAY
for Complete Specifications

PANORAMIC
RADIO PRODUCTS, INC.

Made by the makers of Panadaptor, Panalyzor, Panoramic Sonic Analyzer, and Panoramic Ultrasonic Analyzer

12 South Second Ave., Mount Vernon, N.Y.
Phone: MOunt Vernon 4-3970

Hughes

high temperature operation

Silicon

extremely high back resistance

Junction

exceptionally stable characteristics

Diodes

Actual size,
diode glass body:
0.265 by 0.103
inches, maximum.
Body is coated
with opaque
silicone enamel to
shield crystal from
light. Color-coded
on cathode end.
Ambient operating
temperature range:
−80° to +200° C.

Now you can take advantage of silicon's operating temperature range and obtain, at the same time, a semiconductor device with phenomenally high back resistance. Actually, many of the types of the new Hughes Silicon Junction Diodes provide essentially an open circuit in the back direction. This means that many entirely new circuit applications are now made possible.

The entire line of these new Silicon Junction Diodes is packaged in the one-piece, fusion-sealed glass body, originated and developed at Hughes. This now-famous construction is impervious to moisture penetration—*ensures* electrical and mechanical stability. With their axial leads and subminiature size, Hughes diodes are easier to mount, easier to spot-weld or solder. So, when temperature or high back resistance requirements call for silicon, be sure to specify *Hughes Silicon Junction Diodes.*

Electrical features: Good forward conductance . . . very sharp back voltage breakdown . . . extremely high back resistance.

Physical features: One-piece, fusion-sealed glass body . . . axial leads for easy mounting . . . subminiature size.

Hughes

SEMICONDUCTOR SALES DEPARTMENT

Aircraft Company, Culver City, Calif.

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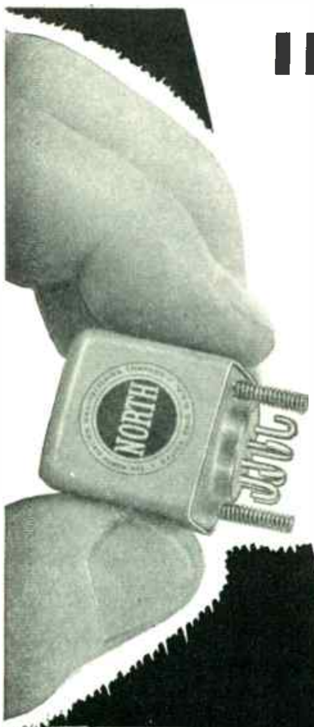
ROTARY ARMATURE

IR 207 RELAYS

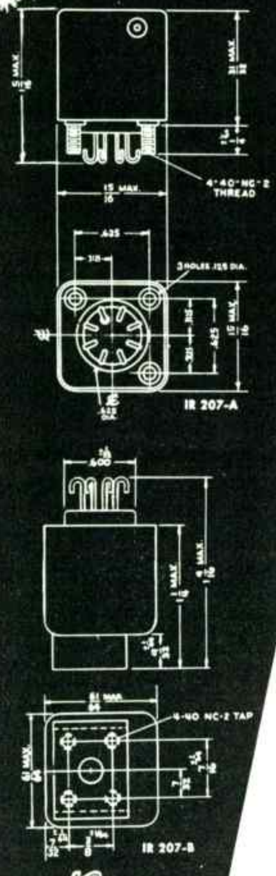
by NORTH

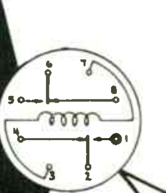


A subminiature rotary armature relay designed for a variety of airborne and guided missile applications where *reliable* operation in severe environment is required.

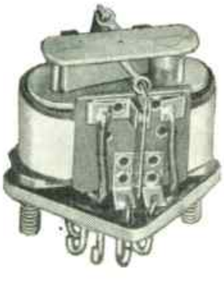
1. Two form C contacts rated at 2 amps, 30 volts, DC resistive.
2. Low capacity between contacts and ground.
3. The standard IR 207 relay meets the reliability requirements under MIL-R-5757B.
4. For critical applications where more reliability is required than is provided under MIL-R-5757B, North's "Special High Reliability" hermetically *sealed* relays are now available.

See our display
at the IRE Show
March 21-24

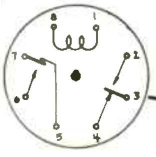




IR 207-B
Bracket Type
mounting equipped
with 4 holes for
4-40 screws



Standard IR 207 Relay:
Internal Structure



IR 207-C Type
with standard
octal plug base

Detailed specifications available on request.

THE NORTH ELECTRIC
MANUFACTURING COMPANY

Originators of ALL RELAY Systems of Automatic Switching

542 South Market Street, Galion, Ohio, U.S.A.

IRE People

NEWBERN SMITH

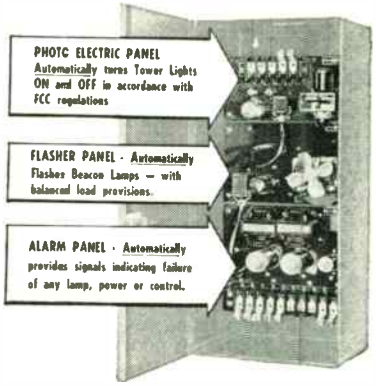
Newbern Smith (A'41–SM'46–F'52) research engineer for the University of Michigan's Engineering Research Institute (ERI), has been named supervisor of Project Michigan, The Institute's university-wide research program sponsored by the military.

As supervisor of Project Michigan, Mr. Smith will head a broad program of study set up last year for the development of methods for gathering accurate, up-to-date combat intelligence through radar, television and other mechanical devices. The largest ERI project, it has been described by Assistant Secretary of the Army, George H. Roderick, as "a concerted effort to apply the miracles of modern science and industry to the problems of the field commander."

Mr. Smith came to the Institute in February from the National Bureau of Standards where he was chief of the central radio propagation laboratory. He joined the bureau in 1935, following receipt of the doctor's degree in physics from the University of Pennsylvania.

(Continued on page 58A)

How to CONTROL and
ALARM the TOWER LIGHTS
of UNATTENDED Microwave
and Communication Stations



Model LC 201
TOWER LIGHTING CONTROL UNIT
(for Two Light Levels)
Model LC 101 (for Single Light Level)
Model LC 301 (for Three Light Levels)
Models also available with separate
Alarm Signal for each Beacon Lamp.

Write for descriptive Bulletins

HUGHEY & PHILLIPS, INC.
Manufacturers of
300MM Code Beacons, Obstruction Lights,
Photo-Electric Controls, Beacon Flashers,
Microwave Tower Control & Alarm Units
Remote Lamp Failure Indicator Systems,
and Complete Tower Lighting Kits.
3300 NORTH SAN FERNANDO BLVD.
BURBANK, CALIF.

World Radio History

new design freedom with

Sprague Button Ceramic Capacitors


Self-Tapping Stud Style


Flatted Screw Thread Mounting Style


Screw Stud Mounting Style


Dual-Section Threaded Shell Style

Sprague button ceramic capacitors offer distinct advantages to designers of ultra-high-frequency TV receivers and electronic equipment. These tiny capacitors are available in many styles for coupling, bypass, and feed-thru applications. Their wafer-dielectric construction makes possible higher self-resonant frequencies than with capacitors using conventional dielectric tubes. Button stand-off types, for example, minimize ground inductance and hold it at a fixed value while providing a short, uniform bypass to ground. They also provide effective shielding of the capacitor element by the outer metal shell. Sprague button capacitors are sealed against moisture by a high temperature resin, and are conservatively rated at 500 volts d-c.

For complete engineering data, write for Bulletin 605A to Technical Literature Section, Sprague Electric Company, 235 Marshall Street, North Adams, Massachusetts.

Sprague, on request, will provide you with complete engineering service for optimum results in the use of ceramic capacitors—buttons, discs, plates, printed r-c networks, high-voltage moldeds, etc.

WORLD'S LARGEST CAPACITOR MANUFACTURER

SPRAGUE®


Ferrule Shank and Clip Style


Tab Mounting Style

KEARFOTT

series #900

. . . all new synchros

Mechanical Stability

Stator integrally bonded with housing prevents null shifts when rotating or clamping synchro in its mount. All materials have similar thermal coefficient of expansion for optimum performance over a wide temperature range. Case provides positive grounding and shielding.

High Accuracy

10 minutes maximum deviation from electrical zero.

Corrosion Resistant

Housings, shafts and ball bearings are stainless steel. Laminations are corrosion resistant, nickel-bearing steel. Non-metallic materials are fungus inert.

Size 11

1.062" Diam. x 1-45/64 long, weight 4 oz.

Options

Available with leads or terminals, single or double ended shafts.

And Low In Price

Type	Model	Price*
Transmitter	RS911-1A	$29.50
Control Transformer	RS901-1A	29.00
Repeater	RS921-1A	31.50
Differential	RS941-1A	51.00
Resolver	RS931-1A	44.00

*Based on 1-25 unit price with leads and standard shaft. Quantity prices on request.

Kearfott Series 900 synchros are dimensionally and electrically interchangeable with Kearfott R200 Series Size 11 Synchros. Write today for data sheets.

KEARFOTT COMPONENTS INCLUDE:

Gyros, Servo Motors, Synchros, Servo and Magnetic Amplifiers, Tachometer Generators, Hermetic Rotary Seals, Aircraft Navigational Systems, and other high accuracy mechanical, electrical and electronic components.

ENGINEERS:

Many opportunities in the above fields are open—please write for details today.

Kearfott

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provides 35,000 engineers educated to buy and specify with your detailed product data for ready reference all year long.

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I R E People

(Continued from page 54A)

The appointment of **B. S. Ellefson** (A'38–M'44–F'48) as Technical Director of Sylvania Electric Products Inc. has been announced. Dr. Ellefson, who has been Director of Research for Sylvania since 1946, will advise the management on its research and engineering programs and will represent the company in technical contacts with the government and industry.

Joining the company in 1937 as a research chemist, Dr. Ellefson specialized in work on fluorescent materials and glass. He served in various engineering capacities until 1946 when he was appointed Director of the Central Engineering Laboratories on Long Island. That same year, he also went to Germany for the Department of Commerce as technical industrial intelligence investigator.

A graduate of St. Olaf College in Northfield, Minn., Dr. Ellefson received the Master of Science degree in physical chemistry from the University of Minnesota in 1933, and the Ph.D. in ceramics from Pennsylvania State College in February, 1937. He is the author of many technical papers.

Among his professional activities are membership in the American Chemical Society, American Ceramic Society, and American Association for the Advancement of Science. He is past Chairman of the Pennsylvania, New York and Western Border Section of the American Chemical Association, representative to the Industrial Research Institute, and Chairman of its Vital Statistics Committee.

⁂


R. G. MADDOX

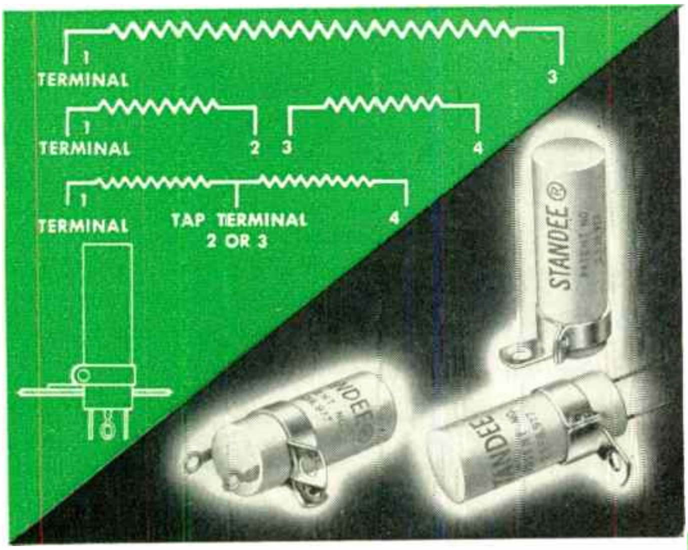
R. G. Maddox (M'53), formerly Technical Service Manager, has been appointed Vice-President in charge of Technical Sales and Service by the Board of Directors of Prodelin Inc., designers and manufacturers of television and microwave antenna system facilities.

In 1923, Mr. Maddox helped in the installation of the first radio arc transmitters used aboard U. S. Navy vessels operating in the Asiatic Fleet. In 1925 he returned to the U.S.A. to work as a field engineer for R.C.A. Radiola Division which he left later to organize and operate his own broadcasting station KFWH.

He later joined the Telephone Equipment and Engineering Company of San Francisco, working on ship-to-shore radio communication. During World War II he was assigned to the engineering staff of the Signal Corps General Development Laboratories at Fort Monmouth, New Jersey.

(Continued on page 60A)

Take that HEAT out of the CHASSIS, by either of these methods...



STANDEE*

Clarostat Series KS above-chassis-mounted power resistors. Handy terminals (lug, standard; or pigtail, at extra cost) for easy wiring. These unique components solve the problem of safe heat dissipation, yet terminals are below chassis, to fulfill UL requirements. Wire winding on glass fiber core, permanently sealed in smooth ceramic casing. Available in single, dual and tapped-section types as shown in wiring diagrams. Adjustable mounting ring provides for any protrusion above or below chassis. In 1½, 2, 2½ and 3" h. sizes. 10, 15, 20 and 25 watt ratings, respectively. Wide range of resistance values.

METAL-CLAD MOLDED

Clarostat Series MMR metal-clad resistors. Resistance winding sealed in molded phenolic and further protected by metal casing, for electrical and mechanical ruggedness. Adequate, but not excessive, phenolic insulation seals against moisture without hampering heat transfer to outer metal casing. No hot-spot troubles. Mounted flush against metal surface for maximum heat dissipation, unit is rated at 5 watts per winding inch, as against 2½ watts in free air. Sizes from 2" to 6" mounting centers. 1 to 10 sections. Breakdown strength over 1000 V.A.C.

ASK FOR LITERATURE!

Engineering Bulletins sent on request. Let our resistor-specialists collaborate on your application problems. and let us quote.

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Controls and Resistors

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In Canada: Canadian Marconi, Co., Ltd., Toronto 17, Ont.

*Reg. U.S. Pat. Off.

IRE People

(Continued from page 58A)

Here he was in charge of the Systems Engineering Branch. In 1944, at the Federal Telephone & Radio Company in Clifton, New Jersey, Mr. Maddox further developed telephone carrier and multichannel radio relay systems for adaptation to commercial application; he also planned and supervised the first commercial installations of telephone microwave relay systems which have since been established in many other services throughout the country.

Mr. Maddox is a member of the Radio-Electronics-Television Manufacturers Association.

⁂

William Firestone (M'49–S'50–SM'53) has been appointed to the newly created position of Assistant Chief Engineer of the research department of Motorola's Communications and Electronics Division. Dr. Firestone now has responsibility for specific phases of departmental administration. He will also continue in his present position as head of the Advanced Investigation Section of the research department. This group is engaged primarily in VHF two-way radio research and pulse code development work.

W. Firestone

Dr. Firestone received his Ph.D. in June, 1952 from Northwestern University. He is a member of Sigma Xi, Tau Beta Pi, Eta Kappa Nu, Pi Mu Epsilon, and AIEE. He is also the author of several technical articles.

⁂

M. W. Horrell (A'37–M'44–SM'50) Director of Engineering and Assistant General Manager of the Bendix Computer Division at Los Angeles since 1952, has been promoted to general manager of the Division.

Mr. Horrell, after extensive experience in the design of electronics equipment with several companies and as a member of the faculty at Kansas State College, in 1948 joined the staff of the Research Laboratories of Bendix at Detroit. In 1950, he was appointed Executive Engineer in charge of administration of the laboratories.

He is a member of the Association for Computing Machinery, and co-author of the textbook, "Basic Electronics."

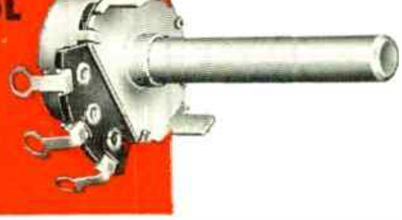
⁂

Howard Walker (SM'45) formerly plant manager of the York Pennsylvania Division has been promoted to general manager of Bendix Aviation Corp. Previ-

(Continued on page 62A)

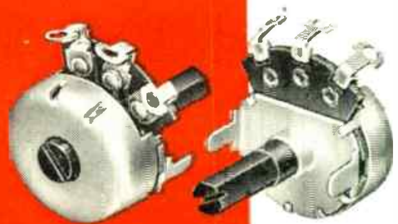
3 Low Cost VARIABLE RESISTORS for COMPACT CIRCUITS

COST-CUTTING TAB-MOUNTING CONTROL



0.5 watt metal shaft type for TV picture adjustment, pre-set gain controls, etc. Tab-mounting cuts mounting time, eliminates hardware. Nine different Stackpole line switches available for this control. *Send for specifications on Type LR-5.*

TAB-MOUNTING "DOUBLE-ENDER"



Just right for rear-of-chassis or concealed front panel controls in TV receivers . . . especially in high voltage circuits. Bakelite shaft can easily be adjusted from either side of control. Measures only .894" in diameter, yet handles a full .5-watt. *Write for data on Stackpole Type LR-6.*

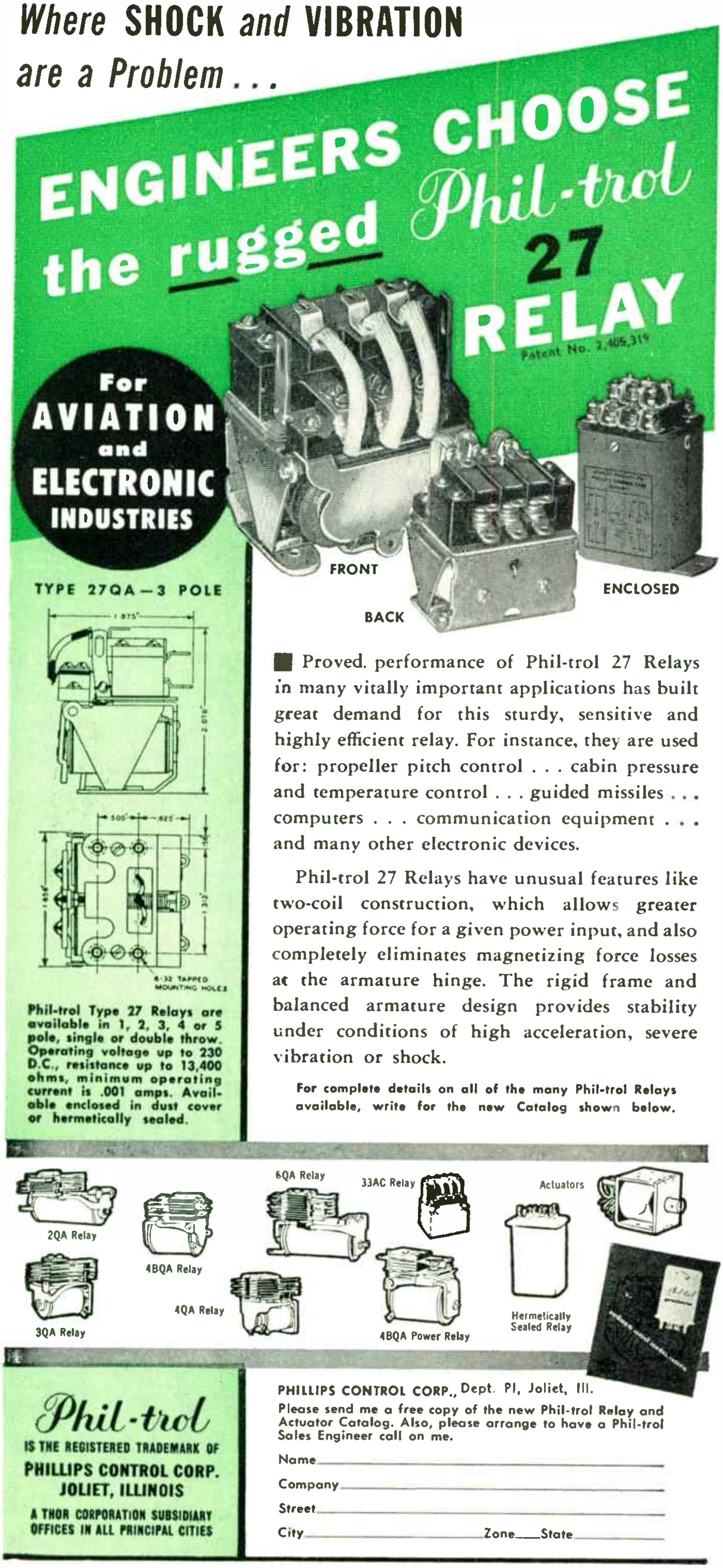
MINIATURE TONE CONTROL with SPECIAL DP-DT SWITCH

A really versatile space-saver for midget radios, combination receivers, or amplifiers. Helps reduce the number of controls on complicated sets. U.L. Approved .5 amp., switch throws at opposite ends of control rotation—maintains full 270° shaft motion in either position. Ideal for band changing, input or bandwidth switching. *Write for details on Stackpole Type LRSS-150.*

Electronic
Components Division
STACKPOLE CARBON COMPANY
St. Marys, Pa.

STACKPOLE

In Canada: Canadian Stackpole Ltd., 550 Evans Avenue, Etobicoke, Toronto 14, Ontario



IRE People

(Continued from page 60A)

ously, Mr. Foster had held the title of General Manager of this division, as well as General Manager of the Radio and Television divisions, Towson, Md.

Mr. Walker joined the Radio division as a junior engineer in 1937. In 1949, he was placed in charge of all engineering service for the division, including field engineering, engineering model shop, engineering administration office, test equipment design, and transformer design. In 1952, he became assistant to the General Manager of the Radio division. In 1953, he was transferred to the newly formed York division as Plant Manager.

He is a member of the American Management Association, and the Armed Forces Communications Association.

❖

The appointment of **A. C. Hall** (A'39–SM'46) as General Manager of the Research Laboratories of the Bendix Aviation Corporation has been announced.

Dr. Hall studied electrical engineering at the Agricultural and Mechanical College of Texas from which he received the B.S. degree. Graduate work was carried on at MIT where he received the D.Sc. Dr. Hall joined the electrical engineering department at MIT in 1937. In 1940, he helped organize the Servo-mechanisms Laboratory. Here he was instrumental in the development of automatic controls and his work is the basis of the design techniques now widely used. He was responsible for the first automatic tracking systems for radar in aircraft as well as the first tracking system for shipboard radar. Toward the latter part of World War II, he directed a group in the development of the control system for the first successful naval guided missile, the BAT, and in 1946, he became Director of the Dynamic Analysis and Control Laboratory at MIT, which was engaged in the further development of analog computers and guided missile control systems.

In 1950, Dr. Hall left MIT to become Associate Director of the Research Laboratories at Bendix. In 1952, he became Technical Director of that laboratory. Since he has been at Bendix, Dr. Hall has directed work in guidance systems for missiles, hydraulic control components, digital and analog computers, automatically controlled machine tools, and special instruments for process controls.

In 1946 he received the Naval Ordnance Development Award for his work in guided missiles. He is a member of Tau Beta Pi, Eta Kappa Nu, Sigma Xi, ASME, of A.C.M., and a fellow of the American Institute of Electrical Engineers.

❖

P. E. Lannan (SM'54), has been made Vice-President and a member of the Board of Directors of Designers for Industry,

(Continued on page 64A)

A
MALLORY
25th Anniversary
VIBRATOR DEVELOPMENT

The *Quietest* Vibrators Ever!

Mechanical hum has been reduced to a new low, in the latest vibrators developed by Mallory. A product of Mallory's 25 years of pioneering research and manufacturing experience in the vibrator field, this new model makes it possible to design automobile radios and other battery-powered electronic equipment for lower hum levels than ever before possible.

"FLOATING" DESIGN. The secret of this vibrator's exceptional performance is a new construction in which the vibrator mechanism "floats" inside the case. Transmission of mechanical hum or shake to the outside of the can or base is held to an absolute minimum.

QUIET IN ANY MOUNTING POSITION. Noise output remains consistently low regardless of the position in which the vibrator is mounted . . . actually is lower in level than the electrical hum emitted by most auto radio speakers.

PREMIUM PERFORMANCE WITHOUT PREMIUM COST. The new, extra-quiet Mallory vibrators cost no more than previous models. They are now the standard type, in most instances bearing the same part number.

For quiet operation, long life and consistent performance, you will find these Mallory vibrators your best choice . . . both for new designs and for the units you now have in production. For specialized consultation on your power supply problems, call on the experience which Mallory has gained during a quarter century of leadership in vibrator development and application. Write today for our Technical Bulletin, or for a call by a Mallory representative.

IN POWER SUPPLIES BE SURE TO USE . . .
Mallory FP Electrolytic Capacitors . . . The original fabricated plate capacitor, FP electrolytics have for many years been built for continuous operation at 85° C. Famous for long shelf and service life.

Expect more . . . Get more from

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Metallurgical—Contacts • Special Metals and Ceramics • Welding Materials

IRE People

(Continued from page 62A)

P. E. Lannan

Inc., a Cleveland research and development firm. His work concerns peacetime and defense research projects which include development of radar-type equipment, computers, television receivers, missile guidance, and high frequency tuners for TV receivers.

During the war Mr. Lannan was on loan for two years to the British Air Commission. The first of these two years was spent at the British Telecommunications Research Establishment at Great Malvern, Worcester, England, in the Radio Research Division. He was made Engineering Officer in research on high frequency generation and propagation, and antenna for the first high frequency radar ever built. The second year, at Leaside, Ontario, Mr. Lannan worked for Research Enterprises, Ltd. in coordination with Canadian engineers. The projects were concerned with development of high frequency radar equipment. Later he went to the Evans Signal Laboratory in Belmar, New Jersey, where he was advisor to the Joint Chiefs of Staff on such specialized equipment as Navigation and Beacon Equipment for the Air Force and Ground Forces. As officer in charge of IFF Navigation and Beacon Section, he headed the section for design, development and production testing of all IFF for the Ground Forces.

After leaving the Signal Corps, Mr. Lannan worked as Technical Representative for the National Union Radio Corporation in Orange, New Jersey. There he supervised specifications, contract preparation, and scheduled work loads in both the Research and the Subminiature Divisions. He also supervised quality control of the Subminiature Division.

As a member of the Stromberg-Carlson Company, he supervised the design-development of micro-wave radio relay equipment and micro-wave airborne communications equipment.

For his work in the Army, Mr. Lannan received the Army Commendation Medal. He is a member of the Armed Forces Communications Association.

1955

RADIO ENGINEERING SHOW

March 21-24, 1955

Kingsbridge Armory

Kingsbridge Palace

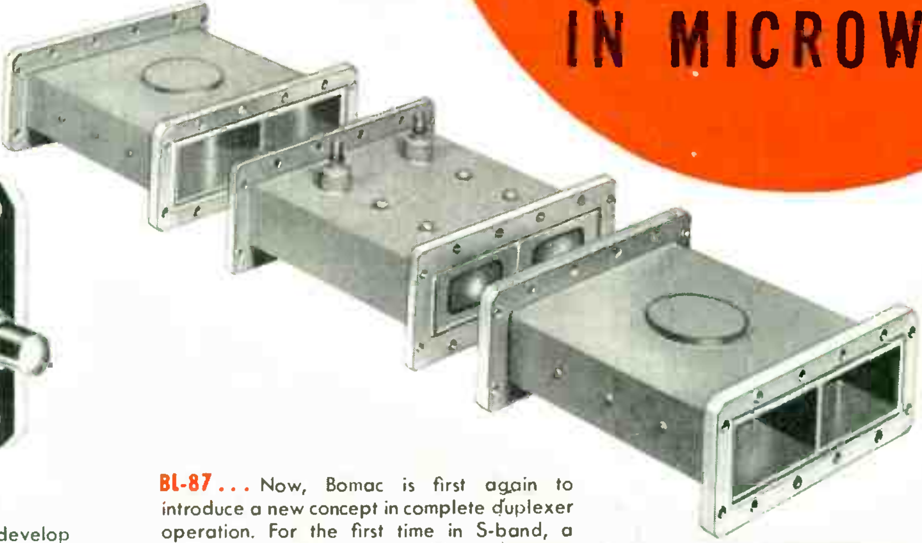
New York City

Bomac Firsts IN MICROWAVE

6738 . . . First again in the field of tube miniaturization, Bomac developed a new type TR tube designated the 6378. Designed specifically for airborne radar equipment, the 6378 is a miniaturized version of the 1B24A (another Bomac first), 1B60 and the 1B24. Size was cut in half, and weight was reduced by one fifth with no sacrifice in performance or efficiency.

1N23D . . . Bomac was the first to manufacture the 1N23D silicon diode. System designers, for the first time, could obtain a diode with greatly increased sensitivity and superior electrical characteristics in relation to existing types.

BL-25 . . . The BL-25 TR tube, designed and developed by Bomac, was the first cell-type tube system — engineered to withstand high power levels and maintain recovery time over a long period of life. The BL-25, although originally designed for a specific piece of equipment, has proven its versatility in various applications within the industry.



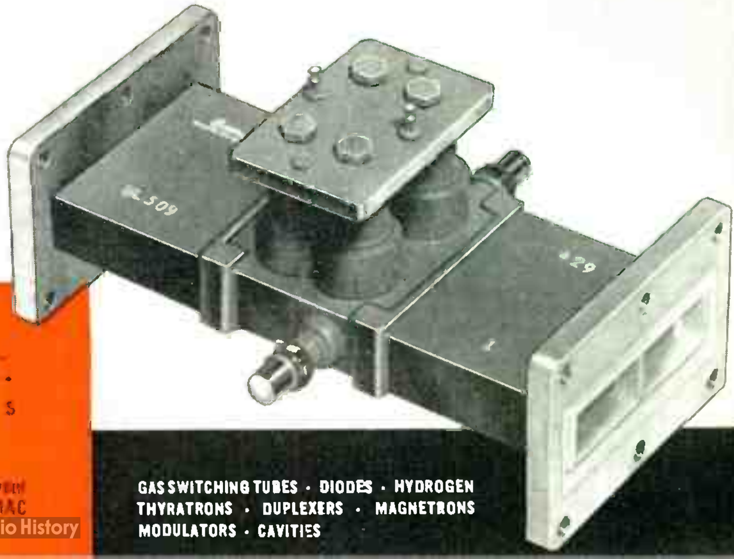
BL-58 . . . Bomac was the first to develop shutter tubes and integral TR-shutter combinations for continuous crystal protection. The BL-58 was the first integral TR-shutter combination developed by Bomac. With integral TR-shutter operation, bulky waveguide shutters could be eliminated at considerable savings in size and weight. This tube has now been superceded by improved models.

BL-87 . . . Now, Bomac is first again to introduce a new concept in complete duplexer operation. For the first time in S-band, a complete duplexer is offered to the industry. The BL-87 is a dual TR tube, complete with perfectly matched hybrids to assure maximum efficiency and long life. Systems designers can now be assured of reliable duplexer operation because Bomac's hybrids are designed specifically for their dual TR tubes. Bomac is first again in design and development of microwave tubes.

BOMAC DUAL TR DUPLEXERS

Tube	Frequency (MC)	Tube	Frequency (MC)
6334 (BL-27)	8490-9578	BL71	8500-9600
BL29	9325-9425	BL78	8490-9578
BL35	15000-17000	BL87	2700-2900
BL47	9325-9425	BL507	8490-9578
BL60	5400-5900	BL600	8490-9578

BL-509 . . . Bomac's BL-509 was the first complete duplexer offered in one compact unit. Combining a Bomac dual TR tube having integral shutters with two perfectly matched hybrid junctions in a single unit, the BL-509 provides duplexer operation and continuous crystal protection in one package. Light weight and compact, the BL-509 assures superior electrical performance and mechanical simplicity.



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BEVERLY, MASSACHUSETTS

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Membership

The following transfers and admissions were approved to be effective as of January 1, 1955:

Transfer to Senior Member

Allen, C. C., 2064 Baker Ave., Schenectady 9, N. Y.
Arfin, B., Box 1423, Stanford University, Stanford, Calif.
Balwanz, W. W., 113 Eastside Dr., Alexandria, Va.
Bechtol, H. D., Davstrom Instrument Division, Archbald, Pa.
Betts, A. L., R.F.D. 4, Stillwater, Okla.
Brogan, F. A., 433 Brees Blvd., San Antonio 9, Tex.
Bryson, H. C., Jr., 5428 Norfolk St., Philadelphia 43, Pa.
Buff, C., R.F.D. 1, Howell Ave., Deer Park, N. Y.
Burke, J. T., 2448 State Rd., Cuyahoga Falls, Ohio
Butler, H. R., 156 Morningside Rd., Verona, N. J.
Byington, P. W., 3523-A Arizona St., Los Alamos, N. Mex.
Cotellessa, R. F., 188 Franklin Ave., Midland Park, N. J.
Dexter, G. W., 7714 Kentwood Ave., Los Angeles 45, Calif.
Donaldson, M. R., 121 W. Malta Rd., Oak Ridge, Tenn.
Falkowski, A. J., 556 Elberon Ave., Dayton 3, Ohio
Garrett, W. O., 383 Meadowbrook Dr., N.E., Atlanta, Ga.
Grant, R. L., 1823 Griswold Dr., Apt. H 12, Fort Wayne 3, Ind.
Greenwood, T. L., 1709 La Grande St., Huntsville, Ala.
Hodgson, R. W., 719 S. Ward Ave., Compton 1, Calif.
Holt, G. W., 4420 N.W. 19 St., Oklahoma City 7, Okla.
Iwakata, H., 871 Daita 2-Chome, Setagaya-ku, Tokyo, Japan
Johnson, H. R., 3418 Halderman St., Los Angeles 66, Calif.
Kean, D. W., 19687 Gary Ave., Sunnyvale, Calif.
Keller, E. A., R.F.D. 2, Red Oaks Mill Rd., Poughkeepsie, N. Y.
Krahe, L. R., 363 E. 75 St., Chicago 19, Ill.
Meissner, E. R., 22 N.W. Ninth Ave., Portland 9, Ore.
Meyers, S., 1940—83 St., Brooklyn 14, N. Y.
Middleton, R. G., 1446 S. Maple Ave., Berwyn, Ill.
Ray, H. B., 1215 Wayne Rd., Falls Church 2, Va.
Rechtin, E., 1397 Wicks Rd., Pasadena 3, Calif.
Roberts, A. K., 83-10—118 St., Kew Gardens 15, L. I., N. Y.
Roberts, T. E., Jr., 78 Bracewood La., Stamford, Conn.
Schwartz, R. F., 744 N. 64 St., Philadelphia 31, Pa.
Slade, B. N., 190 Mills St., Morristown, N. J.
Spitzer, C. F., 243 Buckingham Ave., Syracuse 10, N. Y.
Stiles, R. G., 1212 Ellison St., Falls Church, Va.
Taylor, E. H., 850 W. Jackson Blvd., Chicago 7, Ill.
Uphoff, R. L., Box 235, R.F.D. 1, Murrysville, Pa.
Uttendorfer, E. A., 460 W. 34 St., New York 1, N. Y.
Vasaka, C. S., U. S. Naval Air Development Center, Johnsville, Pa.
Walker, G. A., Sr., 4419 E. Timrod St., Tucson, Ariz.
Wells, W. W., 3220 Hackett Ave., Long Beach 8, Calif.
Wilson, M. C., 1075 Pine Bluff Dr., Pasadena 8, Calif.
Yang, R. F. H., 10401 W. 143 St., Orland Park, Ill.
Zimov, L. R., 1538 Beaverton Ave., Cincinnati 37, Ohio

Admission to Senior Member

Adams, C. W., 52 Massachusetts Ave., Cambridge 39, Mass.

(Continued on page 68A)

Membership

(Continued from page 67A)

Bagwell, C. E., 514 N. Charles St. Ave., Towson 3, Md.
Benjamin, J. M., Jr., 37 Herman St., Philadelphia 44, Pa.
Bevan, P. A. T., Harwood Ct. 14, Upper Richmond Rd., London S.W., England
Bradburn, J. R., 717 N. Lake Ave., Pasadena, Calif.
Brauer, G. W. A., 127 Shepard Ave., Kenmore 17, N. Y.
Brenner, J. C., 47 Spruce La., New Hyde Park, L. I., N. Y.
Brown, C. M., 1655 Highland Ave., Glendale 2, Calif.
Bryan, S., 2104 Dayton St., Silver Spring, Md.
Comerci, F. A., 63 Carlton Ter., Nutley 7, N. J.
Corey, H. E., Jr., Bell Telephone Laboratories, 555 Union Blvd., Allentown, Pa.
Dunlap, W. C., Jr., General Electric Research Laboratory, Schenectady 8, N. Y.
Giroud, P., 79, Blvd. Haussmann, Paris 8 eme, France
Griggs, J. R., 3661 Buckingham Rd., Los Angeles 16, Calif.
Guy, H. D., 41 Lothrup Rd., Reading, Mass.
Holcombe, M. M., 2100 Paxton St., Harrisburg, Pa.
Ketay, M. F., 19 Laurel Dr., Great Neck, L. I., N. Y.
Krause, L. O., 14 Memory La., N. Syracuse, N. Y.
Kusma, D., 130 Glenview Ave., Wyncote, Pa.
Lockwood, E. H., 310 E. Third St., Frederick, Md.
Nichols, M. H., Ramo-Wooldridge Corp., 8820 Bellanca Ave., Los Angeles 45, Calif.
Saunders, N. B., 66 Westland Rd., Weston 93, Mass.
Saunders, R., Jr., 323 Wharton Dr., Marion, Ind.
Smith, O. R., 6819 Crestmont, Houston 21, Tex.
Valley, G. E., Jr., 5 Moon Hill Rd., Lexington 73, Mass
Van Dyke, W. D., Van Dyke Textigraph Co., Inc., 23 W. Second St., Chattanooga 2, Tenn.
Varian, S. B., 4325 Commonwealth, La Canada, Calif.

Transfer to Member

Alpert, E., 18 Frances St., Needham, Mass.
Beam, W. R., RCA Laboratories, Princeton, N. J.
Brown, R. L., American Telephone & Telegraph Co., 195 Broadway, New York 7, N. Y.
Castleman, D. H., 140 Lewis St., Ottawa 4, Ont., Canada
Coleman, J. T., Box 563, John Brown University, Siloam Springs, Ark.
Edgerton, D., Jr., 122 N. Oxford Ave., Los Angeles 4, Calif.
Finley, C. G., 539 E. Indian, Midwest City, Okla.
Geiger, L. C., 2734 N. Farwell Ave., Milwaukee 11, Wis.
Godofsky, M., 1171 Elder Ave., New York 72, N. Y.
Goodhue, W. W., 210 McKendree Ave., Annapolis, Md.
Gruenberg, H., 320 Crestview Rd., Ottawa 1, Ont., Canada
Haagens, D., 91-20 -191 St., Hollis 23, L. I., N. Y.
Himebrook, F. C., 2032 Welwyn Ave., Des Plaines, Ill.
Horvath, J. S., RCA Industry Service Laboratory, 1560 N. Vine St., Hollywood 28, Calif.
Hurlbut, P. R., Box 127, Barrington, Ill.
Jensen, C. L., 4020 School House La., Plymouth Meeting, Pa.
Landfried, H. H., 4842—66 Ave., Parkway Estates, Hyattsville, Md.
Lavin, H., Box 196, Meriden, Conn.
Lewis, R. H., 1908—26 St., Lubbock, Tex.
Madey, R., Brookhaven National Laboratory, Upton, L. I., N. Y.
Mallory, G. L., Bendix Aviation Corp., Pacific Division, 166 W. Olive St., Burbank, Calif.
Morrison, W. J., 725 S. 41 St., Louisville 11, Ky.

(Continued on page 70A)

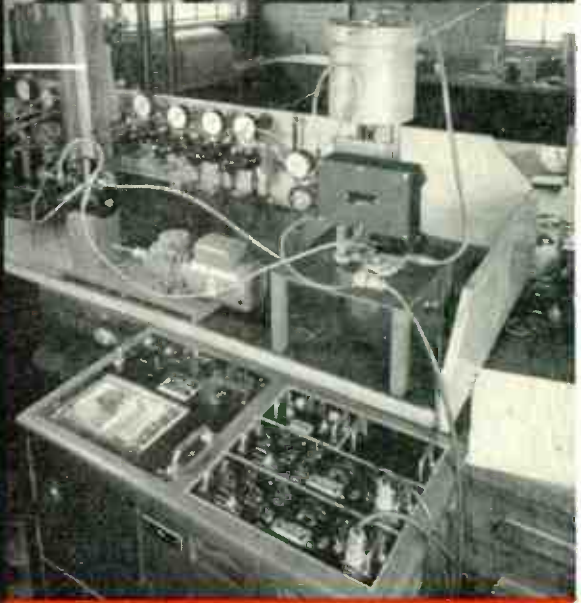
How two TYPICAL production testing headaches were cured with SANBORN OSCILLOGRAPHIC RECORDING SYSTEMS

RAYTHEON MANUFACTURING COMPANY'S Waltham, Mass. Inspection Dept. formerly found their incoming inspection of complex, multi-ganged potentiometers a time-taking and costly job which involved tedious calibration, instrument set-up and testing for *each* of the five potentiometer sections, with each operation subject to inevitable human error.

Today, by using a Sanborn four-channel Recording System and a Potentiometer Power Supply, a visual, concurrent strip-chart record of *five* channels (using marker stylus) of phenomena such as phasing, shorting bar, winding noise, and resolution of winding turns is provided. Inspection time is speeded up 900%, the operator sees immediately all causes for rejection, the chart is a permanent test data record, one inspector takes the place of three, and human error is reduced to a negligible factor.

MOORE PRODUCTS COMPANY of Philadelphia uses a Sanborn Model 60 two-channel Recording System to check the Dynamic Performance of their Valve Positioners, which are used on diaphragm top-work valves and power cylinders. The valve positioner acts as a relay, applying additional air pressure to the cylinder or top-work, overcoming effects of unbalance and friction, and compelling the valve stem to take the position dictated by the pneumatic controller or manually-operated air load. A feed-back linkage assures positioning of the valve stem within plus or minus 0.001".

A pneumatic sine wave generator supplies pneumatic impulses with frequencies as high as 20 cycles per second. These impulses are sent to the valve positioner and to a transducer which converts the signal for the recorder. The response of the valve stem is measured by a strain gage pickup for the second channel of the recorder.



The above cases are but two of the many applications possible with Sanborn one-, two-, four-, six- and eight-channel Recording Systems. With a Sanborn you can register permanently and graphically virtually all electrical phenomena within a frequency range of zero to 100 cps. A choice of the number of channels, plus the ready interchangeability of various type preamplifiers (to meet individual recording problems) offers a wider versatility of use, greater overall economy, and increased operating efficiency.

Added to these advantages are the standard SANBORN instrument features: INKLESS recording in true rectangular coordinates, high torque galvanometer movement, time and code marking, and numerous paper travel speeds.

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Tiedeman, C. R., 4413 Juno Way, Sacramento 21, Calif.
Walbesser, W. J., 27 Linda Dr., Apt. 11 6, Cheektowaga 25, N. Y.
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(Continued on page 72A)

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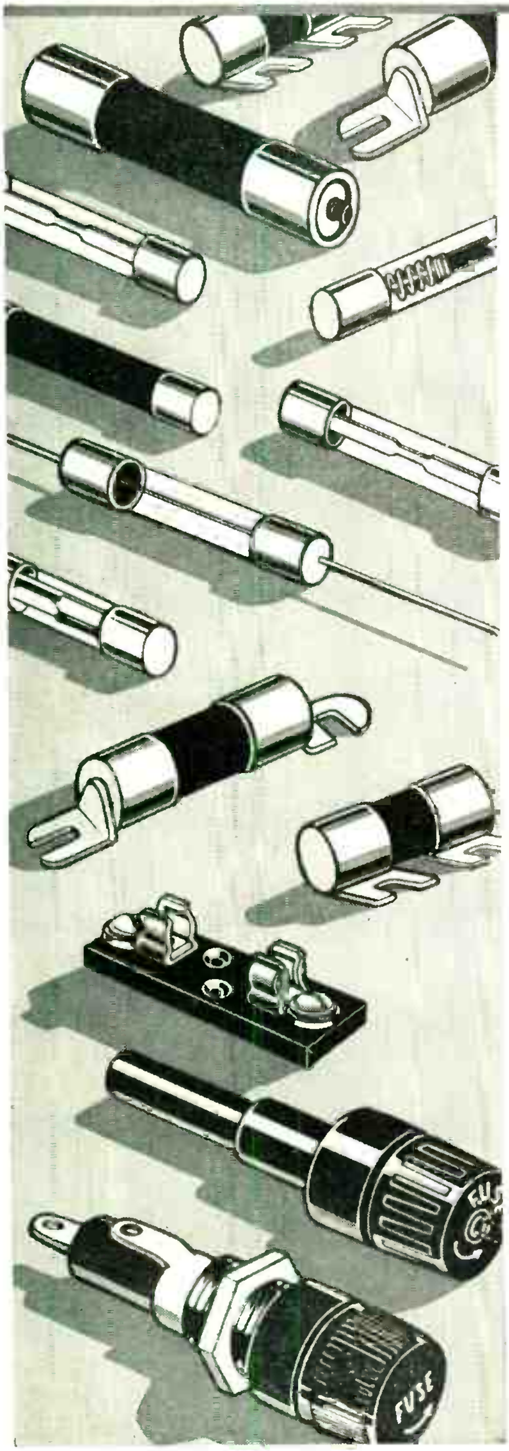

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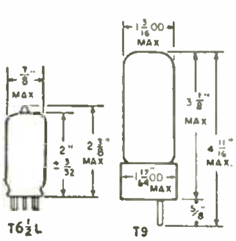

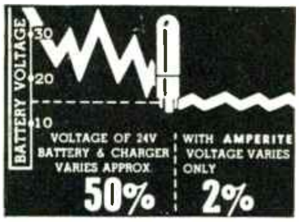

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Anderson, J. B., Woodbury Terrace Apts., Apt. 6 C, Myrtle Ave., Woodbury, N. J.
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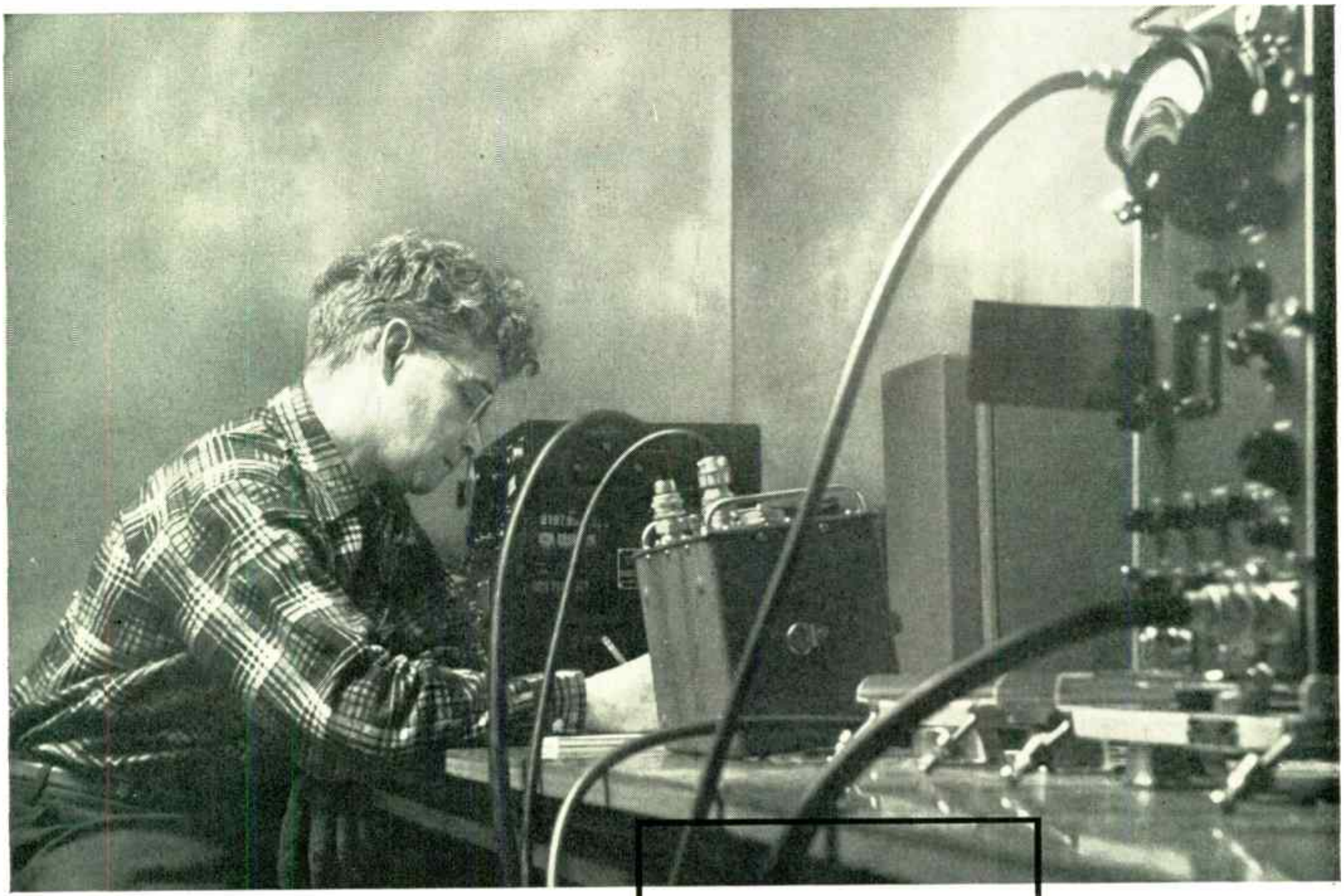

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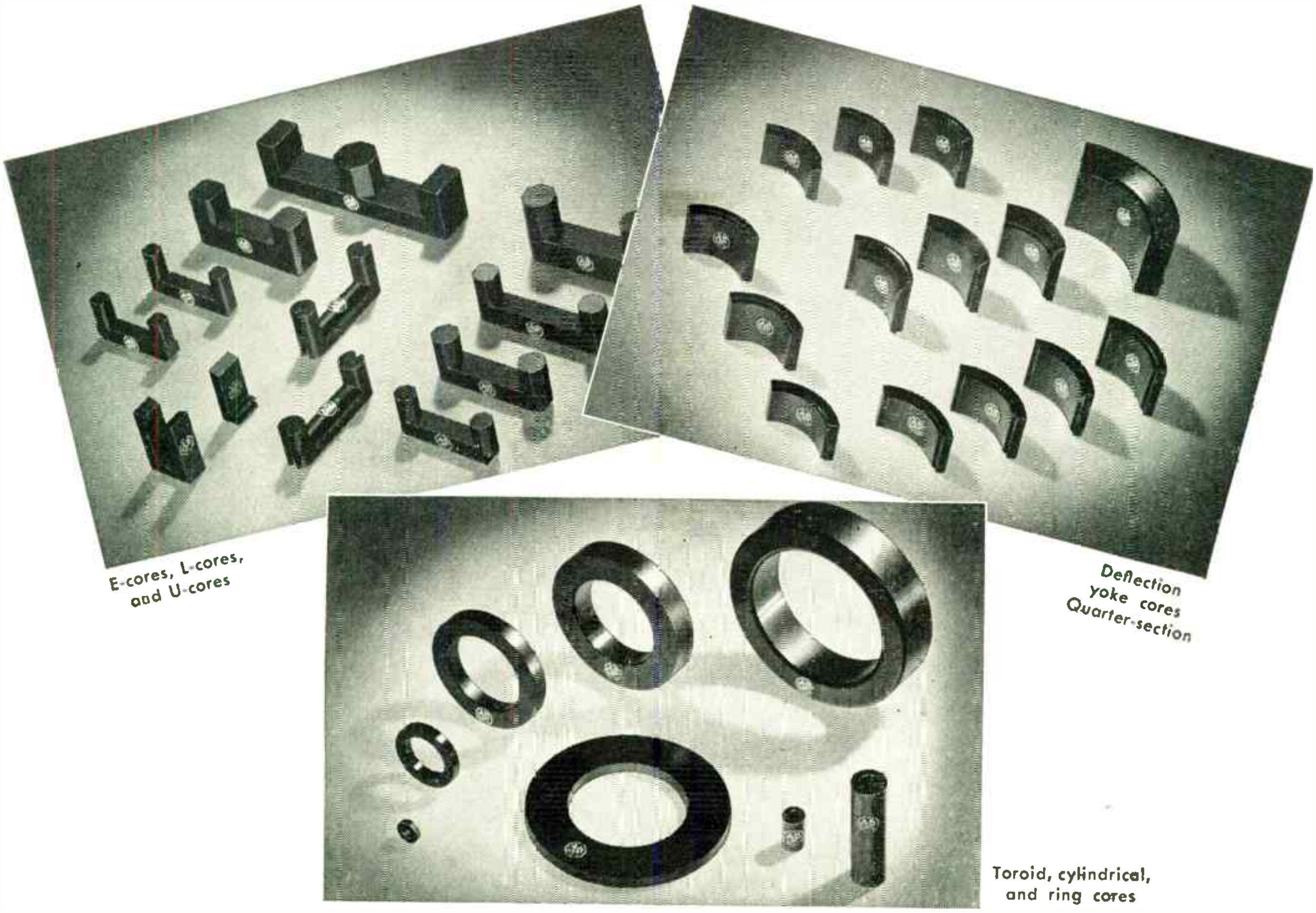

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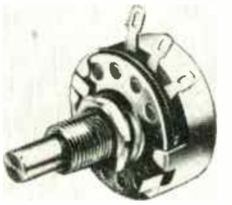

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Randall, C. R., Naval Research Laboratory, Code 5337, Washington, D. C.
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(Continued on page 78A)

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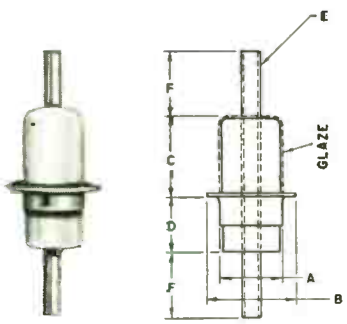
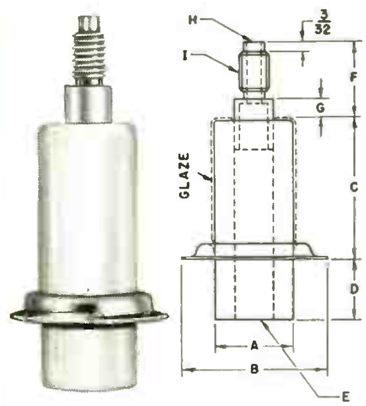
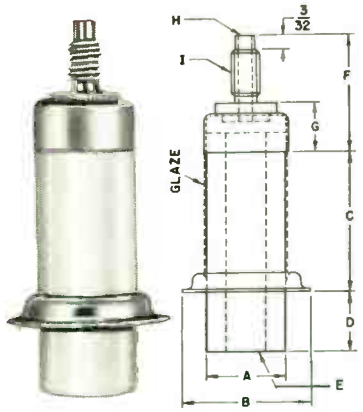
temperatures to 1400°F
...pressures
to 2000 p.s.i.

ADVAC Hermetic Seals are the result of a new metallizing process that actually integrates the metal coating into the ceramic body. This bonding "by integration" effects a seal that is virtually immune to thermal shock, withstands far higher temperature and pressure. ADVAC Seals are readily brazed or soldered to metal parts. Call, write or wire for details!







DIMEN.	PART NO. 187-A	PART NO. 250-A	PART NO. 312-A	PART NO. 375-B	PART NO. 500-B	PART NO. 750-B	PART NO. 1000-B	PART NO. 375-C	PART NO. 500-C	PART NO. 750-C	PART NO. 1000-C
A	3/16	1/4	5/16	3/8	1/2	3/4	1	3/8	1/2	3/4	1
B	5/16	3/8	7/16	11/16	13/16	1-1/4	1-1/2	11/16	13/16	1-1/4	1-1/2
C	3/16	5/16	7/16	1/2	1	1-1/8	1-1/4	5/8	7/8	1	1-1/8
D	1/8	1/4	1/4	3/16	3/8	3/8	3/8	3/16	3/8	3/8	3/8
E	.060 x .010	.075 x .010	.075 x .010	7/32	1/4	3/8	1/2	7/32	1/4	3/8	1/2
F	3/16	1/4	5/16	9/16	9/16	11/16	11/16	11/16	11/16	27/32	27/32
G				3/16	3/16	7/32	7/32	19/64	19/64	23/64	23/64
H				5/64	3/32	3/32	3/32	5/64	3/32	3/32	3/32
I				8/32	10/32	1/4-28	3/8-24	8/32	10/32	1/4-28	3/8-24

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Sikorsky, E., 618 E. King St., Lancaster, Pa.
Skutle, G. O., 11047—83 St., Edmonton, Alta., Canada
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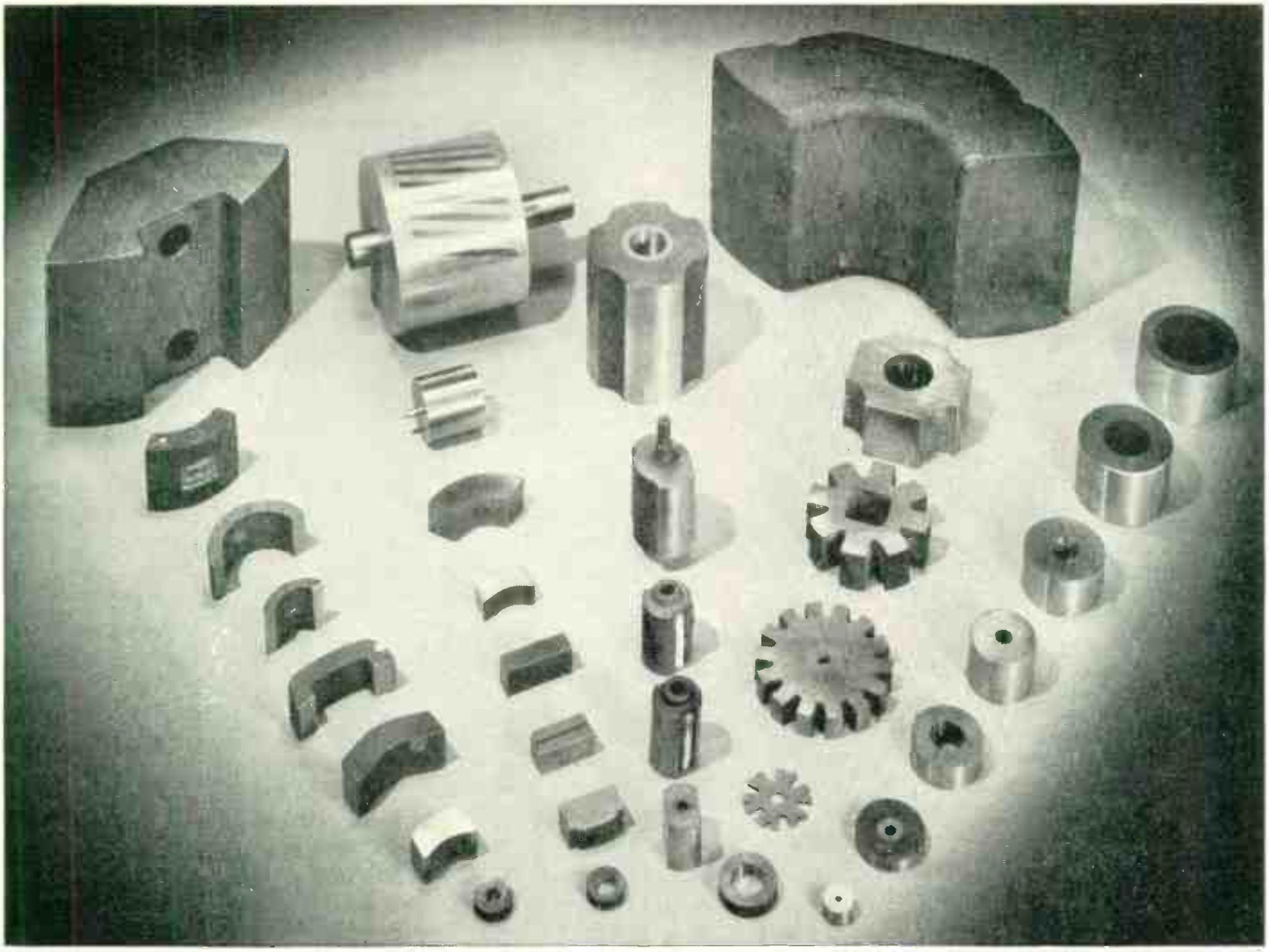
Professional Group Meetings

AERONAUTICAL AND NAVIGATIONAL ELECTRONICS

The New York Chapter of the Professional Group on Aeronautical and Navigational Electronics met on October 21 at the General Electric Auditorium. R. J. Bibbero presided, and M. W. Johnson, Systems Engineer with General Electric, spoke on "Problems and Progress in Automatic Flight Control."

Paul Wiegert presided at the meeting of the Dayton Chapter on October 7 at the Engineers Club. Dr. P. J. Ovrebo, Chief of the Applied Physics Section of the Wright Air Development Center, spoke on "The ABC's of Infra Red." Dr. Ovrebo discussed the basic parameters and characteristics of infra red signals and the effect of atmospheric conditions on these radiations. He made comparisons relative to absorption factors as associated with other portions of the electromagnetic spectrum and described the effect of altitude with regard to frequency absorption.

(Continued on page 82A)



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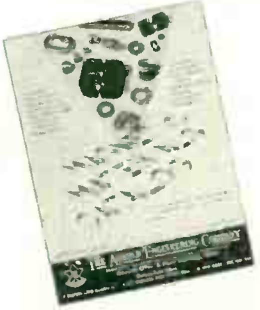

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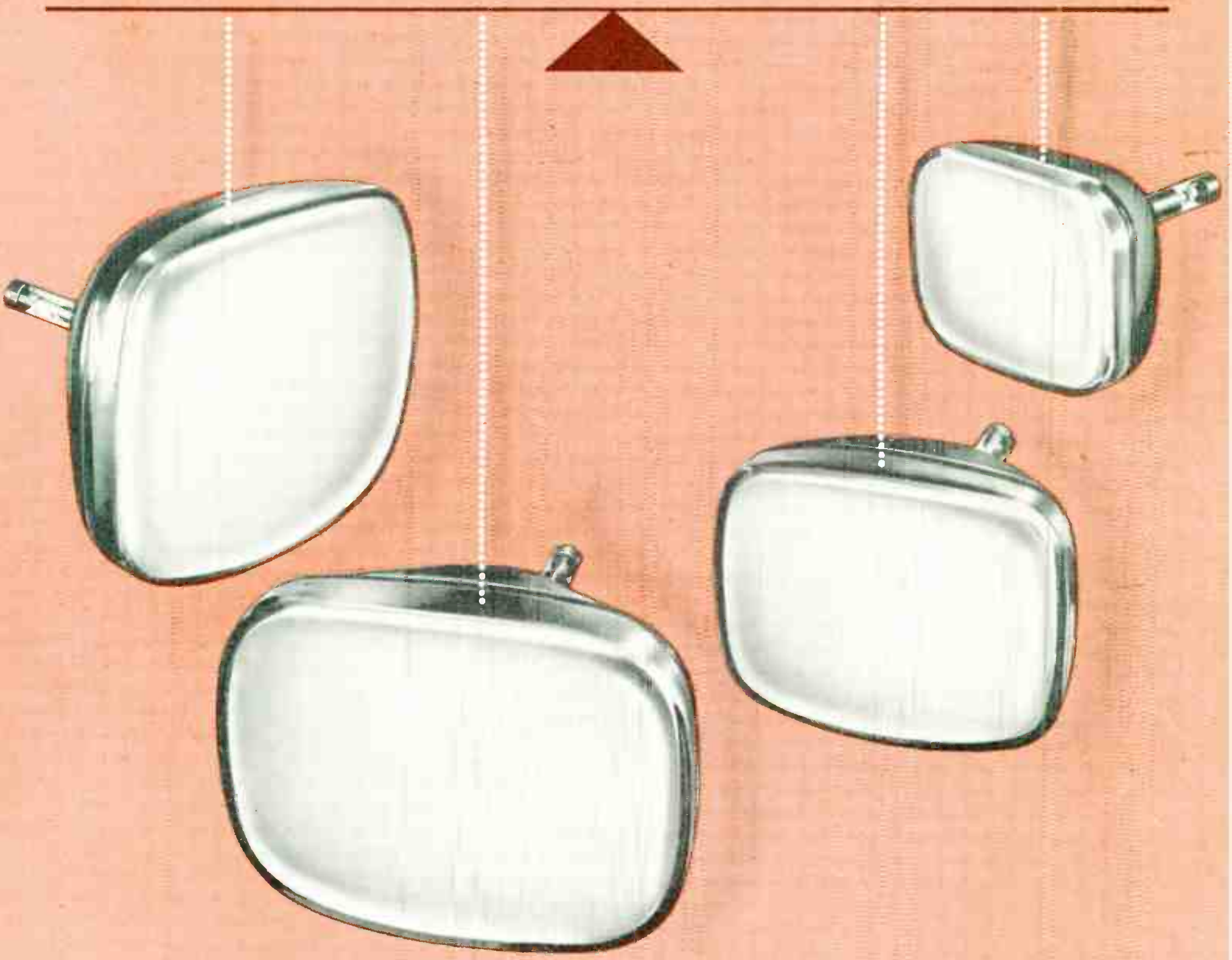

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World Radio History

Franz Tank

VICE-PRESIDENT, 1955

Franz Tank was born in Zurich on March 6, 1890. He received his early education in the schools of Zurich and in 1908 entered the Swiss Federal Institute of Technology, Zurich, where he specialized in mathematics and physics. He received his diploma in 1912 and the same year was appointed assistant to Professor Kleiner at the Physics Institute of the University of Zurich. Here, in addition to his regular duties, he collaborated with Max von Laue, Professor of Theoretical Physics, in his researches connected with the interference of X-rays.

In 1916 Prof. Tank was awarded the Ph.D. by the University of Zurich and two years later was appointed Lecturer in Physics at the university. After a short stay in England he was elected Professor of Physics at the Swiss Federal Institute of Technology, Zurich. From 1934 onward, high frequency technology was included in the sphere of his teaching, and at the same time he was appointed Director of the Institute of High Frequency Engineering of the Swiss Federal Institute of Technology. His particular interest was directed to the study of electronics and circuits of the shortest radio waves, and research was carried out over a period of many years with a large number of collaborators. The results of these researches were published in the "Communications of the Institute of High Frequency Technique, Swiss Federal Institute of Technology, Zurich." From 1934 to 1947 he was Rector of the Swiss Federal Institute of Technology. Since 1950 he has been President of the Swiss National Committee of the U.R.S.I. and, since 1952, President of the Swiss Association of Electrical Engineers.

Prof. Tank is Docteur ès Sciences Techniques Honoris Causa of the Ecole Polytechnique de l'Université de Lausanne, member of the German Academy of Science and Literature in Mainz, of "Det Kongelige Norske Videnskabers Selskab" in Trondheim, and of a number of other scientific societies in Switzerland and abroad. In 1950 he received the IRE Fellow Award "for his contributions to the field of radio education in Switzerland and his accomplishments in ultra short wave communication."

Prompt Proceedings

In March, 1954 the Editorial Board put into operation a revised procedure of reviewing papers for the PROCEEDINGS OF THE I.R.E. The purpose was to speed up the publication of papers. It seems appropriate at this time to report on the encouraging progress that has been made to date.

During the first part of last year the average publication time for papers was approximately ten months, measured from the date the paper was first received to the date of publication. By October the average had dropped to about five months; now well-written papers and those of special importance frequently appear three to four months after receipt.

Efforts to reduce the average publication time further are continuing. An analysis of the October issue shows that the average time factors in publishing a paper were as follows:

Handling	1 week
Review	4 weeks
Revision	2 weeks
Editing	2 weeks
Held over	4 weeks
Production	8 weeks
	Total—21 weeks

The item marked "Held over" signifies that the material on hand exceeds somewhat the allotted PROCEEDINGS space and that some papers must be held over until the next issue. The amount of hold over material varies from month to month, depending on the flow of incoming material and the number of PROCEEDINGS pages budgeted. The four-week figure quoted indicates a backlog equal to one issue. While such a backlog is normal for this type of publication, it has since been reduced further.

Although the time required for review and revision is less than one-third the total, it should not be inferred that reviewers and authors have little effect on the total publication time. Actually, these are the only steps in the publication process, aside from the hold over item, where the time element is not fixed and where a further reduction in time can be made. A delay of three or four days on the part of either can result in missing a deadline and delaying publication of a paper by one month.

Authors can do much to avoid revising or correcting their papers, and other delays, by taking to heart the suggestions and instructions which appeared on pages 1604–1605 of the November, 1954 issue. For example, the author who submits only one copy of his paper instead of the requested three, triples the time required for review and thus delays publication an extra two months.

A large measure of credit for reducing the publication time should go to the two hundred Editorial Reviewers who have volunteered a considerable amount of their time to reviewing the large volume of material that is submitted for publication. Thanks to their prompt and able work, the value of the PROCEEDINGS to its readers and to the profession has been materially increased during the past few months.

—*The Editorial Board*

The Seventh Plenary Assembly of the International Radio Consultative Committee*

E. W. ALLEN†, FELLOW, IRE

THE SEVENTH PLENARY Assembly of the International Radio Consultative Committee (CCIR) was held in London from September 3 through October 7, 1953. Although many members of the Institute may be unfamiliar with the work of this Committee, it may have far-reaching effects upon the progress of radio. The London meeting approved 165 documents, each of them a possible subject for a technical paper. The purpose of this paper is to give a brief outline of the work accomplished in that assembly and to describe briefly the organization and functions of the CCIR.

THE INTERNATIONAL TELECOMMUNICATIONS UNION

The CCIR is that body to which are referred for solution the more technical radio problems arising in the various international conferences and in the continuing activities of the International Telecommunications Union (ITU). The ITU consists of the countries and territories listed in Annex 2 of the current international convention or treaty on telecommunications, and new countries that accede to the convention. The Union had its origin in the International Telegraph Union formed at Paris in 1865. The present treaty is the Buenos Aires Convention (1952), which to a large extent reaffirmed the provisions of the Atlantic City Convention (1947), and to which are annexed the Administrative Radio Regulations adopted at Atlantic City. Under this treaty the organization of the ITU is as shown in Fig. 1. The broad general functions are accomplished by plenipotentiary conferences, which draft the treaties, and by administrative conferences, which are designed to elaborate the Administrative Regulations and to reach agreement on specialized subjects as authorized by the convention. The convention provides for a meeting of the plenipotentiary conference once every five years, and in order to support the conferences and to perform continuing work in the interim between them, a permanent organization is established at Geneva consisting of the General Secretariat, and the International Frequency Registration Board (IFRB). The Administrative Council, composed of eighteen member countries of the ITU, is also a permanent organization and meets at least once a year between plenipotentiary conferences to act on urgent administrative and organizational matters. There are also three technical consultative committees, the CCIR, the CCIF (the International Telephone Consultative Committee) and the CCIT (the International Telegraph Consultative Committee).

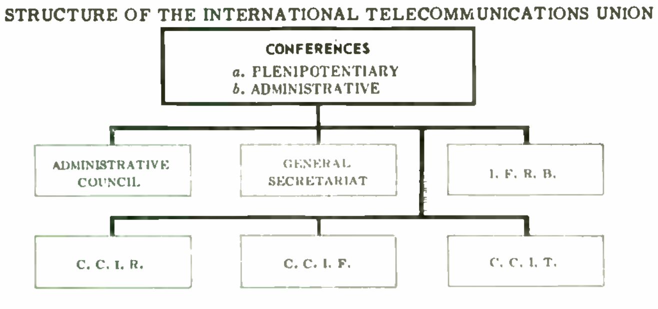
STRUCTURE OF THE INTERNATIONAL TELECOMMUNICATIONS UNION

Fig. 1

Article 8 of the Atlantic City Convention specifies the duties of the International Consultative Committees as follows.

> "1. (1) The duties of the International Telegraph Consultative Committee (CCIT) shall be to study technical, operating and tariff questions relating to telegraphy and facsimile and to issue recommendations on them.
>
> "(2) The duties of the International Telephone Consultative Committee (CCIF) shall be to study technical, operating and tariff questions relating to telephony and to issue recommendations on them.
>
> "(3) The duties of the International Radio Consultative Committee (CCIR) shall be to study technical radio questions and operating questions the solution of which depend principally on considerations of a technical radio character and to issue recommendations on them."

THE INTERNATIONAL STRUCTURE OF THE CCIR

The CCIR is organized in a manner similar to its parent organization, the ITU, as shown in Fig. 2. It is composed of administrations of members of the ITU and recognized private operating agencies and scientific and industrial organizations. Its official actions are taken by the plenary assemblies which normally meet for a period of about six weeks once every three years. It has held Plenary Assemblies at The Hague, The Netherlands, 1929; Copenhagen, Denmark, 1931; Lisbon, Portugal, 1934; Bucharest, Rumania, 1937; Stock-

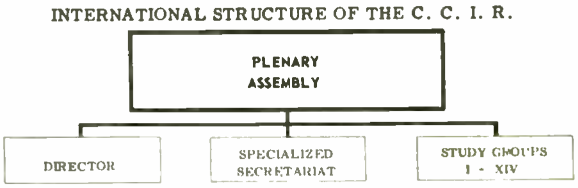
INTERNATIONAL STRUCTURE OF THE C. C. I. R.

Fig. 2

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* Original manuscript received by the IRE October 26, 1954.

† Chief Engineer, Federal Communications Commission, Washington 25, D. C.

holm, Sweden, 1948; Geneva, Switzerland, 1951; London, England, 1953. To support the work of the assemblies and to prepare material for their consideration, there are three permanent branches: the Director and the Vice-Director for Broadcasting, the Specialized Secretariat, and the Study Groups. The offices of the Director, the Vice-Director, and the Secretariat are located in Geneva, Switzerland. There are at present fourteen study groups which are international in character and have no permanent site. Each of these has an international chairman and vice-chairman appointed by the Assembly, and a membership composed of those administrations or recognized private operating agencies that wish to participate. There is a national chairman in each of the participating countries.

The work of the international study groups is carried on principally by correspondence between the international chairman and the various national chairmen of the particular study groups. However, international meetings of one or more study groups may be called in the interim between meetings of the Plenary by the Director and the international chairmen in consultation with his administration, in order to solve some urgent problem or to resolve difficulties that cannot be overcome by correspondence alone. In all cases, the study groups meet during the early part of each Plenary Assembly, to put their product in final form for submission to the plenary sessions which follow. The fields of work of the study groups, and their chairmen and vice-chairmen are:

I. Radio Transmitters
    Dr. E. Metzler (Switzerland)
    Col. J. Lochard (France)
II. Radio Receivers
    Mr. P. David (France)
    Mr. P. Abadie (France)
III. Complete Radio Systems
    Dr. H. C. A. van Duuren (Netherlands)
    Mr. J. Smale (England)
IV. Ground-Wave Propagation
    Prof. L. Sacco (Italy)
    Mr. G. Millington (England)
V. Tropospheric Propagation
    Dr. R. L. Smith-Rose (England)
    Mr. E. W. Allen (U.S.A.)
VI. Ionospheric Propagation
    Dr. J. H. Dellinger (U.S.A.)
    Dr. Newbern Smith (U.S.A.)
VII. Radio Time Signals and Standard Frequencies
    Mr. B. Decaux (France)
    Prof. M. Boella (Italy)
VIII. International Monitoring
    Mr. A. H. Cannon (Australia)
    Mr. J. Campbell (Australia)
IX. General Technical Questions
    Mr. H. Stanesby (England)
    Mr. G. Pedersen (Denmark)
X. Broadcasting
    Mr. A. P. Walker (U.S.A.)
    Mr. K. W. Miller (U.S.A.)
XI. Television
    Mr. E. Esping (Sweden)
    Mr. G. Hansen (Belgium)
XII. Tropical Broadcasting
    Mr. B. V. Baliga (India)
    Dr. M. B. Sarwate (India)
XIII. Operation Questions
    Mr. J. D. H. van der Toorn (Netherlands)
    Mr. J. Soberg (Norway)
XIV. Vocabulary
    Prof. T. Gorio (Italy)
    Mr. R. Villeneuve (France)

The division of the work of the CCIR as represented by this set of study groups is no longer entirely suitable. Its modification is to be studied by an Organization Committee composed of the study group chairmen and the Director of the CCIR. There may be a grouping more along the line of the several radio services. A tendency in that direction was foreshadowed in the assignment by the Seventh Plenary of fixed-service and marine-service topics to Study Groups IX and XIII respectively.

THE U.S.A. NATIONAL STRUCTURE OF THE CCIR

In addition to the international organization described above, there are also associated national organizations in each of the various countries. In the United States the organization consists of a CCIR Executive Committee and fourteen national study groups corresponding to those operating internationally, as shown in Fig. 3. The Chairman of the Executive Committee is a member of the Telecommunications Policy Staff of the Department of State, as are the Vice-Chairman and the Secretary. Membership on the Committee is held by representatives of various government agencies concerned with international radio regulation and usage, together with representatives of commercial radio companies, industry and government organizations, and professional societies. The IRE has named a representative to the Executive Committee. The chairmen of the national study groups are also members of this Committee. The Committee meets about once each month in order to coordinate the work of the various study groups and examine the progress of the national contributions to the international studies.


U. S. NATIONAL STRUCTURE OF THE C. C. I. R.

Fig. 3

Functioning of the CCIR

As stated above, the work of the CCIR is to recommend solutions for problems arising in international radio communications. These problems are raised in the form of Questions which, to the extent practicable, spell out the conditions giving rise to the problem and analyze the problem in terms of specific questions to which answers are desired. Questions are in general presented to the Plenary Assembly for formal adoption, after which the Assembly assigns them to the proper study group for action. Alternatively, questions may be adopted for action between plenary assemblies if asked by twelve or more administrations. If, as is frequently the case, the information necessary to answer a question is not available, a procedure has to be set up for developing the required information. In such cases a Study Program is adopted which will outline in some detail the procedures to be used, the methods of presentation and analysis, and other necessary instructions, so that information obtained from the various contributing organizations will be in proper form to be associated in obtaining an answer to the problem. When the study of a question or a part of a question has been concluded, the study group issues a Recommendation thereon. If the available information is not sufficiently complete to provide the basis for a recommendation, it may nevertheless be felt to be a sufficient contribution to be made of record. In this case the study group will make a Report indicating the status of knowledge on the subject, which may be drawn upon in preparing the final recommendation. The CCIR also finds it necessary or desirable at times to express an opinion on a non-technical subject in the form of a Resolution. These frequently act as directives for specific work by the Director or study groups, or for cooperative action with other organizations. Thus, the product of all CCIR work can be classified under one of these five headings—Question, Study Program, Report, Recommendation or Resolution.

The London Meeting: As stated above, the Seventh Plenary Assembly was held in London from September 3 to October 7, 1953. The separate study groups met between September 4 and September 26; the rest of the time was devoted to plenary sessions at which final action was taken on the proposals evolved by the study groups.

At the London meeting, 40 nations and 28 organizations were represented, with about 250 delegates and 100 auxiliary personnel. The United States had 18 delegates, representing the State Department, Federal Communications Commission, National Bureau of Standards, Army, Navy, American Telephone & Telegraph Company, Radio Corporation of America, and National Association of Radio-Television Broadcasters.

The results of the meeting were responses to all of the various topics that had been established at the Geneva Plenary Assembly in 1951. Some of the results were Recommendations; others were agenda for future work (Questions, Study Programs, Reports, Resolutions). The technical output of the meeting will be of practical use to the radio administrations and companies of the various countries and to the ITU organs, such as the International Frequency Registration Board.

The meeting had a very heavy agenda. Success in dealing with it was largely due to the work that had been done beforehand in the Study Groups. Some problems were given a definitive answer; in many cases the result was essentially a program of further work to be done. There was a total of 165 Recommendations, Questions, Study Programs, Reports and Resolutions.

The scope of the topics treated and the work done is partly revealed by the following list of the Recommendations adopted. The numbers of these Recommendations continue a consecutive numbering with those of the Stockholm 1948 and Geneva 1951 Recommendations.

The London Recommendations

No.

87. Bandwidth of Emissions
88. Bandwidth of Emission Measurements Made Near the Transmitter
89. Harmonics and Parasitic Emissions
90. Frequency Stabilization of Transmitters
91. Arrangement of Channels in Multi-Channel Transmitters for Long-Range Radio Circuits Operating on Frequencies Below About 30 Mc/s
92. Frequency Shift Keying
93. Telegraphic Distortion
94. Noise and Sensitivity of Receivers
95. Selectivity of Receivers
96. Frequency Stability of Receivers
97. Channel Separation
98. Channel Separation Achieved in Practice
99. Bandwidth and Signal-to-Noise Ratios in Complete Systems
100. Reduction of Occupied Bandwidth and Transmitter Power in Radio-Telephony
101. Bandwidth Required at a Telegraph or Telephone Receiver Output
102. Directivity of Antennae at Great Distances
103. Use of Directional Antennae
104. Signal-to-Interference Protection
105. Fading Allowances for the Various Classes of Service
106. Voice Frequency Telegraphy on Radio Circuits
107. Communication Theory
108. Presentation of Antenna Radiation Data
109. Ground Wave Propagation over Mixed Paths
110. Presentation of Data in Studies of Tropospheric Wave Propagation
111. Tropospheric Wave Propagation Curves
112. Best Methods for Expressing Field Strength for Pulse Transmissions
113. Field Strength Measurement. Types of Wave Col-

lector and Equipment for Use in Each Frequency Band

114. Field Strength Measurement. Influence of Local Conditions on Interpretation and Accuracy of Measurements of Field Strength
115. Study of Absorption in the Ionosphere
116. Presentation of Basic Propagation Prediction Charts
117. Prediction of Solar Index
118. Protection of Frequencies Used for Radio Astronomical Measurements
119. Measurement of Atmospheric Radio Noise
120. Revision of Atmospheric Radio Noise Data
121. Local Lightning Flash Counters
122. Standard Frequency Transmissions and Time Signals
123. Accuracy of Field Strength Measurements by Monitoring Stations
124. Watch on the Radiotelephony Distress Frequency of 2182 Kc.
125. Alarm Signal for Use on the Maritime Radio-Telephony Distress Frequency 2182 Kc.
126. Pulse Transmission for Radio Direction Finding
127. Standardization of Phototelegraph Apparatus for Use on Combined Radio and Metallic Circuits
128. Wide Band Radio Systems Operating in the VHF (Metric), UHF (Decimetric), and SHF (Centimetric) Bands. Sub-control stations
129. Methods of Specifying the Power Supplied to an Antenna by a Radio Transmitter
130. Power Relationship for Modulated Emissions
131. Interference to Radio Services
132. Identification of Radio Stations
133. Standards of Sound Recording for the International Exchange of Programs
134. Standards of Sound Recording for the International Exchange of Programs. Lateral Cut Recording on Discs
135. Standards of Sound Recording for the International Exchange of Programs. Single Track Recording on Magnetic Tape
136. Single Sideband Sound Broadcasting
137. Use of Synchronized Transmitters in HF Broadcasting
138. Minimum Permissible Protection Ratio to Avoid Interference in the Bands Shared with Tropical Broadcasting
139. Design of Transmitting Aerials for Tropical Broadcasting
140. Design of Receiving Aerials for Tropical Broadcasting
141. Addition to Appendix 9 of the Radio Regulations
142. Nomenclature of the Frequency and Wave Length Bands Used in Radio Communication
143. Unit Systems
144. Means of Expression. Terms, Definitions, Graphical and Letter Symbols and their Conventional Usage

The names of the Recommendations as listed above show their wide scope as well as diverse character. Some of them consist essentially of specification of technical detail. Some give methods of calculation. Some give sources of information. Some do little more than point out the need for more data. Some indicate action required to secure more data. Some give methods of measurement. Many specify technical procedures.

Of particular interest to radio engineers in general is Recommendation No. 142—"Nomenclature of the frequency and wave length bands used in radio communication." All of us are familiar with the commonly used adjective identifications of the bands of radio frequencies that were adopted at Atlantic City, and many have long realized their ambiguity and wished for a numerical classification that would provide an easily remembered identification. Fig. 4 shows the table adopted in that Recommendation and the present nomenclature.

BAND NUMBER	FREQUENCY RANGE		WAVE LENGTH DESIGNATION	ATLANTIC CITY FREQUENCY DESIGNATION
4	3 - 30	Kc	MYRIAMETRIC	VLF
5	30 - 300	Kc	KILOMETRIC	LF
6	300 - 3000	Kc	HECTOMETRIC	MF
7	3 - 30	Mc	DECAMETRIC	HF
8	30 - 300	Mc	METRIC	VHF
9	300 - 3000	Mc	DECIMETRIC	UHF
10	3000 - 30,000	Mc	CENTIMETRIC	SHF
11	30,000 - 300,000	Mc	MILLIMETRIC	EHF

Fig. 4

It will be noted that a band number N extends from 0.3×10^N to 3×10^N c/s. The upper limit is included in the band; the lower limit is excluded; thus, band 4 designates the frequency range 3×10^3 to 3×10^4 c/s. Scientifically a nomenclature in which band 4 would lie between 10^4 and 10^5 c/s would be preferable. However, we cannot have a simple decimal system for both freespace wavelength and frequency. Also, from an operational and administrative viewpoint, with which the CCIR is primarily concerned, the advantages of having the newly named bands co-extensive with the present frequency and wavelength band terminology are felt to outweigh the advantages of other systems.

The basic role played by radio propagation in practical use of radio was indicated by the adoption of 14 Recommendations, 14 Reports, 5 Resolutions, and 21 Questions and Study Programs on Radio Propagation topics. These included standard curves for ground-wave and tropospheric propagation, extensive information on the reliability of predictions of usable frequencies, and several programs for improving our knowledge of atmospheric radio noise. The latter include the revision of existing world radio noise charts, preparation of specifications for equipment for world wide observations of lightning flashes and the quantitative measurement of atmospheric radio noise.

At the London meeting, the past recommendations of the CCIR were reviewed and their status determined. All of those from the first four plenary assemblies (prior to 1948) were considered obsolete. Of the 85 Recommendations of Stockholm 1948 and Geneva 1951, only 30 were considered to be still useful or valid as written. Of the others, some were declared obsolete and the remainder were modified and became London Recommendations. Volume I of the papers issued as a result of the London meeting contains all of these still valid Recommendations and also the agenda for future work.

Future Work of Study Groups: The agenda for the future work is in four categories: Questions, Study Programs, Reports, and Resolutions. They are numbered consecutively following the consecutive numbering of the corresponding categories from the Stockholm 1948 and Geneva 1951 meetings. Some pre-London topics were continued for future work; in these cases they retain their pre-London numbers.

The agenda for future work, as established in London, comprises 144 topics: 53 Questions, 51 Study Programs, 29 Reports and 11 Resolutions, as follows:

QUESTIONS, ETC., ARRANGED BY STUDY GROUPS

Study Group I—Radio Transmitters

Report 16.	Telegraphic Distortion
Report 17.	Harmonics and Parasitic Emissions
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Study Group XIV—Vocabulary

Report 37.	Decimal Classification
Resolution 5.	Means of Expression (Definitions, Vocabulary, Graphical and Letter Symbols)
Question 72.	Decimal Classification

The meeting also produced four new Questions on operational matters, referring them to the CCIT and CCIF.

A working relation has grown up whereby the International Scientific Radio Union (URSI) handles the more scientific aspects of the topics dealt with by CCIR, and this was further solidified at this meeting. Seventeen of the Recommendations, etc., of the London meeting referred the study of particular aspects to the URSI.

The CCIR to a limited extent utilizes and contributes to the work of still other scientific organizations. Some of the findings dealing with radio noise and electrical interference were referred respectively to the WMO (World Meteorological Organization) and the CISPR (Special International Committee on Radio Interference) which operates under the IEC (International Electrotechnical Commission).

SUMMARY

The above discussion is but an outline of the varied and extensive scope of the work of the CCIR. While its recommendations do not have the force of law, they are persuasive, and many find their way into international regulations that are legally binding upon governments and individuals alike. All of us who are concerned with radio communications should inform ourselves of this work and, to the extent that we can, contribute to it so that our regulations will be designed to yield the maximum benefit from that valuable national and international resource, the radio spectrum. The Technical Secretary of the IRE serves as the coordinator, within the IRE, of the work of the fourteen national Study Groups. Anyone wishing to contribute on any phase of the work should communicate with him for this purpose.

Information about the organization and functions of the CCIR is contained in the International Telecommunication Conventions, Atlantic City, 1947 and Buenos Aires, 1952. The past contributions of the CCIR to international radio regulation are reflected in the Radio Regulations drawn up at Atlantic City, 1947, and annexed to the present Convention of Buenos Aires, 1952. The current work of the CCIR is contained in the papers of the Seventh Plenary Assembly, London, 1953, of which Volumes I and II have been published. It is hoped that arrangements can be made whereby these publications can be obtained through the United Nations' Library at New York City. In the meantime, however, they may be purchased from the Secretary General, International Telecommunication Union, Palais Wilson, Geneva, Switzerland. Orders should be accompanied by an international money order or bank draft in the proper amount. The Atlantic City Convention is 1.50 Swiss francs, the Buenos Aires Convention is 3.25 Swiss francs and the Radio Regulations, 1947, are 710 Swiss francs. Volumes I and II of the CCIR Plenary Assembly at London are 23.10 Swiss francs and 22.00 Swiss francs respectively. The equivalent value of one Swiss franc is approximately twenty-four cents.

ACKNOWLEDGMENT

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* * *

The Regenerative Pulse Generator*

C. C. CUTLER†, ASSOCIATE, IRE

Summary—**This paper describes a new arrangement for generating short pulses. The circuit consists essentially of a loop containing an amplifier, expandor, bandpass filter, a time delay, and a means of automatic gain control. The circuit is controlled to give a round trip gain of unity for the pulse. Under this condition a pulse travels around the loop, alternately being sharpened in the expandor and broadened in the filter. An output tap delivers identical pulses recurring at a rate determined by the loop delay, shape determined principally by the expandor and filter characteristics, and length controlled principally by the filter bandwidth. Pulses modulated in frequency may be obtained by adding a nonlinear phase-frequency characteristic to the loop delay.**

Microwave radio frequency pulses as short as 0.002 microsecond, and direct current pulses as short as 0.005 microsecond (at half-amplitude) have been produced directly. The principles involved may have application in pulse communication and radar, and have already found use in pulse measurements of broadband circuits.

Introduction

In order to utilize the very broad bandwidths which are made possible by the development of the microwave art, methods of generating and handling very short pulses are needed. This paper discusses what is believed to be a new, generic method of pulse generation, which can be used to obtain radio frequency pulses directly, and also reveals some hitherto unappreciated properties of pulse trains.

In addition to the usual length, rate, shape and center frequency that are recognized properties of a pulse train, such a train has phase properties which help to determine its spectrum characteristics, and which are very important in some applications. The nature of these properties is brought out in the analysis and some of the consequences considered. Principally, however, this paper is intended to describe a new method of generating trains of short pulses.

Description of the Basic Circuit

This circuit consists of a feedback loop around which a pulse re-circulates indefinitely, at each traversal giving response at the output terminals. It is evident that such a pulse would soon be degraded unless the effects of noise and distortion are counteracted in some way. An expandor in the loop has the desired effect. It emphasizes the highest amplitude point in the re-circulating pulse, reducing the lower amplitudes, effectively discriminating against noise and reflections, and acting to shorten the pulse until the length is limited by the frequency response of the circuit. In addition, a very simple automatic gain control maintains the amplitude to give a loop gain of unity for the pulse.

A diagrammatic representation of such a circuit is shown in Fig. 1 where various loop characteristics which might be inherent in the amplifier are represented as separate devices. The loop consists essentially of an amplifier, a filter, a delay line, and an expandor. The order in which these functions take place is not significant. An automatic gain control circuit controlled by the pulse amplitude, but with a time constant long with respect to the pulse length, limits the pulse amplitude, prevents overloading, and makes it possible for the circuit to start on a small signal or noise impulse.

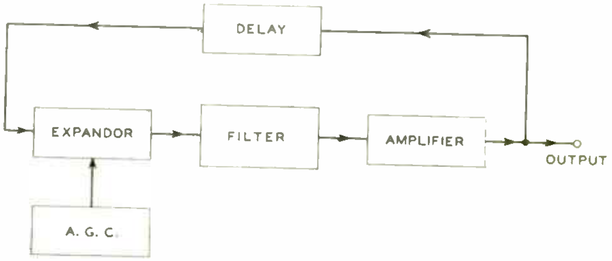

Fig. 1—Block diagram showing the basic elements of the regenerative pulse generator circuit.

The elements of this pulse-generating circuit are all familiar except perhaps for the expandor. The essential requirement of the expandor is that it provides more gain (less attenuation) for a high level signal than for a low level one. Such a characteristic may be obtained by operating a conventional grid control tube with grid bias near or below the cut-off voltage.

At microwave frequencies, where it may not be practical to use grid control, the expansion characteristics may be obtained by using a crystal or other nonlinear impedance as will be described in a later section.

The Nature of the Pulses

In Appendix I it is shown that if the filter has a gaussian characteristic, and the expandor follows a power law, a train of gaussian pulses is obtained. The pulse rate is equal to the reciprocal of the midband loop delay, the pulse length determined by the filter bandwidth, and the center frequency by the median filter frequency. In addition, it is found that adjacent pulses are not necessarily identical in the rf phase. The phase measured with respect to pulse time, in general, changes from pulse-to-pulse, shown in Fig. 2 (opposite page). This change we call "radio frequency precession," and if multiplied by the pulse rate, the "precession rate." The precession rate is equal to the product of pulse ray and the excess phase in the feedback loop, plus a contribution due to the phase distortion of the loop.

The pulse train gives a line spectrum with frequency components separated by intervals equal to the pulse

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rate, and an envelope roughly like that of the filter characteristic. The frequency components differ from multiples of the pulse rate by an interval equal to the precession rate.

Nonlinearity of phase in the feedback loop causes the instantaneous frequency to change throughout the pulse, a second power phase vs frequency characteristic causes the frequency to sweep linearly. A large phase curvature also lengthens the pulse, in the limit giving one whose instantaneous frequency sweeps through a band in width several times the reciprocal of pulse length.

The function of the automatic gain control is to maintain the pulse at such an amplitude that the loop gain is unity for the pulse. This may be done in the conventional way, deriving a dc voltage from the pulse output and feeding it back into the amplifier or expandor with the correct polarity to reduce gain. Providing that the automatic gain control operates with a time constant long with respect to the pulse period, the loop gain is less than unity at all times other than at the peak of the pulse. In the event that two pulses get started at once, any slight inequality, such as that due to a noise impulse, gives the larger one more gain in the expandor and the other less. As a result, the inequality is increased, and upon repeated circulation the smaller pulse is rapidly eliminated.

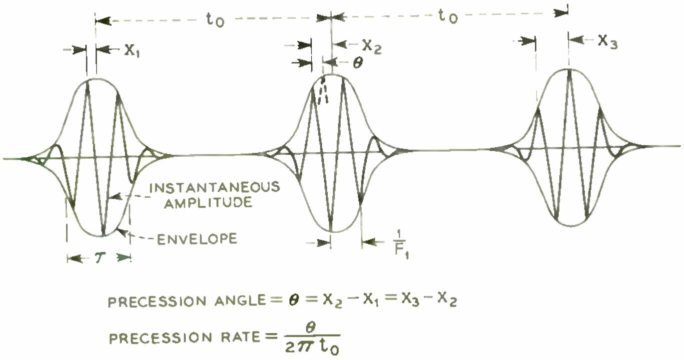

Fig. 2—The rf phase changes from pulse-to-pulse, the rate of change referred to the pulse time being called the phase precession.

The analysis is limited to gaussian pulses, but it is evident that the filter characteristic and the nonlinearity of the loop determine the shape of the pulse. Graphical procedure indicates that using a slicer in place of the expandor (expanding low levels and limiting high levels), results in flat-topped pulses, whose length is determined by the automatic gain control. In this case the maximum level is controlled by the limiting level in the slicer, and the gain control is effective only within the slicer increment, and acts to make the pulse length give a constant average output power.

Questions of stability in pulse length and center frequency are handled for gaussian pulses in Appendix II.

Experimental Base-Band Pulse Generator

We will first describe a base-band pulsing circuit, because it involves more conventional circuitry, and will serve well to illustrate the principles involved. This circuit was built in order to obtain very short, low amplitude pulses.

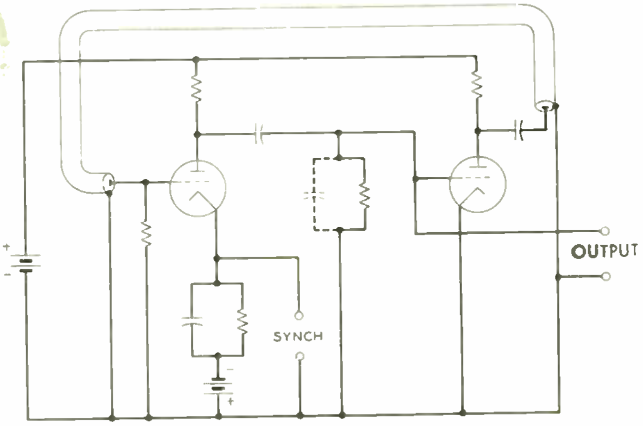

Fig. 3—Circuit for generating dc pulses using conventional components.

In the circuit of Fig. 3, the expansion and automatic gain control are accomplished with one tube, amplification and reinversion require the second. Frequency restriction is inherent in the interstage circuits, and the desired delay is incorporated in interstage circuits. Tube #1 is biased by a cathode resistor to operate class B, and because of the curvature in the Ip-Eg characteristic, gives the desired expansion and acts to sharpen the transmitted pulse. The second tube is operated class A, and acts to reverse the phase and recover the loss due to the inherent frequency restriction in the interstage circuits and the attenuation of the delay line. The output may be taken from the termination at either interstage, depending upon the polarity desired. Synchronizing voltage may be either applied to or derived for external use from the termination of the other interstage circuit or either cathode circuit. Automatic gain control is provided by a large self-biasing cathode resistance in series with the expandor tube.

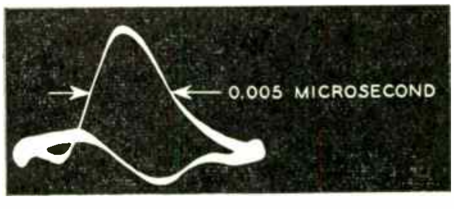

Fig. 4—Micro-oscilloscope photographs of dc pulses from the circuit of Fig. 3.

In operation it was found that the output, consisting of rounded triangular pulses, as shown in Fig. 4,[1] was stable and self-starting or not, depending on the gain adjustment. The stability and freedom from extra pulses was found to be dependent on the values of *R* and *C* in the automatic gain control circuit, but these were not critical. A very wide range of automatic gain control

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[1] This is a photograph taken with the tube using a sine wave sweep, described by J. R. Pierce, "Traveling wave oscilloscope," *Electronics*, vol. 22, pp. 97–99; November, 1949.

could be obtained by substituting the plate resistance of a 6AK5 for the cathode bias resistor. The 20-mc pulse rate could be synchronized with less than 0.01 volt applied to the expandor grid.

The pulse output voltage is, of course, dependent on the interstage impedances. In the case described, the expandor output was limited to about 2 volts into the 125 ohm delay line, which is nearly as low an impedance as the WE 2C51 will work into with sufficient gain. The maximum voltage obtainable is, of course, roughly proportional to the interstage impedance, which conversely limits the pulse sharpness obtainable.

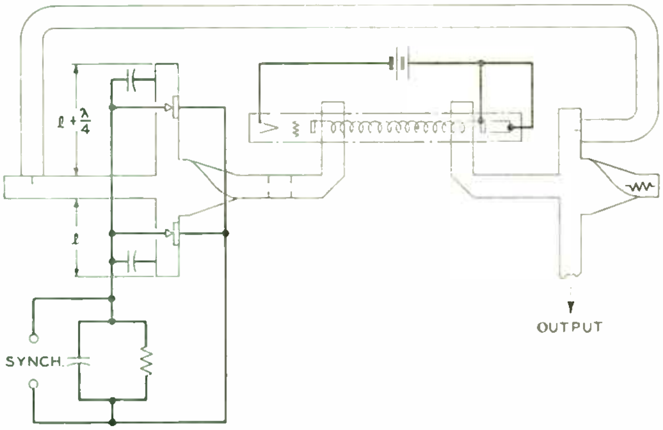

Fig. 5—Circuit using a traveling-wave tube and crystal expandor for the generation of microwave pulses.

Experimental 4,000-Mc RF Pulse Generator

High frequency pulses were generated in a traveling-wave tube circuit, as shown in Fig. 5. In this case the expandor consists of two IN23 silicon crystals, impedance matched at very low levels and placed in opposite branches of a hybrid tee. The reflected waves from the crystals are phased to add in the fourth arm of the tee and cancel in the input arm by including an extra quarter wavelength section in one of the side arms. The output consists of the total reflected power from both crystals which, because of the nonlinearity of the crystal impedance and the impedance match imposed at low levels, varies at a faster rate than the input power level.

The expandor characteristic varies radically as a fixed dc bias is applied to the crystals, as is shown in Fig. 6. Increasing the positive voltage applied to the crystal points causes a marked reduction of transmission at most levels and increases the expansion. This feature provides a simple means of automatic gain control, the self-bias of the expandor itself providing sufficient control for most conditions and a wider range being available by addition of a simple low frequency amplifier-rectifier combination.

The broadband low-level adjustment of this expandor is difficult at best, and is the limiting element in the circuit. Since the expandor functions as such over a limited band of frequencies (about 400 mc), it is necessary to provide a filter to limit the bandwidth of the circuit to a comparable width to insure that the frequencies are confined to the band in which expansion takes place. A simple single-section waveguide filter is adequate, but may not be the most advantageous for this purpose.

The pulse rate is, of course, determined by the total delay in the loop, and may be synchronized and stabilized by a small signal of the desired frequency applied to the expandor crystals. A one-tenth volt was found to be more than adequate for this purpose, and in fact it was found to be enough to pull the pulse rate ±100 kc out of 14.5 mc.

A question as to the possibility of more than one pulse at a time traversing the loop has been raised. Actually, as discussed before, the characteristics of the expandor preclude the possibility of extra pulses, and under the conditions described no difficulty of this nature was experienced.

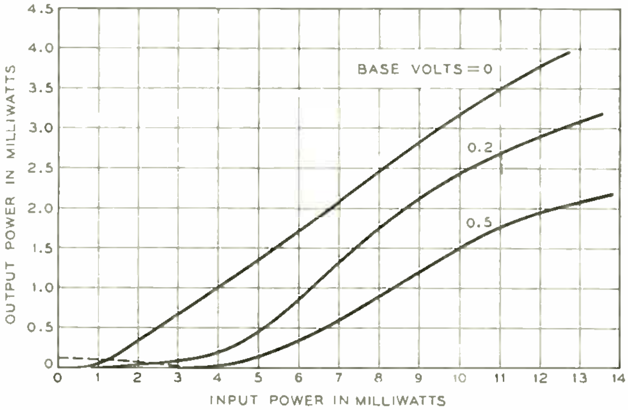

Fig. 6—Expansion and gain control characteristics of the crystal expandor shown in Fig. 5.

RF Pulse Observations

The pulses were observed and measured by a waveguide interferometer method, spectrum observations and (after rectification) oscilloscopic observation. The interferometer observations were particularly interesting because this was the only method available at first. Since the pulses are as short as 2 feet, reflections a foot apart could be resolved. Fig. 7 (next page) shows the waveguide arrangement. By measuring the amplitude variations of the received signal as a function of the movable piston position, it was possible to deduce the pulse length and tell something about the shape. When the piston was withdrawn much more than one foot, the interference variations as a function of piston position, rapidly decreased to zero. The current in the square law detector is proportional to the average power transmitted by the interferometer. This is

$$P = \lim_{T\to\infty} \frac{K}{T} \int_0^T (F(t) + F(t + \Delta))^2 dt$$

where Δ is the difference in delay of the two paths. This gives

$$P = \lim_{T\to\infty} \frac{K}{T}\int_0^T \left[F^2(t) + F^2(t+\Delta) + 2F(t)F(t+\Delta)\right]dt$$

$$= 2K\left[1 + \lim_{T\to\infty}\frac{1}{T}\int_0^T F(t)F(t+\Delta)dt\right],$$

and the second term is simply the autocorrelation function of $F(t)$. The plot of detector current, in Fig. 7, then, is 1 plus the auto-correlation function of the pulse generator output. The auto-correlation function is the Fourier transform of the power spectrum, and assuming we have pulses, gives some idea of the pulse length.

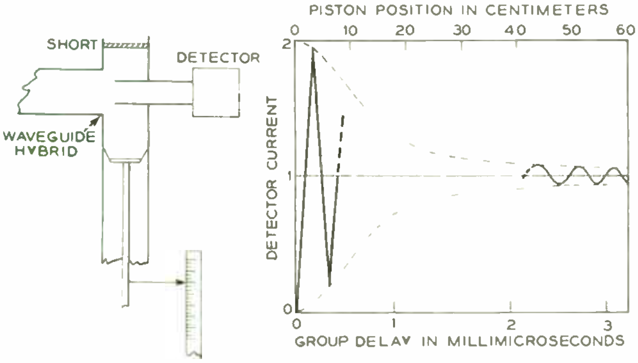

Fig. 7—Waveguide interferometer circuit and response. The response curve is the auto-correlation function of the pulser output.

When viewed with a wide-band spectrum analyzer, a large number of very narrow frequency components were found. The spectrum was observed simply by beating the rf pulse output with a mechanically swept oscillator sweeping a range of 250 mcs at a 60-cycle rate. The beat signal was viewed directly on a low frequency oscilloscope, and appeared as shown in Fig. 8. Although less than half of the pulse spectrum could be observed at a time, it was a very useful method of observation.

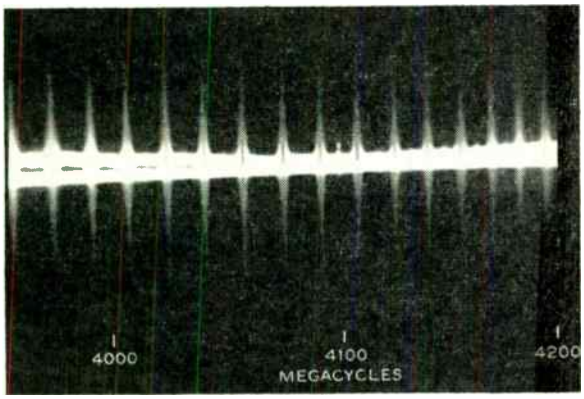

Fig. 8—Section of the spectrum of the radio frequency pulses.

Simultaneous micro-oscilloscope observations of rectified pulse envelope shape (Fig. 9) and spectrum characteristics were very illuminating. The spectrum component separation was, of course, equal to the repetition rate. When the repetition rate was varied by pulling with a synchronizing voltage applied to the expandor crystals, the component frequencies near the center of the spectrum were not significantly changed, but the separation of lines did change, and this change was consistent with the repetition rate. Varying the delay made roughly proportional changes in the component frequencies. Tuning the waveguide filter merely changed the envelope containing the components without materially changing the component frequencies. Breaking a waveguide junction and turning one end of the guide over, oddly enough, caused a frequency shift of all components by half the separation of components, with no visible change in pulse or spectrum envelopes or pulse rates. These observations are all consistent with the analytical results. There is no way to identify any spectrum component as a carrier frequency, or with the rf period within the pulse. The latter is related to the spectrum, as discussed in the Appendix, but the relationship is not so obvious.

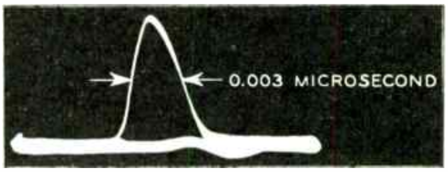

Fig. 9—Micro-oscilloscope photograph of the rectified radio frequency pulse output.

By use of multiple reflections in a series of interferometers, like that shown in Fig. 7, it was possible to build more complex pulse shapes, for instance, flat-topped almost rectangular pulses.

CONCLUSION

The regenerative pulse generator appears to be a generic method of pulse generation. It may be considered a stable self-excited oscillator which generates rf pulses in high frequency circuits, or dc pulses in low-pass circuits.

The pulses generated are the result of complementary action of a frequency filter and a nonlinear circuit, the characteristics of which can be made to produce a wide variety of pulse shapes.

The pulses are coherent, the spectrum components being sharply defined and related to the circuit transmission characteristics in a rather unusual way.

The principles involved have found application in long waveguide measurements,[2] and may have many applications where coherent pulse trains are desired.

APPENDIX I

Theory of Operation

In order to analyze the regenerative pulse generator we idealize it into a series of operations, as indicated by the blocks of Fig. 1. Thus we have a simple nonlinear operation on the time function in the expandor, and then

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[2] A. C. Beck, "Microwave testing with millimicrosecond pulses," TRANS. I.R.E., PGMTT, vol. 2, pp. 93–102; April, 1954.

operation on the frequency (and phase) characteristic in the subsequent elements. In a practical circuit these may be thoroughly mixed, but this should not affect the over-all operation of the circuit. We will treat this circuit by repeated application of Fourier transforms, applying the frequency or amplitude characteristic of each element, and finally equating the characteristics of the returning signal to the characteristics of the assumed initial signal. If the signal entering the expandor is

$$G_1(t)e^{j\psi(t)}, \qquad (1)$$

and indicating the operation of the expandor by the superscript n,

$$E_{\text{out}} = B[E_{\text{in}}]^n. \qquad (2)$$

(In general terms, superscript n can be taken to indicate a nonlinear operation, not necessarily a power law.) The expandor output voltage will be

$$G_2(t) = B[G_1(t)]^n e^{j\psi(t)}. \qquad (3)$$

Here we have applied the nonlinear operation only to the envelope $[G_1(t)]$ and have ignored the effect on the phase function $\psi(t)$. Harmonics of the radian frequency will occur, but are of no consequence because they are generally far outside of the pulse bandwidth and are filtered out in any practical device. They do not appear in the measured characteristic of such expandors as we have met. The amplifier and circuit losses give a net gain "A." We will see later that this must be subject to a long time constant automatic gain control but, for the present, we will take it as a constant.

$$G_3(t) = AB[G_1(t)]^n e^{j\psi(t)}. \qquad (4)$$

To obtain the output of the filter, we must transform to a frequency function, giving a spectrum

$$\begin{aligned} F_3(f) &= \int_{-\infty}^{\infty} G_3(t)e^{-j\omega t}dt \\ &= AB\int_{-\infty}^{\infty} [G_1(t)]^n e^{j\psi(t)}e^{-j\omega t}dt. \qquad (5) \end{aligned}$$

Out of the filter having a frequency function $F(f)$ we have:

$$F_4(f) = F(f)F_3(f), \qquad (6)$$

which in turn transforms to

$$\begin{aligned} G_4(t) &= \int_{-\infty}^{\infty} F_4(f)e^{j\omega t}df \\ &= AB\int_{-\infty}^{\infty} F(f)e^{j\omega t}df \int_{-\infty}^{\infty} [G_1(t)]^n e^{j\psi(t)}e^{-j\omega t}dt. \qquad (7) \end{aligned}$$

The time delay of t_0 seconds brings us back to the expandor input. To have a continuous stable pulse must be identical to the original one except possibly for the instantaneous rf phase. Thus

$$G_1(t)e^{j\psi(t)} - ABe^{-j\theta}\int_{-\infty}^{\infty} F(f)e^{j\omega(t-t_0)}df \cdot \int_{-\infty}^{\infty} [G_1(t-t_0)]^n e^{j\psi(t-t_0)}e^{-j\omega(t-t_0)}dt = 0, \qquad (8)$$

where θ is the phase shift of the rf wave relative to the pulse time.

Given a filter characteristic $[F(f)]$ an expandor of law (n) and a time delay (t_0), this equation specifies the time function $G_1(t)e^{j\psi(t)}$. Unfortunately, it is a bootstrap equation. Let us therefore take

$$G_5(t) = AB\int_{-\infty}^{\infty} F(f)e^{j\omega(t-t_0)}df \cdot \int_{-\infty}^{\infty} [G_1(t_1-t_0)]^n e^{j\psi(t)}e^{j\omega(t-t_0)}dt, \qquad (9)$$

and solve for an output $G_5(t)$ in terms of an assumed input $G_1(t)$. In the event that we find $G_5(t)$ to be a replica of $G_1(t)$, we have a solution of (8).

Solution for Gaussian Pulses

There are certain pulse and filter characteristics which lend themselves well to this kind of solution. This is particularly so of the Gaussian characteristics, provided we take n as a power law.

Suppose we assume a series of gaussian pulses of the form

$$G_1(t)e^{j\psi(t)} = Ee^{j(2\pi f_0 t + bt^2)}e^{-at^2}, \qquad (10)$$

where the first exponent gives the median radio frequency, the second allows for a linear frequency modulation, and the third expresses the gaussian pulse characteristic of length $\tau = 2/\sqrt{a}$ measured at points 1 neper (8.68 db) below the peak.

The expandor affects only the amplitude characteristic,[3] so that plus the amplifier it leaves us with

$$G_3(t) = ABE^n e^{j2\pi f_0 t - ant^2 + jbt^2}. \qquad (11)$$

Using Campbell and Foster[4] Fourier transform pair 729.1, we get

$$F_3(f) = ABE^n\sqrt{\frac{\pi}{an - jb}}\, e^{-[\pi^2(f-f_0)^2/an-jb]}. \qquad (12)$$

We express the phase shift in the loop (including delay) by a series

$$\Phi = \alpha + \beta(f-f_0) + \gamma(f-f_0)^2 \cdots . \qquad (13)$$

This is included in the filter characteristic, giving

$$F(f) = Ce^{-c(f-f_0)^2}e^{-j(\alpha+\beta(f-f_0)+\gamma(f-f_0)^2)}, \qquad (14)$$

where the first exponential indicates that it is a gaussian filter centered on the median frequency of the pulse (f_0) and having a bandwidth of $\mathfrak{F} = 2/\sqrt{c}$ at one neper point. The other terms are the first three of the phase function (13), which accounts for first order phase effects.

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[3] Assuming any frequency discrimination within the pulse bandwidth to be lumped with the filter, and harmonics of the rf wave to be completely outside of the band of interest.

[4] G. A. Campbell and R. M. Foster, "Fourier Integrals for Practical Applications," Bell Sys. Mono. B-584.

The filter output then, from (12) and (14), is

$$F_4(f)=F(f)F_3(f)$$

$$=ABCE^n\sqrt{\frac{\pi}{an-jb}}\,e^{-[(\pi^2/an-jb)+c+j\gamma](f-f_0)^2-j(\alpha+\beta(f-f_0))},\quad(15)$$

for convenience let

$$\delta=\frac{\pi^2}{an-jb}+c+j\gamma \quad (16)$$

$$F_4(f)=ABCE^n\sqrt{\frac{\pi}{an-jb}}\,e^{-\delta f^2+(2\delta f_0+j\beta)f-\delta f_0^2-j\beta f_0-j\alpha}, \quad (17)$$

from Campbell and Foster pair 729

$$G_5(t)=ABCE^n\sqrt{\frac{\pi}{an-jb}}$$

$$\cdot\sqrt{\frac{\pi}{\delta}}\,e^{-\pi^2/\delta(t-\beta/2\pi+j(\delta f_0/\pi))^2-(\delta f_0^2+j\alpha)}. \quad (18)$$

Separating exponents in powers of $[t-(\beta/2\pi)]$

$$G_5(t)=ABCE^n\frac{\pi}{\sqrt{\delta(an-jb)}}\,e^{-\pi^2/\delta(t-\beta/2\pi)^2-j2\pi f_0(t-\beta/2\pi)-j\alpha}. \quad (19)$$

The condition for a continuous stable pulse train is that the pulse shape and amplitude, frequency and frequency modulation in G_5 be identical to G_1. Allowing for a change in time and phase this is

$$G_5(t-t_0)e^{-j\theta}=G_1(t)=E\cdot e^{j2\pi f_0 t-(4/\tau^2)t^2-jbt^2}. \quad (20)$$

Evaluation

By comparing terms in (10), (19), and (20), we can evaluate the pulse characteristics, namely τ, t_0, b, and θ in terms of the circuit parameters $\mathfrak{F}$, α, β, γ, and n.

Pulse Rate: Separation between pulses is seen to be

$$t_0=\frac{\beta}{2\pi}, \quad (21)$$

which is exactly the group time delay $d\Phi/d\omega$ of the assumed phase characteristic at midband frequency. The pulse rate of the continuous train would thus be

$$\text{pulse rate}=\frac{2\pi}{\beta}. \quad (22)$$

Pulse Length: The pulse length τ is obtained by comparing real coefficients in t^2. This gives

$$a-jb=\frac{\pi^2}{\delta}=\frac{\pi^2}{\dfrac{\pi^2}{an-jb}+c+j\gamma} \quad (23)$$

rearranging

$$\frac{(an-jb)(a-jb)}{a(n-1)}=\pi^2\frac{c-i\delta}{c^2+\gamma^2}$$

and separating reals and imaginaries

$$\frac{na^2-b^2}{(n-1)a}+j\frac{(n+1)}{(n-1)}b=\pi^2\frac{c}{c+\gamma^2}-j\pi^2\frac{\gamma}{c^2+\delta^2}$$

equating coefficients of j

$$b=-\frac{n-1}{n+1}\pi^2\frac{\gamma}{c^2+\gamma^2} \quad (24)$$

and from real coefficients, we have

$$na^2-\pi^2\frac{(n-1)c}{c^2+\gamma^2}a-b^2=0$$

substituting for b, and using the binominal expansion

$$a=\frac{(n-1)\pi^2c}{2n(c^2+\gamma^2)}1\pm\sqrt{1+\frac{4n}{(n+1)^2}\frac{\gamma^2}{c^2}} \quad (25)$$

where only the positive sign gives a real solution.

Substituting $c=4/\mathfrak{F}^2$ and $a=4/\tau^2$ (26)

$$\tau=\frac{4}{\pi\mathfrak{F}\sqrt{1-\dfrac{1}{n}}}\left[\frac{2\left(1+\dfrac{\gamma^2\mathfrak{F}^4}{16}\right)}{1+\sqrt{1+\dfrac{n\gamma^2\mathfrak{F}^4}{4(n^2+2n+1)}}}\right]^{1/2}\ \text{seconds} \quad (27)$$

for small values of γ (linear phase) the term in brackets is unity.

This is the pulse length of a gaussian pulse measured at 1 neper points, as seen before the expandor. At the expandor output it is $1/\sqrt{n}$ as long. In the low-pass case, considering $\mathfrak{F}$ to be given by a low-pass gaussian filter, we get half the pulse length indicated above.

Frequency Modulation: The angular frequency is given by the rate of change of phase with time; this is from (10)

$$2\pi f=\frac{d}{dt}(2\pi f_0t-bt^2)$$

$$f=f_0-\frac{bt}{\pi}\ \text{cycles/second}. \quad (28)$$

This indicates that the instantaneous[5] frequency sweeps through the pulse, being equal to the filter midband frequency at the pulse center and sweeping linearly at a rate of

$$\frac{b}{\pi}\ \text{cycles/second}^2. \quad (29)$$

[5] This is properly an instantaneous frequency, meaning events per unit time, but it bears no direct relationship to the spectrum component frequencies.

From (24) this gives

$$-\frac{b}{\pi} = \text{rate of frequency rise}$$

$$= \pi \frac{n-1}{n+1} \frac{\gamma}{\left(\frac{2}{\mathfrak{F}}\right)^4 + \gamma^2}. \tag{30}$$

This frequency modulation may be made quite large, but with ordinary filter characteristics the effect is usually negligible. A quantity of interest in FM pulse application is the product of the frequency swept and the pulse length. From (26) and (29) we find that this has a maximum value of $8/\pi\sqrt{n}$. If one attempts to get a larger value of frequency modulation, the pulse is correspondingly lengthened and the product is not increased.

Phase Precession: As was indicated earlier, the adjacent pulses are not necessarily identical in the rf phase relationship. The rf phase measured with respect to the pulse time changes from pulse-to-pulse. To evaluate this, we must compare the constant multipliers in (10) and (19).

$$ABCE^n \frac{\pi}{\sqrt{\delta(an - jb)}} e^{-j\alpha} = Ee^{j\theta}. \tag{31}$$

Substituting for δ, and for $c+j\gamma$ from (16) and (23), we have

$$e^{j\theta} = ABCE^{(n-1)} \sqrt{\frac{a - ib}{an - jb}}\, e^{-j\alpha},$$

or

$$e^{j\theta} = ABCE^{(n-1)} \left(\frac{a^2+b^2}{a^2n^2+b^2}\right)^{1/4} e^{j(1/2)[\tan^{-1} b/a - \tan^{-2} b/an] - j\alpha}.$$

Substituting for b and a, from (24) and (25), gives

$$e^{j\theta} = ABCE^{(n-1)} \left(\frac{1+\phi^2}{n^2+\phi^2}\right)^{1/4} e^{j(1/2)[\tan^{-1} \phi - \tan^{-1} \phi/n] - j\alpha} \tag{32}$$

Equating exponents in (31) gives

$$\theta = \tfrac{1}{2}\left[\tan^{-1} \phi - \tan^{-1} \frac{\phi}{n}\right] - \alpha. \tag{34}$$

θ is the phase shift change between pulses measured with respect to the pulse time, the total phase shift being

total phase change between pulses

$$= 2\pi f_0 t_0 + \theta = f_0\beta + \theta. \tag{35}$$

θ has two components, α due to the excess phase, and the function of ϕ due to the phase vs frequency curvature. Observing a series of pulses, as in Fig. 2, the phase would appear to move continuously through the pulses at a rate of θ/t_0 radians per second. The rf phase is not a continuous extrapolation from previous pulses, as is obtained by modulating a cw signal, nor is it directly related to the pulse time as would be obtained by shock exciting an oscillatory circuit, nor is it random and uncorrelated as is obtained from pulsed oscillators. We choose to call them coherent pulses, though this calls for a broader definition of the term.[6]

Required Gain: The net gain in the loop must be equal to unity at the peak of the pulse. From (31) we see that the gain in excess of cw losses must be

$$\left(\frac{n^2 + \phi^2}{1 + \phi^2}\right)^{1/4}, \tag{36}$$

which for small values of γ is $\sqrt{n}$.

The Pulse Train: So far we have considered a single repetition of an initial pulse. If we maintain the above gain, the pulse will repeat itself indefinitely at intervals of t_0. The qth pulse may be represented by

$$G_q(t) = Ee^{j2\pi f_0(t-qt_0) - (4/\tau^2)(t-qt_0)^2 + jb(t-qt_0)^2 - jq\theta}. \tag{37}$$

The pulse train would be the sum of such pulses, which may be represented by:

$$G_T(t) = E \sum_{q=-\infty}^{q=+\infty} e^{j2\pi f_0(t-qt_0) - (4/\tau^2)(t-qt_0)^2 + jb(t-qt_0)^2 - q\theta}. \tag{38}$$

The Pulse Spectrum: We can get the spectrum resulting from pulse train by taking Fourier transform of (37).

First separate powers of t giving

$$G_T(t) = E \sum_{q=-\infty}^{\infty} e^{j(2\pi f_0 - j2(a-jb)qt_0)t - (a-jb)t^2 - j2\pi f_0 q t_0 - (a-jb)q^2 t_0^2 - jq\theta}. \tag{39}$$

From Campbell and Foster pair 729.1

$$F_T(f) = E\sqrt{\frac{\pi}{a - jb}} \sum_{q=-\infty}^{\infty} e^{-[\pi^2(f - f_0 - (2j(a-jb)qt_0/2\pi))^2/a-jb] - j(2\pi f_0 q t_0 + q\theta - (a-jb)q_0^2 t_0}. \tag{40}$$

where

$$\phi = \frac{\gamma}{c} \frac{2n}{(n+1)\left(1 + \sqrt{1 + \frac{4n}{(n+1)^2} \frac{\gamma^2}{c^2}}\right)}. \tag{33}$$

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[6] "American Standards Association Definitions of Electrical Terms" ASA C42 No. 65.02.060 defines coherent pulse operation as a "method of pulse operation in which the phase of the radio frequency waves is maintained through successive pulses." In this situation above there is a fixed relationship between phase in successive pulses, but not necessarily continuity of phase.

Regrouping terms

$$F_T(f) = E\sqrt{\frac{\pi}{a-jb}}\,e^{-[\pi^2 a(f-f_0)^2/a^2+b^2]-[j\pi^2 b(f-f_0)^2/a^2+b^2]}\sum_{q=-\infty}^{\infty} e^{-jq(2\pi f t_0+\theta)}. \tag{41}$$

To evaluate the summation, first take a limited length of pulse train, from $q=-Q$ to $+Q$

$$\text{Sum} = \sum_{q=-Q}^{q=+Q} e^{-jQ(2\pi f t_0+\theta)}. \tag{42}$$

We can evaluate this by applying the equation for the sum of a geometrical progression

$$\text{Sum} = a_s\frac{(r_s^{n_s}-1)}{(r_s-1)} \tag{43}$$

where

a_s is the first term
r_s the common ratio
n_s the number of terms.

Applying this to (41) and normalizing we get

$$F_N(f) = \left[KE\sqrt{\frac{\pi}{a-jb}}\,e^{-[\pi^2 a(f-f_0)^2/a^2+b^2]-j[\pi^2 b(f-f_0)^2/a^2+b^2]}\right][\chi], \tag{44}$$

where

$$\chi = \left[\lim_{q\to\infty}\frac{\left[e^{-jQ(2\pi f t_0+\theta)}\dfrac{e^{-j(2\pi f t_0+\theta)(2\pi+1)}-1}{e^{-(2\pi f t_0+\theta)}}\right]}{2Q}\right].$$

At the limit χ is unity provided

$$(2\pi f t_0+\theta) = 2N\pi, \tag{45}$$

where N is an integer. Otherwise χ is zero. Thus (43) or (40) gives us a line spectrum, the first term in the exponent giving the gaussian envelope containing the spectrum, and the second giving the relative phase of the various frequency components.

Eq. (45) tells us

$$f = \frac{N}{t_0} - \frac{\theta}{2\pi}\frac{1}{t_0}. \tag{46}$$

Thus, the frequency components are separated by intervals equal to the pulse rate, but are not harmonically related. The difference between the frequency of any component and a harmonic of the pulse rate being equal to the precession rate mentioned heretofore.

Appendix II

Stability Conditions

Stability of Pulse Length

Following the analysis used in Appendix I of this paper, but neglecting nonlinear phase effects (i.e., $\gamma=0$), we find that a pulse of length

$$\tau_q = \frac{2}{\sqrt{a}} \tag{47}$$

produces a next pulse of length

$$\tau_{q+1} = a\sqrt{\frac{1}{na}+\frac{c}{\pi^2}} \tag{48}$$

from (16) and (19).

Substituting for a and c from (26),

$$\tau_{q+1} = \sqrt{\frac{\tau_q^2}{n}+\frac{16}{\pi^2\mathfrak{F}}}, \tag{49}$$

and substituting for $\mathfrak{F}$ from (27),

$$\tau_{q+1} = \sqrt{\frac{\tau_q^2}{n}+\tau^2\left(1-\frac{1}{n}\right)}$$

or

$$(\tau_{q+1}^2-\tau^2) = \frac{1}{n}(\tau_q^2-\tau^2), \tag{50}$$

where τ is the equilibrium pulse length. From (50) it can be that if $n>1$ each succeeding pulse rapidly approaches the limiting equilibrium pulse length τ.

Stability of Pulse Frequency

Suppose we start as in (10) with a pulse of median frequency different from that of the filter, neglecting γ,

$$G_1(t) = Ee^{(p_q t-at^2)}, \tag{51}$$

giving

$$F_3 = ABE^n\sqrt{\frac{\pi}{na}}\,e^{1/(4na)(p-p_q)^2}; \tag{52}$$

combining with the filter characteristic (14), we get

$$F_4(f) = ABCE^n\sqrt{\frac{\pi}{na}}\,e^{1/(4na)(p-p_q)^2+F/(4\pi^2)(p-p_0)} \tag{53}$$

or

$$\left[\frac{1}{4na}+\frac{c}{4\pi^2}\right]\left[p-\frac{\dfrac{p_q}{4na}+\dfrac{cp_0}{4\pi^2}}{\dfrac{1}{2na}+\dfrac{c}{4\pi^2}}\right]^2. \tag{54}$$

$F_4(f) = \text{constant } xe$, which transforms to

$$-\left[\left[\frac{p_q + \dfrac{canp_0}{\pi^2}}{1 + \dfrac{can}{\pi^2}}\right] t + \frac{t^2}{\dfrac{1}{na} + \dfrac{c}{\pi^2}}\right] \qquad (55)$$

$G_4(t) = \text{constant } e$.

Thus the new pulse has an instantaneous frequency of

$$f_{q+1} = f_q \left[\frac{1 + \dfrac{can}{\pi^2}\dfrac{f_0}{f_q}}{1 + \dfrac{can}{\pi^2}}\right]. \qquad (56)$$

If the pulse has the equilibrium length given by (27), we get from (26)

$$\frac{can}{\pi^2} = (n - 1), \qquad (57)$$

giving

$$(f_{q+1} - f_0) = \frac{1}{n}(f_q - f_0), \qquad (58)$$

which says that if $n > 1$, the succeeding pulse is between the filter midband frequency and the instantaneous frequency of the preceding pulse, and in succeeding pulses will converge on the filter midband frequency.

NOMENCLATURE

A	Amplifier gain
a	A number related to pulse length $a = 4/\tau^2$
α	Phase shift component independent of frequency
B	Amplification in the expandor at unity voltage input
b	Frequency modulation term $= -\pi$ times rate of frequency rise
β	Phase shift component proportional to $(f - f_0)$
C	Attenuation in the filter
c	A number related to the bandwidth of a gaussian frequency characteristic $c = 4/\mathfrak{F}^2$
γ	Phase shift component proportional to $(f - f_0)^2$
d	Differential operator
Δ	Difference in delay in the interferometer paths
δ	A convenient parameter (16)
E	Constant multiplier = voltage at zero time
e	Base of the natural logarithms
$F(f)$	A function of frequency defining the frequency characteristic of a filter
f	Frequency
f_0	Midband frequency
$\mathfrak{F}$	Filter bandwidth at 1 neper points (−8.68 db)
$\psi(t)$	A function of time, expressing the phase character of the pulse
I	Relative current
j	$\sqrt{-1}$
θ	A phase constant equal to the rf phase precession between pulses
N	An integer
n	Indicates a nonlinear operation. Except as otherwise indicated it is a number indicating the power law of a simple expandor
p	An abbreviation for $j\omega$
q	An integer defining a particular pulse
Q	Limit of summation of q
T	Limit of integration in determining pulse power
τ	(Subscript) indicates a train of pulses
t	Time parameter, seconds
t_0	Time delay, seconds
τ	Pulse length measured at 1 neper points (−8.68 db)
$\Phi(f)$	Phase shift function of frequency
ϕ	A convenient parameter
χ	A function equal to unity when the argument equals $2N\pi$, otherwise zero (45).

Correction

W. Sichak, author of the paper, "Coaxial Line with Helical Inner Conductor," which appeared on pages 1315–1319 of the August, 1954 issue of the PROCEEDINGS OF THE I.R.E., has brought the following corrections to the attention of the editors:

1. In the second line preceding eqs. (3) and (5), change λ to read λ_0.
2. The square bracket in eq. (9) should be

$$\left[\frac{(1 - a^2/b^2)\ln(b/a)}{2}\right]^{1/2}.$$

3. The second part of eq. (9) should be

$$= 120\pi NaT\left(\frac{\epsilon_0}{\epsilon_2}\right)^{1/2} \ln(b/a).$$

Electromagnetic Wave Propagation on Helical Structures (A Review and Survey of Recent Progress)*

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Summary—**The progress which has been made in recent years in analyzing and understanding the electromagnetic properties of helical structures is reviewed here. After a brief account of work prior to about 1950, the results obtained from an analysis of the sheath helix model are summarized. The more physically realistic tape helix model and its characteristics—forbidden regions, space harmonics, etc.—are discussed. Recent extensions to the analysis of the sheath helix model including the effect of radially stratified mediums, both isotropic and anisotropic, are noted. Also, additional work using the tape or finite wire helix model is reviewed. Finally, the recent investigations of filter helixes and contrawound helixes are discussed.**

INTRODUCTION

ALTHOUGH helical structures have long been used in various ways as electromagnetic devices, their recent use in traveling-wave tubes and in antennas has stimulated a renewed interest in their properties, particularly at frequencies higher than those normally used in the past. It is the purpose of this paper to describe some of the recent progress which has been made in analyzing and understanding the electromagnetic properties of such structures.

As in the case of others configurations which can support electromagnetic waves, one desires to know the characteristics of those solutions of Maxwell's equations which match the boundary conditions prescribed by the helix or related devices.

The properties of those waves with harmonic time dependence $e^{j\omega t}$ which propagate as $e^{-j\beta z}$, with β real and z the axial co-ordinate, are of interest. In particular, it is important to know the values of β as a function of the frequency and the various electrical and physical properties of the system. These waves with exponential dependence, which also are called natural waves, free modes, or residue waves, are of great significance in traveling-wave tubes, since it is with these waves that an axial electron beam interacts, and gain results. In this paper we shall be concerned only with electromagnetic wave propagation on helical structures in the absence of an electron beam. However, as Pierce,[1] among others, has shown, a knowledge of the characteristics of these modes enables many of the properties of operating traveling-wave tubes to be calculated.

Incidentally, it appears that the free modes are also important in the radiation from a finite helix in that, as in other finite radiating structures, they transport energy between the driving source and the ends. However, considerably more analysis is required of this problem before the details of the role played by the free modes in the operation of a finite helix can be clarified.

HISTORICAL REVIEW OF PROBLEM

In order to place the recent advances in their proper perspective, some discussion of past work is necessary. Only a small number of the papers which appeared prior to about 1950 are mentioned below. For more extensive reviews the reader is referred to reports by Kline,[2] Kornhauser,[3] Roubine,[4] and Sensiper.[5]

Up to About 1940

The earliest work on the helix problem seems to have been done by Pocklington.[6] In his analysis the helix wire was assumed to be very thin and a perfect conductor. An integral equation for the free modes was derived and approximate solutions obtained which predicted a traveling wave whose axial phase velocity is near the velocity of light c (assuming the helix is immersed in free space) for low frequencies, and whose axial phase velocity is reduced to $c \sin \psi$ (where ψ is the pitch angle of the helix) for high frequencies. This latter is equivalent to a wave with a phase velocity c traveling along the wire. Although these solutions are more or less correct in view of present knowledge, the fine structure of the solutions was completely missed. Pocklington's approach is representative of what can be called the thin wire approximation.

Ollendorf[7] analyzed the so-called sheath model of the helix which replaces the helix by an anisotropic current conducting sheet and obtained solutions for the $n=0$ mode which are essentially equivalent to those obtained by more recent investigators.

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[1] J. R. Pierce, "Traveling-Wave Tubes," D. Van Nostrand Co., Inc., New York, N. Y.; 1950.

[2] M. Kline, "Theory of the Traveling-Wave Tube," Final Rept. New York Univ. Math. Res. Group; October, 1953.

[3] E. T. Kornhauser, "Electromagnetic Wave Propagation in Helical Structures," D.Sc. Thesis, Harvard Univ., June, 1949; also Cruft Lab. Tech. Rep. No. 88, August, 1949.

[4] E. Roubine, "Study of electromagnetic waves guided by helical circuits," *Ann. des Telecommun.*, vol. 7, p. 206, May, 1952; p. 262, June, 1952; p. 310, July–August, 1952.

[5] S. Sensiper, "Electromagnetic Wave Propagation on Helical Conductors," Sc.D. Thesis, Dept. of Elec. Eng., MIT, May 1951; also in abbreviated form as MIT Res. Lab. Elec. Tech. Rep. No. 194; certain portions reviewed by R. G. E. Hutter, "Traveling-Wave Tubes, Advances in Electronics," Academic Press, New York, N. Y.; vol. VI; 1954.

[6] H. C. Pocklington, "Electrical oscillations in wires," *Proc. Camb. Phil. Soc.*, vol. 9, p. 324; 1897.

[7] F. Ollendorf, "Die Grundlagen der Hochfrequenztechnik," J. Springer, Berlin, Ger., p. 79; 1926.

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may be. Since there is cylindrical symmetry, it is to be expected that waves which have exponential dependence on z exist and these correspond to waves guided by the helix. Because of the uniformity of the boundary conditions, it is also to be expected that an infinite set of modes characterized by different angular variations exists, although these modes undoubtedly do not constitute a complete set. Further, it can be anticipated, in view of the peculiar nature of the boundary conditions, that the solutions consist of a mixture of TE (traverse electric) and TM (transverse magnetic) waves.

In solving the sheath helix problem, one can consider the homogeneous or source-free case, or the inhomogeneous or source-present case. The former is simpler and yields considerable information concerning the free modes. The latter, although more difficult, can yield even more information, particularly as regards the amplitudes of the free modes, and is especially useful in determining the significance of the various higher order waves which exist on the sheath helix. In the following discussion it is possible to consider only the homogeneous problem in some detail, but a brief review of the inhomogeneous problem is also included.

The Determinantal Equation and its Solutions: Since the procedure here is quite standard, only an outline will be given. Although this is a vector problem, the components of the field may be obtained from two scalar quantities, one for the TE portion, the other for the TM part. Among the several choices possible, the z components of the electric and magnetic Hertzian potentials, π_z and π_z^*, respectively, are convenient ones. π_z and π_z^* satisfy the homogeneous scalar wave equation, and proceeding in the standard separation of variables fashion, one finds that

$$\pi_z^{i,e} = A_n^{i,e} \begin{matrix} I_n(\gamma r) \\ K_n(\gamma r) \end{matrix} e^{-j\beta z} e^{-jn\theta} \begin{matrix} r \leqq a \\ r \geqq a \end{matrix} \tag{1}$$

with

$$\gamma^2 = \beta^2 - k^2. \tag{2}$$

A similar equation results for $\pi_z^{*i,e}$, but with $B_n^{i,e}$ replacing $A_n^{i,e}$. I_n and K_n are the modified Bessel functions of order n, with n an integer, and are chosen so that the solutions behave properly in the regions $r \leqq a$ and $r \geqq a$, to which the superscripts i and e refer respectively. Determining the electric and magnetic fields with (1) and its counter part for $\pi_z^{*i,e}$, and then using these in the boundary conditions already noted for being satisfied for each n separately. Note also that solutions of (3) can only occur, except for isolated cases, for $|\beta| > k$, hence, in general, only slow waves exist on the sheath helix.

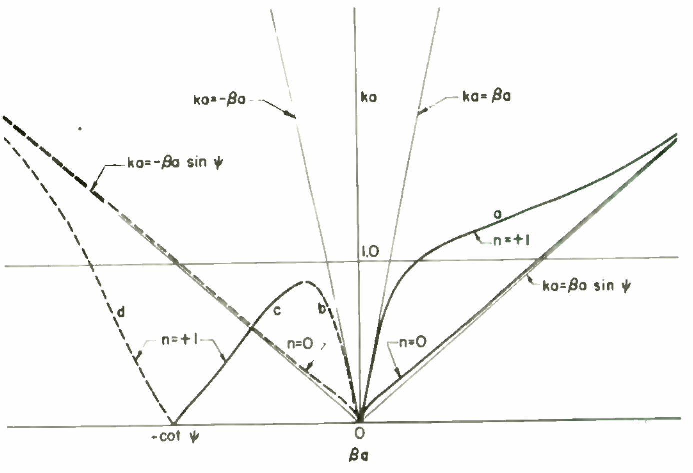


Fig. 2—Solutions of the sheath helix determinantal equation, ka vs βa for $n=0$, 1, 90 degrees $>\psi>0$ degrees (from reference 5).

In order to solve (3) for γa, and then βa as a function of ka and $\cot \psi$, a combination of analytical, numerical, and graphical means can be used. The results for $n=0$ and $n=+1$ are shown in Fig. 2, where a ka versus βa plot is shown. In such a diagram the phase velocity of the wave is given by the slope of a straight line drawn from origin to point of interest on the curve, and group velocity by the slope of the curve at that point; i.e.,

$$\frac{v_p}{c} = \frac{ka}{\beta a}, \tag{4}$$

and

$$\frac{v_g}{c} = \frac{d(ka)}{d(\beta a)}. \tag{5}$$

The results for the $n=0$ case are well known; the wave has large dispersion for very small ka, but for larger ka the dispersion becomes small and the phase velocity ratio is given quite closely by $v_p/c = \sin \psi$. For $|n| \geqq 1$ the results are considerably more complicated and may be characterized by noting that several waves per mode number n occur, and that some of these may have their phase and group velocities in opposite directions. In Fig. 2 the solutions with positive group velocity are shown as solid lines, those with negative group velocity as dotted lines. Although only the source-free case is being con-

Nicholson[8] attempted to solve the helix problem by finding a proper co-ordinate system to define the helix surface, but did not obtain useful results. His analysis is representative of what can be called the exact approach.

Among the very early experimenters, Hertz measured the velocity of propagation along a helix and, as noted by Kornhauser,[3] obtained a value which is quite accurate. Experiments were also performed later by Hofmeier, as noted by Roubine.[4]

1940 to 1950 Approximately

The results of an analysis of the $n=0$ mode of the sheath helix by Schelkunoff were given by Pierce and were reviewed in his book.[1] It is this mode which has proved so useful in normal helix traveling-wave tube amplifiers. Schulman and Heagy[9] discussed the sheath model and considered the $n=0$ mode, as well as the higher modes, those in which the field components vary in angle. Phillips and Malin[10] also analyzed the higher mode problem in some detail.

Further attempts to solve the helix problem by means of the exact approach were also reported by Bagby[11] and Sollfry.[12] However, the intractableness of Maxwell's equations in the required co-ordinate systems was great, requiring relatively drastic approximations and giving results of only limited utility.

In addition to more analytical work, more extensive measurements were being made in this period. Cutler[13] reported measurements of phase velocity which agreed quite closely with predictions obtained from the sheath model for a relatively wide range of frequencies. Cutler also noted that the impedance ($E_z^2/2\beta^2P$, as defined by Pierce[1]) was lower than that given by the sheath model, and Pierce[1] indicated how this reduction could be computed. Kraus[14] and his co-workers noted that, although for low frequencies the measured phase velocity of the only observable wave on a helix corresponded to that predicted by the sheath theory, for frequencies above the point where the helix circumference is approximately a wavelength, an anomalous change in the phase velocity occurred.

1950 to the Present

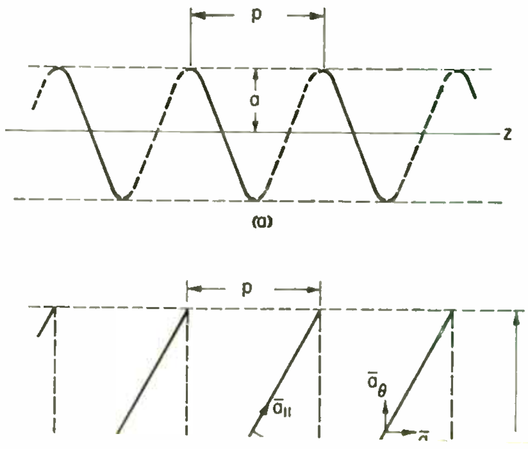
In this period an increasing number of reports have appeared. Rather than continue the historical approach, it appears more useful to describe the work of the writer and the relationship of his analyses to those of others, and then to discuss very recent work, some still unpublished, by several investigators.

THE SHEATH HELIX

Even though the properties of the sheath helix, most particularly for the lowest or $n=0$ mode, have been extensively covered elsewhere, many characteristics of this model warrant additional consideration. This is so not only because such consideration serves as an excellent introduction to the more exact representation now available, but also because at least one of the higher mode solutions has become important in connection with the backward-wave oscillator.

Boundary Conditions; The Determinantal Equation and its Solutions; The Inhomogeneous Problem

Boundary Conditions: Consider a helix wound of a perfect conducting wire, as shown in Fig. 1(a), with the axis of the helix along the z axis of the circular cylindrical co-ordinate system. A developed view is shown in Fig. 1(b), where the unit vectors $\bar{a}_\theta$ and $\bar{a}_z$ are drawn with $\bar{a}_\parallel$ and $\bar{a}_\perp$ defined in an obvious fashion. It will be assumed that the helix is immersed in free space, although if other surroundings are considered, for example a cylindrical dielectric tube enclosing the helix, the method used to obtain solutions can be the same. The simplest case will be considered here to avoid unnecessary complications. In addition to p, a, $\psi=\cot^{-1}(2\pi a/p)$ the pitch, radius, and pitch angle of the helix, respectively, $k=2\pi/\lambda$ with λ the free space wavelength will be used. Harmonic time dependence like $e^{j\omega t}$ should be understood.



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sidered, the results are best understood by assuming a source located at $z=0$, with the sheath helix extending to infinity in both directions along the z axis. Then for z large so that any modified radiation field can be considered small, for $n=0$ a single wave occurs for $+z$ and another for $-z$, both having their phase and group velocities directed away from the source. However, for $n=+1$, again for large z and depending on the value of ka, one or two waves occur for $+z$ corresponding to branches a and c, and one or two waves occur for $-z$ corresponding to branches b and d. Branch c is particularly noteworthy, since its phase and group velocities are oppositely directed. Its characteristics are quite similar to that space harmonic field component of the single wire helix and to the dominant field component of the bifilar helix operating in the push-pull mode which are useful in helix-type backward-wave oscillators. (See below.) Solutions of (3) for $n=-1$ may be obtained from those for $n=+1$ by rotation about ka axis, with solid lines becoming dotted and vice versa. This type of symmetry between solutions for positive and negative values of n is generally true.

For $n\geqq 2$, the solutions of (3) look similar to those for $n=1$, but with some modifications. Among these are that the c and d branches coincide at $\beta a=-n\cot\psi$ for $ka=0$, and that the a and b branches do not occur below some minimum value of ka, which depends on n and $\cot\psi$. Still other alterations occur such as the splitting of branch a into additional branches for quite small values of ψ (this also occurs for $n=1$), and the disappearance of branch b for $n\geqq 3$, if ψ is larger than some minimum value. Characteristics of higher order modes of the sheath helix are discussed in detail elsewhere.[5]

The Inhomogeneous Problem: Instead of neglecting the source, one can assume some generator, for example a gap source located at $z=0$ with $e^{-jn\theta}$ variation, and by means of the usual Fourier integral methods obtain integral representations for the vector potential and the field components. In this case, one obtains, for example,

$$\pi_z{}^{i,e} = e^{-jn\theta}\int_C A_n{}^{i,e} \begin{matrix} I_n(\gamma r) \\ K_n(\gamma r) \end{matrix} e^{-j\beta z}d\beta \quad \begin{matrix} r \leqq a \\ r \geqq a, \end{matrix} \tag{6}$$

where C is a contour along the real axis properly indented about poles and branch points, β is now a general complex variable, and $A_n{}^{i,e}$ is determined from the boundary conditions and the source. It is found that the poles of the integrand in (6), the zeros of the denominator of $A_n{}^{i,e}$, correspond to the particular solutions of (3). The amplitudes of the free modes, natural waves, or residue waves are easily calculated by the well known procedures of residue calculus. The remaining portion of the integral becomes a branch cut integration and corresponds to the modified radiation field of the source. Deformation of the contour of integration, which is performed differently depending on whether $z>0$ or $z<0$ is considered, enables one to determine which of the free modes occurs in the different regions. It is this procedure which is the basis for the comments made previously.[5]

Special Cases; Power Flow and Impedance

Special Cases, $\psi=0$ Degrees and $\psi=90$ Degrees: With $\psi=0$ degrees, the sheath helix becomes what has been called the sheath ring.[6] No solutions for $n=0$ exist for $\psi=0$ degrees. The solutions for $n=1$ can be deduced from Fig. 2, since branch d disappears leaving only branches b and c for $\beta a<0$. For $\beta a>0$ another branch comes in to join a, so that the plot is symmetrical about the ka axis. For $n\geqq 2$ the ka-βa plot has a similar appearance, except that the nth mode solutions exist only over the narrow range $|n|+\Delta_n\geqq ka>\sqrt{n^2-1}$, with Δ_n a small positive number which decreases for increasing n. From symmetry it is clear that the solutions for negative and positive n are identical.

With $\psi=90$ degrees the sheath helix becomes the sheath tube. In this case the solutions become TEM waves with $|\beta|=k$, $|v_p/c|=1$, and the modes correspond to the various symmetrical component waves or modes which can exist on a multiwire "cage" transmission line as the number of wires becomes infinitely large. Here also no $n=0$ mode exists in the sense that no finite source can excite such a mode.

It is possible to follow the mode solutions for the sheath system as ψ goes from 0 to 90 degrees and, indeed, a knowledge of the solutions at these end points facilitates obtaining the solutions for all ψ. It is worthwhile noting that ordinary wave-guide-type modes can exist in the interior of a sheath system for $\psi=0$ degrees, or $\psi=90$ degrees, the TE_{om} type for the former, the TM_{nm} for the latter. For these $|\beta|<k$, $|v_p/c|>1$, and the solutions are fast waves. However, for $\psi\neq 0$ degrees, or 90 degrees, no such waves are possible, and it can be concluded that these modes are not stable in a sheath system.

Power Flow and Impedance: Using the field components deduced from (1) and a similar one for $\pi_z{}^{*i,e}$, and proceeding in the usual way, one obtains the average power flow P in the z direction. With this the impedance $E_z^2/2\beta^2P$ and other impedances, which may be useful for matching purposes, are obtained. For the $n=0$ mode Pierce[1] gives quite complete results, and results for the higher modes are also available.[5]

THE TAPE HELIX

Although the sheath helix model yields much valuable information, the limitations resulting from the omission of the periodic character of the helix, as well as the finite wire size, are serious. These limitations can be overcome by using a model of the helix called the tape helix.[5] From this, the role played by space harmonics and the so-called forbidden regions of propagation constant, as well as other significant points, appear quite naturally.

Definitions; Potential and Field Expressions; Boundary Conditions and the Determinantal Equation

Definitions: The tape helix is a helix wound of a wire which is assumed to be a perfect conductor with very small (actually it is taken to be zero) radial extension but finite axial extension. Such a helix is shown in Fig. 3(a) and a developed view is shown in Fig. 3(b). p, a, and ψ are defined as before, and δ and δ' are the tape and gap width, as shown. The helix is again assumed to be immersed in free space, although the method of analysis would be much the same for simple cylindrical surroundings, and one might even account for a finite radial extent of the tape. However, the simplest case will be considered here to avoid unnecessary complications. Also, the helix, whose axis is taken to coincide with the z axis, is assumed to be infinite in extent, and the homogeneous or source-free problem is considered.

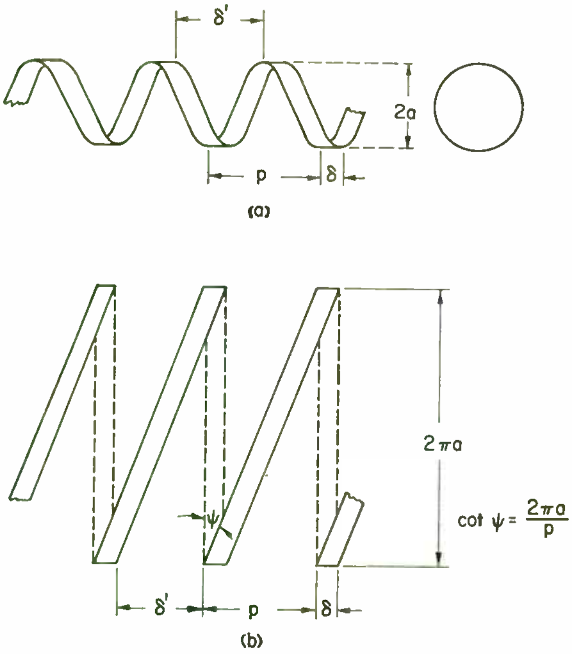

Fig. 3—(a) Tape helix; (b) Developed tape helix.

Potential and Field Expressions: Since the helix is a periodic structure, the fields are multiplied only by some complex constant if one moves down the helix a distance p. This is clear since, if the helix is displaced along the z axis by a distance p, it coincides with itself, and the new fields can differ from the previous ones only by a constant factor. It is evident that a simple form of z dependence, which satisfies this requirement, is

$$e^{-j\beta_0 z}e^{-jm(2\pi/p)z} = e^{-j\beta_m z}, \tag{7}$$

where

$$\beta_m = \beta_0 + m\frac{2\pi}{p}, \tag{8}$$

and m can have any integer value. Since π_z and π_z^* must satisfy the scalar wave equation, it is found that the angular dependence of the solutions is given by $e^{jn\theta}$, and the radial dependence is given by the modified Bessel functions. In addition to the periodicity in z noted above, it is obvious that if the helix is translated along its axis some distance less than p, it may be rotated so that it again coincides with itself. The consequence of this invariance to the differential screw transformation is that $n = m$ only. As a result, the electric Hertzian potential becomes

$$\pi_z{}^{i,e} = e^{-j\beta_0 z}\sum_m A_m{}^{i,e} \begin{matrix} I_m\left(\eta_m \dfrac{r}{a}\right) \\ \\ K_m\left(\eta_m \dfrac{r}{a}\right) \end{matrix} e^{-jm((2\pi/p)z-\theta)} \qquad \begin{matrix} r \leqq a \\ \\ r \geqq a \end{matrix} \tag{9}$$

with a similar expression for $\pi_z{}^{*i,e}$. In (9)

$$\eta_m{}^2 = (\beta_m{}^2 - k^2)a^2. \tag{10}$$

The representations for the surface current density components at $r = a$ must have the same form as the field components, so that

$$K_{\theta,z} = e^{-j\beta_0 z}\sum_m \kappa_{\theta,z_m} e^{-jm((2\pi/p)z-\theta)}, \tag{11}$$

where κ_{θ,z_m} are the Fourier coefficients of the current density expansions. Using (9) and its counterpart for $\pi_z{}^{*i,e}$ to determine the field components, and then using the continuity conditions which the field components must satisfy, one can express the field components in terms of sums involving κ_{θ,z_m}. These continuity conditions are, of course, that, at $r = a$, the tangential electric field is continuous, and the discontinuity in the tangential magnetic field is proportional to the total surface current density.

Boundary Conditions and the Determinantal Equation: Further boundary conditions must be applied to obtain the required determinantal equation. These are that the tangential electric field on the tape be zero and that the magnetic field be continuous through the gap, this latter requirement being equivalent to the requirement that current exist only on the tape. By means of a re-expansion procedure commonly used in multi-region boundary value problems, it is possible to apply these conditions, and to obtain doubly infinite sets of homogeneous simultaneous equations from which one can at least formally obtain the determinantal equation. It is also possible, by a procedure which is equivalent to minimizing the complex power flow out of the cylindrical surface $r = a$, to obtain the same formal determinantal equation. Both these procedures were illustrated by the writer,[5] although errors were made in applying the magnetic field condition in the gap and in the minimization process. These errors have since been corrected by Chodorow and Chu,[15] and the advantages of the minimization procedure noted. More is said of this later.

A very useful approximate boundary condition matching-procedure, which is also quite common, can be used and gives reliable results. Specifically, the current is assumed to flow on the tape and only in the direction of

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[15] M. Chodorow and E. L. Chu, "The Propagation Properties of Cross-Wound Twin Helices Suitable for Traveling-Wave Tubes," paper presented at the Electron Tube Res. Conf., Stanford Univ.; June, 1953 (to be published).

the tape, that is along $a_\parallel$ in Fig. 1(b), and the electric field $E_\parallel$ at $r=a$ on the center of the tape is required to be zero. Conversely, the electric field in the gap at $r=a$ is assumed to consist only of a component perpendicular to the tape edges, and the surface current density $K_\perp$ at $r=a$ in the center of the gap is required to be zero. It can be expected that the first approximation is good for narrow tapes, δ/p small, whereas the second approximation is good for narrow gaps, δ'/p small. If one carries through this procedure for the narrow tape, the following approximate determinantal equation results:

$$0 \approx \sum_m \left\{\left(\beta_0^2a^2 - k^2a^2 + k^2a^2\frac{m^2\cot^2\psi}{\eta_m^2}\right) I_m(\eta_m)K_m(\eta_m) + k^2a^2\cot^2\psi\, I_m'(\eta_m)K_m'(\eta_m)\right\} D_m. \quad (12)$$

In (12) D_m is equal to $(\sin u_m\delta)/u_m\delta$ or $J_0(u_m\delta)$, depending on whether the magnitude of the current density on the tape (or the electric field in the gap) is assumed to be constant, or whether a more realistic inverse square root distribution is taken. u_m depends on the assumption made regarding the phase distribution of the tape current (or gap field). For the narrow gap case (12) is modified only in that the mth term is multiplied by $1/\eta_m^2 I_m(\eta_m)K_m(\eta_m)I_m'(\eta_m)K_m'(\eta_m)$ and δ' replaces δ in D_m. For $\delta=\delta'$, where both are small, the modification alters the solution to (12) only for small values of ka and not too significantly even there.

The Forbidden Regions; Solution of the Determinantal Equation

The Forbidden Regions: If β_0 is real, then η_m must be real and positive, since, otherwise, terms would occur in the field expressions corresponding to infinitely long (in the z direction) line type sources. Such sources, of course, are not present and, in fact, the problem here is the homogeneous or source-free case. The requirement that η_m be real and positive leads to the existence of forbidden regions in the β_0, k diagram, in which free mode solutions are not allowed. This restriction is quite analogous to the one in the sheath helix case, as in other open homogeneous boundary systems, where only $|\beta|>k$ is permitted. In the actual helix case only $|\beta_m|>k$ is permitted or, put another way, the phase velocity of all the space harmonic waves must be less than the velocity of light. In addition to the forbidden region restriction when β_0 is real, it is possible to show, although not rigorously yet since (12) must be used, that no free mode solutions exist for complex or pure imaginary β_0. Incidentally, this last point can be proved rigorously for the sheath helix case.

It should be emphasized that the forbidden region restriction is not dependent on any approximations and would apply to an exact solution if it were available. Further, the restriction also applies to other types of helical structures and actually to other open periodic structures. It should be noted too, that the restriction is not the same as in many other problems concerning periodic structures, where, although wave propagation does not occur within restricted frequency bands, exponentially damped solutions which satisfy the boundary conditions do exist in such bands.

Solution of the Determinantal Equation: In order to solve (12) for β_0, with given values of ka, $\cot\psi$, and δ, a combination of analytical, numerical, and graphical procedures is used. The use of some excellent algebraic approximations for the modified Bessel function products, and of some simple procedures for improving convergence, enables one to put (12) in a form such that solutions may be readily obtained for a wide range of parameters. Fig. 4(a) (opposite) shows solutions for the particular case $\psi=10$ degrees and $\delta/p=0.1$ for $\beta_0a>0$. Note that different branches a, b, c, d, and e corresponding to different modes occur; some are shown as solid lines, whereas others are dotted. As before, the solid lines correspond to waves with positive group velocity, whereas the dotted lines correspond to waves with negative group velocity. Fig. 4(b) shows the entire β_0, k plane. Note that, for some values of ka, several waves can exist. The interpretation is the same as in the sheath helix case; that is, if the helix is excited by a source at $z=0$, then for $z>0$ those waves with positive group velocity can exist, whereas for $z<0$ those waves with negative group velocity can occur. For smaller values of ψ, the solutions would appear much the same except that more branches occur.

Fig. 5 (opposite) shows a $|v_p/c|$ versus $ka/\cot\psi$ plot. Note that, except for the occurrence of branch d as well as branches b and c, particularly for small values of ka, and the effect of the forbidden regions in eliminating solutions for some values of ka, the $|v_p/c|$ versus $ka/\cot\psi$ plot is not too different from one obtained from the $n=0$ mode sheath helix. This explains the past success of the sheath model for relatively small values of ka. The characteristics of branch c also explain the anomalous results noted by Kraus[14] and others. As noted by the writer,[5] the significance of branches b and c in Figs. 4 and 5 may be understood by noting that they appear to be perturbed uniform plane waves that are essentially circularly polarized.

Space Harmonics; Power Flow

Space Harmonics: Contrary to the sheath helix case where, although there can be several waves per mode number n, the n modes are independent. in the tape helix case, not only can several modes exist simultaneously, but also each mode must contain the entire m set of space harmonics in order to match the boundary conditions. It is evident from (8) that the phase and group velocity ratios of the mth harmonic wave component are given by

$$\frac{v_{pm}}{c} = \frac{ka}{\beta_m a} = \frac{ka/\cot\psi}{m + \beta_0 a/\cot\psi} \quad (13)$$

and

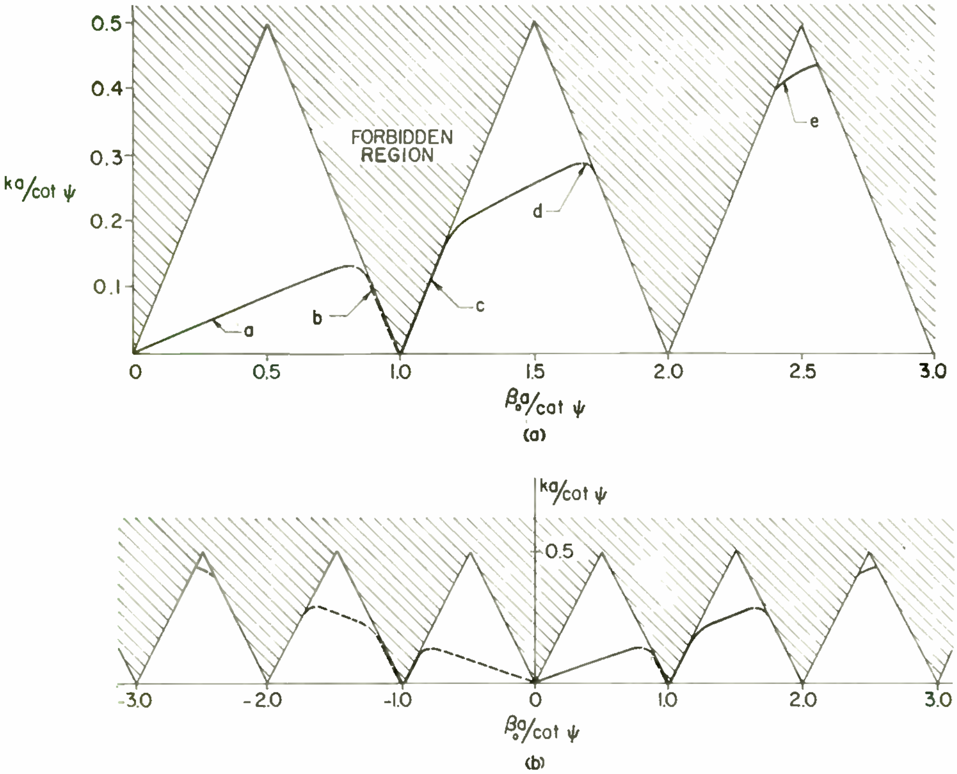

Fig. 4 (a) and (b)—Solutions of the tape helix determinantal equation, $ka/\cot\psi$ vs $\beta_0 a/\cot\psi$ for $\psi=10$ degrees, $\pi\delta/p=0.1$ (from reference 5).

$$\frac{v_{gm}}{c} = \frac{v_{g0}}{c} = \frac{d(\beta_0 a)}{d(ka)} \cdot \tag{14}$$

Quite clearly the group velocities of the space harmonics of a given wave are identical, since they are all associated with the same wave. From (13), by an obvious construction that consists of shifting the origin m units along the $\beta_0 a/\cot\psi$ abscissa, one can obtain the phase velocity of the $-m$th space harmonic. Thus, for example, although the 0, 1, 2, $\cdots$ etc., space harmonic components of the *a* branch or mode in Fig. 4(a) have positive phase velocities, the -1, -2, $\cdots$ etc., space harmonic components have negative phase velocities.

Since the phase and group velocities of the -1 space harmonic component are in opposite directions, the helix is a useful structure in backward-wave oscillators of the type described by Kompfner and Williams.[16] However, this characteristic can also be disadvantageous in helix-type traveling-wave tube amplifiers, unless some effort is made to avoid or suppress oscillations resulting from backward-wave interaction. Since developments using the velocity characteristics of the higher-order space-harmonic components of the helix are relatively new, further comment is reserved till later.

Power Flow: From the field expressions, the average axial power flow can be readily computed in the usual way. The power flow of the separate waves or modes can be calculated separately, and by virtue of θ orthogonality, the total power flow in each mode is the sum of the power flow in each space harmonic component comprising the mode. It is found that a considerable fraction of the total power is carried by the space harmonic components. Thus, it is evident that the impedance quantity $E_{zm}^2/2\beta_m^2 P_t$ (where E_{zm} is the axial electric field of a particular space harmonic with which an electron beam interacts, β_m is the phase constant given by (8), and P_t is the total average axial power) is usually reduced from the same quantity obtained from the sheath model. Put another way, although the space harmonics carry power, they do not correspond to a use-

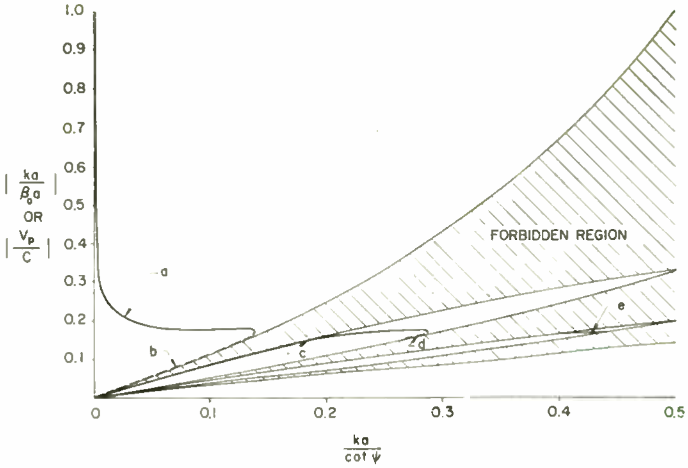

Fig. 5—Phase velocity-frequency characteristics for the tape helix, $|ka/\beta_0 a|$ or $|v_p/c|$ vs $ka/\cot\psi$ for $\psi=10$ degrees, $\pi\delta/p=0.1$ (from reference 5).

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[16] R. Kompfner and N. T. Williams, "Backward-Wave Tubes," Proc. I.R.E., vol. 41, pp. 1603–1611; November, 1953.

ful field with which the electron beam can interact, because the electron velocity is generally in near synchronism with only one of the space harmonic components. Using the narrow tape or narrow gap approximation, one can express the total power flow in terms of the assumed current density on the tape or the field in the gap. The writer has demonstrated that E_z at $r=0$ for the single tape helix, in general, is reduced considerably from that computed from the sheath helix model on the assumption of identical axial power flow.[5] Further work concerning this item is mentioned later. With the average power flow available, it is also possible to compute the attenuation constant, by using the usual small loss approximation.

Multifilar Helixes; The Tape Ring System

Multifilar Helixes: The theory developed above is quite successful in explaining the performance of a multifilar or multiwire helix, as well as of the single wire helix. A multifilar helix is one which results when several single helixes, each with the same pitch and radius, are equally spaced in the axial direction. The question arises here as to how to specify the phase relationships between the currents flowing in the different wires. From the theory of symmetrical components, it is evidently convenient and sufficient to consider that the phases of equal amplitude currents in the wires or tapes differ by $t[n(2\pi/N)]$ at any cross section of constant z. In this, n is essentially the sequence number which can be positive or negative and is fixed for any particular mode, t refers to a particular tape and runs from 0 to $N-1$, and N is the number of conductors. The requirement that $E_{\parallel}=0$ at the center of each tape leads to a determinantal equation identical to (12), except that the summation is not taken over all m but rather for $m=-n+qN$, where q takes on all integer values. The roots of the determinantal equation can be found as before. It is now evident that many of the space harmonic components will be missing for a particular n in an ideal multifilar helix. It should also be noted that the sequence number n here corresponds to the mode number n in the sheath helix, and as N becomes infinite, the determinantal equation and the field expressions for the multifilar helix go over into those for the sheath helix.

The multifilar helix also has a modified forbidden region plot which can be most easily described by referring to Figs. 4 and 5. For the multifilar helix the abscissa points $\cdots -1,\ 0,\ 1, \cdots$ etc., must be relabeled $\cdots -N,\ 0,\ N, \cdots$ etc., and the ordinate point 0.5 must be relabeled $N/2$. Similarly in Fig. 5, if the abscissa point 0.5 is relabeled $N/2$, the same diagram, excluding the single wire helix solution, of course, is correct for the multifilar helix.

The solutions for the multifilar helix are also modified. For example, with reference to Fig. 4(a), for $n=0$ and $N=2$, the solution corresponding to branch b disappears, as does the portion of the c branch along the forbidden region boundary (this always occurs for $n=0$ with $N \geqq 2$), the a and remaining portion of the c branch then joining through the now vanished forbidden region. The e branch is modified to the extent of occurring over a wider range of $ka/\cot\psi$. For $|n| \geqq 1$, with $N \geqq 2$, of course, the roots of the determinantal equation for the multifilar helix bear a close resemblance to those obtained for the sheath helix, except for the modifications required by the forbidden regions.

The Tape Ring System: The sheath helix system for $\psi=0$ degrees becomes what has been called here, the sheath ring. For a physical helix, the smallest pitch angle is limited by the tape width or wire diameter, but a relatively realistic configuration can be considered which is related to the sheath ring. This consists of an infinite series of circular rings of radius a, coaxial with the z axis, and spaced uniformly a distance p apart. The tapes are taken to have an axial width δ with their edges separated by δ', so that $\delta+\delta'=p$, and to have infinitesimal radial thickness. In the tape ring system, by virtue of symmetry, it is possible to have independent modes characterized by θ variation of the form $e^{in\theta}$. Using either the narrow tape or narrow gap approximation, one can readily derive a determinantal equation whose solution yields the propagation constant.[5] No detailed investigation of the determinantal equation for the tape ring has been made so far. However, it is clear that its solutions are similar to those of the sheath ring, except for the modifications and restrictions introduced by the forbidden regions which, of course, occur here also.

THE INTEGRAL EQUATION APPROACH

Although the approach to the solution of the helix problem by means of the tape helix model is quite convenient in that the presence of space harmonics, forbidden regions, etc., occurs quite naturally, it is also possible to derive a determinantal equation that the free mode solutions must satisfy by means of an integral equation approach closely related to the original work of Pocklington.[6] In addition, the solution of the inhomogeneous or source-present problem is readily carried through by this approach.

The Source-Free Problem

If a constant amplitude current of the form e^{-ihs} is assumed to flow along a helical line, where s is the distance measured along the line and h is assumed real, it is possible to write an integral which defines an electric Hertzian potential only from which the electric and magnetic field components at all points can be found. h is simply related to β_0, the axial phase constant. The integral can be evaluated, and it turns out, as it should, that the resulting fields are identical to those resulting when the tape helix width δ is allowed to approach zero while the total tape current remains finite.[5] If, now, the electric field, parallel to the current carrying line but displaced from it by the wire radius, is required to be zero, a determinantal equation results whose solutions are essentially identical to those of (12), given here for the narrow tape helix. In fact, it can be shown, as might be anticipated, that the only significant difference is a difference in the cross-sectional dimensions of the conductor.[5]

The procedure described above is that used by Kogan,[17] whose work preceded by a short time that reported by the writer. Phillips[18] and Sollfrey[12] also evaluated the fields resulting from a current carrying-line helix via integral expressions for the potential. However, the former did not apply the boundary conditions to a displaced surface, whereas the latter did not attempt to apply the boundary conditions to obtain a determinantal equation. The work of Roubine[4] appears to be related to Sollfrey's in this regard.

The Source-Present Problem

If, now, the transverse dimensions of the helix are sufficiently small so that it can be considered a one-dimensional conductor, the current can be written as

$$I(s) = \int_{-\infty}^{\infty} I(h) e^{-jhs} dh, \qquad (15)$$

with s as before and h now a general complex variable. Similarly a Fourier integral can be written for $E_\parallel$ at $r=a$, which is zero everywhere but over a short section of the helix, say near $z=0$. Then, equating a relatively well known expression for the electric field at the surface of a wire conductor in terms of the current to the Fourier integral for $E_\parallel$, previously noted, one can solve for $I(h)$ in terms of the known helix parameters. As in the sheath helix, the poles of $I(h)$ correspond to the free modes, and the remaining branch cut integrations correspond to the modified local and radiation fields of the source. A more complete account is given elsewhere;[5] it should be acknowledged that Kogan[19] also considered this problem and in an essentially identical fashion.

RECENT PROGRESS

Since about 1950 an increasing number of both theoretical and experimental investigations concerning the helix and related structures have been reported. The remainder of this paper is concerned with a review of some of this work.

Sheath Helix

Simple Boundary Restrictions: In technologically useful devices it is usually necessary to immerse the helix in media other than free space. Only the propagation characteristics of structures with no electron beam present are, of course, still being considered. The case of a sheath helix, surrounded by a dielectric medium, has been considered by Harris and others,[20] Jones,[21] and more recently by Muller,[22] and the effect on phase velocity and impedance determined. The case where a metallic outer shield surrounds the sheath helix has been considered by Lund,[23] Mathers and Kino,[24] Sichak,[25] as well as others. Bryant[26] discussed the various cases of a sheath helix in the presence of additional inner and outer coaxial conductors. Using the concept of radial transmission lines, Birdsall[27] has shown how the determinantal equation for relatively complicated, radially stratified structures, involving a sheath helix, can be easily derived; further, he defined and gave tables of special functions, so that the propagation characteristics can be readily computed and showed several examples. Tonning[28] has considered the case of a sheath helix surrounded by a concentric cylinder that has a finite resistance. On the other hand, Webber[29] shows results for a sheath helix, with a coincident finite resistance surface, surrounded by a perfectly conducting coaxial shield. Bryant and White[30] have computed the transmission loss and power-handling capabilities of a helix with or without an outer coaxial uniformly-conducting shield.

The use of a short length of helix, wound in the opposite direction to that of the main helix and surrounding it, was suggested by Kompfner[31] as a means for simply coupling to the main helix. This arrangement has recently been used with success, both as a means for coupling and to obtain attenuation, by Stark[32] and Owens.[33] Wade[34] has analyzed the coupled helix configuration based on two approaches; one uses field theory with sheath helixes, the other uses equivalent coupled transmission lines in a manner previously suggested by Pierce.[1] Lacy[35] and Lichtenberg[36] have also

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[17] S. Kh. Kogan, "The propagation of waves along an endless helix," *Compt. Rend. Acad. Sci.* (*URSS*), vol. 66, p. 867; June, 1949.

[18] R. S. Phillips, "The Electromagnetic Field Produced by a Helix," Rep. TW-11, New York Univ. Math. Res. Group, June, 1949; *Quart. Appl. Math.*, vol. 8, p. 229; October, 1950.

[19] S. Kh. Kogan, "The excitation of a helical conductor," *Compt. Rend. Acad. Sci.* (*URSS*), vol. 74, p. 489; September, 1950.

[20] L. A. Harris, H. R. Johnson, A. Karp, and L. D. Smullin, "Some Measurements of Phase Velocity along a Helix with Dielectric Supports," Tech. Rep. No. 93, Res. Lab. Elec., MIT; January, 1949.

[21] E. M. T. Jones, "A Negative Dispersion Helix Structure," Stanford Univ. Elec. Res. Lab. Tech. Rep. No. 27; August, 1950.

[22] M. Muller, "Dielectric in the field of helical lines," *Die Telefunkenrohre*, no. 4; 1953.

[23] C. O. Lund, "Broadband transition from coaxial line to helix," *RCA Rev.*, vol. 11, p. 133; March, 1950.

[24] G. W. C. Mathers and G. S. Kino, "Some Properties of a Sheath Helix with a Center Conductor or External Shield," Stanford Univ., Elec. Res. Lab. Tech. Rep. No. 65; June, 1953.

[25] W. Sichak, "Coaxial line with helical inner conductor," PROC. I.R.E., vol. 42, pp. 1315–1319; August, 1954.

[26] J. H. Bryant, "Some wave properties of helical conductors," *Elec. Comm.*, vol. 31, p. 50; March, 1954.

[27] C. K. Birdsall, "A Simple Method for Obtaining Phase Velocity, Attenuation, and Impedance of a Sheath Helix in Arbitrary Surroundings," paper presented at Electron Tube Res. Conf., Stanford Univ.; June, 1953 (to be published).

[28] A. Tonning, "Propagation of an Electromagnetic Wave Along a Helix Surrounded by a Resistance Sheath," Technical Rep. No. 232, Res. Lab. Elec., MIT; May, 1952.

[29] S. E. Webber, "Calculations of wave propagation on a helix in the attenuation region," TRANS. I.R.E., vol. ED-1, pp. 35–39; August, 1954.

[30] J. H. Bryant and E. J. White, "Attenuation and power-handling capability of helical radio-frequency line," TRANS. I.R.E., vol. *MTT-1*, pp. 33–38; November, 1953.

[31] R. Kompfner, "Some Theory and Experiments on Coupled Helices," paper presented at Electron Tube Res. Conf., Stanford Univ.; June, 1953.

[32] L. Stark, "A Helical-Line Phase Shifter for Ultra-High Frequencies," Tech. Rep. No. 59, Lincoln Lab., MIT; February, 1954.

[33] O. G. Owens, "Coupled Helix Attenuators for Traveling-Wave Tubes," Stanford Univ., Elec. Res. Lab. Tech. Rep. No. 68; August, 1953.

[34] G. Wade, "Study of Microwave Noise in Beam-Type Devices," Stanford Univ., Elec. Res. Lab. Tech. Rep. No. 75; April, 1954.

[35] P. O. Lacy, "Applications of Coupled Helices," paper presented at I.R.E. West Coast Convention, San Francisco, Calif., August, 1953.

[36] A. J. Lichtenberg, "Helical Coupling Systems," S.M. Thesis, Dept. Elec. Eng., MIT; June, 1954 (unpublished).

examined the coupled helix problem. All of the above investigators have considered the $n=0$ mode exclusively in their theoretical work.

Nonreciprocal Media: The use of deliberately introduced loss that is reciprocal is quite common, even essential, in simple helix-type traveling-wave tube structures. This loss is required in order to avoid regeneration or oscillation resulting from reflections at the helix terminals, as well as to damp oscillations caused by backward-wave interaction. Unfortunately, such loss reduces gain and efficiency, does not always eliminate backward-wave oscillations, and can result in large fluctuations in the gain-frequency characteristic.[37]

It has been shown very recently that, by combining gyromagnetic media with a helix, it is possible to obtain very high loss in the backward direction and very little loss in the forward direction. Suhl and Walker[38] have given a quite complete theoretical treatment of the plane sheath helix (see Pierce[1] for a description of this model), where the ferrite media is restricted to one side of the sheath and is magnetized in what is equivalent to the circumferential direction. They also show results which are not so comprehensive for the case of a cylindrical sheath helix operating in the $n=0$ mode, surrounded by a circumferentially magnetized ferrite cylinder.[38] Cook, Kompfner, and Suhl,[37] experimentally, have demonstrated the use of circumferentially magnetized ferrite material surrounding a helix so as to obtain the desirable nonreciprocal loss. Further, they have shown that, if the ferrite is formed into a helix, the magnetic field normally used for beam-focusing produces a circumferentially directed component of magnetization in the ferrite, so that no auxiliary field-producing apparatus is required.[37]

Webber and Rich[39] have described experiments in which tubes of ferrite material surrounding a helix were magnetized in the longitudinal or axial direction. Although it might be anticipated that the nonreciprocal effect would not be large in this case, substantial differential losses were noted. No theoretical treatment of this arrangement so far has been reported.

Tape or Wire Helix

General Investigations: Although the mode structure of the unshielded tape helix was quite thoroughly investigated,[5] some questions remained concerning the modes and the relationship between the unshielded and shielded helix. These were answered to some degree by the work of Stark,[40] who analyzed the case of a helix surrounded by a concentric perfectly conducting shield by the use of methods similar to those used by the writer. However, he used the condition of no complex power flow into the helix surface in a more satisfactory manner to obtain the required determinantal equation. Stark showed that, in the case of the shielded helix, branch a in Fig. 4(a) is altered only in that its low frequency dispersion is markedly reduced. Also, he showed that mixed TE-TM modes occur as well as predominantly TE modes, which are essentially perturbations of the higher-order modes in a uniform coaxial line, and predominantly TM modes, which are essentially perturbations of the waveguide modes of the outer shield. For example, it appears from Stark's results that, branches b and c in Fig. 4(a) are the limiting results of the forward- and backward-wave coaxial TE_{11} mode, as the outer shield radius becomes infinite. Also, the forbidden regions become exceptional regions in which the mixed and perturbed higher-order coaxial and waveguide modes occur.

Using the general approach of coupled modes (Pierce[41]), Pierce and Tien[42] have shown how the complicated propagation characteristics of helixes can be quite simply explained and understood. By considering the coupling between the space harmonics of the basic helix mode (one which travels with the velocity of light along the helix wires and consequently with reduced axial velocity) with circularly polarized plane waves, they showed that the propagation characteristics of the unshielded helix, for relatively small values of ka, are easily deduced. By analyzing the coupling between the basic helix mode and the higher-order modes in a uniform coaxial line, they derived the mode structure for the shielded helix structure; and, then, by idealizing the unshielded helix as one in which the shield becomes infinitely large in diameter, they showed that the propagation characteristics for the open helix in the remaining range of ka are revealed. Pierce and Tien[42] also demonstrated how the coupled mode approach is useful in obtaining the properties of a bifilar helix, and recommended this method in other cases where a direct mathematical attack is too complicated.

Using a method closely allied to the one already described here in some detail, Vakin[43] has computed the propagation characteristics of, what has been called here, the narrow gap helix. He obtained results substantially similar to those described above, but he evidently did not consider the various details. Fowler[44] derived equivalent circuit parameters for both the single

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[37] J. S. Cook, R. Kompfner, and H. Suhl, "Nonreciprocal loss in traveling-wave tubes using ferrite attenuators," Proc. I.R.E., vol. 42, pp. 1188–1189; July, 1954.

[38] H. Suhl and L. R. Walker, "Topics in guided wave propagation through gyromagnetic media, part II—transverse magnetization and the non-reciprocal helix," *Bell Sys. Tech. Jour.*, vol. 33, p. 939; July, 1954.

[39] S. E. Webber and J. A. Rich, "Ferrite Attenuators in Helices," private communication from the authors.

[40] L. Stark, "The Lower Modes of a Concentric Line Having a Helical Inner Conductor," Tech. Rep. No. 26, Lincoln Lab., MIT; July, 1953; also *Jour. Appl. Phys.*, vol. 25, p. 1155; September, 1954.

[41] J. R. Pierce, "Coupling of modes of propagation," *Jour. Appl. Phys.*, vol. 25, p. 179; February, 1954.

[42] J. R. Pierce and P. K. Tien, "Coupling of modes in helixes," Proc. I.R.E., vol. 42, pp. 1389–1396; September, 1954.

[43] S. A. Vakin, "Propagation of electromagnetic waves along an infinite helical aperture," *Compt. Rend. Acad. Sci. (URSS)*, vol. 84, p. 37; 1952.

[44] V. J. Fowler, "Helical Electrodes for Transmission Line Tubes—Analysis of Helical Transmission Lines by Means of the Complete Circuit Equations," Tech. Rep. No. 1-1, Electron Tube Res. Sec., Elec. Eng. Res. Lab., Univ. of Illinois, March, 1953; also, Trans. I.R.E., AP-2, pp. 132–143; October, 1954.

and double helix by means of the field potentials, and demonstrated the existence of the forbidden regions. The double helix is a system containing two coaxial helixes both wound in the same direction. Fowler[44] also computed characteristic impedances which might be useful in these cases. By means of an approach somewhat akin to that used by the writer[5] and described previously, Kirschbaum[45] analyzed the case of a shielded finite wire helix. By means of the usual quasi-stationary assumptions, expressions for the inductance and capacitance were computed, from which the impedance and phase velocity were obtained in the usual way. Excellent agreement with experimental results was shown for relatively low frequencies, that is for frequencies where the effect of the forbidden or exceptional regions can be neglected.

In many applications it is necessary to match the usual coaxial or other type standard transmission system to a helix, and to obtain minimum reflections over a medium or broad band. Various methods of accomplishing this have been used and described by several authors. Typical and useful examples were described by Lund[23] and White.[46] The work on coupled helixes, which also applies here, has been mentioned previously.

Space Harmonics; Traveling-Wave Tube Parameters; Backward-Wave Effects

By virtue of the space harmonics, the impedance $E_{z0}^2/2\beta_0^2P_t$, for a finite wire helix, is reduced over what it would be for the sheath helix. A dielectric sheath surrounding the helix will also reduce this impedance. Tien[47] has computed the effect of both these factors, on the assumption that the phase velocity for the actual helix surrounded by dielectric is not significantly different from the velocity for a sheath helix surrounded by dielectric, and has demonstrated that quite good agreement results with measured values. Watkins and Siegman,[48] using an electron beam to probe the fields, in other words, a specially constructed traveling-wave tube, experimentally verified the presence and predicted characteristics of the tape or wire helix modes, and measured the impedance $E_{zm}^2/2\beta_m^2P_t$ for both the $m=0$ and $m=-1$ space harmonics. They also demonstrated the use of a single wire helix as a backward-wave oscillator. Harman[49] has also observed the various helix modes.

The mechanism of backward-wave oscillations in traveling-wave tubes, where the circuit structure can support a wave whose phase and group velocities are in opposite directions, has been described by Kompfner and Williams,[16] Heffner,[50] Harman,[49] and others, and indicated by Pierce.[1] A detailed description of this phenomenon cannot be given here, although it is clear from the analysis, and the work of Watkins and Siegman,[48] and Harman,[49] that the helix is a quite satisfactory structure to use in backward-wave oscillators. Tien[51] has shown the mode structure for a bifilar helix and has illustrated, through computations, that the bifilar helix operating in the push-pull mode has substantially higher impedance for the desired mode for backward-wave oscillations than the single helix. The bifilar helix has the additional advantage of permitting electrostatic focusing of the electron beam in an operating tube, as demonstrated by Tien.[51] Using a developed model of the helix, in which a static field distribution in a plane perpendicular to the wires is assumed to be an adequate approximation (see Pierce[1]), Watkins and Ash[52] have computed the backward-wave impedance for the single and bifilar tape helix, as well as for a round wire helix, and obtained results substantially similar to those of Tien.[51] They also computed the effect of dielectric supports on the phase velocity and the impedance. Currie[53] observed the various helix modes and harmonics, and obtained generally good agreement between measured and computed values of the backward-wave impedances. His values were in essential agreement with those obtained by Tien[51] and Watkins and Ash.[52]

Although the finite wire helix leads to the most satisfactory picture of space harmonic effects, the higher modes of the sheath helix are closely related to these space harmonics as noted previously.[5] This relationship has also been explored by Johnson and Everhart,[54] who demonstrated that the sheath helix is still a very useful model even for the higher modes or harmonics.

Filter Helixes

Although the helix has the advantage of being useful over extreme bandwidths, there are many applications where such bandwidths are not required. Dodds and Peter[55] described various types of filter-helixes obtained by loading or varying the helix in a periodic manner. They analyzed the structure by conventional filter theory and demonstrated that, by virtue of the in-

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[45] H. S. Kirschbaum, "The Characteristic Impedance and Phase Velocity of a Shielded Helical Transmission Line," Rep. C.I.T. 7, Dept. Elec. Eng., Carnegie Inst. Tech. (undated).

[46] R. E. White, "Coaxial-to-helix transducers for traveling-wave tubes," Elec. Commun., December, 1953; also 1953 I.R.E. CONVENTION RECORD, part 10, p. 43.

[47] P. K. Tien, "Traveling-wave tube helix impedance," PROC. I.R.E., vol. 41, pp. 1617–1623; November, 1953.

[48] D. A. Watkins and A. E. Siegman, "Helix impedance measurements using an electron beam," *Jour. Appl. Phys.*, vol. 24, p. 917; July, 1953; also vol. 25, p. 133, January, 1954.

[49] W. A. Harman, "Backward-Wave Interaction in Helix-Type Tubes," Stanford Univ., Elec. Res. Lab. Tech. Rep. No. 13; April, 1954.

[50] H. Heffner, "Analysis of backward-wave traveling-wave tube," PROC. I.R.E., vol. 42, pp. 930–937; June, 1954.

[51] P. K. Tien, "Bifilar helix for backward-wave oscillators," PROC. I.R.E., vol. 42, pp. 1137–1143; July, 1954.

[52] D. A. Watkins and E. A. Ash, "The Helix as a Backward-Wave Circuit Structure," *Jour. Appl. Phys.*, vol. 25, p. 782; June, 1954.

[53] M. R. Currie, "The Electronic Impedance Characteristics of Waves on a Helix, Univ. of California, Berkeley, Elec. Res. Lab. Rep. Ser. No. 60, Issue No. 111, April, 1954; also, "Modulation and Demodulation of an Electron Stream by Backward-Wave Interaction," Ph.D. Thesis, Dept. Elec. Eng., Univ. of California, Berkeley, August, 1954 (unpublished).

[54] H. R. Johnson and T. E. Everhart, "Theory and Experiments on Multifilar Helices," paper presented at Electron Tube Res. Conf., Univ. of Maine; June, 1954.

[55] W. J. Dodds and R. W. Peter, "Filter helix traveling-wave tube," *RCA Rev.*, vol. 14, p. 502; December, 1953.

creased dispersion of the circuit, increased impedance over a restricted band could be obtained. Siegman and Johnson[56] have used filter helix structures to separate the forward- and backward-phase velocities, and have shown that backward-wave oscillation can be prevented even for large helix circumference to wavelength ratios.

Cross-Wound or Contra-Wound Helixes

If one attempts to use a simple helix in the higher voltage and power ranges, so that an increased pitch and diameter are required, it is found that not only is the impedance of the fundamental mode reduced because of increased power in the space harmonics, but also the impedance of the $m=-1$ space harmonic is increased.[47,51] Although the first effect is a serious limitation, the second is even more so, since it can result in backward-wave oscillations. The latter limitation is particularly critical for high-power amplifiers because, in this case, one often wishes to use a large-diameter electron beam nearly filling the helix, and it is near the helix that the axial field of the $m=-1$ harmonic is strong.

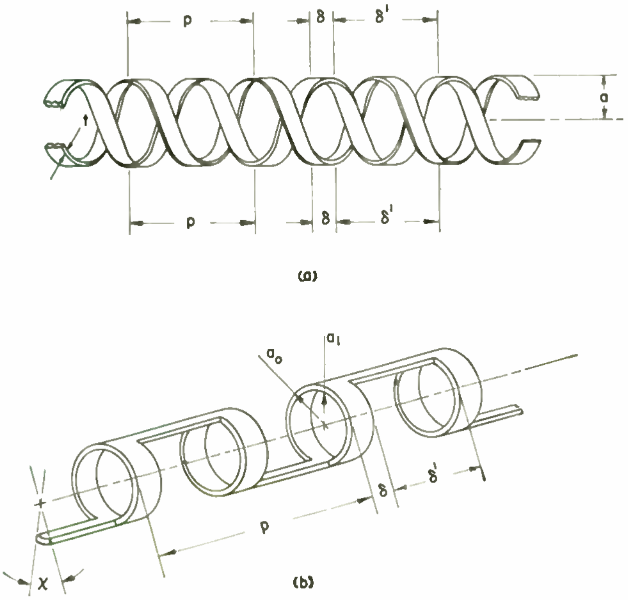

Fig. 6—(a) Contra-wound helix (from reference 15); (b) Contra-wound helix (from reference 57).

Chodorow and Chu[15] have analyzed a structure which overcomes both of the above difficulties, and Birdsall[57] has described a modification of their structure that appears to have additional advantages. The structure is the cross-wound or contra-wound helix consisting of two helixes wound in opposite directions, as illustrated in Fig. 6(a). Birdsall's modification is illustrated in Fig. 6(b), and can be seen to consist of a spatial distortion of the simple contra-wound helix, the modification having simplicity of construction, at least, as one of its advantages. It should be noted that one can construct multifilar helixes of the contra-wound variety of either the simple [Fig. 6(a)] or modified [Fig. 6(b)] type. Geiger and Wilmarth[58] considered such multifilar types.

The advantages of this circuit are a result of the symmetry, and can be indicated by some arguments advanced by Chodorow and Chu.[15] If one considers the superposition of the fields of the helixes operating in the symmetric mode, that is, such that the axial electric fields of the fundamental components add, then the resultant axial magnetic field of the fundamental components is identically zero, as is the energy storage associated with this component. On examination, it turns out that, in the single tape helix in the fundamental component, one has roughly equal amounts of electric and magnetic energy, or energy contained in the TM and TE portions of the field. In the contra-wound helix, by virtue of symmetry, the fundamental component of the TE portion of the field is nonexistent, so that the higher order space harmonics must have most of their energy in the magnetic or TE part of the field. This implies that the higher-order space harmonics have small axial electric field components and, consequently, small impedances for the backward waves. Incidentally, the above argument can be applied to the anti-symmetric mode and indicates zero fundamental component impedance and high space harmonic impedances.

For the symmetric mode, a detailed calculation verifies the qualitative arguments given above. Chodorow and Chu[15] have shown such a calculation for both the contra-wound helix and the simple helix proceeding in a manner somewhat similar to the writer.[5] However, they approached the problem through a Lagrangian, and showed that the complex power flow into the helix surface is variational in character. This approach is not only somewhat more physically satisfying than the writer's, but has the advantage of leading to a more rapidly convergent determinantal equation.

For the single helix, Chodorow and Chu[15] obtained a determinantal equation like (12) here, except the D_m term becomes squared. The solutions are essentially identical to those already shown. For the contra-wound helix, because of symmetry, the potential and field expressions take the form[15] shown for one component as follows:

$$\pi_z{}^{i,e} = e^{-j\beta_{0,0}z} \sum_l \sum_m A_{l,m}^{i,e} \begin{matrix} I_m(\gamma_{l,m}r) \\ K_m(\gamma_{l,m}r) \end{matrix} e^{-j[(2\pi/p)(l+2m)z-l\theta]}, \quad \begin{matrix} r \leqq a \\ r \geqq a \end{matrix} \tag{16}$$

with

$$\gamma_{l,m}^2 = \beta_{l,m}^2 - k^2, \tag{17}$$

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[56] A. E. Siegman and H. R. Johnson, "Suppression of Backward-Wave Oscillation by Filter Helix Methods," paper presented at Electron Tube Res. Conf., Univ. of Maine; June, 1954.

[57] C. K. Birdsall, "Modified Contra-Wound Helix Circuits for High Power Traveling Wave Tubes," paper presented at Electron Tube Res. Conf., Univ. of Maine; June, 1954 (to be published).

[58] R. H. Geiger and R. W. Wilmarth, "Results on Multiple-Wire and Multiple-Wire Contra-Wound Helices," paper presented at Electron Tube Res. Conf., Univ. of Maine; June, 1954.

$$\beta_{l,m} = \beta_{0,0} + \frac{2\pi}{p}(l + 2m). \qquad (18)$$

The current on the tapes takes the form

$$K_{\theta,z} = e^{-j\beta_{0,0}z} \sum_{l} \sum_{m} \kappa_{\theta,z_{l,m}} e^{-j[(2\pi/p)(l+2m)z - l\theta]}. \qquad (19)$$

The procedure is now as follows, where only the case for the tape thickness $t = 0$ in Fig. 6(a) has been considered: the fields are expressed in terms of the currents, the symmetry properties of the tape currents are used, the current is taken to flow only on the tapes and in the direction of the tapes (the narrow tape approximation), and the complex power flow expression is computed from which the determinantal equation is obtained by means already noted. This equation is then put in a form for ease in computation by methods previously described. Both a single-term approximation and a three-term approximation to the tape current distribution have been used, with the former yielding reliable quantitative results.

A $ka/\cot\psi$ versus $\beta_{0,0}a/\cot\psi$ plot for a particular example is shown in Fig. 7, where the solid and dotted lines have the same significance as before. All the branches for $\beta_{0,0}/\cot\psi > 0$ are shown for the particular case, although branch a is of the most practical importance. The forbidden region restriction applies to the unshielded contra-wound helix, as it does to the single tape helix, and the entire set of space harmonics exists with their phase constants related to $\beta_{0,0}$ by (18). The solution for a single-tape helix is also shown in Fig. 7.

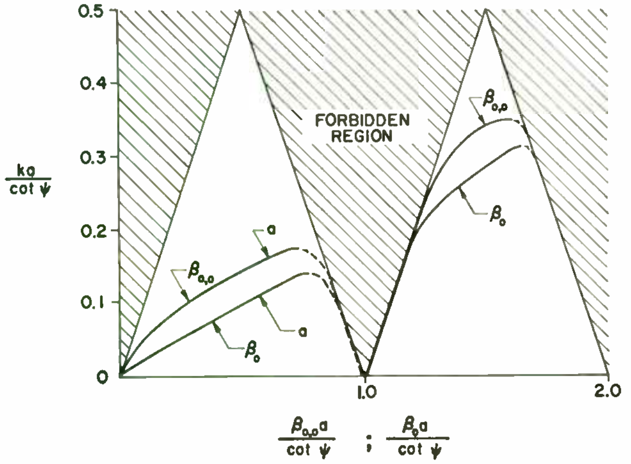

Fig. 7—Solutions of the contra-wound and single tape helix determinantal equations, $ka/\cot\psi$ vs $\beta_{0,0}a/\cot\psi$ and $\beta_0 a/\cot\psi$ for $\psi = 11.3$ degrees, $\pi\delta/p = 1/2$ ($\beta_{0,0}a/\cot\psi$ from reference 15).

It will be noted that, as opposed to the single-tape helix, the contra-wound helix has a larger phase velocity for a given ka, and that its dispersion is greater (that is, its group velocity changes more rapidly). In general, the single-tape helix has less dispersion and wider bandwidth than the contra-wound helix, and the phase velocity increases with increasing tape width, but much more slowly for the former than for the latter.

An extensive examination of the fundamental and space harmonic stored energies has verified the original qualitative arguments concerning the possible advantage of this structure.[15] Some typical calculations show that, in the useful range of circumference/wavelength and velocity ratios, the impedance of the fundamental component of the contra-wound helix is about twice that for the single helix, and the impedance of the space harmonics is reduced by factors of the order of five-to-ten. This results in a marked advantage of the contra-wound helix over the single helix for high-voltage traveling-wave tubes. Measurements on the contra-wound helix have resulted in close agreement with the results of the calculations, particularly for narrow tapes in contact or for wider insulated tapes, for which cases the theory applies.[15]

Birdsall[57] has reported the results of extensive measurements to determine the phase velocity and impedance characteristics of the modified or slot-type contra-wound helix. Although the propagation characteristics are generally related to those of the simple contra-wound helix, they vary in considerable detail from them. In general, the dispersion of the modified structure is higher, and a larger fundamental mode impedance has been obtained. Over a wide range of parameters, the fundamental mode impedance is twice that of the sheath helix. Geiger and Wilmarth[58] have performed tests on helixes of the multifilar contra-wound variety, using an electron beam as a probe to determine phase velocity and impedance.

CONCLUSION

In this review and survey we have examined some of the past and recent progress made in analyzing and understanding the electromagnetic properties of helical structures. It is clear that much still remains to be done, not only in the performance of further theoretical and experimental work on such subjects as nonreciprocal media, coupled systems, modified structures, end effects, etc., but also in synthesizing and compiling in a useful form that work which has already been accomplished.

Finally, although some reference has been made here to reports published elsewhere, the writer has confined himself mostly to work done by investigators in the United States, partly because of equivalences between local and foreign work, and partly because of a greater familiarity with the former. The writer would welcome hearing of any work he has not mentioned, or which has not been mentioned in surveys referred to here.

ACKNOWLEDGMENT

The writer would like to thank the various members of the Electron Tube Laboratory, Hughes Research and Development Laboratories, for the many discussions concerning the subject of this paper.

Progress in Electron Emission at High Fields*

W. P. DYKE†

Summary—**At high electric fields, electron current densities exceeding 10^8 acm² are emitted from metals, the emission process requiring no energy. The present paper discusses properties of such emitters and progress towards stabilizing their electrical performance under useful conditions.**

INTRODUCTION

ELECTRONICS depends on electron sources, and in particular, vacuum tube devices require sources of electron currents in vacuum. A convenient source is found in the copious free conduction electrons in metals, which can be removed by several methods. In thermal emission, the metal is heated; in photoelectric emission the metal is exposed to light or other radiant energy; in secondary emission the metal is bombarded with particles. Each of these emission processes is in wide use in electronics, the workhorse being thermal emission.

There is one metallic cathode which has many unique electrical properties but which has not yet enjoyed widespread practical application to electronic devices. The electron emission from this cathode depends primarily on the presence of a high electric field, the emission from the cold cathode being field emission[1] and from the heated cathode, still in the presence of field, T-F emission, an abbreviation for temperature-and-field emission.[2]

History has shown that new or improved electron sources are often followed by important advances in electronics, in the form of devices built around the unique cathode properties. There are many unique and apparently useful properties of the field and T-F emission cathodes. Why then have they not enjoyed extensive application? Several answers to this question may be found: first, many of the cathode properties have just been determined; second, until recently the cathodes have suffered from erratic and unstable performance; third, the cathodes have emerged from obscurity too recently to have yet attracted the interest of enough scientists and engineers to bring about widespread application. The present discussion is undertaken in order to describe the properties of these cathodes, to report recent progress toward stability and long life, and to suggest possible directions for useful development.

PROPERTIES OF FIELD AND T-F EMITTERS

The distinction between both field and T-F emission and the better-known thermionic emission involves two related concepts: first, the energy distribution of the free electrons in the metal, and second, the type of potential barrier encountered by the electrons in seeking to escape from the surface. In thermionic emission, the barrier may be "infinitely thick" and several volts higher than the level of the most energetic electrons of the cold metal; hence energy must be added (in the form of heat) to make electron emission possible over the top of the barrier. In field emission the effect of the applied electric field is to lower and thin the barrier. The quantum-mechanical theory[1] then predicts a finite probability of barrier penetration by electrons even of low energy; this is the so-called "tunnel effect," and no energy needs to be added for such emission to take place. In T-F emission, the barrier is again lowered and thinned by the applied field; however, a small amount of thermal energy is also added, increasing the supply of electrons at higher levels where the probability of escape is greater, thus increasing the current. Most of the T-F emission current described herein is supplied by barrier penetration, with only a negligible fraction of electrons reaching energy level required for thermionic emission.

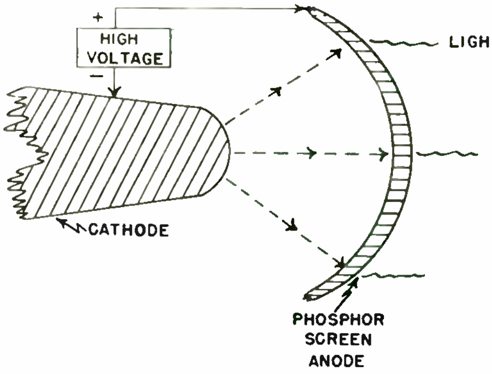

Fig. 1—Schematic of field emission microscope with single crystal tungsten cathode and aluminum backed willemite phosphor anode; electrons from cathode (dashed arrows) diverge towards anode on which enlarged cathode emission pattern is viewed.

When a cold needle-shaped metallic cathode in vacuum, such as that shown in Fig. 1, is subjected to a high electric field, due to a positive potential of a few kilovolts on a nearby electrode, an electron current is observed to flow from cathode to anode. This process, called field emission, was discovered in 1897 by Wood.[3]

Perhaps the most remarkable properties of the field emission cathode are its enormous electron current

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† Dept. of Physics, Linfield College, McMinnville, Ore.

[1] A. Sommerfield and H. Bethe, "Hand. d. Physik," J. Springer, Berlin, Ger., ch. XXIV, sec. 2, p. 441; 1953.

[2] W. W. Dolan and W. P. Dyke, *Phys. Rev.*, vol. 95, p. 327; 1954.

[3] R. W. Wood, *Phys. Rev.*, vol. 5, p. 1; 1897.

density and microscopic size. The cathode will emit current densities as great as a hundred million amperes per square centimeter,[4] or in other words about a million times the current density of its nearest competitor, the thermal cathode. For engineers, this means that electron currents of several amperes can be obtained from a cathode so small it can be seen only by the best microscopes. These properties of the field emission cathode may permit accomplishment of new electronic tasks. Increased electron currents permit more power to be drawn from electronic devices; when, at the same time, the cathode size is reduced, the generation of high power can be extended to yet higher frequencies.

A unique property of the field emission cathode was predicted theoretically in 1928 by Fowler and Nordheim,[5] and confirmed experimentally in 1940 by Fleming and Henderson:[6] the emission process does not require that energy be added to the cathode. In this respect the emitter is unique among cathodes in widespread use. A practical advantage results from this property; power sources required by other cathodes and associated equipment, such as filament transformers, may be avoided. A saving in weight, power, heat dissipation, size, and insulation difficulties is thereby effected.

Another useful cathode property is that a small increase in applied voltage causes a large increase in field current. The relationship between field current I and voltage V, announced in 1928 by Millikan and Lauritsen,[7] is

$$I = Ce^{-B/V} \tag{1}$$

where C and B are constants. This equation stands correct today for low current densities, and is illustrated by the linear portion A-C of the graph in Fig. 2. The practical significances of (1) are several, one being that accurate control of the electron current is afforded by direct electronic methods. Similar control of thermally emitted electron currents usually requires the complication of added electrode structures, since the emission process is itself dependent on temperature, a parameter which is rapidly varied only with difficulty; grid structures may be avoided in some cases when field cathodes are used. The highly sensitive current-voltage relationship in (1) may permit single tube, precision voltage control devices in the kilovolt range; high gain transducers that convert mechanical motion into electrical response are another possibility.

Serious attempts made between 1920 and 1940 to apply field emission to X-ray tubes and electron microscopy resulted in a considerable number of patents. These applications use another important property of the needle-shaped cathode: it is a point source of radially divergent electrons which can be focused into a narrow beam or small spot by straightforward electron optical methods. Widespread use of these devices was precluded at that time by emitter instability. Since causes for instability have recently been identified and cured under conditions to be described later, use of these devices may now be reconsidered. Early workers recognized two such causes, a poor vacuum and resistive heating of the emitter. Progress was formerly inhibited by inability to resolve the geometric detail of the minute field emitters by use of available optical microscopes. As a result, the values of both electric field and current density were uncertain—variables that are fundamental to an understanding of the emission process.

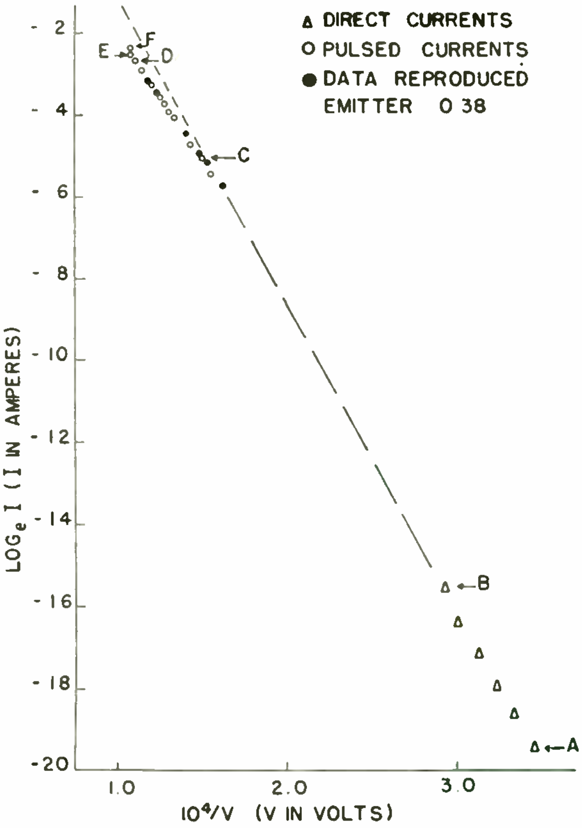

Fig. 2—Typical experimental relationship between field current I and applied voltage V for both direct current (triangles) and pulsed (circles) operation. A to C, space-charge-free emission; C to D, space-charge-limited emission; D to F, high emitter temperature due to resistive heating initiates vacuum arc at F.

In 1946 it appeared that these difficulties might at last be resolved by use of several techniques which had recently become available to scientists. Electron microscopy could be used to resolve the emitter geometry. Vacuums had been improved by a factor of more than a million, and at residual gas pressures of 10^{-14} mm of Hg, gas effects are minimized. The field emission microscope could be used to observe effects of cathode contamination and bombardment, which were suspected to contribute to emitter instability. This technique will be illustrated further on. Finally, pulse electronic tech-

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[4] W. P. Dyke and J. K. Trolan, *Phys. Rev.*, vol. 89, p. 799; 1953.

[5] R. H. Fowler and L. W. Nordheim, *Proc. Roy. Soc. Austl.*, vol. 119, p. 173; 1928.

[6] G. M. Fleming and J. E. Henderson, *Phys. Rev.*, vol. 59, p. 907; 1941.

[7] R. A. Millikan and C. C. Lauritsen, *Proc. Nat. Acad. Sci. U. S.*, vol. 14, p. 1; 1928.

niques were highly developed and, it appeared, could be used to draw very large electron current densities for short periods of time while minimizing undesired cathode effects due to resistive heating, bombardment, and contamination. A research program was established in 1946 at Linfield College for studying further the field emission process using the techniques just described.

In describing the field and T-F emitters, one deals with both large and small numbers. For the emission of current densities of 10^8 a/cm^2, an electric field of nearly 10^8 v/cm is required at the tungsten surface. To provide such fields with reasonable potentials, say a few kilovolts, on nearby electrodes, the cathode may be needle-shaped,[8] having a hemispherical tip of radius between 10^{-5} and 10^{-4} cm. Such cathode radii are about equal to a wavelength of visible light; hence the cathode is not well resolved in an optical microscope and can better be "seen" through electron micrographs such as that shown in Fig. 3, in which the cathode is tungsten fabricated by electrolytic etch.[8]

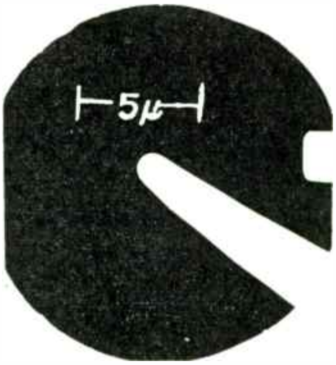

Fig. 3—Electron micrograph of typical tungsten field emission cathode.

Cathode properties often limit the design and operation of vacuum tubes. As electron current density is increased, a cloud of electrons accumulates just outside the cathode surface which repels other electrons trying to escape the metal. This phenomenon, called space-charge-limited emission, sets a definite limit on the value of current density that can be drawn conveniently from a given cathode. With most cathodes in common usage, the value of the electric field at the cathode is small and space charge is likely to be a problem; a current density of about 10 a/cm^2 can readily be drawn from the plane thermal cathode with reasonable voltages, but further increases in current density are made at the expense of large voltage increases. On the other hand, space charge is negligible in field and T-F emission, unless the current density exceeds about 10^7 a/cm^2, since the large electric field present is more effective in removing emitted electrons from the neighborhood of the cathode surface.[9] In other words, current density can be increased about a million times without space charge limitation when the field emitter is used instead of conventional cathodes. Field emission free of space charge is seen in the linear portion A-C of the curve in Fig. 2, in which the emission from clean tungsten is correctly described by (1). At C, the current density is 6×10^6 a/cm^2.

From C to D the emission is space charge limited.[9] Above D, when current density approaches 10^8 a/cm^2, resistive heating[10] becomes appreciable and a further increase in current to F raises the emitter tip to temperatures near the melting point, initiating a violent vacuum arc in which the vaporized emitter material participates.[11] Currents during the arc may exceed the initiating field current by more than a factor of one hundred; however, the emitter is likely to be melted and thus damaged through geometric change during the arc. The arc has several important contacts with practice. First, it sets a definite upper limit on the field current density that a given emitter can stand; stable emission is readily achieved by operating the emitter in a voltage range such that the critical current density is not exceeded. Secondly, the arc is an undesirable form of electrical breakdown when insulation is required, and doubtless occurs on a fairly widespread scale throughout the electronics industry; it may well account for tube failures in many cases. However, the arc can also be useful, since it provides a convenient means for altering the shape and purity of the field emitter tip. It may thus be used to effect the operation of several field emitters in parallel, and to improve their electrical stability when effects due to impurities in the emitter are avoided.[12]

Another factor which can limit the performance of vacuum tubes, particularly at high frequencies, is transit time, i.e., the time required for electrons to cross the gap between electrodes. Short transit times are often desirable and require high electron acceleration away from the cathode surface and/or short gap spacing. The former is achieved, in the case of the field emitter, by the very large surface electric field; the latter, i.e., miniaturization of tube elements, is possible because of the small cathode size. For these reasons, electron transit times in devices may be lowered by using the field emitter.

The cathode is of such a nature that its ruggedness can be improved. Its small mass plus the fact that it can be a single metallic crystal provides increased resistance to mechanical shock. Very long cathode life may be the expected result of continued research and development; evaporation of cathode material is negligible because temperature is low; oxide- or barium-coated cathodes which deteriorate are not now used, and longer life is expected for the clean, refractory metal surface that is employed.

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[8] W. P. Dyke, J. K. Trolan, W. W. Dolan, and G. Barnes, *Jour. Appl. Phys.*, vol. 24, p. 570; 1953.

[9] J. P. Barbour, W. W. Dolan, J. K. Trolan, E. E. Martin, and W. P. Dyke, *Phys. Rev.*, vol. 92, p. 45; 1953.

[10] W. W. Dolan, W. P. Dyke, and J. K. Trolan, *Phys. Rev.*, vol. 91, p. 1054; 1953.

[11] W. P. Dyke, J. K. Trolan, E. E. Martin and J. P. Barbour, *Phys. Rev.*, vol. 91, p. 1043; 1953.

[12] U. S. Patent Application ".407,700, by W. P. Dyke and J. K. Trolan.

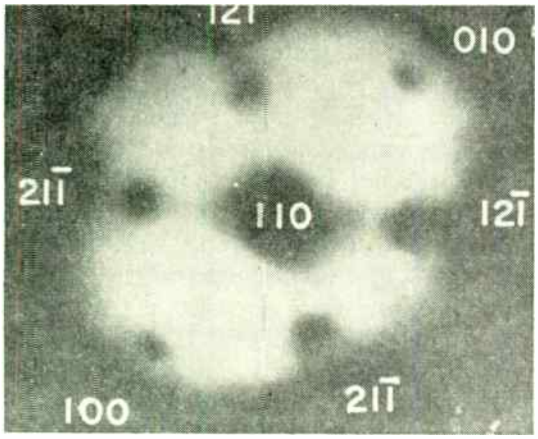

Fig. 4—Emission pattern from tungsten cathode obtained with the arrangement shown in Fig. 1. Bright areas correspond to dense electron emission; dark areas show lack of emission, and are labeled to correspond to crystal facets similarly identified on the crystal model in Fig. 5.

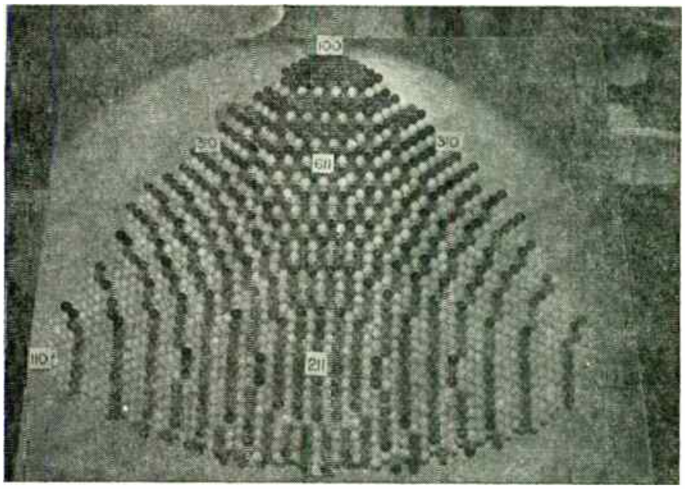

Fig. 5—"Marbles-for-atoms" model of a portion of a hemispherical tungsten field emitter tip with several crystal facets identified in correspondence with areas in emission pattern of Fig. 4.

An important factor in the operation of much electronic gear is cathode warm-up time. Short warm-up time is usually desired, though seldom achieved, particularly in high power devices with thermal cathodes. Use of such gear is prevented during warm-up time, and in some cases tube damage can result from the application of high potential during the warm-up period. The field emitter requires no warm-up time; the T-F emitter can require a period as short as 0.001 second, due to the small cathode size. These latter cathodes may be useful when short warm-up periods are required.

The extreme miniaturization of tube elements made possible by use of these cathodes is noteworthy; in principle, a current of several amperes could be obtained from a cathode the volume of which is less than 10^{-11} cm^3.

Electrical Stability of Field anf T-F Emitters

A number of the unique properties of the field emission cathode have been discussed. The extent to which these can be given widespread use in electronic devices built around the cathode will depend on the extent to which its electrical performance can be maintained stable during required life periods and at useful levels of power and duty cycle. Considerable progress in this direction will be described next. Mechanisms contributing to emitter instability will be identified. Since identification is best done through observations made with the field emission microscope, that instrument will be briefly discussed. Finally, a method by which the electrical characteristics of the T-F emitter are stabilized during pulsed operation will be described.

One of the most interesting displays in cathode physics is seen when a tungsten needle is pointed at a phosphor screen maintained at a positive potential of a few kilovolts relative to the cathode. This device, illustrated in Fig. 1, is the field emission microscope introduced by Mueller.[13] A high electric field causes electron emission at the hemispherical cathode tip, the electrons diverging along approximately radial trajectories (dashed lines in Fig. 1) until they strike the screen on which is viewed an enlarged emission pattern, such as that shown in Fig. 4. In that pattern, the bright areas correspond to regions on the emitter surface where current density is high; the symmetrically arranged dark areas correspond to reduced emission and are a distinctive feature of the emission pattern. The dark areas correspond to faces on the single-crystal emitter tip where atoms are close-packed and the surface is smooth, as a result of which electrons have difficulty in escaping the metal. This correlation is indicated by comparing Figs. 4 and 5, the latter being a "marbles-for-atoms" model of a portion of the single-crystal tungsten hemisphere. Corresponding crystal faces in the model and emission pattern are labeled. The colors of the marbles are an indication of the relative binding forces on atoms in the crystal surface, which are important in studies of such phenomena as adsorption and surface migration; black marbles have four "nearest neighbors," or marbles in direct contact, gray marbles have five, and white marbles have six or more nearest neighbors.

With this introduction to the emission pattern at hand, it is possible to illustrate another useful property of the field and T-F emitters, namely, that several cathodes can be operated in parallel with a common value of applied potential. In this way, current can be increased to a desired level at a given voltage. The parallel operation of field emitters has been reduced to practice through several embodiments, that shown in Fig. 6(a) (next page) consisting of two needle-shaped cathodes mounted on a common support. Proof for the effective and simultaneous parallel operation of both cathodes is seen in their similar and overlapping emission patterns shown in Fig. 6(b). That the figure contains two distinct patterns, each characteristic of a single, clean tungsten emitter, may be judged by comparison with Fig. 4. These cathodes emitted a combined microsecond cur-

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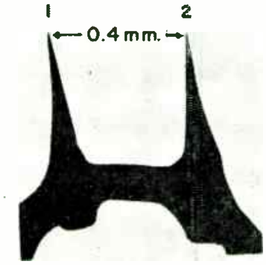
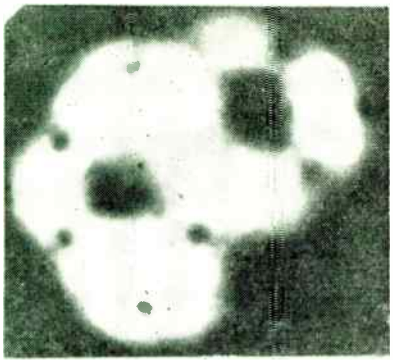
[13] E. W. Mueller, *Z. Physik.*, vol. 106, p. 541; 1937.

rent of 0.22 a at a potential of 17 kv. However, a larger needle-shaped cathode has emitted 6, and a razor-edged emitter has yielded 4 a, both at 80 kv applied potential. There is no reason to expect that these will be limiting levels of current and power.



EMITTER ASSEMBLY
(a)

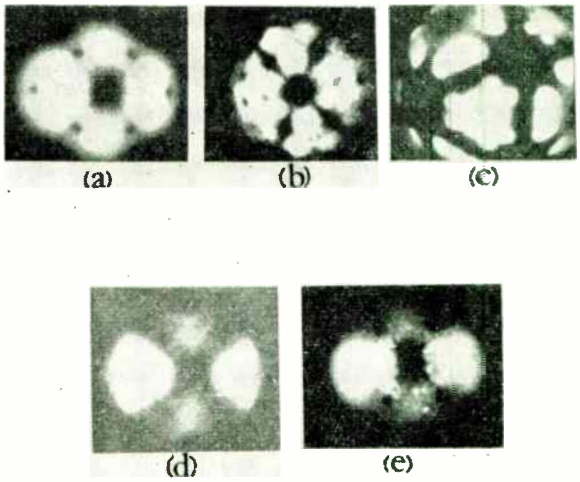


(b)

Fig. 6—Experimental data confirming the parallel operation of two field emission cathodes: (a) emitter assembly showing two needle-shaped tungsten cathodes 1 and 2 on a common support filament; (b) two simultaneous overlapping emission patterns, one from each cathode. (Compare patterns with that from the single emitter in Fig. 4.)

Returning to the question of emitter stability, two remarkable features of the field-emission microscope will be useful, namely, its linear magnification, easily a million times,[13] and its high resolving power, about 40 angstroms.[14] It is thus possible to distinguish electron emission from small areas on the cathode about 10 atom diameters in cross section. In fact, more refined arguments suggest that the outlines of large single molecules adsorbed on the emitter surface can be "seen."[15] As applied to the problem of emitter instability, this is a most powerful tool, because effects due to the bombardment of the cathode by perhaps one atom, and certainly due to its contamination (poisoning) by as few as a hundred atoms or so, can be readily distinguished by the corresponding changes caused in the emission pattern. Let us next note several ways in which adsorbed contaminants can alter the emission from the cold cathode.

Consider for example the changes in the emission pattern that result when barium is evaporated onto the originally clean tungsten surface, that is, on the tip of the needle shown in Fig. 1. The emission pattern from clean tungsten is shown in Fig. 7(a); for barium-on-tungsten,[16] the pattern is that shown in Fig. 7(b), when the coating is less than a monolayer, that is, one atom thickness. The emission pattern in Fig. 7(c) shows thorium-on-tungsten and has a remarkable snowflake-like symmetry which is readily identified. On the other hand, oxygen-on-tungsten[13] appears as in Fig. 7(d), which pattern is also distinctive and easily recognized. Thus the field emission microscope can be used in many cases to detect and identify cathode contaminants and to measure the extent of contamination. This is important to the development of the stable T-F emission source, since most contaminants alter the current-voltage relationship from that characteristic of clean tungsten and therefore are one cause of emitter instability. If the voltage is held constant, a coating of barium or thorium on tungsten increases the current by decreasing the work function of the emitting surface. On the other hand, a coating of oxygen decreases the current by increasing the work function. Since residual gas, electrode surfaces, glass tube walls, etc., are sources of contaminants that can reach the cathode when power is dissipated in the tube, such contamination, or poisoning, of the cathode surface is a probable process and doubtless accounts for much of the instability of field-emission cathodes reported by earlier workers.



(a) (b) (c)

(d) (e)

Fig. 7—Field emission patterns from clean tungsten (a) and from tungsten cathodes with various surface coatings (b) through (e): (b) barium-on-tungsten; (c) thorium-on-tungsten; (d) oxygen-on-tungsten; (e) the effect of energetic helium ions incident on tungsten.

The field-emission microscope permits identification of the cause of another type of electrical instability in which the current-voltage relationship is also changed. If helium is present at a pressure of 10^{-8} mm of Hg or more, the cold tungsten cathode surface is apparently roughened when high-energy helium ions impinge on its

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[14] R. Gomer, *Jour. Chem. Phys.*, vol. 20, p. 1772; 1952.

[15] E. W. Mueller, "A. Naturforschung *Va*," p. 473; 1950.

[16] J. A. Becker, *Bell Tech. Jour.*, vol. XXX, p. 907; 1951.

surface. At small localized surface projections, the electric field and hence the field current density is increased. This effect is identified in Fig. 7(e) through the small "bright spots" corresponding to the small areas of increased current density. Two undesired effects can result; first, the current-voltage relationship may be changed, and second, an arc may result from resistive heating caused by excessive current density. The effect is frequently encountered in field emission due to helium supplied by diffusion through pyrex tube walls from the atmosphere; electronic pumping of helium reduces the rate but does not avoid the effect under such conditions.

It has been said that at least half of the battle is the recognition of the problems at hand. It has been shown that roughness or adsorbed contaminants on the tungsten cathode surface contribute to its electrical instability during electron emission at high electric fields. Knowing this, two methods for improving stability are seen. The first is to reduce the amount of material which can bombard and contaminate the cathode, and the second is, to maintain a smooth, clean cathode surface in spite of incident material.

One means for accomplishing the former is to remove sources of material which can reach the cathode. Such sources are residual gases, contaminants on other electrodes or on glass tube walls, fragments of the electrode materials, etc. These sources are minimized by use of high vacuums and clean surfaces; work in this direction has yielded cold-cathode stability for periods up to a few hours for both steady state and pulsed operation. However, this method is not yet sufficiently developed to permit widespread use of the field emitter in applications.

On the other hand, the development of a stable T-F emitter is much further along due to another method, which has provided excellent cathode stability for periods as long as 200 hours during pulse operation. This method uses an intermediate cathode temperature to maintain a smooth, clean cathode surface in spite of incident material.[17] When repetitive microsecond emission is drawn from the tungsten cathode which is stabilized by use of an intermediate temperature, the emission pattern shows none of the undesirable effects described in Fig. 7. Rather, the emission pattern remains that of clean tungsten during long periods of operation. For example, the pattern in Fig. 8(a) was taken before, and that in Fig. 8(b) was taken after 200 hours of repetitive microsecond operation, during most of which the repetition rate was 300 pps, the current was 0.2 a and the applied voltage was 40 kv. The identity of the two patterns illustrates the electrical stability observed during the test; none of the pattern changes in Fig. 7 associated with emitter instability were observed. Other stabilized T-F emitters have been successfully operated at higher power but at lower duty cycles, a limitation which has been imposed by immediately available pulser equipment. The method appears useful at duty cycles up to about 0.25.

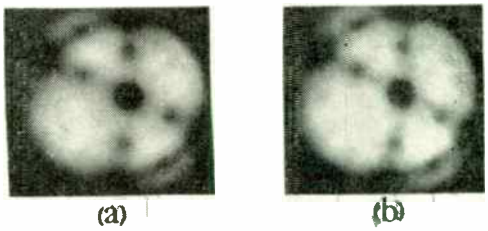

Fig. 8—Emission patterns from a thermally stabilized pulsed tungsten T-F emitter: (a) at the start of and (b) at the completion of a 200-hour life test; identity of patterns illustrates electrical stability achieved by this method. During most of the test, current was 0.2 a, voltage 40 kv, microsecond pulses at 300 pps.

Use of an intermediate temperature thus appears to offer considerable promise for stabilizing the pulsed emission of electrons from metals at high electric fields; however, it will probably not be useful for steady state operation (direct currents), since the cathode gradually distorts geometrically during continued exposure to both high field and high temperature. The desirable electrical properties of the tungsten field emitter are conserved at the temperatures used, although in the strict sense the emission is then T-F emission. The energy that must be added to the cathode for this purpose is quite small in view of the microscopic cathode size, and is negligible compared with that required by the thermal emitter the major difficulties of which are in this respect avoided.

Will the field and T-F emitters receive widespread use in electronic devices? An answer to that question can be found only through continued research and development, and increased interest and participation by application engineering. It is clear, however, that these emitters have remarkable properties around which significant electronic devices can be designed. Now, for the first time, it seems likely that electrical stability and life can be obtained under useful conditions.

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[17] W. P. Dyke, J. P. Barbour, E. E. Martin, and J. K. Trolan (to be published).

Odd Integer Magnetic Frequency Multipliers[*]

LEO J. JOHNSON[†] AND S. E. RAUCH[‡]

Summary—**A mathematical analysis of odd integer frequency multiplication is presented in this paper. Experimental examples of a 300 watt, 400–2,000 cps tripler and a 3 watt, 400–2,000 cps quintupler are discussed. Output wave forms are shown for multipliers employing two types of core materials. The improved circuitry and appropriate selection of magnetic materials as employed in today's magnetic frequency multipliers make the generation of power in the 400–2,000 cps range simple and reliable, and such that efficiencies in the order of 80–90 per cent are possible. In addition, the features of space conservation and power economy can be obtained.**

INTRODUCTION

MAGNETIC frequency multipliers were used first for the production of radio frequency power during the first two decades of this century. Its predecessor, the arc transmitter, was erratic in power output and demanded physically large electromagnets similar in magnitudes to those used for the early cyclotrons. The development of magnetic frequency multipliers was pioneered primarily by scientists of Germany. The models developed during the period of 1915–1925 offered improvements such as increased efficiency over the arc transmitters; however, they also suffered from the problems of large weight and volume.[1–5] The development of satisfactory electronic tubes greatly simplified the techniques for generating radio frequency power and thus quickly replaced the magnetic frequency multiplier.

Present day demands for frequency multiplication are arising in the band below radio communication frequencies but above the standard power frequencies. Examples of industrial computers, telemetering devices, and carrier frequency systems can be found at present employing high frequency power ranging from 400–20,000 cycles. In many instances electronic tube sources such as multivibrators are being used. Since large quantities of these devices are in operation, the reliability and efficiency of the power sources have become very important. In particular, maintenance problems must be continually minimized. In such applications the magnetic frequency multiplier has distinct advantages over its electronic counterpart. Magnetic frequency multipliers can produce power with efficiencies of the order of 90 per cent, which is better than the typical efficiency of electronic systems. Furthermore, the magnetic frequency multiplier offers exact frequency multiplication with an exact phase relationship between output frequency and supply frequency. Equally important is the reliability factor of such devices which is similar to power transformers that employ single magnetic cores with single windings.

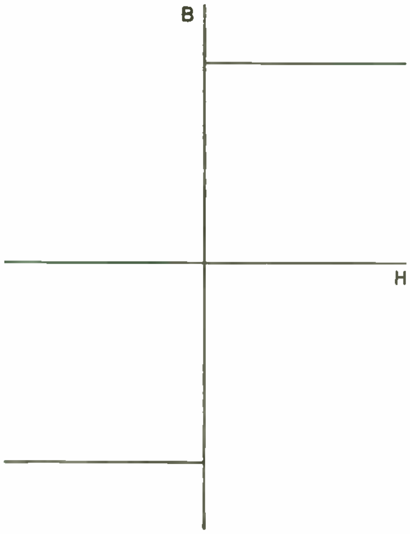

Fig. 1—Idealized rectangular core material having negligible hysteresis loss.

ANALYSIS OF ODD INTEGER FREQUENCY MULTIPLICATION

Consider the odd integer frequency multiplication in which an idealized rectangular core material is used (Fig. 1) and which employs a circuit (Fig. 2, opposite), having n supplies of the same amplitude and frequency but differing in phase by θ_f radians. That is:

$$\begin{aligned} E_1 &= E_{\max} \sin \theta, \\ E_2 &= E_{\max} \sin (\theta + \theta_f), \\ E_3 &= E_{\max} \sin (\theta + 2\theta_f), \\ &\vdots \qquad\quad \vdots \\ E_n &= E_{\max} \sin [\theta + (n - 1)\theta_f], \end{aligned} \tag{1}$$

where θ_f is so chosen that

$$\theta_f = \left(\frac{n-1}{n}\right)\pi.$$

An idealized rectangular core material having a negligible hysteresis loss will be used for the analysis in this section. The use of an ideal rectangular core material permits a simplified discussion of the frequency analysis

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[1] N. Lindenblad and W. W. Brown, "Frequency multiplication, principles and practical applications of ferro-magnetic methods," *AIEE Transactions*, vol. XLIV, pp. 491–495.

[2] A. N. Goldsmith, "Radio frequency changers," PROC. I.R.E., pp. 55–79; March, 1915.

[3] J. Zennech, "A contribution to the theory of magnetic frequency changers," PROC. I.R.E., pp. 468–492; December, 1920.

[4] M. Latour, "Static frequency multipliers for the production of very high frequencies in radio telegraphy," *Revue Generale de l'Electricite*, July, 1922.

[5] Dornig, "Contribution to frequency transformation by means of iron core inductance," *Elektrote Chresche Zeclsikrift*, vol. 45, pp. 1107–1108; October, 1924.

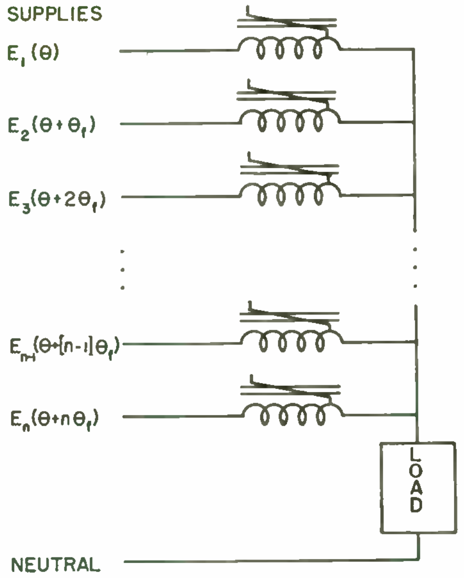

Fig. 2—Schematic of odd integer frequency multiplication circuit having n supplies and a common load.

since definite firing angles are produced. Although rectangular material does not necessarily produce the most desired wave form, as will be shown, it is useful, nevertheless, for demonstration of principles. It is well known that the relationship between induced voltage, E, and flux, ϕ is given by:

$$E = N \frac{d\phi}{dt} \times 10^{-8} \tag{2}$$

or

$$\phi = \frac{10^8}{N} \int_0^t E(t)dt.$$

Let the supply voltage $E(t) = E_{\max} \sin \theta$ where $\theta = wt$, and define $\Delta\phi$ as the total flux change from negative to positive saturation. Then an angle θ_f, is defined such that

$$\Delta\phi = \frac{E_{\max}}{N\omega} \times 10^8 \int_0^{\theta_f} \sin \theta d\theta, \tag{3}$$

or

$$\Delta\phi = \frac{E_{\max}}{N\omega} \times 10^8(1 - \cos \theta_f),$$

where θ_f is called the firing angle. The parameters are chosen such that the saturable reactor in any supply has a firing angle, θ_f. The load voltage contribution for the single phase, E_1, is shown in Fig. 3.

It can be concluded that the following basic principles in phase multiplication will be in effect.

1. No even harmonics are generated in any single phase; therefore, even harmonics are not present in the load voltage.
2. The angle between consecutive phases in the supply voltage is equal to the period of the desired frequency; thus, only those harmonics having periods which are integer multiplications of the desired frequency period will appear in the output wave.

The load voltage wave for the phase, E_1, can be described as follows (see Fig. 3):

$$E_1(\theta) = 0 \text{ for } -\pi < \theta < -\pi + \theta_f,$$
$$E_1(\theta) = E_{\max} \sin \theta \text{ for } -\pi + \theta_f < \theta < 0,$$
$$E_1(\theta) = 0 \text{ for } 0 < \theta < \theta_f,$$
$$E_1(\theta) = E_{\max} \sin \theta \text{ for } \theta_f < \theta < \pi.$$

The harmonic components of $E_1(\theta)$ can be determined by the usual Fourier analysis,

$$E_1(\theta) = \sum_{m=1}^{\infty} (a_m \cos m\theta + b_m \sin m\theta), \tag{4}$$

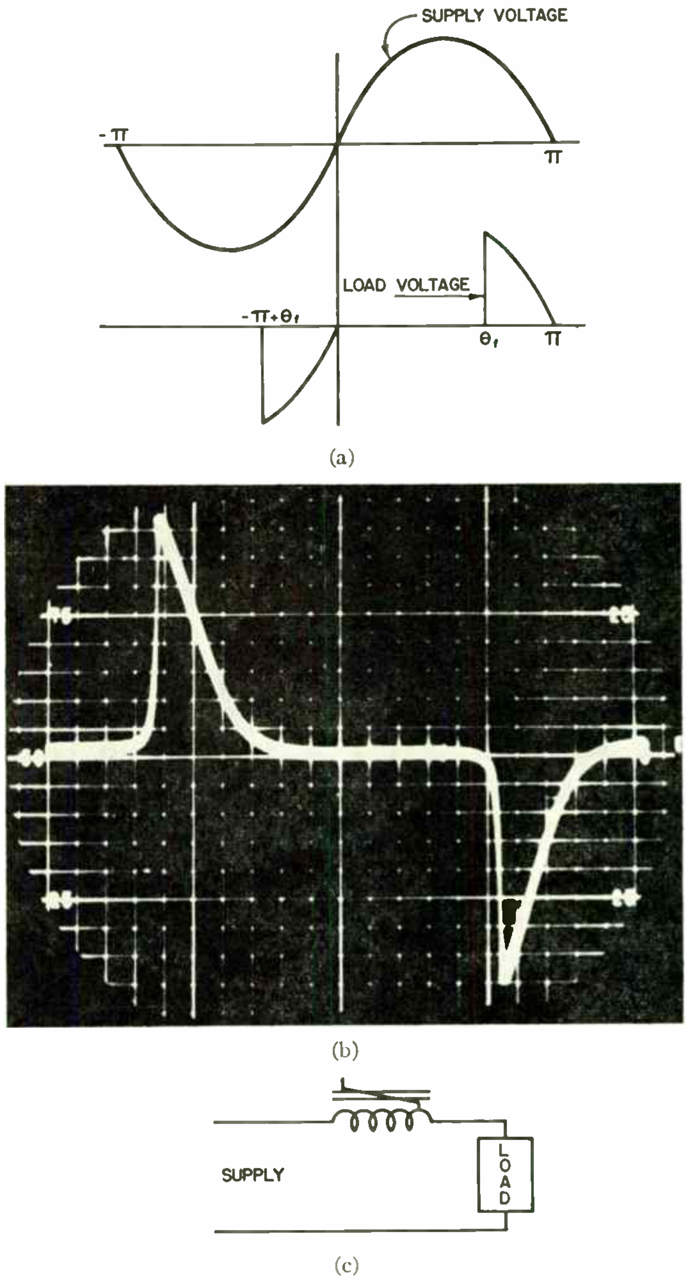

Fig. 3—(a) Supply voltage and corresponding load voltage from a single saturable reactor having rectangular core material and a firing angle, $\theta_f = 120°$. (b) Oscillogram of load voltage from a saturable reactor using a highly oriented nickel-iron core material and a firing angle, $\theta_f = 120°$. (c) Simple saturable reactor circuit used for obtaining oscillogram in Fig. 3(b).

TABLE I

LOAD VOLTAGE COMPONENTS OF A SINGLE-PHASE SATURABLE REACTOR USING RECTANGULAR CORE MATERIAL. THE SINE WAVE SUPPLY HAS $E_{\max}=1$

Multiplication Factor n	Firing Angle θ_f	Fundamental Magnitude A_1	Phase Angle α_1	Third Harmonic Magnitude A_3	Phase Angle α_3	Fifth Harmonic Magnitude A_5	Phase Angle α_5	Seventh Harmonic Magnitude A_7	Phase Angle α_7	Ninth Harmonic Magnitude A_9	Phase Angle α_9
3	120°	.308	−50°41′	.238	30	.138	60°	.0866	60°	.0630	10.5°
5	144°	.121	23.4°	.110	17.8°	.0919	35.6°	.069	5.5°	.0277	12.5°
7	154°17′	.0627	16.7°	.060	38.6°	.0856	39.6°	.0473	31.2°	.0392	20.5°
9	160°	.0381	13.0°	.0373	39.9°	.0352	23.1°	.0323	4.26°	.029	32.2°

where

$$a_m = \frac{1}{\pi}\int_{-\pi}^{\pi} E_1(\theta)\cos m\theta d\theta$$

and

$$b_m = \frac{1}{\pi}\int_{-\pi}^{\pi} E_1(\theta)\sin m\theta d\theta.$$

Since no even harmonics are present, then a_m and b_m are zero when m is an even integer. Thus, for odd m it can be shown that

$$a_m = \frac{E_{\max}}{\pi}\left\{\frac{1-\cos(m-1)\theta_f}{m-1} - \frac{1-\cos(m+1)\theta_f}{m+1}\right\}, \quad (5)$$

$$b_m = \frac{E_{\max}}{\pi}\left\{\frac{\sin(m+1)\theta_f}{m+1} - \frac{\sin(m-1)\theta_f}{m-1}\right\}. \quad (6)$$

It is possible to express $E_1(\theta)$ in the form

$$\begin{aligned} E_1(\theta) &= A_1\sin(\theta+\alpha_1) + A_3\sin(3\theta+\alpha_3) \\ &\quad + A_5\sin(5\theta+\alpha_5)\cdots, \\ E_1(\theta) &= \Sigma A_m\sin(m\theta+\alpha_m) \end{aligned}$$

where m takes on only odd integer values, and

$$A_m = (a_m{}^2 + b_m{}^2)^{1/2}, \qquad \alpha_m = \arctan\left(\frac{a_m}{b_m}\right). \quad (7)$$

Similarly, the k_{th} supply, $E_k(\theta)$, which is displaced in phase by $k\cdot\theta_f$ is expressed as:

$$E_k(\theta) = \sum A_m \sin[m(\theta+k\theta_f)+\alpha_m], \quad (8)$$

where m has all odd integer values and A_m and α_m are similar magnitudes as defined for $E_1(\theta)$.

As only those harmonics having periods which are odd integer multiples of the desired frequency period will appear in the final output wave, it is possible to write an expression for the load wave, $E_L(\theta)$, for any given odd integer frequency multiplication, n,

$$E_L(\theta) = \sum_{k=1}^{n} E_k(\theta),$$

$$E_L(\theta) = n\cdot\sum_{i=1}^{\infty} A_{n(2i-1)}\sin[n(2i-1)\theta + \alpha_{n(2i-1)}], \quad (9)$$

where (5) and (7) define the magnitudes of $A_{n(2i-1)}$ and $\alpha_{n(2i-1)}$.

THEORETICAL EVALUATION OF MULTIPLIERS USING RECTANGULAR CORE MATERIAL

The behavior of a single phase saturable reactor circuit is described by (8). Table I shows an evaluation of (8) for a single phase circuit in which rectangular core material is used. It is noted that a complete spectrum of odd harmonics is present in each single phase.

It is apparent from Table I that frequency multiplication can be obtained from the basic single phase circuit; however, the problems involved in eliminating the unwanted frequencies by filtering make it difficult to obtain reasonable power at the desired frequency. An important difficulty arises because of the necessity of eliminating frequencies both above and below the selected one. In addition, as the output wave is discontinuous, it is necessary to store energy at the desired frequency in order to obtain a sinusoidal output. The magnitudes of the frequency components, as shown in Table I, are obtained on the basis of unity magnitude for $E_{\max}$ in the supply sine wave. The reader's attention is called to the presence of the large percentages of higher harmonics.

Table II shows a breakdown of the various load voltage components for several odd integer multiplications in which rectangular core material is used. The harmonics evaluated in Table II are defined in terms of the basic supply frequency. For example, the third harmonic of the basic supply frequency is the fundamental voltage output for a tripler but is expressed as the third harmonic in Table II. It is noted that the magnitudes are based upon a peak supply voltage of unity magnitude. The decreasing values of the voltages for increasing frequencies as shown in Table II illustrates the reduction of power for a given physical size as the multiplication value, n increases.

TABLE II

LOAD VOLTAGE HARMONIC MAGNITUDE COMPONENTS OF THE OUTPUT WAVE FOR VARIOUS MULTIPHASE MULTIPLIERS WHICH USE RECTANGULAR CORE MATERIAL. ALL SINE WAVE SUPPLIES HAVE $E_{\max}=1$

Multiplication Factor n	Harmonic	Magnitude	Harmonic	Magnitude	Harmonic	Magnitude
3	3rd	.71	9th	.19	15th	.11
5	5th	.46	15th	.13	25th	.075
7	7th	.33	21st	.095	35th	.056
9	9th	.26	27th	.075	45th	.044

Multiphase supplies provide a continuous output wave which thereby eliminates the need for energy storage at the desired frequency. Another improved result of multiphase multiplication is obtained from the cancellation of all frequencies except the selected frequency and its odd harmonics. The magnitudes of the output frequency as obtained from each of the supply phases are additive, which therefore provides a maximum output voltage. Table II further illustrates the undesirability of rectangular core characteristics since appreciable harmonic values are present in the load voltage. It would appear that a less rectangular core material could be selected for specific multiplication values which would reduce output voltage distortion.

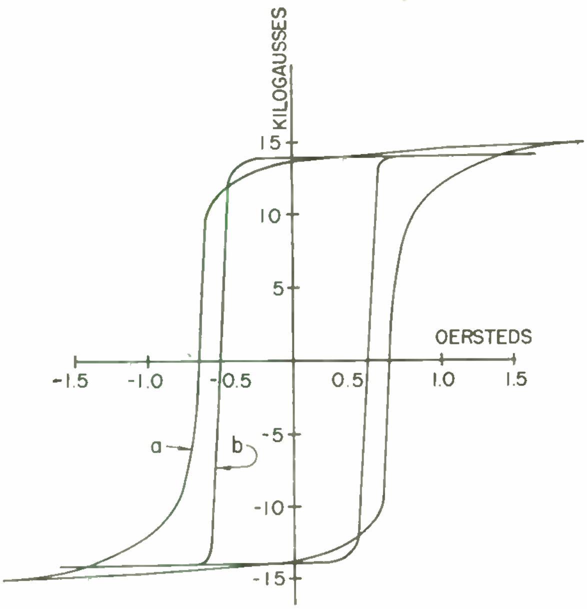

Fig. 4—Typical 400 cps hysteresis curves of two core materials: curve a—oriented silicon steel, curve b—highly oriented nickel-iron such as Orthonol or Deltamax.

EXPERIMENTAL EVALUATION OF A FREQUENCY TRIPLER USING ORIENTED SILICON STEEL CORES

On the market today are a wide variety of materials applicable to frequency multiplication some of which approach closely the ideal characteristic of negligible hysteresis. In this group are materials which can yield a nearly sinusoidal output wave form for a given application. Fig. 4 illustrates two typical types of core materials. The rounded loop (curve a) can be obtained from oriented silicon steel, while, in contrast, a rectangular loop (curve b) is available in the highly oriented nickel-iron materials such as Orthonol or Deltamax. The single phase output wave characteristic comparisons for these two materials are shown in the oscillograms of Figs. 5 and 3(b) respectively. The firing angle chosen for the oscillograms is $\theta_f = 120$ degrees, which is used for a frequency tripler. It is apparent that the wave of Fig. 5 contains a larger percentage of third harmonic and a much smaller proportion of higher harmonics. This observation is supported in the experimental evidence which follows.

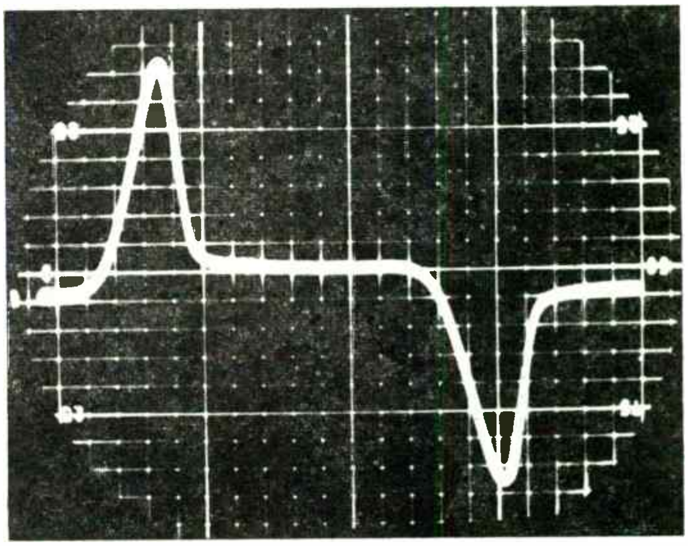

Fig. 5—Oscillogram of load voltage from a saturable reactor using oriented silicon steel and a firing angle $\theta_f = 120°$.

For the purpose of experimental evaluation, a frequency tripler was built using oriented silicon steel cores. The tripler was designed to transform 200 watts from 400 cps to 1,200 cps. Fig. 6 shows the schematic of the circuit employed. A 1,200 cycle transformer was included for circuit isolation and output voltage adjustment. The voltage regulation and efficiency of the system of Fig. 6 are presented graphically in Fig. 7 (next page). Note that the voltage regulation is typical of power supplies in general. The droop in over-load voltage is due primarily to the internal winding resistance. The efficiency curve includes the losses in the 1,200 cps transformer which were abnormally high. The core losses in this transformer were unnecessarily large because higher frequency laminations were not available.

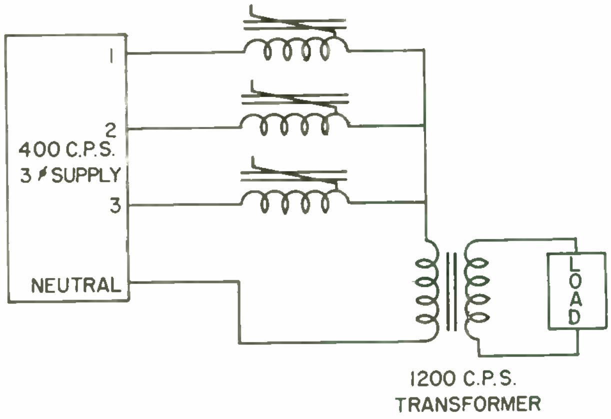

Fig. 6—Schematic of the experimental frequency tripler, transforming 200 watts from 400 cps to 1,200 cps.

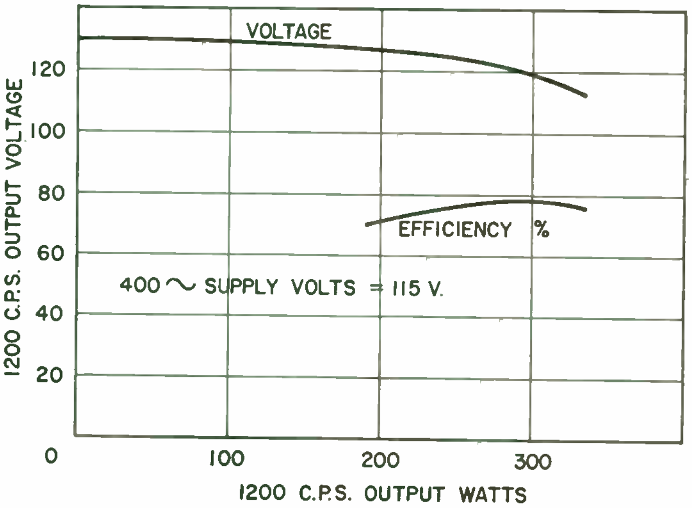

Fig. 7—Voltage regulation characteristic and corresponding efficiency of the experimental frequency tripler having a 200 watt rating.

The 1,200 cycle transformer loss was 32 watts full load and 25 watts no load.

A full load, unfiltered output wave is shown in Fig. 8. The upper oscillogram of this figure displays the harmonic components of the unfiltered wave. The total harmonic distortion in the output wave is less than 10 per cent. The wave form may be improved over that shown in Fig. 8 by the use of a more carefully selected saturable core material or by filtering. The filtered output wave for the experimental tripler is shown in Fig. 9.

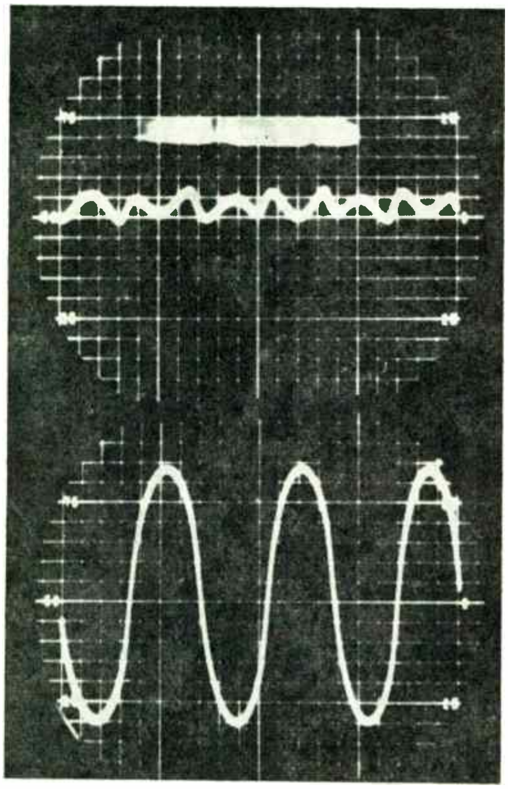

Fig. 8—Oscillogram of the full load, unfiltered output wave of the experimental frequency tripler. Upper oscillogram shows the harmonic content of the 1,200 cps unfiltered load wave.

The total distortion does not exceed 0.5 per cent. The experimental tripler described herein weighs 12 pounds and occupies a volume of 120 cubic inches.

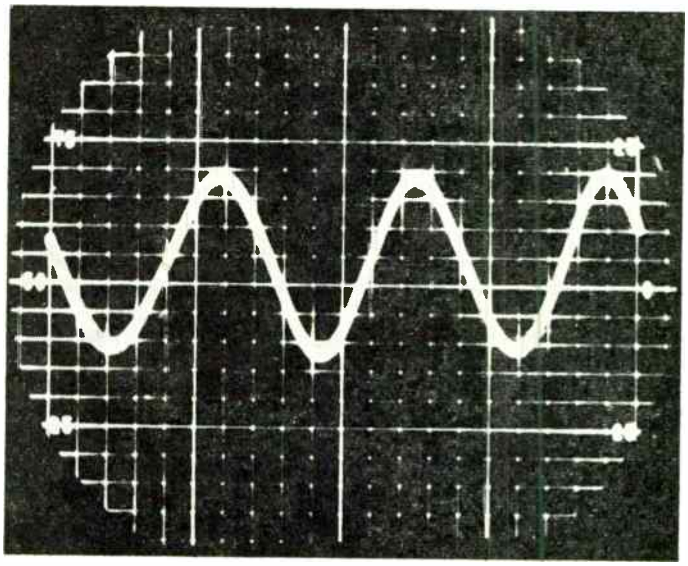

Fig. 9—Oscillogram of full load, filtered output wave of the experimental frequency tripler with a total distortion less than 0.5 per cent.

In order to give the reader a more complete perspective of the operation of frequency multipliers, a voltage regulation for a quintupler is given in Fig. 10. This figure includes two regulation curves for a 3 watt nominal, 400–2,000 cps multiplier. The relative impedance of output voltage to supply voltage can be seen for the 3 watt rating.

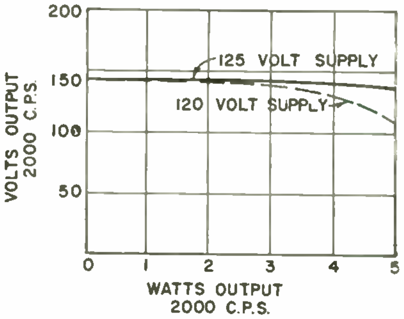

Fig. 10—Voltage regulation characteristics of a 3 watt, 400–2,000 cps quintuplar.

General Discussion

Comparison with Y-Δ Circuitry

The circuit arrangements for the examples shown in this paper have a distinct advantage over previously described multiplier circuits.[6] For the multipliers described therein, each reactor has two windings. The voltages are applied to the primary winding. Thus, the

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[6] L. C. Harriott, "Magnetic frequency conversion," *Proc. of the National Electronic Conference*, vol. 9, pp. 78–87; 1953.

window space is divided between the two windings. The multipliers described herein use single winding reactors, which reduces the internal impedance and improves the efficiency and power output per unit volume.

Cascading Advantages

When the higher multiples of frequency are desired, multiplication by stages may prove to be simpler and more efficient than full multiplication in a single stage. For example, consider a case in which power is desired at the ninth harmonic. This can be accomplished by the use of nine supply phases and nine saturable reactors. A more practical arrangement can be achieved by the use of two 3-phase supplies and six saturable reactors for producing two-phase, tripled frequency. This output is then tripled by the use of three saturable reactors and one phase-changing transformer. In the first case, all saturable reactors must be built for the basic supply frequency, and as a result they are relatively large. In contrast, the cascading method uses large reactors only in the first stage. The higher frequency supplies for the second stage require much less iron and copper. Table II illustrates the advantage of power efficiency and conservation of weight when using a two-stage system. Specifically, the magnitude coefficient of the third harmonic is 0.71, whereas the magnitude component for the ninth harmonic is 0.26. In the case of the ninth harmonic the tabulated magnitude of 0.26 can be used, while in the case of the third harmonic cascading in two stages a magnitude of $0.71 \times 0.71 = 0.50$ is obtained. Power magnitudes are proportional to the square of the voltage; thus, the power rating for the single stage is approximately one fourth the power for an equivalent volume of material in a two stage system. Furthermore, the firing angles involved in the single-stage, $n = 9$ multiplier, are very critical and thereby require very close voltage regulation in the supplies. The comparative two-stage system employs less critical firing angles, which permits more latitude in supply regulation.

Frequency Multiplier Power Factor

The elements contained in a magnetic frequency multiplier store negligible energy. The power to the output is transmitted directly from the supply through the saturable reactor. Since reactive energy is stored energy, it can be seen that high power factors must result when negligible reactive energy is stored. This is the case for the type of magnetic frequency multiplier discussed here. In general, magnetic frequency multipliers operate with high power factors.

High Frequency Load Power Factor

Reactive components of power in the high frequency load will shift the firing angle of the saturable reactors. The resultant firing angle shift changes the mode of operation of the multiplier elements, which, during switching, can cause a short circuiting of a pair of reactors. However, in the steady state no ill effects arise since each saturable core has a constant volt-second absorption product. In other words, reactive loads can create a shift in the firing angle but must shift also the initiating flux change in the opposite direction in the early portion of each half cycle.

Effect of Non-Linear Loads such as Magnetic Amplifiers

For a single stage, the output impedance characteristic of a magnetic frequency multiplier reflects the impedance of the primary source plus a single winding resistance of the saturable reactor windings. In practice, the saturable reactor windings are designed for minimum resistance; therefore, non-linear loads such as magnetic amplifier loads affect the regulation and wave form of frequency multipliers in much the same manner as they affect primary power sources.

Cross Firing from Sharp Saturation

It can be seen in the Fourier analysis of the output wave form that not all generated harmonics in the individual pulses appear in the output wave. The suppressed harmonics are dissipated through pairs of reactors instead of appearing in the load. Such conditions increase harmonic currents in the reactors and therefore represent internal losses. For this reason, it is desirable to use core materials which produce a maximum proportion of the harmonic to undesired harmonics.

CONCLUSION

It has been demonstrated that the performance of magnetic frequency multipliers is dependent upon the type of core material and the circuit employed. For the higher frequency multiples, multistage circuits exhibit definite advantages over the equivalent single stage design. Suitable selection of core materials can yield a low harmonic distortion in the high frequency output. Furthermore, experimental evidence[7] shows that efficiency ratings equivalent to that of rotating machinery are obtainable.

ACKNOWLEDGMENT

The authors take pleasure in acknowledging the cooperation of the Naval Research Laboratory for supporting the early investigations on the present subject material. In particular, recognition is given to Bruce G. Bingham for his valuable contributions in reviewing the information contained in the literature.

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[7] L. J. Johnson and S. E. Rauch, "Magnetic frequency multipliers," *AIEE Transactions*, Technical Paper No. 54-248, 1954.

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Discoidal vs Tubular Feed-Through Capacitors*

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Summary—The coupling impedance and its frequency dependency of tubular and disc-type ceramic feed-through capacitors are investigated theoretically and experimentally. The superiority of discoidal feed-throughs with respect to high-frequency performance and mechanical ruggedness is shown. In the UHF range filtering gains of 20 db to 30 db can be achieved when replacing tubular feed-throughs by discoidal units. Because of this merit, improved shielding methods, which are discussed, are required.

INTRODUCTION

Standard ceramic capacitors are unsuitable for filtering purposes at higher frequencies, since unavoidable lead length introduces a high impedance in the form of a series inductance in the shunt branch of the filter. Use of the tubular feed-through capacitor removes this inductance from the shunt arm and places it in the series branch where it is desirable. However, internal cavity effects inherent in the tubular element cause parallel resonance of the coupling impedance at relatively low frequencies. Since parallel resonance represents a high impedance, which is quite the opposite of what is desired in the shunt branch of any low-pass filter, these resonances must be eliminated or shifted to higher frequencies where the capacitor will not be used.

A recent paper discusses methods of minimizing the pronounced resonance effects occurring in tubular feed-through capacitors used in the UHF range.[1] The present paper, rather, deals predominantly with discoidal feed-through capacitors, and shows theoretically and experimentally their superiority over the tubular type with respect to UHF performance. Mechanical ruggedness of discoidal feed-through capacitors represents an added merit.

COUPLING IMPEDANCE OF TUBULAR FEED-THROUGH CAPACITORS

The significant parameter determining the effectiveness of a filter capacitor is its coupling or transfer impedance Z_2[Fig. 1(b)]. Since the high-frequency energy is actually fed "through" the tubular capacitor, the four-pole equations of the line-like element have to be taken into consideration. The cascade matrix of a uniform transmission line is

$$\|A\| = \begin{Vmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{Vmatrix} = \begin{Vmatrix} Z \cosh g & Z \sinh g \\ \frac{1}{Z} \sinh g & Z \cosh g \end{Vmatrix}. \quad (1)$$

For simplicity, the line is assumed, to start with, to be nondissipative. Then (1) reduces to

$$\|A\| = \begin{Vmatrix} \cos b & iZ \sin b \\ i\frac{1}{Z} \sin b & \cos b \end{Vmatrix}. \quad (2)$$

Now, since

$$Z_2 = \frac{1}{A_{21}}, \quad (3)$$

$$Z_2 = -iZ\frac{1}{\sin b}. \quad (4)$$

The frequency dependency of Z_2 of a nondissipative tubular feed-through capacitor is plotted in Fig. 1(c).

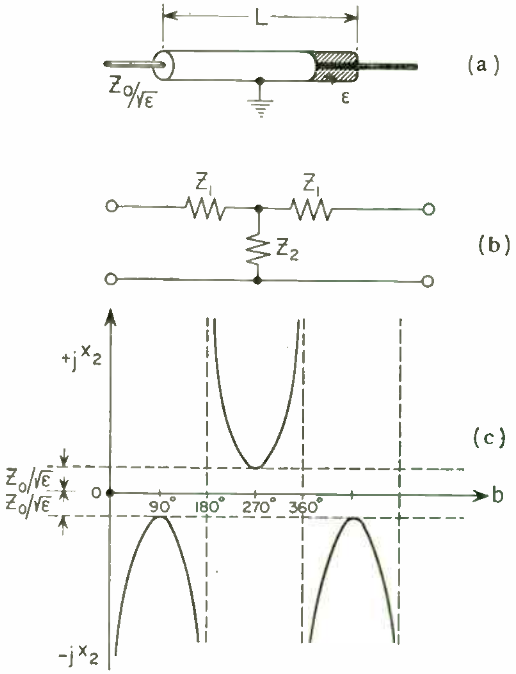

Fig. 1—Tubular feed-through capacitor.

An exemplification pertaining to the order of magnitude of the parameters involved seems indicated. A dielectric constant of $\epsilon = 3{,}600$ makes the line act as if it were $\sqrt{3{,}600} = 60$ times longer electrically than it is mechanically. Simultaneously, if the characteristic impedance of the coaxial structure, neglecting the high ϵ dielectric, is Z_0, (let us say 100 ohms), the characteristic impedance of the feed-through is $Z_0/\sqrt{\epsilon}$ (or, in the case cited, 1.66 ohms). The minimum of Z_2, being $Z_0/\sqrt{\epsilon}$, at 90 electrical degrees, is thus smaller for decreasing values at Z_0 and increasing values of ϵ.

Limitation in mechanical strength prevents making the ceramic tube too thin-walled, thus restricting a drastic decrease in Z_0 and hence, in $Z_{2\,\mathrm{min}}$. Conse-

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† The Allen-Bradley Co., Milwaukee 4, Wis.

[1] W. Slate, "Resonance effects in tubular feed-through capacitors," *Teletech.*, pp. 98–101, 180, 182, 374–78; June, 1954.

quently, $Z_{2\,\text{min.}}$ is in the order of magnitude of 1 ohm for practical tubular capacitors. The parallel resonance of Z_2, occurring at 180 electrical degrees, has an impedance of $(Z_0/\sqrt{\epsilon})Q$. Since Q is in the neighborhood of 2 to 10, the $Z_{2\,\text{max.}}$ is in the vicinity of 2–10 ohms.

More recently, thick-walled tubular feed-through capacitors have been introduced in television tuners, thus securing greater mechanical ruggedness. However, the thicker the wall, the larger Z_0, and therefore, the less is the filtering action. Designers of UHF tuners often specify tubular feed-through capacitors of 200 pF to 300 pF only to avoid resonance effects. Unfortunately, the filtering effect is correspondingly reduced.

Further pertinent points pertaining to the tubular feed-through capacitor will be discussed when comparison is made with the discoidal type.

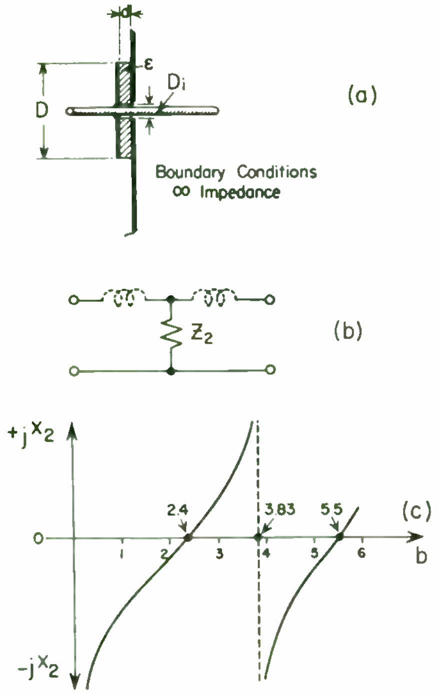

Fig. 2—Discoidal feed-through capacitor.

RESONANCES IN DISC-TYPE FEED-THROUGH CAPACITOR

In contrast to the tubular feed-through capacitor, the discoidal type may be considered as a two-pole, the impedance characteristic of which is to be determined. The lead inductance can be neglected, since it forms part of the desirable series inductance [Fig. 2(b)]. By proper design, the disc feed-through capacitor may be considered as a disc transmission line, the center impedance of which is of interest. To simplify the calculation, the center conductor is assumed to have an infinitely small diameter. Corrections for a finite diameter of the center lead are small for practical purposes and only complicate the transparency of the derivation.

Using nomenclature previously provided,[2] and singling out the $TM^{0\infty}$ modes as the only ones realizable for any kind of excitation with an E_z component, the field equations for H and E are:

$$E_r = -\frac{K_3}{K} J_l'(K_1 r) \cos l\phi \sin K_3 Z, \tag{5}$$

$$E_\phi = l \frac{J_l(K_1 r)}{K_1 r} \sin l\phi \sin K_3 Z, \tag{6}$$

$$E_Z = \frac{K_1}{K} J_l(K_1 r) \cos l\phi \cos K_3 Z, \tag{7}$$

$$H_r = -l \frac{J_l(K_r r)}{K_1 r} \sin l\phi \cos K_3 Z, \tag{8}$$

$$H_\phi = -J_l'(K_1 r) \cos l\phi \cos K_3 Z, \tag{9}$$

$$H_Z = 0. \tag{10}$$

Continuing the process of elimination of possible modes, only quasi-degenerated modes are selected as the ones having the lowest resonant frequencies; hence, the condition $n=0$ reduces (5) and (6) to zero.

Since the wave impedance of the unmetallized periphery of the disc must approach "infinity,"[3] resonances will occur as shown in Table I. The ensuing field distributions are plotted in Fig. 3 (following page) and depicted symbolically in Fig. 4 (following page).

TABLE I

Mode	$\frac{D\pi}{\lambda'}$ for $\frac{d}{D} \to 0$	Conditions: $x \neq 0$ and:
$TM_{110}{}^{0\infty}$	1.83	$J_1'(x)=0$
$TM_{210}{}^{0\infty}$	3.05	$J_2'(x)=0$
$TM_{010}{}^{0\infty}$	3.83	$J_0'(x)=0$

As measurements with a grid-dip meter verify, the two lowest possible modes $TM_{110}{}^{0\infty}$ and $TM_{210}{}^{0\infty}$ can exist by proper feeding of energy from the outside to the cavities. However, having no radial symmetry, they cannot be excited when the capacitor is used as a "feed-through." The $TM_{010}{}^{0\infty}$ mode, then, determines the lowest critical resonance frequency of the discoidal capacitor. At $D/\lambda' = 2.4/\pi$, the voltage is 90 degrees out of phase as seen from the center. Since the disc line is open-ended, the input impedance must correspond to a series resonance as indicated in Fig. 2(c).

Fig. 5 (next page) shows the cross section of a high voltage discoidal feed-through capacitor for shielded two-wire lines carrying subcarrier frequencies. The basic frequency and odd harmonics driving in push-pull (a) are easily filtered with a relatively low capacity, since the magnetic fields cancel in the coaxial structure. The even harmonics (b), however, operating in push-push, condition a high capacity value for effective filtering because of the relatively low frequencies involved. Ferrite rings, applied around the center conductors and not af-

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[2] H. M. Schlicke, "Quasi-degenerated modes in high ϵ dielectric cavities," *Jour. Appl. Phys.*, pp. 187–191; February, 1953.

[3] *Ibid.*, eq. 24(a), p. 188.

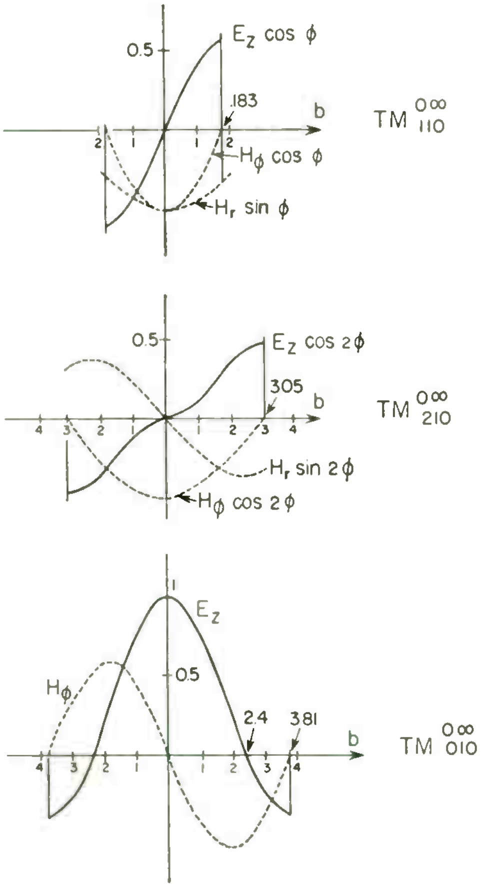


Fig. 3—Lowest quasi-degenerated modes in discoidal feed-through capacitors: field distribution diagrams.

fecting the odd frequencies, permit the use of smaller capacity values because of increased series inductance.

COMPARISON OF BOTH TYPES

The greatest merit of the discoidal feed-through capacitor is its optimum utilization of mechanical dimensions in terms of wave length. Equating the maximum dimension of both structures, namely, length L for the tubular type and diameter D for the disc-type, the $Z_{2\,\mathrm{min.}}$ occurs at

$$\lambda_D' \approx D \frac{\pi}{2.4} \text{ (for the disc)}, \tag{11}$$

and at

$$\lambda_T' = 4L \text{ (for the tube)}. \tag{12}$$

Hence,

$$\frac{\lambda_D'}{\lambda_T'} \approx \frac{\pi}{2.4 \times 4}, \tag{13}$$

or, for the same maximal dimensions of the metallized dielectric, the disc has a series resonant frequency approximately three times higher.

Since the thickness of the dielectric is usually smaller in discs than in tubes, and since the mean diameter of the tube is in practical cases smaller than the length of the tube, then, with both types having the same maximal dimensions, the disc will have the larger capacity. Hence, for the same capacity, the ratio λ_T'/λ_D' can exceed 3 by a perceptible margin.

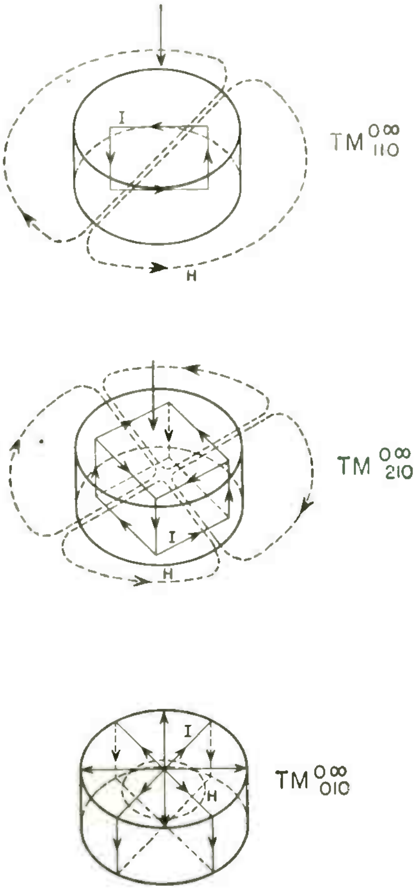


Fig. 4—Field distribution of Fig. 3 shown in schematic, pictorial manner.

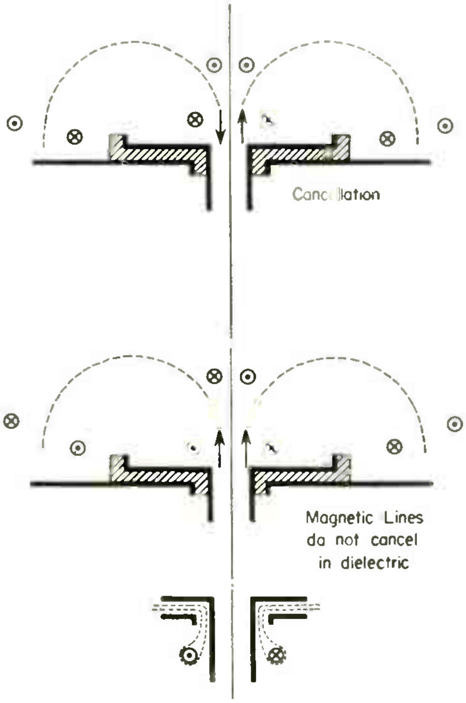


Fig. 5—Discoidal feed-through capacitors for shielded two-wire lines.

An equally significant advantage of the disc is that $Z_{2\,\min.}$ is a "real" series resonance; the minimum resistance, magnitudewise, is given by the equivalent of the series loss resistance of the capacitor at the series resonant frequency, and correspondingly by the parallel loss resistance at the parallel resonant frequency. With the small Q's prevailing in high dielectric constant ceramics at UHF, these values of parallel resonant impedance can be expected to be low. Compare with this the far more limited conditions of the tubular type [eq. (4) and context].

The thickness d and the mean radius being constant, the capacity C_T of the tubular capacitor is

$$C_T = K_1 \epsilon L, \qquad (14)$$

where K_1 is a constant and L is the length of the circular electrode. Since, furthermore, for parallel resonance,

$$\lambda\big|_T = \sqrt{\epsilon}\, 2L \qquad (15)$$

with λ being the wavelength in air, the combination of (14) and (15) renders

$$\lambda\big|_T = \frac{2}{K_1} \frac{C_T}{\sqrt{\epsilon}} \cdot \qquad (16)$$

This means that the parallel resonant frequency is higher for increasing values of $\sqrt{\epsilon}$, and also, that the parallel resonant frequency is inversely proportional to the value of the capacity.

In the case of the discoidal capacitor (as before, with the premise of constant thickness d and negligible r_i), the capacity C_D increases with the square of the radius r_0, thus,

$$C_D \approx K_2 \epsilon r_0^2. \qquad (17)$$

The parallel resonance occurs at

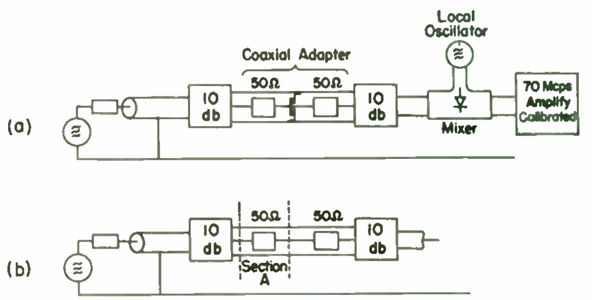
$$\lambda\big|_D \approx \sqrt{\epsilon}(2r_0) \frac{\pi}{3.83} \cdot \qquad (18)$$

Hence, from (17) and (18),

$$\lambda\big|_D \approx \frac{2\pi}{3.83} \frac{\sqrt{C_D}}{\sqrt{K_2}} \cdot \qquad (19)$$

In a disc-type feed-through capacitor, the resonant frequency is independent of the dielectric constant and is proportional only to the reciprocal of the square root of the capacitance.

The frequency dependency of the absolute value of the coupling impedance Z_2 of both types of capacitors was determined experimentally by measuring the insertion loss in coaxial structures, as shown in Fig. 6. Typical examples selected from an extensive experimental investigation are juxtaposed in Fig. 7. The results confirm the theoretical statements made before, when the dispersion of ϵ occurring in the UHF range and the corrections for finitely thin center holes in the discs are taken into account. These corrections, being quite involved, have been omitted from this report. In addition, further corrections for "Effective" Q's are required from a theoretical standpoint, particularly since the Q's encountered in GMV dielectrics are small in the uhf range. The frequency for the minimum of Z_2 for discoidal capacitors can, in practical cases, be up to 20 per cent lower than the series resonance frequency calculated. Actually, then, determination of Z_2, either, as indicated, by insertion loss measurements or by slotted line measurements, is to be preferred to evaluation of the dielectric per se.



(a) $\left.\begin{matrix}1000\,pF\\100\text{ Mcps}\end{matrix}\right\}-j\,1.6\,\Omega$ $\frac{50\Omega}{1.6\Omega} = 30$ db

(b) Section A: $\alpha = \frac{R}{2Z} = \frac{50}{100}$ not admissible since approximation for small a

Actually measured : 2 db at VHF
2.5 db at UHF

Hence: 1000pF at 10^8cps is 30 db − 2 db = 28 db

Fig. 6—Schematic diagram for determining insertion loss.

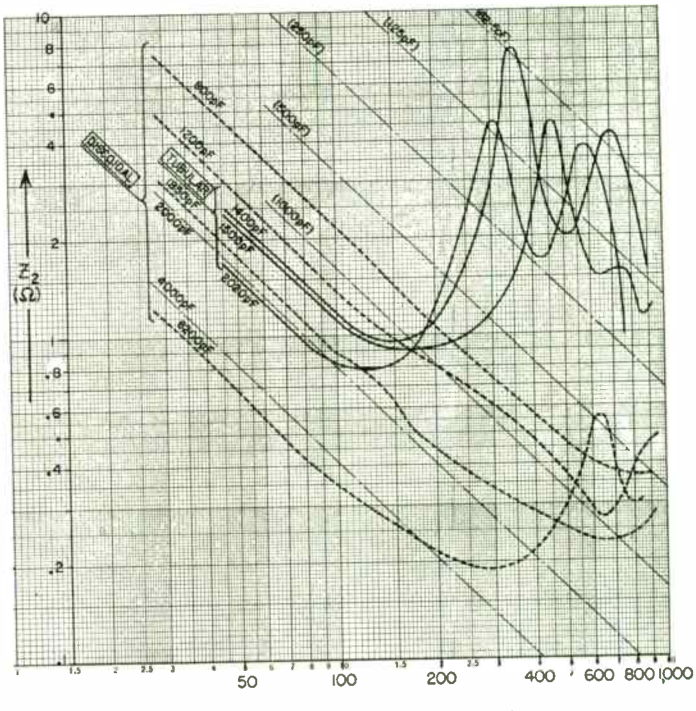


Fig. 7—Comparison of coupling impedance Z_2 for discoidal and tubular feed-through capacitors.

Fig. 7 gives the absolute value of the coupling impedance over frequency for discs (broken lines) and tubes (solid lines). Although the main interest is centered on the capacitance range between 1,000 pF to 2,000 pF, a disc feed-through capacitor of 6,200 pF with a ceramic disc a half inch in diameter is included in the diagram, to shift a parallel resonance of the discoidal types into the UHF range. All other disc-type feed-through capacitors are made of ceramic discs less than a quarter of an inch in diameter which have their parallel resonances in the neighborhood of 2,000 mc. The tubular feed-through capacitors are representative of commercially available types like those used in television tuners and military equipment.

It is evident from Fig. 7 that the use of discoidal feed-through capacitors in certain frequency ranges can easily provide a gain of 20-30 db over the tubular type, though both types have the same capacitance value. Tests of the mechanical strength of discoidal feed-through capacitors showed that rather than the capacitor being destroyed, the eyelets are bent by mechanical impact. Prototypes of discoidal feed-through capacitors are shown in Fig. 8.

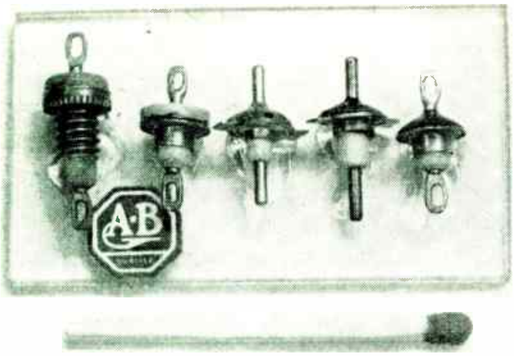


Fig. 8—Some prototypes of discoidal feed-through capacitors.

ADDITIONAL SHIELDING CONSIDERATIONS

Since, as shown, the discoidal feed-through capacitor provides perceptibly improved filtering, shielding problems must also be considered. In order not to upset the gain obtained by use of the discoidal capacitor, more effective means of shielding than might normally be considered necessary may be required.

It is assumed that the proper techniques for the most effective arrangement of joints is known. However, in a number of cases, holes may have to be provided in the shield for the purpose of ventilation, accessibility of adjusting elements, or for mechanically moving members. Two cases are distinguished: Fig. 9(a), penetration of an electric field through a hole of radius r; and Fig. 9(b), penetration of the magnetic field through a hole of radius r. In the former case, if the distance R is much larger than r, the penetrating electric field can be represented by an electric dipole, generating a potential

$$U_C = \frac{r^3}{3\pi R^2} E_0 \cos\delta. \tag{20}$$

In the latter case, again for $R \gg r$, the penetrating magnetic field can be substituted for by a magnetic dipole

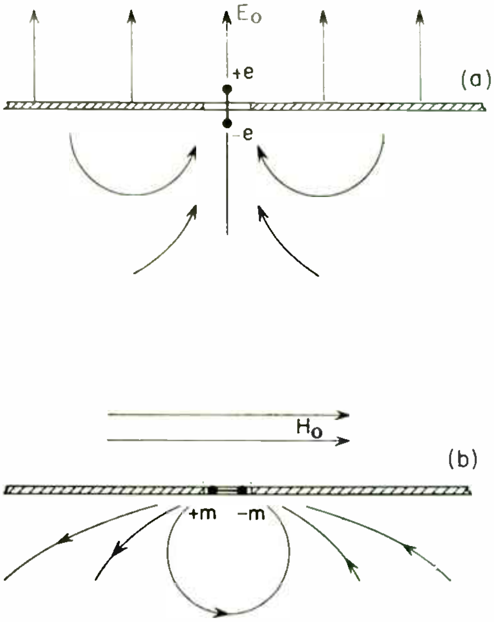


Fig. 9—Equivalent dipole sources for holes in shields.

generating a potential

$$I_m = \frac{r^3}{3\pi R^2} H_0 \sin\phi \sin\delta.\text{[4]} \tag{21}$$

By use of metallic tubes which are attached to the holes and act as attenuating wave-guides below cut-off frequency, undesirable emergence of HF fields through holes, can be effectively suppressed. Fig. 10 facilitates the calculation of this "chimney effect."

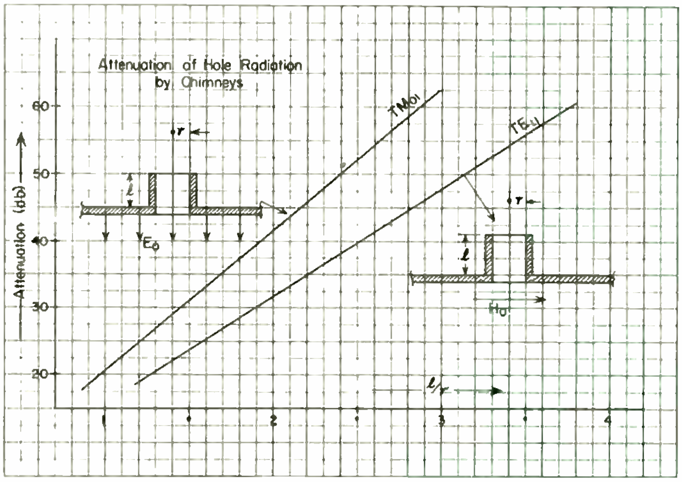


Fig. 10—"Chimney effects" of metallic tubes.

ACKNOWLEDGMENT

The author greatly appreciates the assistance in making the measurements given by R. Wickline.

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[4] Eqs. (20) and (21) are taken from H. Kaden, "Die elektromagnetische Schirmung in der Fermelde und Hochfrequenz Technik," *Springerverlag*, pp. 163, 174; 1950.

Theory and Design of Wide-Band Multisection Quarter-Wave Transformers*

R. E. COLLIN†

Summary—**A general theory of the n-section quarter-wave transformer is presented. It is shown that optimum bandwidth with a minimum pass band tolerance is obtained when the power loss ratio is chosen to give Tchebycheff behavior in the pass band. A comparison is made of the Tchebycheff transformer and the maximally flat transformer, and shows that the former gives a large increase in bandwidth—e.g., up to 44 per cent for a 2-section transformer and up to 75 per cent for a 4-section transformer. Design formulas are given for the 2, 3 and 4-section transformers.**

INTRODUCTION

TO DATE NO general theory of the n-section quarter-wave transformer has been advanced. It is a simple task to design an n-section transformer to give a match at a single frequency f_0, the requirements being that each section is a quarter-wave long at the frequency f_0 and that

$$\frac{Z_1}{Z_2}\frac{Z_3}{Z_4}\frac{Z_5}{—}\cdots\frac{Z_n}{\sqrt{R}} = 1$$

where Z_i is the normalized characteristic impedance of section (i) and R is the normalized resistive load impedance. This does not give a unique design and the performance of any particular design over a band of frequencies may be far from optimum. In the past it has been the usual practice to arrange the characteristic impedances according to the following empirical law:[1]

$$\log\frac{Z_{i+1}}{Z_i} = \frac{C_i{}^n \log R}{\sum_{i=0}^{n} C_i{}^n},$$

where $C_i{}^n$ is the binomial coefficient given by

$$C_i{}^n = \frac{n(n-1)(n-2)\cdots(n-i+1)}{i!}.$$

The resulting transformer is referred to as a binomial transformer for obvious reasons. A somewhat different binomial transformer design, whereby the reflection coefficients from the various sections are made proportional to $C_i{}^n$, has also been used.[2] For values of R close to unity the two design procedures are identical. The 2-section binomial transformer has a maximally flat bandwidth curve for all values of R. For $n>2$ it may be shown that the binomial transformer does not represent a maximally flat design except for values of R close to unity. In general, the first design discussed above gives a closer approximation to a maximally flat bandwidth curve than does the alternative design. An n-section transformer is said to have a maximally flat bandwidth curve when the reflection coefficient and its first n-1 derivatives with respect to frequency vanish at f_0.

It is known that by tolerating a certain mismatch in the pass band, a greater over-all usable bandwidth can be obtained.[3,4] The problem is very similar to that of designing a pass band filter or a broadside antenna array to give an optimum beamwidth with as low a side lobe level as possible.[5-7] In view of this, it is not surprising to find that optimum performance is obtained by the use of Tchebycheff polynomials. The procedure adopted in this paper is, briefly, to determine the characteristic impedances Z_i, so that the load is perfectly matched at n different frequencies and the maximum mismatch between the zeros in the pass band is constant.

WAVE MATRIXES

The type of structure to be analyzed is illustrated in Fig. 1. The transformer consists of n lossless sections, each of electrical length θ, and terminated in a pure resistive normalized load R. The normalized characteristic impedance of section (i) is Z_i. It is assumed that the phase velocity in any section (i) and the characteristic impedances Z_i are independent of frequency. Thus the phase shift across any section at a frequency f is equal to $(\pi/2)\ (f/f_0)$ where f_0 is the frequency at which each section is a quarter-wave long. For a wave incident on section (i) from the left, the reflection coefficient and

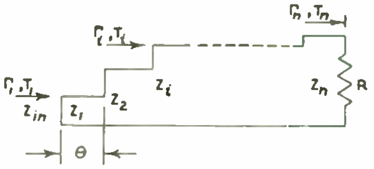

Fig. 1—Schematic of n-section transformer.

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† Canadian Armament Res. and Dev. Establishment, Valcartier, Quebec, Can.

[1] G. C. Southworth, "Principles and Application of Waveguide Transmission," D. Van Nostrand Co., Inc., New York, N. Y., pp. 272–273; 1950.

[2] G. J. Halford, "A wide-band waveguide phase-shifter," *Jour. I.E.E.*, Part III, vol. 100, pp. 117–124; May, 1953.

[3] Halford, *ibid.*

[4] R. E. Collin and J. Brown, "Properties of two quarter-wave transformers," *Wireless Eng.*, vol. 31, pp. 31–35; February, 1954.

[5] D. Krauss, "Antennas," McGraw Hill Book Co., Inc., New York, N. Y., pp. 97–108; 1950.

[6] P. I. Richards, "Universal optimum response curves for coupled resonators," PROC. I.R.E., vol. 34, pp. 621–629; September, 1946.

[7] P. I. Richards, "Resistor-transmission-line circuits," PROC. I.R.E., vol. 36, pp. 217–220; February, 1948. Richards has shown here, by the introduction of a frequency transformation, that there is a one-to-one correspondence between the driving point impedance of lumped-constant circuits and circuits composed of resistors and transmission lines of commensurable length.

amplitude transmission coefficient are Γ_i and T_i respectively. The reflection and amplitude transmission coefficients are related to the impedances Z_i as follows:

$$\Gamma_i = \frac{Z_i - Z_{i-1}}{Z_i + Z_{i-1}}, \qquad T_i = 1 + \Gamma_i. \tag{1}$$

It is required to find the over-all transmission coefficient for the whole structure, and this is most readily accomplished by matrix methods.

Consider, first of all, a general discontinuity in a transmission line, as illustrated in Fig. 2. The incident and reflected waves are related through the reflection and transmission coefficients looking into the ends of the structure as follows:

$$b_1 = \Gamma_1 a_1 + T_2 b_2$$
$$a_2 = \Gamma_2 b_2 + T_1 a_1,$$

or in matrix form:

$$\begin{bmatrix} b_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} \Gamma_1 & T_2 \\ T_1 & \Gamma_2 \end{bmatrix} \begin{bmatrix} a_1 \\ b_2 \end{bmatrix}. \tag{2}$$

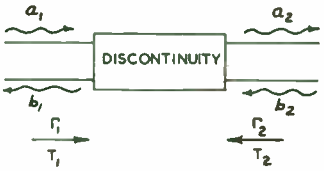

Fig. 2—General discontinuity on a transmission line.

Since an n-section transformer is a cascade structure, it will be more convenient to have a relation connecting the values of the input quantities to those of the output quantities. Since the discontinuity is a linear passive structure, one may write:

$$\begin{bmatrix} a_1 \\ b_1 \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} a_2 \\ b_2 \end{bmatrix}. \tag{3}$$

The matrix elements A_{ij} are obtained from (2) and are given by:[8]

$$A_{11} = \frac{1}{T_1}, \quad A_{12} = \frac{-\Gamma_2}{T_1}, \quad A_{21} = \frac{\Gamma_1}{T_1}, \quad A_{22} = T_2 - \frac{\Gamma_1\Gamma_2}{T_1}, \tag{4}$$

where

$$\Gamma_1 = \frac{b_1}{a_1}\bigg|_{b_2 = 0}, \qquad \Gamma_2 = \frac{a_2}{b_2}\bigg|_{a_1 = 0},$$

$$T_1 = \frac{a_2}{a_1}\bigg|_{b_2 = 0}, \qquad \frac{b_1}{b_2}\bigg|_{a_1 = 0} = T_2 = T_1.$$

It has been assumed that the amplitudes have been normalized, so that $a_i a_i^*$ is equal to the power carried by the wave of amplitude a_i. The equality of T_1 and T_2 follows by the reciprocity theorem in view of the above conditions. For a cascade connection, the output quantities of one section are the input quantities of the next section; so it is readily seen that the over-all A matrix will be the matrix product of the individual A matrixes. Furthermore the over-all transmission coefficient T is equal to the reciprocal of the element in the first row and column of the resultant A matrix, i.e., $1/T = A_{11}$. By analogy with circuit theory, the quantity $1/T$ will be called the voltage insertion ratio and $1/TT^*$ the power loss ratio, since it is equal to the ratio of the incident power to the power absorbed by the load.

Wave Matrix for Junction of Two Transmission Lines

Before the A matrix for the transformer illustrated in Fig. 1 can be obtained, it is necessary to obtain the matrix for the junction of two transmission lines as illustrated in Fig. 3. Absolute amplitudes are used and, hence, $T_1 \neq T_2$, since the characteristic impedance of each line is different. The amplitudes can be normalized by dividing them by the square root of the characteristic impedance of the appropriate transmission line.

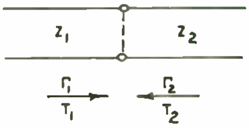

Fig. 3—Junction of two transmission lines.

Looking into the junction from the left, the reflection and amplitude transmission coefficients are Γ_1 and T_1 respectively, and are given by:

$$\Gamma_1 = \frac{Z_2 - Z_1}{Z_2 + Z_1}, \qquad T_1 = 1 + \Gamma_1 = \frac{2Z_2}{Z_2 + Z_1}.$$

Looking into the structure from the right, the corresponding quantities are:

$$\Gamma_2 = -\Gamma_1, \qquad T_2 = 1 + \Gamma_2 = \frac{2Z_1}{Z_2 + Z_1} \neq T_1.$$

From (4) the matrix elements are found to be:

$$A_{11} = \frac{1}{T_1} = \frac{Z_2 + Z_1}{2Z_2}, \quad A_{12} = \frac{\Gamma_1}{T_1} = \frac{Z_2 - Z_1}{2Z_2}, \quad A_{21} = A_{12},$$

$$A_{22} = T_2 - \frac{\Gamma_1\Gamma_2}{T_1} = \frac{T_2T_1 + \Gamma_1^2}{T_1} = A_{11}. \tag{5}$$

For the junction of two transmission lines one therefore has:

$$\begin{bmatrix} a_1 \\ b_1 \end{bmatrix} = \frac{1}{T_1} \begin{bmatrix} 1 & \Gamma_1 \\ \Gamma_1 & 1 \end{bmatrix} \begin{bmatrix} a_2 \\ b_2 \end{bmatrix},$$

which, in terms of the impedances Z_1 and Z_2, may be

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[8] G. L. Ragan, "Microwave Transmission Circuits," McGraw-Hill Book Co., Inc., New York, N. Y., Radiation Lab. Series, vol. 9, pp. 551–553; 1948.

written as:

$$\begin{bmatrix} a_1 \\ b_1 \end{bmatrix} = \frac{1}{2Z_2}\begin{bmatrix} Z_2+Z_1 & Z_2-Z_1 \\ Z_2-Z_1 & Z_2+Z_1 \end{bmatrix}\begin{bmatrix} a_2 \\ b_2 \end{bmatrix}. \qquad (6)$$

In a similar manner, it is easily shown that the A matrix for a transmission line of electrical length θ is simply:

$$\begin{bmatrix} e^{j\theta} & 0 \\ 0 & e^{-j\theta} \end{bmatrix}. \qquad (7)$$

This assumes that the phase change in a wave propagating down the line is $e^{-j\theta}$. One may now write the matrix for the junction of the two transmission lines, plus a line of electrical length θ, by multiplying the A matrixes from (6) and (7) together. Thus:

$$\begin{aligned} A &= \frac{1}{2Z_2}\begin{bmatrix} (Z_2+Z_1)e^{j\theta} & (Z_2-Z_1)e^{-j\theta} \\ (Z_2-Z_1)e^{j\theta} & (Z_2+Z_1)e^{-j\theta} \end{bmatrix} \\ &= \frac{1}{2}\left[A + \frac{Z_1}{Z_2}B\right], \end{aligned} \qquad (8)$$

where A and B are the following matrixes:

$$A = \begin{bmatrix} e^{j\theta} & e^{-j\theta} \\ e^{j\theta} & e^{-j\theta} \end{bmatrix}, \qquad B = \begin{bmatrix} e^{j\theta} & -e^{-j\theta} \\ -e^{j\theta} & e^{-j\theta} \end{bmatrix}.$$

Wave Matrix for Cascade Connection of n Sections

Referring to Fig. 1, it is seen that an n-section transformer is a cascade connection of transmission line junctions, each separated by a length of transmission line of electrical length θ. By an application of (8), the over-all A matrix may be written down at once and is given by:

$$A = \frac{1}{2^{n+1}}\left[\prod_{i=1}^{n}\left(A + \frac{Z_{i-1}}{Z_i}B\right)\right]\left[A_0 + \frac{Z_n}{R}B_0\right], \qquad (9)$$

where the matrixes A_0 and B_0 are defined as follows:

$$A_0 = \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}, \qquad B_0 = \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}.$$

This matrix product will contain such terms as A^n, B^n, $A^r B^{n-r}$, $B^r A^{n-r}$, $B^s A^r B^{n-s-r}$ etc., which are all post-multiplied by either A_0 or B_0. The reduction of these terms to simpler forms is easily carried out by means of the identities given in Table I. These reduction formula were obtained by a simple, straightforward application of the rules of matrix multiplication. The element A_{11} will be the sum of all the elements from the first row and first column of each individual matrix product term. The elements A_{11}, for the various types of terms that arise, are given in Table II. The over-all amplitude transmission coefficient, which is equal to A_{11}^{-1}, may now be evaluated for any particular case by reference to Tables I and II (at right).

Power Loss Ratio Polynomial

The reciprocal of the amplitude transmission coefficient is the element A_{11} from the over-all A matrix. Therefore the power absorbed by the load, when a wave of unit amplitude is incident on the transformer, is $(A_{11}A_{11}^*R)^{-1}$ where A_{11}^* is the complex conjugate of A_{11}. The power loss ratio is $A_{11}A_{11}^*R$ and the insertion ratio is $A_{11}\sqrt{R}$. Tables I and II demonstrate that the power loss ratio has the following properties:

1. It is an even polynomial of $\cos\theta$ of degree $2n$. From Table I it is seen that when the matrix term contains A or B, the sum of the powers of $\cos\theta$ and $\sin\theta$ is equal to $n-1$. When the matrix term contains the product AB or BA, the sum of the powers of $\sin\theta$ and $\cos\theta$ is $n-2$. From Table II it is seen that the elements A_{11} will be of the form $(2\cos\theta)^n$, $j(2\cos\theta)^{n-1}\sin\theta$, $(2\cos\theta)^{n-2}\sin^2\theta$, $j(2\cos\theta)^{n-3}\sin^3\theta$ or, in general, $(2\cos\theta)^{n-2s}\sin^{2s}\theta$, $j(2\cos\theta)^{n-2s-1}\sin^{2s+1}\theta$. Thus the real part of the voltage insertion ratio contains only even powers of $\sin\theta$ not exceeding n and only the odd or even powers of $\cos\theta$ up to n. The imaginary part contains only the odd powers of $\sin\theta$ not exceeding n and only the even or odd powers of $\cos\theta$ up to $n-1$. Therefore the power loss ratio contains only even powers of $\cos\theta$ up to $2n$. The terms involving even powers of $\sin\theta$ may be reduced by the trigonometric identity $\sin^2\theta = 1-\cos^2\theta$.

2. The power loss ratio for an n-section transformer is of the degree $2n$ and has, at most, $n+1$ adjustable coefficients. When $\cos\theta=1$, each section is of electrical length zero and the input impedance is simply R. Thus the power loss ratio must be equal to $(R+1)^2/4R$, since the amplitude transmission coefficient is $2R/(R+1)$ when $\cos\theta=1$. This relation determines one point on the power loss ratio polynomial and leaves, at most, n adjustable coefficients determinable by specifying the n characteristic impedances Z_i. Alternatively one may specify the n adjustable coefficients to give a certain specified behavior; then determine impedances Z_i.

3. Since the power loss ratio polynomial is an even function of $\cos\theta$, it is symmetrical about the point $\cos\theta=0$, i.e., symmetrical with respect to frequency about the frequency $f=f_0$ where $\theta=\pi/2$.

TABLE I

A^n	$=(2\cos\theta)^{n-1}A$
B^n	$=(2\cos\theta)^{n-1}B$
A^rB^{n-r}	$=(2\cos\theta)^{n-2}AB$
B^rA^{n-r}	$=(2\cos\theta)^{n-2}BA$
$A^sB^rA^{n-s-r}$	$=(2\cos\theta)^{n-3}(-4\sin^2\theta)A$
$B^sA^rB^{n-s-r}$	$=(2\cos\theta)^{n-3}(-4\sin^2\theta)B$
$A^sB^rA^tB^{n-s-r-t}$	$=(2\cos\theta)^{n-4}(-4\sin^2\theta)AB$
$(AB)^s$	$=(-4\sin^2\theta)^{s-1}AB$
$(BA)^s$	$=(-4\sin^2\theta)^{s-1}BA$
etc.	

TABLE II

Matrix	Element A_{11}
AA_0	$2\cos\theta$
AB_0	$2j\sin\theta$
BA_0	$2j\sin\theta$
BB_0	$2\cos\theta$
ABB_0	$4j\sin\theta\cos\theta$
ABA_0	$-4\sin^2\theta$
BAB_0	$-4\sin^2\theta$
BAA_0	$4j\sin\theta\cos\theta$

$$ABABAB\cdots,\ n \text{ factors} = \begin{cases} (-4\sin^2\theta)^{n-1/2}A, & n \text{ odd} \\ (-4\sin^2\theta)^{n-2/2}AB, & n \text{ even} \end{cases}$$

Specification of Power Loss Ratio Polynomial

If one writes the power loss ratio polynomial as:

$$\text{Power loss ratio} = P_L = 1 + Q_{2n}(\cos\theta),$$

where $Q_{2n}(\cos\theta)$ is an even polynomial of degree $2n$ in $\cos\theta$, then physical intuition suggests that optimum performance will be obtained if the polynomial Q_{2n} has n double zeros in the pass band and is such that the power loss ratio reaches the same maximum between zeros in the pass band. This same requirement is specified in the design of pass band filters and hence P_L will be put equal to:[9]

$$1 + k^2T_n^2\left(\frac{\cos\theta}{p}\right), \tag{10}$$

where $T_n(x)$ is the Tchebycheff polynomial of degree n, p is a scale factor, and k^2 is a constant which will be called the pass band tolerance, since $1+k^2$ is the maximum value of P_L in the pass band. The Tchebycheff polynomials are chosen because they oscillate between ± 1, pass through the points $1, \pm 1; -1, \pm 1$; and all the zeros of $T_n(x)$ occur in the range $|x| < 1$. The transformer designed to give Tchebycheff behavior in the pass band will be referred to as the Tchebycheff transformer. The determination of the Z_i to give Tchebycheff behavior will be considered in a later section.

Characteristics of Tchebycheff Transformer

The bandwidth and pass band tolerance of an n-section transformer are determined by the properties of the Tchebycheff polynomial of degree n and the load impedance R without a knowledge of the impedances Z_i. The zeros of $T_n\,[(\cos\theta)/p]$ occur when $\cos\theta = px_s = \cos\theta_s$ and $s = 1, 2, \cdots n$, where x_s are the zeros of $T_n(x)$. The scale factor p is given by:

$$p = \frac{\cos\theta_s}{x_s}, \tag{11}$$

where s corresponds to any one particular zero of $T_n(x)$. When $\cos\theta = 1$ the input impedance to the transformer is R and the amplitude transmission coefficient is $2R/(R+1)$. Therefore the power loss ratio is:

$$\begin{aligned} P_L = \frac{(R+1)^2}{4R} &= 1 + k^2T_n^2\left(\frac{1}{p}\right) \\ &= 1 + k^2T_n^2(x_s \sec\theta_s). \end{aligned} \tag{12}$$

This equation may be solved for the pass band tolerance k^2 and gives:

$$k^2 = \frac{(R-1)^2}{4R}\,T_n^{-2}(x_s\sec\theta_s). \tag{13}$$

It is seen that if the scale factor p is chosen, the pass band tolerance is fixed, and vice versa. The edge of the pass band occurs when $T_n(x) = Tn(1) = 1$, or $\cos\theta = p = (\cos\theta_s)/x_s$. If p were taken equal to unity, then the pass band would cover a 200 per cent frequency band and the tolerance in the pass band would be $(R-1)^2/4R$, which would give a power loss ratio equal to that existing when there is no matching transformer. For any practical case, therefore, p will always be less than unity. The final expression for the power loss ratio is:

$$P_L = 1 + \frac{(R-1)^2}{4R}\,\frac{T_n^2(x_s\sec\theta_s\cos\theta)}{T_n^2\,(x_s\sec\theta_s)}. \tag{14}$$

Expressions for the reflected power are easily derived from (14), since $1-\rho^2 = P_L{}^{-1}$, where ρ is the modulus of the reflection coefficient. A typical curve of P_L versus frequency, for the case of $n=4$, is given in Fig. 4.

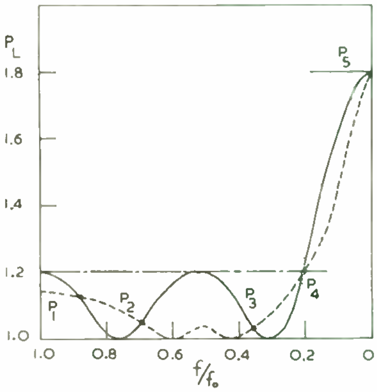

Fig. 4—Typical power loss ratio curve as a function of frequency;

———— $1 + k^2T_4^2\left(\dfrac{\cos\theta}{p}\right)$

- - - - $1 + Q_8(\cos\theta)$

$R = 5, \quad k^2 = 0.2.$

The power loss ratio polynomial has the following properties:

1. It is equal to unity at n values of θ given by $\cos\theta = (\cos\theta_s)x_i/x_s$, $i = 1, 2 \cdots n$ where x_i is a zero of $T_n(x)$. At these points all the incident power is transmitted to the load.
2. Between the zeros P_L has a maximum value of
$$1 + \frac{(R-1)^2}{4R}\,T_n^{-2}(x_s\sec\theta_s),$$
which corresponds to a reflected power of $k^2/(1+k^2)$.
3. The edge of the pass band occurs when $T_n(x) = T_n(1) = 1$, or $\cos\theta = p = (\cos\theta_s)/x_s$, where $\cos\theta_s$ is the value of $\cos\theta$ at the zero x_s.
4. There is no other even polynomial Q_{2n} $(\cos\theta)$ of degree $2n$ passing through the points $\cos\theta = \pm 1$ and $\cos\theta = \pm p$, which has a smaller tolerance in the pass band. If there were, it would have to cross the polynomial $T_n^2[(\cos\theta)/p]$ in at least $n-1$ points in the range $|\cos\theta| < p$. (See Fig. 4 for an illustration of the

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[9] S. Darlington, "Synthesis of reactance 4-poles," *Jour. Math. Phys.*, vol. 18, pp. 257–353; September, 1939.

case where $n=4$.) Therefore the two polynomials have $n+1$ points in common. Since the polynomial is an even function of $\cos\theta$, it has, at most, $n+1$ unknown coefficients and, consequently, the two polynomials must be identical since they have $n+1$ points in common.

5. Conversely no other even polynomial with the same pass band tolerance can have a greater bandwidth, since, if it did, it would imply that the Tchebycheff transformer of the same bandwidth would have a greater tolerance in the pass band and this violates Condition 4 above.

From the above considerations it is concluded that a transformer designed to give Tchebycheff behavior in the pass band is an optimum design as far as maximum bandwidth and minimum pass band tolerance are concerned.

In order to determine the improvement or gain in bandwidth that can be obtained by increasing the number of sections (i.e., increasing n), and keeping the pass band tolerance constant, it is necessary to know how the scale factor p will vary with n. If the power loss ratio tolerance is kept constant at a value that gives a maximum power loss ratio of P_m, then

$$P_m = 1 + \frac{(R-1)^2}{4R}\, T_n^{-2}\left(\frac{1}{p}\right)$$

and, hence,

$$T_n\left(\frac{1}{p}\right) = \sqrt{\frac{(R-1)^2}{4R(P_m-1)}} = C.$$

Solving this equation for p gives:

$$\frac{1}{p} = \frac{1}{2}\left[\left[C+\sqrt{C^2-1}\right]^{1/n} + \left[C-\sqrt{C^2-1}\right]^{1/n}\right].$$

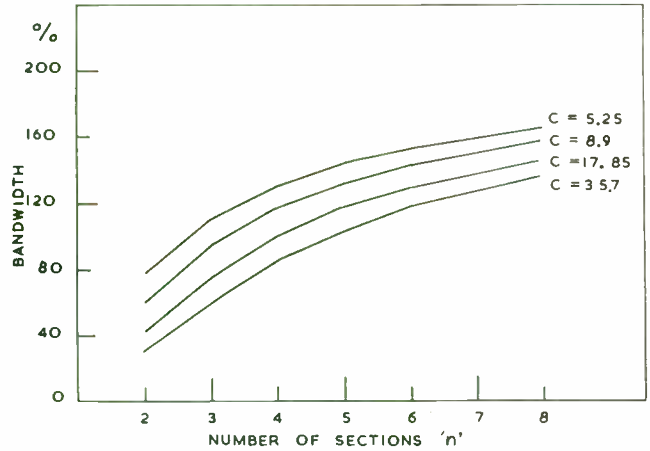

Fig. 5—Bandwidth as a function of n for four values of 'c'

$$c = \frac{R-1}{2\sqrt{R}\sqrt{P_m-1}}.$$

In Fig. 5 above, bandwidth is plotted as function of n for four values of C. These values of C correspond to voltage-standing-wave-ratios in the input line of 1.05, 1.105, 1.225, and 1.355, when $R=5$. The curves show than as n increases, the increase in bandwidth due to additional sections, decreases. It is also seen that a 4-section transformer designed to match a normalized load impedance of 5, with a standing-wave ratio not exceeding 1.05 in the pass band, has an 84 per cent bandwidth.

Comparison with Maximally Flat Transformer

A maximally flat transformer results when the n double zeros all coincide at the frequency f_0, where $\cos\theta=0$. One may therefore write for the power loss ratio:

$$P_L = 1 + k^2\cos^{2n}\theta. \tag{15}$$

When $\cos\theta=1$ [from (12)], $P_L=(R+1)^2/4R$ and, hence, $k^2=(R-1)^2/4R$; and, therefore,

$$P_L = 1 + \frac{(R-1)^2}{4R}\cos^{2n}\theta. \tag{16}$$

To compare the bandwidth of the maximally flat transformer with that of the Tchebycheff transformer it is only necessary to equate (16) to the maximum value of the power loss ratio of the Tchebycheff transformer in the pass band. Thus:

$$1 + \frac{(R-1)^2}{4R}\cos^{2n}\theta_B = 1 + \frac{(R-1)^2}{4R}\, T_n^{-2}(x_s\sec\theta_s),$$

or

$$\sec^n\theta_B = T_n(x_s\sec\theta_s), \tag{17}$$

where θ_B defines the bandwidth limit of the maximally flat transformer. In Fig. 6 the ratio of the Tchebycheff transformer bandwidth to the maximally flat transformer bandwidth is plotted as a function of the maximally flat transformer bandwidth for values of 'n' equal to 2, 3, and 4. It is seen that bandwidth increases of 44, 63 and 75 per cent over the maximally flat transformer bandwidth can be obtained with a properly designed 2, 3, or 4-section transformer, respectively.

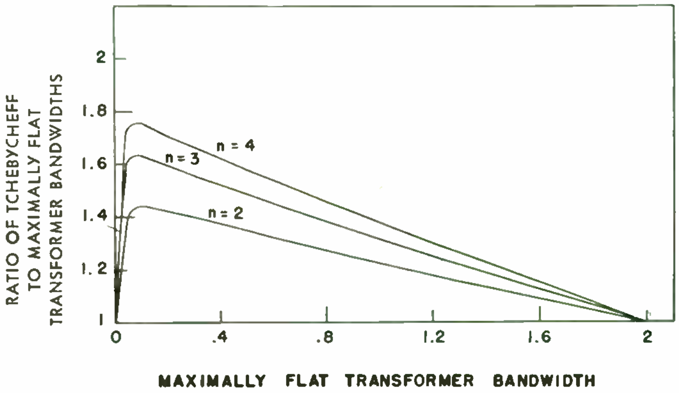

Fig. 6—Ratio of Tchebycheff to maximally flat transformer bandwidths for $n=2$, 3, and 4.

DETERMINATION OF THE IMPEDANCES Z_i

The appropriate values for the characteristic impedances Z_i to give Tchebycheff behavior in the pass band, may be obtained by equating the coefficients of like powers of $\cos\theta$ in the two expressions $A_{11}A_{11}^*R$ and $1+k^2T_n^2[(\cos\theta)/p]$. The procedure is straightforward but becomes very tedious as 'n' increases. The results for $n=2$, 3, and 4 have been worked out and are given below. It is doubtful if in practice a transformer consisting of more than four sections would be required.

2-Section Transformer

The impedance Z_1 is related to the zero θ_1 by the following expression:

$$Z_1^2 = \sqrt{\frac{(R-1)^2}{4\tan^4\theta_1} + R} + \frac{R-1}{2\tan^2\theta_1}$$

where θ_1 is the value of θ at the zero of $T_2[(\cos\theta)/p]$. The value of Z_2 is given by

$$Z_2 = R/Z_1. \tag{19}$$

From (19) it may be shown that $\Gamma_1=\Gamma_3$. The maximally flat transformer is obtained when $Z_1=R^{1/4}$, as may be found from (18) when $\tan\theta_1$ approaches infinity—i.e., the zeros coalesce at $\theta=\pi/2$. This is the binomial transformer. The bandwidth limit of the Tchebycheff transformer occurs at the value of θ given by:

$$\cos\theta = \frac{\cos\theta_1}{x_1} = \sqrt{2}\cos\theta_1. \tag{20}$$

The corresponding bandwidth limit of the 2-section binomial transformer is determined from:

$$\sec^2\theta_B = T_2(x_1\sec\theta_1) = 2x_1^2\sec^2\theta_1 - 1 = \tan^2\theta_1. \tag{21}$$

The power loss ratio is given by:

$$P_L = 1 + \frac{(R-1)^2}{4R}\,\frac{(\sec^2\theta_1\cos^2\theta - 1)^2}{\tan^4\theta_1}. \tag{22}$$

3-Section Transformer

The impedance Z_1 is related to the zero θ_2 by the following equation:

$$\frac{R-1}{\tan^2\theta_2} = Z_1^2 + 2\sqrt{R}Z_1 - \frac{R}{Z_1^2} - \frac{2\sqrt{R}}{Z_1}, \tag{23}$$

where θ_2 is the value of θ at the zero of $T_3[(\cos\theta)/p]$ occurring in the range $0<|\cos\theta|<p$. The values of Z_2 and Z_3 are given by the following relations:

$$Z_1Z_3 = R, \tag{24}$$

$$Z_2^2 = R. \tag{25}$$

The power loss ratio is:

$$P_L = 1 + \frac{(R-1)^2}{4\kappa}\,\frac{T_3^2(x_2\sec\theta_2\cos\theta)}{T_3^2(x_2\sec\theta_2)}$$

$$= 1 + \frac{(R-1)^2}{4R}\,\frac{(\sec^2\theta_2\cos^2\theta - 1)^2\cos^2\theta}{\tan^4\theta_2} \tag{26}$$

The value of θ at the bandwidth limit may be found from:

$$\cos\theta = \frac{2}{\sqrt{3}}\cos\theta_2. \tag{27}$$

If Z_1 is put equal to R^y, then it is found that θ_2 is relatively independent of R as long as the parameter y is held constant. y will lie in the range $1/8 \leqq y < 1/4$. As y approaches 1/8 the zeros come closer together and, in the limit, as R approaches unity, the value $y=1/8$ gives maximum flatness. This is the binomial transformer, and it should be noted that it is maximally flat only in the limit as R approaches unity. For large values of R, y is greater than 1/8 for maximum flatness. However, the binomial transformer does not depart appreciably from a maximum flat design for values of R less than 5. The value of θ at the bandwidth limit of the maximally flat transformer is found from:

$$\sec^3\theta_B = T_3\left(\frac{\sqrt{3}}{2}\sec\theta_2\right) = \frac{3\sqrt{3}}{2}\sec\theta_2\tan^2\theta_2. \tag{28}$$

This is also approximately the value of θ at the bandwidth limit of the binomial transformer. The correct value of Z_1 to give maximum flatness may be found by equating the right-hand side of (23) to zero. The values of Z_2 and Z_3 are given by (24) and (25).

4-Section Transformer

To obtain Tchebycheff behavior in the pass band the impedances Z_1 and Z_3 must be determined to satisfy the following two equations:

$$\tan^2\theta_1\tan^2\theta_2 = \frac{R(R-1)Z_1^2Z_3^2}{(Z_1^4Z_3^4 - R^3)} \tag{29}$$

$$\tan^2\theta_1 + \tan^2\theta_2 = \frac{Z_1^2Z_3^2}{Z_1^4Z_3^4 - R^3}\Bigg[2Z_1Z_3R + \frac{2Z_1R^2}{Z_3} + \frac{R^3}{Z_3^2} + Z_1^2R - \frac{2R^2}{Z_1Z_3} - \frac{2Z_3R}{Z_1} - Z_3^2 - \frac{R^2}{Z_1^2}\Bigg], \tag{30}$$

where θ_1 and θ_2 are the values of θ at the zeros of $T_4[(\cos\theta)/p]$. Eq. (29) may be solved for Z_1Z_3 and gives:

$$Z_1^2Z_3^2 = \frac{R(R-1)}{2\,T_4(x_s\sec\theta_s)} + \sqrt{\frac{R^2(R-1)^2}{4\,T_4^2(x_s\sec\theta_s)} + R^3}$$

$$= \frac{R(R-1)}{2\tan^2\theta_1\tan^2\theta_2} + \sqrt{\frac{R^2(R-1)^2}{4\tan^4\theta_1\tan^4\theta_2} + R^3}. \tag{31}$$

The power loss ratio is given by:

$$P_L = 1 + \frac{(R-1)^2}{4R}\,\frac{T_4{}^2(x_s \sec\theta_s \cos\theta)}{T_4{}^2(x_s \sec\theta_s)}$$
$$= 1 + \frac{(R-1)^2}{4R}\,\frac{[(3+2\sqrt{2})\sec^4\theta_2\cos^4\theta - (4+2\sqrt{2})\sec^2\theta_2\cos^2\theta + 1]^2}{\tan^4\theta_1\tan^4\theta_2}. \tag{32}$$

The values of Z_2 and Z_4 are found from:

$$Z_1Z_4 = Z_2Z_3 = R. \tag{33}$$

The bandwidth limit may be found from the value of θ given by:

$$\cos\theta = \frac{2\cos\theta_2}{(2+\sqrt{2})^{1/2}}, \tag{34}$$

where θ_2 is the value of θ corresponding to the larger root of $T_4[(\cos\theta)/p]$.

For a maximally flat transformer $Z_1{}^4Z_3{}^4 = R^3$, and the quantity in brackets on the right-hand side of (30) must vanish. The binomial transformer is maximally flat only in the limit as R approaches unity. However, the departure from maximum flatness is small for moderate values of R. The bandwidth limit may be determined from the value of θ given by:

$$\sec^2\theta_B = \tan\theta_1\tan\theta_2, \tag{35}$$

and for practical purposes this may also be taken as the bandwidth limit of the binomial transformer.

CONCLUSIONS

It has been shown that, to obtain the maximum bandwidth with a minimum pass band tolerance, an 'n' section transformer must be designed to give Tchebycheff behavior in the pass band. The characteristic of the n-section Tchebycheff transformer is uniquely determined by the properties of the Tchebycheff polynomial of degree n and the value of the normalized load impedance R. This optimum design leads to large increases in bandwidth as compared with the bandwidth of the maximally flat transformer or the binomial transformer.

For the 3- and 4-section transformer, it may be shown that the following relationships hold between the reflection coefficients: $\Gamma_1 = \Gamma_4$, $\Gamma_2 = \Gamma_3$, and $\Gamma_1 = \Gamma_5$, $\Gamma_2 = \Gamma_4$, respectively. This suggests the general law that for an n-section Tchebycheff transformer

$$\Gamma_i = \Gamma_{n+1-i}$$

where $i = 1, 2, \cdots \frac{n}{2}$ for n even and

$i = 1, 2, \cdots \frac{n+1}{2}$ for n odd.

To date, however, no proof of this has been found.

The above theory was restricted to the particular case where the electrical length of all the transformer sections was the same. For the most general case, when the electrical lengths are noncommensurable, the analysis becomes much more involved, since it is now no longer possible to represent the power loss ratio as a finite Fourier series. However, it is doubtful if superior performance could be obtained by using unequal lengths, since in an n section transformer it is not possible to have more than n zeros in the pass band. Each zero requires an adjustment of two parameters (a phase and a modulus) out of a total of $2n$. For the simplest case, that of the 2-section transformer, it can be easily shown that a perfect match at two frequencies is possible only if the lengths of both sections are equal. Although it has not been proved, this result probably holds also for $n > 2$.

APPENDIX A

FIRST-ORDER THEORY FOR SMALL REFLECTIONS

Halford[10] has shown that for small reflections, where all $\Gamma_i \ll 1$, the first-order approximation to the total reflection coefficient is simply:

$$\Gamma = \Gamma_1 + \Gamma_2 e^{-2j\theta} + \Gamma_3 e^{-4j\theta} + \cdots \Gamma_{n+1} e^{-2nj\theta}.$$

Imposing the condition that $\Gamma_1 = \Gamma_{n+1}$, $\Gamma_2 = \Gamma_n$, etc.,

$$\Gamma = {}_2e^{-jn\theta}(\Gamma_1 \cos n\theta + \Gamma_2 \cos \overline{n-2}\theta + \cdots).$$

The power loss ratio is $P_L = (1 - \Gamma\Gamma^*)^{-1}$ which, since $|\Gamma| \ll 1$, may be written as $1 + \Gamma\Gamma^*$. Thus, for Tchebycheff behavior in the pass band, one has

$$P_L = 1 + \Gamma\Gamma^* = 1 + \frac{(R-1)^2}{4R}\,\frac{T_n{}^2(x_s \sec\theta_s \cos\theta)}{T_n{}^2(x_s \sec\theta_s)}$$

and, hence,

$$_2(\Gamma_1 \cos n\theta + \Gamma_2 \cos \overline{n-2}\,\theta + \cdots)$$
$$= \frac{R-1}{2\sqrt{R}}\,\frac{T_n(x_s \sec\theta_s \cos\theta)}{T_n(x_s \sec\theta_s)}.$$

This equation is easily solved for the unknown reflection coefficients Γ_i.

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[10] Halford, *ibid.*

A New High Temperature Silicon Diode*

C. G. THORNTON† AND L. D. HANLEY†, ASSOCIATE, IRE

Summary—**A method of preparing high back voltage silicon by bombarding the surface with oxygen has been devised and a new type of point contact diode prepared. The diode is characterized by: (1) very low saturation currents of the order of 1 microampere, (2) high inverse operating voltages (70–200v), (3) very low barrier capacitance (<0.3 $\mu\mu$f) and rapid recovery times, and (4) operation at elevated temperatures up to 200 degrees C.**

INTRODUCTION

MICROWAVE mixer crystals for radar and video applications have been satisfactorily produced from heavily doped silicon for several years. However, most attempts to produce high back voltage point contact silicon rectifiers by similar techniques have resulted in units which were far inferior to germanium point contact rectifiers.

This paper describes the preparation and properties of a new type of high back voltage point contact diode The diode is characterized by: (1) very low saturation currents of the order of 1 microampere, (2) high inverse operating voltages (70–200v), (3) very low barrier capacitance (<0.3$\mu\mu$f) and rapid recovery times, and (4) operation at elevated temperatures up to 200 degrees C. The diode is produced by a surface bombardment technique which produces desired rectification properties and leaves surface with a thin protective layer.

The use of silicon in high back voltage rectifiers is predicated on the fact that it will withstand a considerably higher temperature rise than germanium without losing its rectification properties. Where the upper limit of satisfactory operation for germanium rectifiers is reached in the range of 75 to 100 degrees C., silicon junction rectifiers have been constructed that operate at temperatures up to 300 degrees C. without suffering a serious loss of rectification efficiency.

PREPARATION

The technique to be reported here was developed after an investigation of the ionic bombardment procedure described by Ohl.[1] The apparatus used is shown schematically in Fig. 1. The filament, grid, and heated support for the silicon, are all enclosed in a suitable high vacuum system, to which a given gas is introduced to a predetermined pressure through a controlled leak. When the system is energized, electrons from the heated filament will pass through the grid structure into the space above the silicon sample, where collisions with molecules of the ambient gas will take place resulting in ion formation. These ions are accelerated through a potential field of several kv and uniformly bombard the silicon surface.

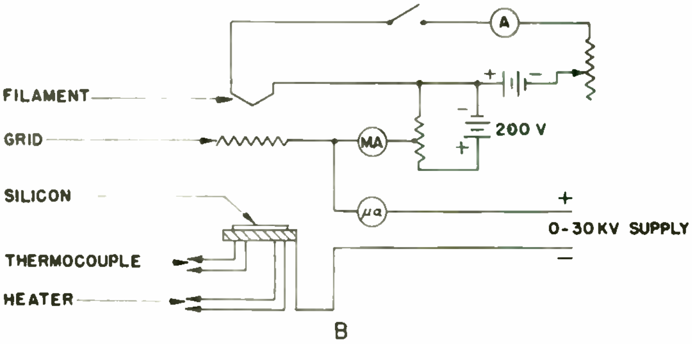

Fig. 1—Oxygen bombardment apparatus.

Several different gases were used in the initial investigation, including helium, argon, nitrogen, and hydrogen. Suitable steps were taken to obtain a good (<10^{-5} mm) vacuum in the system, and the purity of the incoming gas was carefully assured. Under these conditions, only a very slight change could be detected with bombardment. It was decided to try oxygen as a bombarding gas in contrast to the inert or reducing gases mentioned above. The results are shown in Fig. 2, as obtained first with helium and then oxygen on the same starting material. The surprising result was obtained that, the peak inverse voltage could be increased

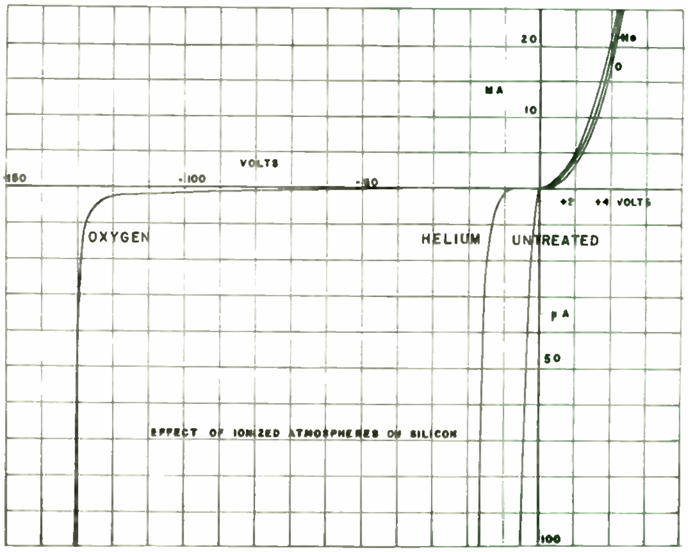

Fig. 2

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† Sylvania Elec. Prods., Inc., Elec. Div., Ipswich, Mass.

[1] R. Ohl, "Properties of ionic bombarded silicon," *Bell Sys. Tech. Jour.*, pp. 104–121; January, 1952.

more than an order of magnitude by this treatment, when oxygen was used as compared with helium with reverse resistances as high as 10 megohms up to −40v. It was discovered that the process was readily reproducible and that similar results could be obtained with both high and low resistivity silicon. The chief difference between the two resistivities is the time required to complete the bombardment, and with lower resistivity silicon a lower forward resistance is obtained. On the basis of this observation, it was concluded that the reverse characteristic is relatively independent of the carrier concentration in the silicon substrate.

In view of the extremely large increase in the peak inverse voltage, it is believed that the effect of the bombardment is to reduce the effective carrier concentration at the surface through the introduction of new trapping levels in the forbidden region. Possible mechanisms include: (1) actual bombardment damage as described by Lark-Horovitz[2] for bulk semiconductors tending to shift the Fermi level toward the center of the forbidden region, and (2) an effective change in the chemical composition (formation of an oxide or an adsorbed oxygen layer) at the surface which could function as a trapping site. Additional experiments are presently being carried out which should shed further light on this aspect of the problem.

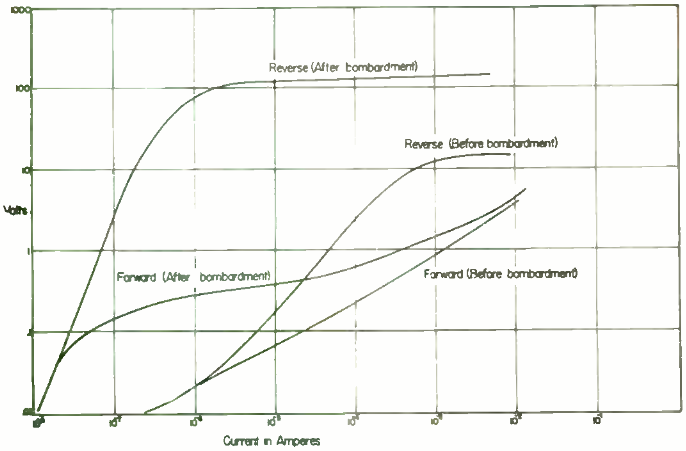

Fig. 3—Rectification characteristics of oxygen bombarded silicon.

A typical point contact rectification curve for oxygen bombarded silicon is shown in Fig. 3. The initial material was about 0.5 ohm cm p-type silicon, with a peak inverse voltage of about 10v. Although the forward resistance of the diode is increased slightly by the treatment, the increase in resistance in the reverse direction is considerably greater, causing an increase in rectification ratio at 5v from 60 to 10^5.

An additional advantage accrues to the fact that after oxygen bombardment, the surface is found to be extremely inert with respect to the effects of humidity and other surface contaminants. This is attributed to the possible formation of a thin oxide protective layer that appears to passivate the silicon surface. It was found early in the investigation that the effects of the bombardment could be annealed out at temperatures above 300 degrees C. and, therefore, the time during which effective bombardment can be carried on, in this temperature range, is limited to the time required for equilibrium to be established between the annealing and bombarding processes. At temperatures below 250 degrees C., the bombarded surfaces are found to be completely stable. For this reason lower temperatures are presently used and the bombardment can be carried on to advantage for several hours, at the rate of 10 microamperes per square centimeter.

Fig. 4—Silicon single crystal.

In the actual process of preparing the diode, single crystals of boron doped silicon, having the appropriate resistivity, are used. These ingots, such as that shown in Fig. 4, are sliced to obtain wafers about 20 mils in thickness, which are then brought to a high metallographic polish on the sides to be bombarded. The reverse sides of the dice are all plated to obtain a good ohmic contact. These slices are then diced and assembled into diodes, as shown in Fig. 5. Both glass- and ceramic-type packages are shown. The latter is useful where it is desirable to avoid photoelectric effects.

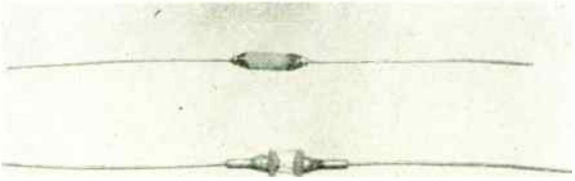

Fig. 5—Silicon point contact high back voltage rectifiers.

Applications

The rectification characteristics of the finished diode, and the effect of temperature up to 150 degrees C., are shown in Fig. 6 (next page). Changes in diode characteristics with temperature should not be interpreted as resulting entirely from changes in silicon surface, as there is unavoidable expansion in the package at elevated temperatures. It is to be noted that the diode adequate-

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[2] K. Lark-Horovitz, "Semiconducting Materials," Butterworth's Scientific Publications, Ltd., London, Eng.; 1951.

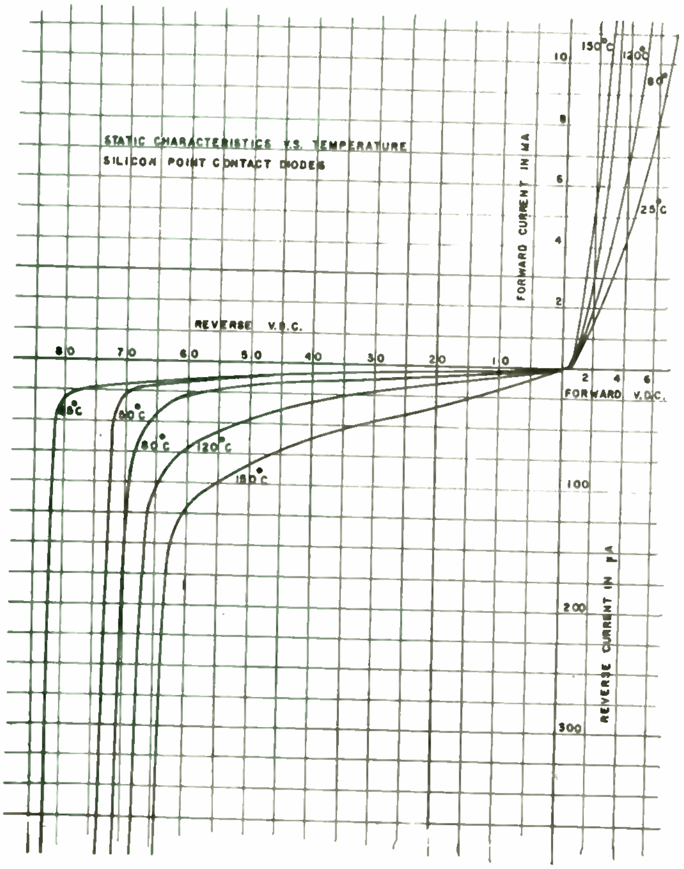

Fig. 6

ly covers a range of operating temperatures where germanium has lost its useful semiconductor properties. Such diodes have been operated at temperatures of 200 degrees or higher, without serious changes in the rectification properties.

In view of the recent development of several types of silicon junction rectifiers, it is useful to compare their electrical properties and applications. The capacitance of silicon junction rectifiers prepared in this laboratory

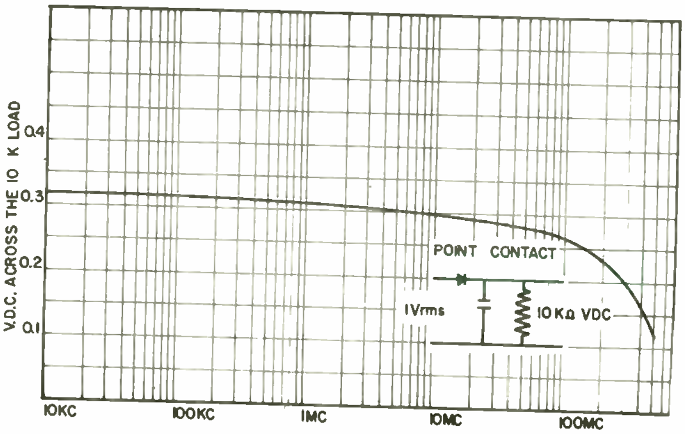

Fig. 7—Frequency response of high temperature diode.

are the order of 10 μμf compared with measured values of less than 0.3 μμf for diodes of the point-contact variety. The frequency response of the point-contact rectifiers is shown in Fig. 7. The frequency cutoff, for the bombarded point contact diodes, is approximately 400 mc, and could probably be extended further by a special package design of the type used in microwave circuits. This may be compared with a frequency cutoff from 0.1 to 15 mc for junction units.

In many computer-type circuits the recovery time of a switching diode is of considerable importance. The recovery time may be specified as that time required to regain 90 per cent of the initial reverse resistance, after switching from the heavy forward current obtained with a forward voltage to a voltage in the reverse direction. The recovery time obtained for germanium point contacts varies from 0.5 microsecond, in a very favorable case, to as long as 5 microseconds. For the silicon diodes described in this paper, the measured recovery time averaged less than 0.1 microsecond. The diodes also have very marked photoelectric effects, and may find wide application in photoelectric devices.

IRE Standards on Radio Aids to Navigation: Definitions of Terms, 1954*

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1. INTRODUCTION

1.1 Definition

Navigation is the process of directing a vehicle to reach the intended destination.

Note 1: Navigation is inherently three-dimensional. It is often reduced to two dimensions by projecting all positions, courses, and speeds upon the surface of the earth. The measurement of a navigational co-ordinate defines a surface of position. The intersection of this surface of position with the surface of the earth is the conventional line of position. The position of the vehicle is at the intersection of three surfaces of position; it may be so defined or it may be defined as the intersection of two lines of position (at the surface of the earth). Thus altitude is ordinarily dealt with independently as one co-ordinate, while the other two are converted into horizontal distance and direction or into latitude and longitude. When the vertical component of a course is of comparable importance to the horizontal components, it is often advantageous to treat the navigational process in terms of three appropriate surfaces of position.

Note 2: Navigation is ordinarily carried out continuously throughout a journey. All observed quantities are functions of time.

Note 3: Several different directions are of interest when a vehicle moves from one point to another as follows:

a. The instantaneous direction in which a vehicle is pointed. (Called "heading" or "ship's head" by mariners.)

b. The intended or average direction in which a vehicle is pointed. (Called "heading" by airmen and "course" or occasionally "course to steer" by mariners.)

c. The intended direction of travel. (Called "course.")

d. The direction of travel at any instant.

e. The average or resultant direction of travel during any given period. (Called "course made good.")

1.2 Conditions

Navigation must be carried on under one or more of three sets of conditions that apply at various distances from the starting point, way points, or destination:

1.2.1 At distances such that the knowledge of position alone is adequate to determine the proper course to the objective.

1.2.2 At distances such that the operation of other vehicles in the vicinity becomes a vital factor in the choice of procedure.

1.2.3 At distances such that the relation between the course of the moving vehicle and the positions of fixed bodies, such as docks or landing strips, assume paramount importance.

1.3 Operations

Navigation consists of four basic operations: dead-reckoning, fixing, pilotage and homing.

1.3.1 Dead-reckoning is the procedure of advancing a known position (computing present position from previous known position) by addition of one or more vectors representing courses and distances.

Note: One or more of the vectors may represent currents in the sea or air. The distances are ordinarily found by measurements of speeds and time intervals.

1.3.2 Fixing is the determination of position without reference to any former position.

Note: In case the various elements of a fix are not obtained simultaneously, they may be converted to a common time. Having obtained two or more fixes, at known time intervals, the navigator may determine or verify certain of the vectors which he uses in dead-reckoning.

1.3.3 Pilotage is the process of directing the movements of a vehicle by reference to recognizable landmarks or soundings. Observation of these may be by optical, aural, mechanical, or electronic means.

1.3.4 Homing is the process of approaching a desired point by maintaining constant some indicated navigational quantity (other than altitude).

1.4 Radio Fixing Aids

There have come into use electronic computers which may or may not use electromagnetic radiation but which can operate solely within the body of a vehicle without the necessity for co-operating radio transmitters located at places other than on the vehicle. This class of system is sometimes referred to as the "self-contained" or non-classical system; for example, navigational airborne radar without racons.

Generally speaking, however, the largest number of radio aids to navigation require the installation of equipment in a vehicle and a counterpart located at a known point. This class of system may be called the "classical" type.

1.4.1 The classical type of radio fixing aids to navigation may be classified in terms of the geometrical relation between the vehicle and the following known points, lines or surfaces:

1.4.1.1 *Single Fixed Vertical Line in Space* (In two-dimensional navigation, the identification of a single point on the surface of the earth.)

1.4.1.2 *Radial Lines-of-Position*

a. Directional aids—The frame of reference is attached to the vehicle.
Example: Radio direction finding from the vehicle.
b. Azimuthal aids—The frame of reference is fixed with respect to the earth.
Example: Omni-Directional Range.

1.4.1.3 *Distance Measurement*

a. Distance from one or more discrete points. (Circular lines of position.)

Example: Shoran, Oboe, or Distance Measuring Equipment (DME).

Note: The measurement involves transmission in both directions over the path. The measurement may be initiated from either the fixed points or the vehicle.

b. Distance from a line. (Cylindrical surface of position.)

Example: Maintenance of a signal of constant amplitude by traveling at a constant distance from a long wire radiating electromagnetic waves with uniform cylindrical symmetry.

c. Distance from a surface. (The surface of position dependent upon the reference surface.)

Example: Radio altimeter (reference is surface of earth).

1.4.1.4 *Distance-Difference Measurement* (Hyperbolic lines of position.)

The difference between the distances from two fixed points is measured without knowledge of either distance.

Example: Loran, Gee.

1.4.1.5 *Distance-Sum Measurement* (Elliptical lines of position.)

The sum of the distances of two fixed points is measured without knowledge of either distance. This process is similar to 1.4.1.3a, except that the transmitter and receiver of the transponder are separated by a fixed known distance.

1.4.1.6 *Composite Aids to Fixing*

The basic process and co-ordinate systems, outlined above, are not mutually exclusive. They may be combined in a wide variety of ways (sometimes by the use of computers) to form numerous specific navigational systems. The various elements of a fix (i.e., co-ordinates of position) may be determined by different basic methods, of which the following are typical examples:

a. Polar co-ordinate methods.

Examples: Radar-PPI (combining 1.4.1.2a and 1.4.1.3a) Omni-Directional Range plus Distance Measuring Equipment (combining 1.4.1.2b and 1.4.1.3c).

b. Point identification (combining 1.4.1.1 and 1.4.1.3c).

Example: Z (Zone) Marker plus altimeter.

c. Hyperbolic-elliptical co-ordinate methods (combining 1.4.1.4 and 1.4.1.5).

d. Intersection of two identifiable surfaces.

Examples: Beam-type instrument approach system (ILS), Ground control of approach radar (GCA).

1.4.2 The classical type of radio fixing aids to navigation may also be classified in terms of the electrical principles, operations, measurements and technique assumed or employed in their operation and construction as follows:

1.4.2.1. *Principles of Classical Type Radio Aids to Navigation*

All classical radio aids to navigation are based on the assumption that propagation is generally over the shortest radio path.

All radio aids to navigation operate on the assumption that the velocity of propagation of radio waves is constant.

Some classes of radio aids to navigation are based on the assumption that radio waves travel at a constant and *known* velocity of propagation. That is, if the velocity of propagation were not known, or were in question, these classes of aids would not be used.

Example: Radar, DME, Benito.

1.4.2.2 *Methods of Operation*

All classical types of radio aids to navigation utilize the transmission of radio waves over one or more paths and the making of a time measurement.

1.4.2.2.1 The first method of operation requires a radio wave to travel only one way from a vehicle to a known point, or from a known point to a vehicle. It is necessary to know the velocity of propagation and it is necessary that there be at one point a device which has a priori knowledge of the time of occurrence of electrical phenomena at the corresponding radio station.

Example: Crystal clock, the output phase of which is compared with that of a received emission (Navarho).

1.4.2.2.2 The second method of operation requires transmission on a round-trip path. The transmission is made from one point and is returned to the same point, permitting the measurement of transit time. This system requires a knowledge of the velocity of propagation.

Examples: Radar, DME, Benito

1.4.2.2.3 The third method of operation requires transmission of radio waves which travel over a multiplicity of paths diverging from the transmitting point.

Example: Direction Finders receiving signals from nondirectional transmitters.

1.4.2.2.4 The fourth method of operation requires transmission of radio waves over a multiplicity of paths which converge on the receiving point.

Examples: Omni-directional radio range; Loran.

1.4.2.3 Time Measurements

1.4.2.3.1 The first class of time measurements determines only the conditions which make the time of transmission over several paths equal.

Example: Rotating-Loop Direction Finder

1.4.2.3.2 The second class of time measurements determines the time difference of transmission over a multiplicity of paths.

Examples: Loran, Decca

1.4.2.3.3 The third class of time measurements determines the total time required for transmission over a path.

Examples: Radar, DME

2. DEFINITIONS OF STANDARD NAVIGATION NOMENCLATURE

Four terms used in navigation: "azimuth," "bearing," "heading," and "course" are defined later. When these words are used without modifier, the reference line from which measurements are made is indefinite. Thus, the definitions of these terms involve measurement of angles from references which are unstated.

Modifiers are used with these words to define the reference. For example, there may be "true heading," and "true course." Each of these is defined hereafter. The modifier "true" gives the reference direction as "true north." The angles for bearing, heading, and course in their "true" sense may be measured by any desired means.

The modifiers and their reference directions are as follows:

True. The reference direction is "true north." In navigation, azimuth is the same as "true bearing." It is suggested, however, that the word azimuth be reserved for celestial angles as used in navigation and for other purposes. Thus, for purely terrestrial navigational use, the term "true bearing" is preferred.

Magnetic. The reference direction is magnetic north.

Compass. The reference direction is north as indicated by a magnetic compass (or repeater). Deviation and calibration error have an effect on the angle of the north point of the card with reference to magnetic north. However, the reference as stated is the north mark on the compass card and the reference reading is obtained at the lubber line on the compass case as indicated on the marked compass scale. "Corrected-compass" means "magnetic," which is given above.

Relative. The reference direction is the vehicle's heading, which is the forward direction along the vehicle's longitudinal center line. "Relative heading" and "relative course" should not be used. The proper terms are, respectively, "heading" and "crab angle."

Grid. The direction of the reference line is established arbitrarily. In grid navigation, a grid is superimposed, in any convenient orientation, over a map. One of the grid lines is designated as the reference line and its direction establishes grid north. In polar navigation, the reference line coincides with Greenwich meridian. North on this grid is usually the direction of the North Pole from Greenwich.

3. DEFINITIONS OF TERMS

A and R Display (also *A and R Scan* or *A and R Scope*). See *Display*.

Absolute Delay. In *Loran* the interval of time between the transmission of a signal from the "*A*" *Station*, and transmission of the next signal from the "*B*" *Station*.

ADF. A designation for an *Automatic Direction Finder* originally designed for use on board aircraft.

A-Display (also *A-Scan* or *A-Scope*). See *Display*.

Aerophare. In air operations a name for *Radio Beacon*.

Aided Tracking. A tracking system in which the manual correction of the tracking error automatically corrects the rate of motion of the tracking mechanism.

AI Radar (Airborne Intercept). An airborne *Radar* used for searching for and tracking other aircraft.

Airport Surveillance Radar (ASR). A *Radar* operating at or near an airport, and used for observation of the *Positions* of airborne aircraft. It is primarily employed in the control and organizing of local traffic.

Air Speed. The rate of motion of a *Vehicle* relative to the air mass.

Alford Loop. A multielement antenna, having approximately equal and in-phase currents uniformly distributed along each of its peripheral elements, producing a substantially circular radiation pattern in the plane of polarization (originally developed as a four-element, horizontally-polarized vhf loop-antenna).

Altimetric Flare-Out. A nonunique descent-path in which the rate of descent is reduced as the touchdown point is approached. The rate reduction is a function of the altimetric measurement of height above ground.

Ambiguity. In *Navigation*, the condition obtaining when *Navigation Co-ordinates* define more than one point, *Direction*, *Line of Position*, or *Surface of Position*.

Amplitude Balance Control. In *Navigation*, that portion of a system which may be varied to adjust the relative output levels of two related signals. Originally used in ILS and later in *Loran*.

Amplitude Discriminator. A circuit, the output of which is a function of the relative magnitudes of two signals.

Angular Deviation Sensitivity. The ratio of change of *Course* indication to the change of angular displacement from the *Course Line*.

Angular Resolution. The ability of a *Radar* to distinguish between two *Targets* solely by the measurement of angles. It is generally expressed in terms of the minimum angle by which *Targets* must be spaced to be separately distinguishable.

Angular Width. See *Course Width.*

Antenna Effect. In navigation systems employing antennas, any output signals due to the directional array acting as a non-directional antenna (also called height effect).

Note: In usual direction finding practice on ground waves *Antenna Effect* would be manifested: If in phase by an angular displacement of the nulls from 180° displacement; if in quadrature, by a residual signal obscuring the nulls. The in-phase effect is often used to eliminate the 180° ambiguity, i.e., to permit *Sense* finding.

Anti-Clutter Circuits. In *Radar*, circuits which attenuate undesired reflections to permit detection of *Targets* otherwise obscured by such reflections.

Anti-TR Box—Deprecated. See *Anti-TR Switch.*

Anti-TR Switch. A gas-discharge switch, employed when a common transmitting and receiving antenna is used, which automatically decouples the transmitter from the antenna during the receiving period.

Approach Navigation. *Navigation* during the time that the approach to a dock or runway is of immediate importance.

Approach Path. That portion of the *Flight Path* in the immediate vicinity of a landing area where such *Flight Path* terminates at the touchdown point.

A-Scan. See *Display.*

A-Scope. See *Display.*

ASR. See *Airport Surveillance Radar.*

"A" Station. In *Loran*, the designation applied to the transmitting station of a pair, the signal of which always occurs less than half a repetition period after the next preceding signal and more than half a repetition period before the next succeeding signal of the other station of the pair, designated a *"B" Station.*

Aural Radio Range. A *Radio Range* station providing *Lines of Position* by virtue of aural identification or comparison of signals at the output of a receiver. (See *A-N Radio Range* in Glossary.)

Automatic Chart-Line Follower. A device which automatically derives error signals proportional to the deviation of the track of a *Vehicle* from a predetermined *Course Line* drawn on a chart.

Automatic Direction Finder. A *Direction Finder* which automatically and continuously provides a measure of the *Direction* of arrival of the received signal. Data are usually displayed visually.

Automatic Gain Control, Instantaneous. See *Instantaneous Automatic Gain Control.*

Automatic Pilot (Autopilot). Equipment which automatically stabilizes the attitude of a *Vehicle* about its pitch, roll and yaw axes.

Automatic Track-Follower. See *Automatic Chart-Line Follower.*

Automatic Tracking. Tracking in which a servo-mechanism automatically follows some characteristic of the signal.

Autopilot Coupler. In *Navigation*, the means used to link the *Navigation* system receiver output to the *Automatic Pilot.*

Autoradar Plot. See *Chart Comparison Unit.*

Azimuth. See *Bearing.*

Azimuth Discrimination—Deprecated. See *Angular Resolution.*

Azimuth Marker. See *Calibration Markers.*

Azimuth-Stabilized PPI. A PPI on which the reference *Bearing* remains fixed with respect to the indicator, regardless of the *Vehicle* orientation.

Background Returns (Radar). See *Clutter.*

Back Scatter—Deprecated. A general term for *Echoes* which may include both *Clutter* and desired *Echoes* from a *Target.*

Baseline. In *Navigation* the line joining the two points between which electrical phase or time is compared in determining *Navigation Co-ordinates.* (For two ground stations this will be the line joining the two stations, and in the case of a rotating collector system it is the line joining the two sides of the collector.)

Basic Repetition Rate. In *Loran*, the lowest *Pulse Repetition Rate* of each of the several sets of closely-spaced *Repetition Rates* employed by *Loran.*

B-Display (also *B-scan* or *B-scope*). See *Display.*

Bearing. A *Direction* at a reference point, expressed as the angle in the horizontal plane between a *Reference Line* and the line joining the reference point to another point, usually measured clockwise from the *Reference Line.*

Note: In *Navigation*, the terms *Azimuth* and *Bearing* have the same meaning; however, the term *Bearing* is preferred for terrestrial *Navigation* and the term *Azimuth* is preferred for celestial *Navigation.*)

Bend. In a rectilinear navigational system the departure of a defined *Course Line* from a straight line.

Blind Speed. In *Radar* MTI, the *Radial* velocity of a moving *Target* which traverses one-half wavelength, or multiples thereof, between successive pulses.

Blinking. In pulse systems, a method of providing information by modifying the signal (at its source) so that the signal presentation on the *Display* alternately appears and disappears; e.g. in *Loran* means for indicating that a station is malfunctioning.

Blip (PIP). On a *Radar Display* a deflection, or a spot of contrasting luminescence, caused by the presence of a *Target.*

Blooming. An increase in the *Blip* (spot) size caused by an increase in signal intensity. *Blooming* may be employed in navigational systems with intensity modulation *Displays* for the purpose of conveying information.

Boresighting. In radio the process of aligning a directional antenna system by an optical procedure.

"B" Station. In *Loran* the designation applied to the transmitting station of a pair, the signal of which always occurs more than half a repetition period after the next succeeding signal and less than half a repetition period before the next preceding signal from the other station of the pair, designated an *"A" Station.*

Calibration Markers. In *Radar*, calibration marks on the *Display* to delineate *Bearing*, distance, height or time.

Cancellation Ratio. In a *Radar* MTI system, the ratio of a fixed *Target* signal voltage after MTI cancellation to the voltage of the same *Target* without MTI cancellation.

Cancelled Video. In a *Radar* MTI system, the video output remaining after the cancellation process.

Carrier-Controlled Approach System (CCA). An aircraft carrier *Radar* system providing information by which aircraft approaches may be directed via radio-communications.

CCA. See *Carrier-Controlled Approach System.*

C-Display (also *C-Scan* or *C-Scope*). See *Display.*

Center Line. The locus of the points equidistant from two reference points or lines.

Chain. A network of similar stations operating as a group for determination of *Position* or for furnishing navigational information over an area greater than can be covered by a single station.

Challenge. See *Interrogation.*

Challenger. See *Interrogator-Responsor.*

Chart-Comparison Unit. A device for the simultaneous viewing of a navigational *Position* presentation and a navigational chart in such a manner that one appears superimposed upon the other.

Check Point. See *Way Point.*

Clearance. 1. In *Navigation*, the *Depth of Modulation* differences at various *Elevation Angles* or *Bearings.* 2. In *Instrument Landing Systems*, the deviation indicator current produced at various elevations or *Bearings.*

Clutter. In *Radar* the display of a conglomeration of unwanted echoes.

Code Distinguishability. The quality of a coded *Radio Beacon* which permits it to be distinguished from all other emissions from the beacon such as those giving distance.

Coder, Pulse-Duration. In *Navigation* a device which generates a code by the varying of the pulse lengths.

Coding Delay. In a *Loran* system, an arbitrary time delay in the transmission of pulse signals from the *"B" Station* to permit the resolution of ambiguity that occurs in certain cases.

Note: The term *Coding* as applied to the delaying of an action in a *radio Navigation* system after the time when another phenomenon takes place purely for reasons of improving the instrumentation problem is deprecated. The term *Suppressed Time Delay* accurately expresses what is being accomplished and should be employed instead.

Cohered Video. In *Radar* MTI, video signal output employed in a *Coherent System.*

Coherent Oscillator. In MTI an oscillator which has as its function the provision of a reference by which changes in the radio-frequency phase of successive received pulses may be recognized.

Coherent System. In *Navigation*, a system in which the signal output is obtained by demodulating the received signal after mixing with a local signal having a fixed-phase relation to that of the transmitted signal to permit use of the information carried by the phase of the received signal.

COHO. Abbreviation for a *Coherent Oscillator.*

Complex Target. In *Radar*, a *Target* composed of a number of reflecting surfaces which in aggregate are smaller in all dimensions than the resolution capabilities of the *Radar.*

Composite Pulse. In pulse *Navigational* systems a pulse composed of a series of overlapping pulses received from the same source via several paths.

Compound Target. In *Radar*, a *Target* composed of a number of randomly disposed reflecting surfaces the aggregate extent of which exceeds any of the dimensions of the *Pulse Packet.*

Cone of Silence. A conically-shaped region above an antenna where, because of the configuration of the antenna system, the field strength is relatively low, e.g., the *Cone of Silence* above a *Radio Range* station.

Constant-Delay Discriminator. See *Pulse-Demoder.*

Corner Reflector. In *Radar*, three conducting surfaces mutually intersecting at right angles designed to return electro-magnetic radiations toward their sources and used to render a *Position* more conspicuous to *Radar* observations.

Corrected Compass Course. Same as magnetic *Course-*

Corrected Compass Heading. Same as magnetic *Heading.*

Cosecant-Squared Pattern. An antenna field in which the signal-power pattern in the vertical plane, above a prescribed angle of elevation, varies as the square of the cosecant of the elevation angle.

Note: With a cosecant-squared pattern approximately uniform signal is obtained for *Echoes* received from objects at the same altitude, but at varying distances.

Count Down. In a *Transponder*, the ratio of the number of interrogation pulses not answered to the total number interrogation pulses received by the *Transponder.*

Coupler. In *Navigation*, that portion of a navigational system which receives signals of one type from a *Sensor* and transmits signals of a different type to an *Actuator;* i.e., a transducer.

Course. 1. The intended direction of travel, expressed as an angle in the horizontal plane between a *Reference Line* and the *Course Line*, usually measured clockwise from the *Reference Line.* 2. The intended direction of travel as defined by navigational facility.

Note: Course is also commonly used as a synonym for *Course Line.*

Course Error—Deprecated. Deprecated, since it is identical with the more-expressive term, *Drift Angle.* The angular difference between the *Course* and the *Course Made Good.*

Course Error, Indicated. See *Indicated Course Error.*

Course Line. The projection in the horizontal plane of the proposed *Path* of travel.

Course Line Deviation. The difference between the *Track* of a *Vehicle* and the *Course Line* expressed in terms of either angular or linear measurement.

Note: In common parlance navigators speak of deviating from *Course;* what is meant is that the *Track* deviates from the *Course Line.*

Course Made Good. The resultant *Direction* of actual travel projected in the horizontal plane expressed as an angle from a *Reference Line* to a line extending in the *Direction* of actual travel, usually measured clockwise from the *Reference Line.* This is the equivalent of the *Bearing* of the *Vehicle* from the point of departure.

Course Push (or Pull). An erroneous deflection of the indicator of a navigational aid, produced by altering the attitude of the receiving antenna. (This effect is a manifestation of *Polarization Error* and results in an apparent displacement of the *Course Line.*)

Course Sensitivity. The displacement (of the *Vehicle*) from the *Course Line* which produces a given change of course indication (usually full scale).

Course Softening. The intentional decrease in *Course Sensitivity* upon approaching a navigational aid such that the ratio of indicator deflection to linear displacement from the *Course Line* tends to remain constant.

Course Width. In *Navigation*, the arithmetic sum of the plus and minus lateral deviations from the *Course Line* within which the *Course* defining parameters do not vary by a detectable amount. (See also *Course Sensitivity* and *Deviation Sensitivity.*)

Coverage Diagram. In *Navigation*, a diagram depicting the *Service Area.*

Crab Angle. In *Navigation*, the angular difference between *Course* and *Heading*, identical with *Drift Correction Angle.*

Crossing Angle. In *Navigation*, the angle at which two *Lines of Position* or *Course Lines* intersect.

Crossover Characteristic Curve. In *Navigation*, the graphical representation of the indicator current variation with change of *Position* in the *Crossover Region.*

Crossover Region. In an *Instrument Approach System*, a zone in space close to the *Localizer On-Course Line* or *Glide Slope* in which the pointer of the indicator is in a position between the full-scale indications.

Cross Section—Deprecated. In *Radar*, a term used in referring to the equivalent echoing area of a *Target.*

Crystal-Video Receiver. A receiver consisting of a crystal detector and a video amplifier.

Dark Trace Tube. A cathode ray tube, of which the face is bright, and signals are displayed as dark traces or dark *Blips.*

Data Handling Capacity. In *Navigation*, the maximum number of unit situations that can be handled within a specified period without deteriorating the performance below certain minimum values.

Data Stabilization. In *Radar*, stabilization of the display of signals with respect to a selected reference regardless of changes in Radar-Carrying *Vehicle* attitude, e.g. *Azimuth-Stabilized PPI.*

Dead Reckoning. The procedure of advancing a known *Position* to give a *Position* at a later time by addition of one or more vectors representing *Courses* and distances.

Note: In air *Navigation*, it is customary to allow for wind when determining *Dead Reckoning Positions;* however, the best marine usage now excludes effects of wind, currents, etc. and considers a *Dead Reckoning Position* as one determined by advancing a known *Position* for *Course* steered and speed through the water. The expression "estimated position" is used in marine *Navigation* when allowance is made for wind and current.

Dead Time. The minimum interval following a pulse during which a *Transponder*, or component circuit thereof, is incapable of repeating specified performance.

D-Display (also *D-Scan or D-Scope*). See *Display*.

DDM. See *Difference in Depth of Modulation*.

Delayed PPI. A PPI (*Plan Position Indicator*) in which the initiation of the *Time Base* is delayed.

Depth of Modulation. In a radio guidance system obtaining directive information from two spaced lobes of a directional antenna system, the ratio of the difference in field strength of the two lobes to the field strength of the greater at a given point in space.

Desired Track. See *Course Line*.

Deviation From Pulse Flatness. The difference between the maximum and minimum amplitudes of a pulse divided by the maximum amplitude, all taken between the first and last knees of the pulse.

Deviation Sensitivity. The rate of change of course indication with respect to the change of displacement from the *Course Line*.

Deviation Sensitivity, Angular. See *Angular Deviation Sensitivity*.

Difference Detector. A detector circuit in which the output is a function of the difference of the peak amplitudes or rms amplitude of the input waveforms.

Difference in Depth of Modulation (DDM). In directive systems employing overlapping lobes with modulated signals (such as instrument low approach systems) a fraction obtained by subtracting from the percentage of modulation of the larger signal the percentage of modulation of the smaller signal and dividing by 100.

Differential Gain Control Circuit. That portion of a system which adjusts the gain of a single radio receiver or circuit to obtain desired relative output levels from two or more sequential unequal input signals.

For Example: The circuits in the *Loran* receiver which adjust the gain between successive pulses.

Directed Reference Flight. That type of *Stabilized Flight* which obtains control information from external signals which may be varied as necessary to direct the flight.

For Example: Flight of a Guided Missile or a *Target* aircraft.

Direction. The *Position* of one point in space relative to another without reference to the distance between them.

Note: Direction may be either three-dimensional or two-dimensional. *Direction* is not an angle but is often indicated in terms of its angular difference from a reference *Direction*.

Directional Homing. The process of *Homing* wherein the navigational quantity maintained constant is the *Relative Bearing*.

Direction Finder (DF). A radio aid to *Navigation* that determines the *Direction* of arrival of a radio signal by measuring the orientation of the wave-front or of the magnetic or electric vector of a radio wave.

Direction-Finder Deviation—Deprecated. The *Direction-Finder Deviation* is the difference between the observed radio *Bearing* and the corrected radio *Bearing*. (It is the sum of all known corrections to the indication of the *Direction Finder*.)

Note: This definition is deprecated because of the confusion with the increasing use of deviation as pertaining to errors in the mathematical sense.

Discriminator. A circuit in which the output is dependent upon how an input signal differs in some aspect from a standard or from another signal.

Discriminator, Constant Delay. See *Pulse-Demoder*.

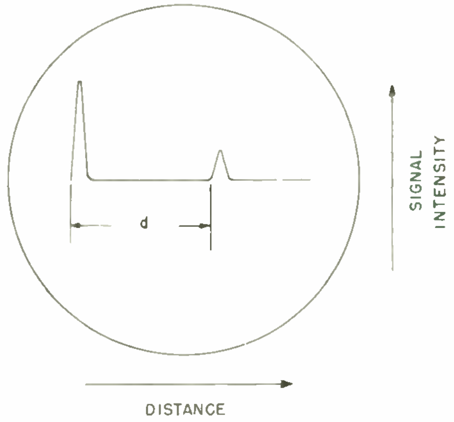
Discriminator, Pulse Duration. See *Pulse Duration Discriminator*.

Dish. A colloquial term for a microwave antenna reflecting surface.

Display. In *Navigation* the pattern representing the output data of any navigational system employing a graphic presentation.

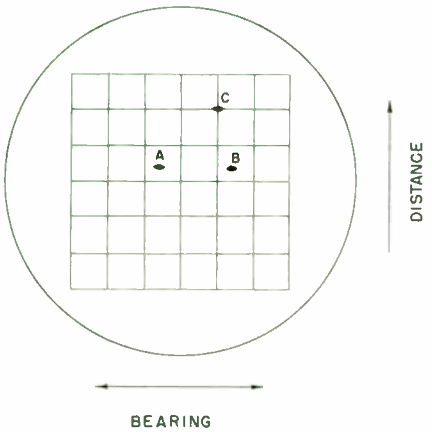
A and R Display. An *A-Display*, any portion of which may be expanded.

A-Display. In *Radar*, a *Display* in which *Targets* appear as vertical deflections from a line representing a Time Base. *Target* distance is indicated by the horizontal *Position* of the deflection from one end of the Time Base. The amplitude of the vertical deflection is a function of the signal intensity.



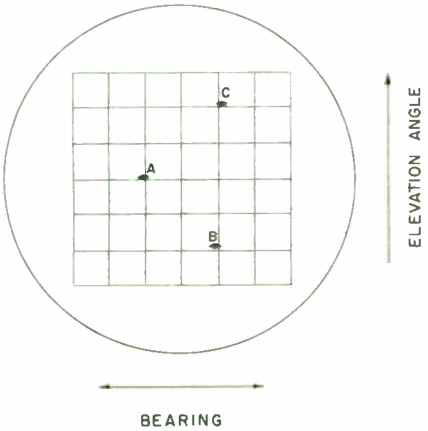
A—Display

B-Display. In *Radar*, a rectangular *Display* in which *Targets* appear as *Blips* with *Bearing* indicated by the horizontal coordinate and distance by the vertical coordinate.



B—Display

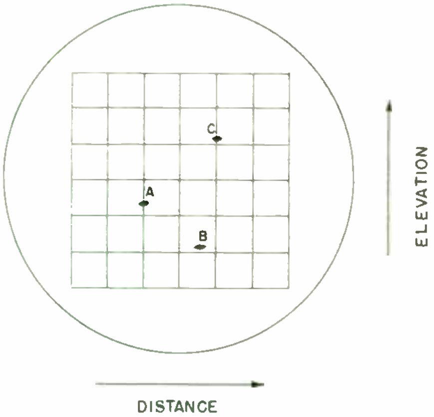
C-Display. In *Radar*, a rectangular *Display* in which *Targets* appear as *Blips* with *Bearing* indicated by the horizontal co-ordinate and *Angles of Elevation* by the vertical co-ordinate.



C—Display

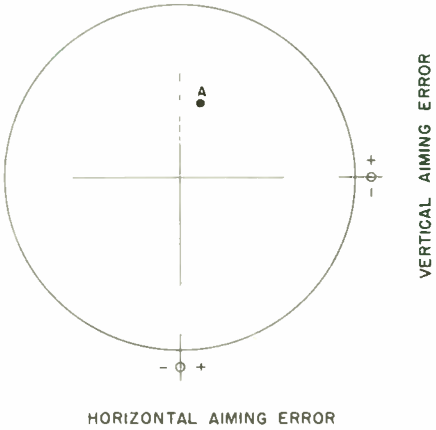
D-Display. In *Radar*, a *C-Display* in which the *Blips* extend vertically to give a rough estimate of distance.

E-Display. In *Radar*, a rectangular *Display* in which *Targets* appear as *Blips* with distance indicated by the horizontal co-ordinate and elevation by the vertical co-ordinate.



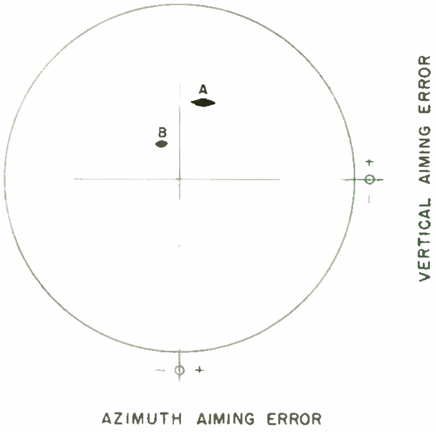
E—Display

F-Display. In *Radar*, a rectangular *Display* in which a *Target* appears as a centralized *Blip* when the *Radar* antenna is aimed at it. Horizontal and vertical aiming errors are respectively indicated by the horizontal and vertical displacement of the *Blip*.



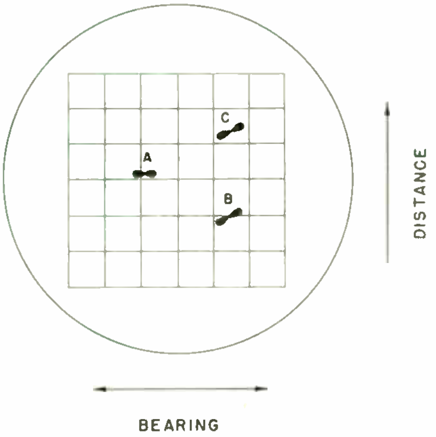
F—Display

G-Display. In *Radar*, a rectangular *Display* in which a *Target* appears as a laterally-centralized *Blip* when the *Radar* antenna is aimed at it in azimuth and wings appear to grow on the *Blip* as the distance to the *Target* is diminished. Horizontal and vertical aiming errors are respectively indicated by horizontal and vertical displacement of the *Blip*.



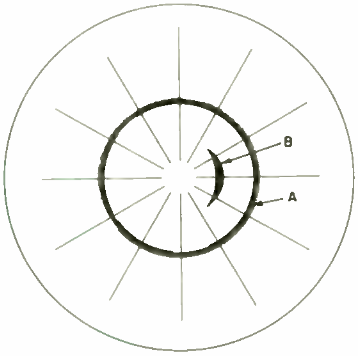
G—Display

H-Display. (On the following page.) In *Radar*, a *B-Display* modified to include indication of angle of elevation The *Target* appears as two closely-spaced *Blips* which approximate a short bright line, the slope of which is in proportion to the sine of the angle of *Target* elevation.



H—Display

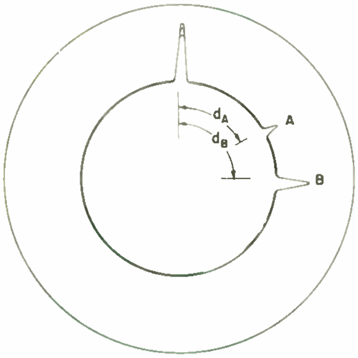
I-Display. In *Radar*, a *Display* in which a *Target* appears as a complete circle when the *Radar* antenna is correctly pointed at it and in which the radius of the circle is proportional to *Target* distance. When not correctly pointing at the *Target*, the circle reduces to a segment of a circle, the segment length being inversely proportional to the magnitude of the pointing error and its angular *Position* being reciprocal to the *Direction* of pointing error.



TWO TARGETS (A,B)
AT DIFFERENT DISTANCES.
RADAR AIMED ON TARGET A

I—Display

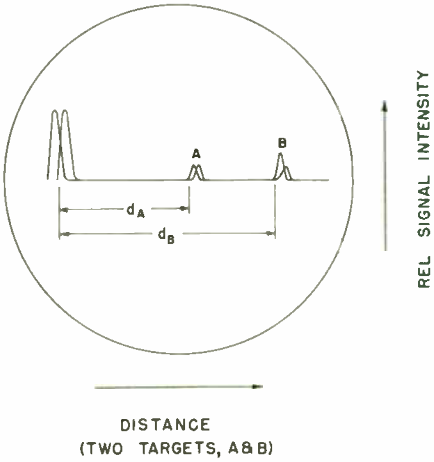
J-Display. In *Radar*, a modified *A-Display* in which the Time Base is a circle. The *Target* signal appears as a radial deflection from the Time Base.



TWO TARGETS (A,B)
AT DIFFERENT DISTANCES

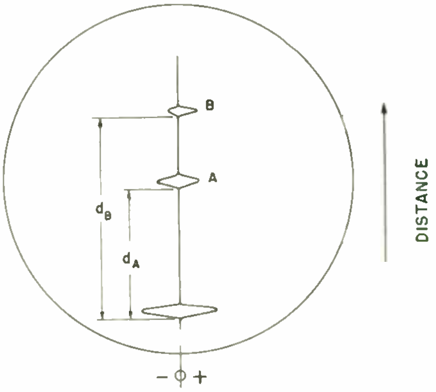
J—Display

K-Display. In *Radar*, a modified *A-Display* in which a *Target* appears as a pair of vertical deflections or *Blips* instead of a single deflection. When the *Radar* antenna is correctly pointed at the *Target* in azimuth, the *Blips* are of equal height. When not correctly pointed, the difference in *Blip* height is an indication of *Direction* and magnitude of azimuth pointing error.



K—Display

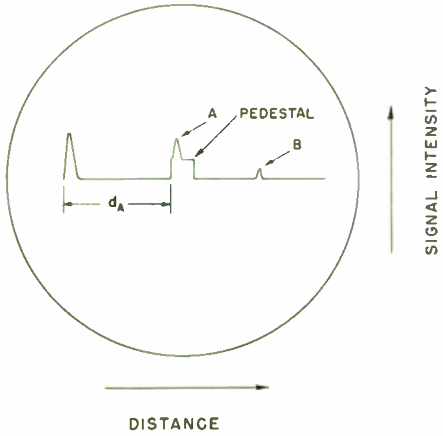
L-Display. In *Radar*, a *Display* in which a *Target* appears as two horizontal *Blips*, one extending to the right and one to the left, from a central vertical Time Base. When the *Radar* antenna is aligned in azimuth at the *Target* both *Blips* are of equal amplitude. When not correctly pointed the relative *Blip* amplitude indicates the pointing error. The *Position* of the signal along the *Baseline* indicates *Target* distance. The *Display* may be rotated 90 degrees when used for elevation instead of *Azimuth* aiming.



HORIZONTAL POINTING ERROR
TWO TARGETS, A&B AT DIFFERENT DISTANCE.
RADAR AIMED ON TARGET A

L—Display

M-Display. In *Radar*, a type *A-Display* in which *Target* distance is determined by moving an adjustable pedestal signal along the *Baseline* until it coincides with the horizontal *Position* of the *Target* signal deflections. The control which moves the pedestal is calibrated in distance.



M—Display

N-Display. In *Radar*, a *Display* similar to the type *K-Display* in which the *Target* appears as a pair of vertical deflections or *Blips* from the horizontal Time Base. *Direction* is indicated by the relative amplitude of the vertical deflections; *Target* distance is determined by moving an adjustable pedestal signal along the *Baseline* until it coincides with the horizontal *Position* of the vertical deflections. The pedestal control is calibrated in distance.

P-Display. See *Plan Position Indicator.*

Pip-Matching Display. In *Navigation*, a *Display* in which the received signal appears as a pair of *Blips*, the comparison of the characteristics of which provides a measure of the desired quantity. (See, for example, *K*, *L*, or *N-Display.*)

Sector Display. In *Radar*, a limited *Display* in which only a sector of the total service area of the *Radar* system is shown. Usually the sector to be displayed is selectable.

Distance Mark. In *Radar* technique, a calibrated mark on the *Radar Display* developed by a special signal generator and used in determining *Target* distance.

Distance Resolution. The ability of a *Radar* to differentiate *Targets* solely by distance measurements. *Distance Resolution* is generally expressed as the minimum radial distance by which *Targets* must be separated to be separately distinguishable.

Doppler System. In *Radar*, any system utilizing the Doppler effect for obtaining information.

Doppler System, Pulsed. See *Pulsed Doppler System.*

Drift Angle. The angular difference between the *Course* and the *Course Made Good.*

Drift Correction Angle. The angular difference between the *Course* and the *Heading*. (Sometimes called the *Crab Angle.*)

Duplex Cavity (Radar). See *TR Cavity (Radar).*

Duplexing Assembly (Radar). See *TR Switch.*

Duty Cycle—Deprecated for use in Radar. See *Duty Ratio.*

Duty Ratio. In a pulse *Radar* or similar system the ratio of average to peak pulse power.

Echo. In *Radar*, the portion of energy of the transmitted pulse which is reflected to a receiver.

Echo Box. In *Radar*, a calibrated resonant cavity which stores part of the transmitted pulse power and gradually feeds this energy into the receiving system after completion of the pulse transmission.

Echo, Second-Time-Around. An *Echo* received after an interval exceeding the pulse repetition interval.

Echo Suppressor. In *Navigation*, a circuit which desensitizes the equipment for a fixed period after the reception of one pulse, for the purpose of rejecting delayed pulses arriving from indirect reflection *Paths.*

E-Display (also called *E-Scan* and *E-Scope*). See *Display.*

Electrical Distance. The distance between two points expressed in terms of the duration of travel of an electromagnetic wave in free space between the two points.

Note: A convenient unit of *Electrical Distance* is the *Light Microsecond* or approximately 983 feet (300 meters). In the use of this unit, the *Electrical Distance* is numerically equal to the transmission time in microseconds.

Elements of a Fix. The specific values of the *Navigation Co-ordinates* necessary to define a *Position.*

Enabling Pulse. A pulse which prepares a circuit for some subsequent action.

Equiphase Zone. The region in space within which difference in phase of two radio signals is indistinguishable.

Equisignal Localizer. A *Localizer* in which the *Localizer-On-Course* line is centered in a zone of equal amplitude of two transmitted signals and deviations from this zone are detectable as unbalance in the levels of these signals.

Error, Height—Deprecated. See *Ionospheric Height Error.*

Error, Instrumental. In *Navigation*, the error due to the calibration, limited *Course Sensitivity* and other inaccuracies introduced in any portion of the system by the mechanism of translating pathlength differences into *Navigation Co-ordinate* information.

Error, Sky (Error, Sky-Wave)—Deprecated. See *Ionospheric Error.*

Exponential Flare-Out. See *Altimetric Flare-Out.*

False Course. In *Navigation* normally providing one or more *Course Lines*, a spurious additional *Course Line* indication due to undesired reflections or to a maladjustment of equipment.

Fan Beam. A field pattern having an elliptically-shaped cross section in which the ratio of the major to minor axes usually exceeds 3 to 1.

Fast-Time-Constant Circuit. In *Radar*, a circuit with short time-constant used to emphasize signals of short duration to produce discrimination against low frequency components of *Clutter.*

F-Display (also called *F-Scan* or *F-Scope*). See *Display.*

Fix. Position determined without reference to any former *Position.*

Flag Alarm. A semaphore-type indicator in certain types of *Navigation* instruments to warn that the readings are unreliable.

Flare-Out. That portion of the *Approach Path* of an aircraft in which the vertical component is modified to lessen the impact of landing.

Flat Spot. In *Navigation*, a point of zero incremental *Deviation Sensitivity* occurring with the *Crossover Region.*

Flight Path. A line in space planned for a *Vehicle.*

Flight Path Computer. A computer including all of the functions of a *Course-Line Computer* and, in addition, providing means for controlling the altitude of an aircraft in accordance with a desired plan of flight.

Flight Path Deviation. The difference between the *Flight Track* of an aircraft and the *Flight Path* expressed in terms of either angular or linear measurement.

Flight-Path Deviation-Indicator. An instrument providing a visual indication of deviation from a *Flight Path.*

Flight-Path-Reference Flight. That type of *Stabilized Flight* which obtains control information from a navigational system capable of providing *Heading* or altitude guidance, or both, with respect to a desired *Flight Path.*

For Example: Flight in which information derived from VOR, DME, ILS and the like is fed into a conventional *Automatic Pilot.*

Flight Track. The *Path* in space actually traced by a *Vehicle. Flight Track* is the three-dimensional equivalent of *Track.*

FTC. Abbreviation for *Fast-Time-Constant.*

Gain-Control, Temporal. See *Temporal Gain-Control.*

Gain Time Control. See *Sensitivity Time Control.*

Gain Turn Down. In a *Transponder*, the automatic receiver gain control incorporated for the purpose of protecting the transmitter from overload.

Gap Coding. In *Navigation*, a process of communicating information by so interrupting the transmission of an otherwise regular signal that the interruptions form a telegraphic-type message.

G-Display (also called *G-Scan* or *G-Scope*). See *Display.*

Geodesic. The shortest line between two points measured on any specified surface which includes the points.

Geometrical Error. In *Navigation*, (a) *Systematic Error* due to calibrating a system on the basis of spherical rather than oblate spheroidal earth; (b) sometimes used as a synonym for *Ionospheric Height Error.*

Geometrical Factor. In *Navigation*, the ratio of the change in a navigational co-ordinate to the change in distance, taken in the direction of maximum navigational-co-ordinate change. That is, the magnitude of the gradient of the navigational-co-ordinate.

Ghost Pulse. See *Ghost Signals.*

Ghost Signals. (a) In *Loran* and *Gee*, identification pulses which appear on the display at less than full *Repetition Rate:* (b) in *Loran*, signals appearing on the *Display* which have a *Basic Repetition Rate* other than the *Basic Repetition Rate* being observed.

Glide-Path. The *Path* used by an aircraft in approach procedures as defined by an instrument landing facility.

Glide-Slope. An inclined surface which includes a *Glide Path* and which is generated by an instrument-landing facility.

Glide-Slope Angle. See *Slope Angle.*

Glide-Slope Deviation. The difference between the projection in the vertical plane of the actual *Path* of movement of a *Vehicle* and the planned *Slope* for the *Vehicle*, expressed in terms of either angular or linear measurements.

Glide-Slope Facility. The means of providing a *Glide Slope.*

Glide-Slope Sector. In an equisignal *Glide-Slope*, the sector containing the *Glide-Slope*, the sector being bounded above and below by *Radial* lines from the *Glide-Slope* transmitter, along each of which *Radial* lines there exists a specified *Difference In Depth of Modulation.*

Grass. In *Radar*, a descriptive colloquialism used to refer to the indication of Noise on an "A" or similar type *Display.*

Ground Clutter. *Clutter* resulting from the ground or objects on the ground.

Ground Distance. The mean sea-level great-circle component of distance from one point to another.

Ground Return (Radar). See *Ground Clutter*

Ground Speed. In *Navigation*, the speed of a *Vehicle* along its track.

H-Display (also **H-Scan** or **H-Scope**). See *Display*.

Heading. The horizontal *Direction* in which a *Vehicle* is directed, expressed as an angle between a *Reference Line* and the line extending in the *Direction* the *Vehicle* is headed, usually measured clockwise from the *Reference Line*.

Height Error. See *Ionosphere Height Error*.

Height Error, Ionospheric. See *Ionospheric Height Error*.

Height Markers (Radar). See *Calibration Markers*.

Homing. 1. The process of approaching a desired point by maintaining constant some indicated navigational parameter (other than altitude). 2. In missile guidance, the use of radiation from a *Target* to establish a collision course.

Hyperbolic Flare-Out. A *Flare-Out* obtained by changing the *Glide Slope* from a straight line to a hyperbolic curve (at an appropriate distance) from touchdown.

Identification. In *Radar*, the process of determining the identity of a particular displayed *Target* (Who are you? or the determination of which, of a number of *Blips*,) represents a specific *Target* (Where are you?).

I-Display (also **I-Scan** or **I-Scope**). See *Display*:

Indicated Course Error. In *Navigation*, an instrumental error resulting in a discrepancy between the actual *Line of Position*, offered by a navigation facility, and the intended *Line of Position*.

Instantaneous Automatic Gain Control. In *Radar*, that portion of a system that so automatically adjusts the gain of an amplifier for each pulse as to obtain a substantially constant output pulse peak amplitude with different input pulse peak amplitude, the adjustment being sufficiently fast to operate during the time a pulse is passing through the amplifier.

Instrument Approach. The process of making an approach to a landing by the use of *Navigation* instruments without direct visual reference to the terrain.

Instrumental Error. See *Error, Instrumental*.

Instrument Approach System. In *Navigation*, a system furnishing guidance in the vertical and horizontal planes to aircraft during descent from an initial-approach altitude to a point near the ground. Completion of a landing requires guidance to touchdown by other means.

Instrument Landing System. As a general term: A system which provides, in the aircraft, the lateral, longitudinal and vertical guidance necessary for a landing.

Intensity Modulation. In *Radar*, a process employed in certain types of *Display* by which the luminance of the signal indication is a function of the received signal-strength.

Interrogation. Transmission of a radio signal or combination of signals intended to trigger a *Transponder* or group of *Transponders*.

Interrogator. The transmitting component of an *Interrogator-Responsor*.

Interrogator-Responsor (IR). A radio transmitter and receiver combined to interrogate a *Transponder* and display the resulting replies.

Ionosphere Error. See *Ionospheric Error*.

Ionosphere Height Error. See *Ionospheric Height Error*.

Ionospheric Error. In *Navigation*, the total *Systematic* and *Random Error* resulting from the reception of the navigational signal after ionospheric reflections. It may be due to (a) variations in transmission paths, (b) nonuniform height of the ionosphere, or (c) nonuniform propagation within the ionosphere.

Ionospheric Height Error. In *Navigation*, the systematic component of the total *Ionospheric Error* due to the difference in geometrical configuration between ground paths and ionospheric paths.

IR. See *Interrogator-Responsor*.

J-Display. See *Display*.

Jitter. Small rapid variations in a waveform due to mechanical disturbances or to changes in the supply voltages, in the characteristic of components, etc.

K-Display (also **K-Scan** or **K-Scope**). See *Display*.

Keep-Alive Circuit. In a *TR* or *Anti-TR Switch*, a circuit for producing residual ionization for the purpose of reducing the initiation time of the main discharge.

Kink. In *Navigation*, a point in a *Crossover Region* where the *Deviation Sensitivity* reverses sign.

Lane. In *Navigation*, the indicated navigational parameter of which is cyclic, the surface bounded by adjacent *Lines of Position* having the same value of the cyclic parameter.

Lattice. In *Navigation*, a pattern of identifiable intersecting *Lines of Position* laid down in fixed *Positions* with respect to the transmitters that establish it.

L-Display (also *L-Scan* or *L-Scope*). See *Display*.

Leader Cable. A navigational aid in which the *Path* to be followed is defined by a magnetic field around a cable.

Light-Microsecond. The distance a light wave travels in free space in one-millionth of a second. See *Electrical Distance*.

Limited Signal. In *Radar*, a signal that is intentionally limited in amplitude by the dynamic range of the system.

Linearity Region. In an *Instrument Approach* and similar guidance system, that region in which the *Deviation Sensitivity* remains within specified values.

Line of Position (LOP). The intersection of two *Surfaces of Position.*

Lin-Log Receiver. In *Radar*, a receiver having a linear amplitude response for small amplitude signals and a logarithmic response for large amplitude signals.

Lobe Switching. A means of *Direction* finding or giving in which a signal transmitted or received in a given *Direction* is amplitude-modulated as a function of *Direction* by varying or switching the shape of the antenna radiation-pattern as a function of time. Compare with *Simultaneous Lobing.*

Localizer. A radio facility which provides signals for use in lateral guidance of aircraft with respect to a runway centerline.

Localizer On-Course Line. A line in a vertical plane passing through a *Localizer* and on either side of which indications of opposite *Sense* are received.

Localizer Sector. In an *Equisignal Localizer*, the sector included between two *Radial* lines from the *Localizer* along each of which lines there exists the same specified *Difference in Depth of Modulation.*

Long Distance Navigation Aid. A navigational aid usable at distances beyond the radio line of sight.

Loop, Alford. See *Alford Loop.*

LOP. See *Line of Position.*

Loran Repetition Rate. See *Repetition Rate.*

Lorhumb Line. In *Navigation*, a *Course Line* in a *Lattice* such that the derivative of one co-ordinate with respect to the other co-ordinate constantly equals the ratio of the difference of the co-ordinates at the beginning and end points of the *Course Line.*

Low Clearance Area. In an Instrument *Approach System*, any area containing only *Low Clearance Points.*

Low Clearance Points. In an Instrument *Approach System*, locations in space outside of the *Crossover Region* at which off-course indicator current is below some arbitrary value, usually the full-scale deflection.

Master Station. The station of a synchronized group of radio stations to which the emissions of other station or stations of the group are referred.

Maximum Distance. The Maximum Distance at which a navigational system will function within its prescribed tolerances.

M-Display (also *M-Scan* or *M-Scope*). See *Display.*

Minimum Distance. The shortest distance at which a navigational system will function within its prescribed tolerances.

Moving Target Indicator (MTI). A device which limits the *Display of Radar* information primarily to moving *Targets.*

MTI. See *Moving Target Indicator.*

MTI Subclutter Visibility. The gain in signal to *Clutter* power ratio produced by the MTI.

MTI Target Visibility. In *Radar MTI*, one factor in MTI circuit performance expressed as the ratio of the signal strength from a *Target* traveling at a specified radial velocity to the signal strength from the same *Target* when it is traveling at an optimum radial velocity. The factor applies only when the *Target* is not in *Clutter.*

Multiple Course. One of a family of *Lines of Position* defined by a navigational system, which may or may not be ambiguous, any one of which may be selected as a *Course Line.*

Navigation. The process of directing a *Vehicle* to reach the intended destination.

Navigation Co-ordinate. A quantity, the measurement of which serves to define a *Surface of Position* (or a *Line of Position* if one surface is already known) of a *Vehicle.*

Navigational Parameter. A visual or aural output of a navigational aid having a specific relation to *Navigation Co-ordinates.*

N-Display (also *N-Scan* or *N-Scope*). See *Display.*

Night Effect—Deprecated. In *Navigation*, a special case of *Polarization Error* occurring predominantly at night and so called because it is usually associated with those frequencies at which the sky-waves are normally absorbed during the day time.

Note: This is a term which occurs chiefly in older literature and is deprecated in favor of more accurate modern terminology.

North-Stabilized PPI. An *Azimuth-Stabilized PPI* on which the reference *Bearing* is north.

Nutating Feed. In a tracking *Radar* an oscillating antenna feed for producing an oscillating deflection of the beam in which the plane of polarization remains fixed.

Nutation Field. The time variant three-dimensional field pattern of a directional or beam-producing antenna having a *Nutating Feed.*

Off Center PPI. In *Radar*, a *PPI* (*Plan Position Indicator*) which has the zero position of the *Time Base*, at a position other than the center of the *Display*, thus providing the equivalent of a larger *Display* for a selected portion of the service area.

Off-Set Crossover Characteristic—Deprecated. See *Crossover Characteristic Curve.*

Omnibearing. A *Bearing* indicated by a navigational receiver on transmissions from an *Omnirange.*

Omnibearing-Distance Facility. A radio facility consisting of an *Omni-Directional Range* in combination with *Distance Measuring Equipment* (*DME*).

Omnibearing-Distance Navigation (OBD). Radio *Navigation* utilizing a polar co-ordinate system as a reference, making use of *Omnibearing-Distance Facilities.* (See also *OBD*; See also *Rho-Theta.*)

Omni-Directional Range (Omnirange). A radio facility providing *Bearing* information to or from such facilities at all *Azimuths* within its *Service Area.*

On-Course Curvature. In *Navigation*, the rate of change of the indicated *Course* with respect to distance along the *Course Line* or *Path.*

Open Center PPI. A *PPI* (*Plan Position Indicator*) in which the *Display* of the initiation of the Time Base precedes that of the transmitted pulse.

Over Interrogation Control. See *Gain Turn Down.*

Path. In *Navigation*, a line connecting a series of points in space and constituting a proposed or travelled route.

P-Display. See *Plan Position Indicator* (*PPI*).

Pencil Beam. Emission, from an antenna, having the form of a narrow conical beam.

Permanent Echo. In a primary *Radar* system a signal reflected from an object fixed with respect to the *Radar* site.

Phanton Target. See *Echo Box.*

Phase Localizer. A *Localizer* in which the *Localizer On-Course* line is centered in an *Equi-Phase Zone*, and right-left deviations from this zone are detectable as reversals of phase of one of the two radiated signals.

Pilotage. The process of directing the movement of a *Vehicle* by reference to recognizable landmarks or soundings. Observations of these may be by optical, aural, mechanical or electronic means.

PIP. See *Blip.*

PIP Matching. See *Display, PIP Matching.*

Plan Position Indicator (PPI). In *Radar* technique, a cathode ray indicator on which *Blips* produced by signals from reflecting objects and *Transponders* are shown in plan *Position*, thus forming a man-like *Display.*

Plumbing. In *Radar*, a colloquial expression for pipe-like waveguide circuit elements.

Polarization Error. In *Navigation*, the error arising from the transmission or reception of a radiation having a polarization other than that intended for the system.

Polyplexer. In *Radar*, equipment combining the functions of duplexing and *Lobe Switching.*

Position. The location of a *Vehicle* as determined by specific values of three *Navigation Co-ordinates.*

PPI. See *Plan Position Indicator.*

Preamplifier. In *Radar* an amplifier separated from the remainder of the receiver and located so as to provide the shortest possible input circuit Path from the antenna so as to avoid deterioration of the signal-to-noise ratio.

PRF (Pulse Repetition Frequency). See *Repetition Rate.*

Primary Radar. See *Radar.*

Pulsed Doppler System. A pulsed *Radar* system which utilizes the Doppler Effect for obtaining information about the *Target* (not including simple resolution from fixed *Targets*).

Pulse Duration Coder. See *Coder, Pulse Duration.*

Pulse-Demoder (Constant-Delay Discriminator). A circuit which responds only to pulse signals which have a certain spacing between pulses for which the device is adjusted. Contrast with *Pulse-Moder.*

Pulse Duration Discriminator. A circuit in which the sense and magnitude of the output is a function of the deviation of the pulse length from a reference.

Pulse Flatness, Deviation From. See *Deviation From Pulse Flatness.*

Pulse Forming Line. In a *Radar* modulator a continuous line or ladder network whose parameters are selected to give a specified shape to the modulator pulse.

Pulse, Ghost. See *Ghost Signals.*

Pulse-Moder. A device for producing a pulse mode. Contrast with *Pulse-Demoder.*

Pulse Packet. In *Radar* the volume of space occupied by the *Radar* pulse energy.

Pulse Rate. See *Repetition Rate.*

Pulse Repetition Frequency. See *Repetition Rate.*

Pulse Repetition Rate (PRF). See *Repetition Rate.*

Radar. A general name for radio detecting and ranging systems that determine the distance and usually the *Direction* of objects by the transmission and return of electromagnetic energy.

Note: The terms "*Primary Radar*" and "*Secondary Radar*" may be used when the return signals are, respectively, by reflection and by the transmission of a second signal as a result of triggering a *Responder Beacon* by the incident signal.

Radar Equation. A mathematical expression which relates the transmitted and received powers and antenna gains of a *Primary Radar* system to the *Echo* area and distance of the *Radar Target.*

Radar Performance Figure. The ratio of the pulse power of the *Radar* transmitter, to the power of the minimum signal detectable by the receiver.

Radar Pilotage Equipment. Equipment utilizing *Primary Radar* techniques and carried on a *Vehicle* for the purpose of determining *Bearing* and distance of recognizable landmarks and for indicating the relative *Position* of other *Vehicles*.

Radar Range Equation. See *Radar Equation*.

Radar Relay. In *Radar*, an equipment for relaying the *Radar* video and appropriate synchronizing signals to a remote location.

Radar Shadow. In *Radar*, a region shielded from *Radar* illumination, by an intervening reflecting or absorbing medium; this region appearing as an area void of *Targets* on a *Radar Display*.

Radial. In *Navigation*, one of a number of Radial *Lines of Position* defined by an azimuthal radio navigational facility, and identified in terms of the *Bearing* (usually magnetic) of all points on that line from the facility.

Radial Time Base Display. See *Plan Position Indicator*.

Radio Beacon. A facility, usually a nondirectional radio transmitter, emitting identifiable signals intended for *Radio Direction Finding* observations.

Radio Direction Finding. *Radiolocation* in which only the *Direction* of a source of radio emission is determined by means of a directive receiving antenna system.

Radiolocation. Determination of one or more *Navigation Co-ordinates* made possible by the constant velocity of rectilinear propagation properties of Hertzian waves.

Radio Magnetic Indicator (RMI). An indicating instrument which presents a *Display* combining *Vehicle Heading*, *Relative Bearing*, *Magnetic Bearing* and *Omnibearing* of the radio station being utilized for *Navigation* purposes.

Radiophare. See *Radio Beacon:*

Note: This term is identical with *Radio Beacon* and is commonly used in international terminology.

Radio Range. A radio facility which provides *Radial Lines of Position* by having special characteristics in its emissions recognizable as *Bearing* information and useful in lateral guidance of aircraft.

Note: The word "beacon" is used to designate a facility which emits signals not having the above special characteristics and from which *Bearing* information can be obtained only by having directional characteristics in the receiving equipment.

Rain Return. In *Radar*, *Clutter* due to rain.

Random Errors. Those errors which can be predicted only on a statistical basis.

Range. In *Navigation*, a *Radio Range*.

Note: In *Navigation*, the use of *Range* as a synonym for distance is deprecated.

Range Mark—Deprecated. See *Distance Mark*.

Range Resolution—Deprecated. See *Distance Resolution*.

Range, Visual-Aural. See *VAR* (Glossary).

Range, Visual Radio. The name applied to a specific four or six-course *Radio Range* which included a vibrating reed presentation.

Note: This facility is now obsolete, but the term has since been applied to other experimental *Radio Ranges* with visual presentations.

RDF—Radio Direction Finding (formerly used by the British for *Radio Distance Finding*, that is, "*Radar*").

Receiver Gating. The application of operating voltages to one or more stages of a receiver only during that part of a cycle of operation when reception is desired.

Recurrence Rate. See *Repetition Rate*.

Reference Line. A line from which angular measurements are made.

Reflection Error. In *Navigation*, the error due to the presence of wave energy reaching the receiver by virtue of undesired reflections.

Refraction Error. In *Navigation*, error due to bending of one or more wave paths by undesired refraction.

Relative Bearing. A *Bearing* in which the *Direction* of the *Reference Line* is the *Heading* of the *Vehicle*.

Relay Radar—Deprecated. See *Radar Relay*.

Repetition Frequency. See *Repetition Rate*.

Repetition Rate. The rate at which recurrent signals are transmitted.

Repetition Rate, Basic. See *Basic Repetition Rate*.

Repetition Rate, Specific. See *Specific Repetition Rate*.

Reply. In *Transponder* operation, a radio frequency signal or combination of signals transmitted as a result of an *Interrogation*.

Reply Efficiency, Transponder. See *Transponder Reply Efficiency*.

Residual Error. The sum of the *Random Errors* and the uncorrected *Systematic Errors*.

Resolving Time. The minimum time interval by which two events must be separated to be distinguishable in a *Navigation* system, by the time measurement alone.

Responder Beacon. See *Transponder*.

Responsor. The receiving component of an *Interrogator-Responsor*.

Rho Theta—(*Navigation* system). A polar co-ordinate *Navigation* system providing data with sufficient accuracy to permit the use of a computer which will provide arbitrary *Course Lines* anywhere within the coverage area of the system.

Ring Around. 1. In *Secondary Radar*, the undesired triggering of a *Transponder* by its own transmitter. 2. In *Secondary Radar*, the triggering of a *Transponder* at all *Bearings* causing a ring presentation on a *PPI*.

Ring Time. In *Radar*, the time during which the output of an *Echo Box* remains above a specified level. The *Ring Time* is used in measuring the performance of *Radar* equipment.

RMI. See *Radio Magnetic Indicator*.

RT Box—Deprecated. See *Anti-TR Switch*.

Sampling Gate. A device which extracts information from the input waveform only when activated by a *Selector Pulse*.

Saturated Signal—Deprecated. See *Saturating Signal*.

Saturating Signal. In *Radar*, a signal of an amplitude greater than the dynamic range of the receiving system.

Scatterband. In pulse systems, the total bandwidth occupied by the frequency spread of numerous *Interrogations* operating on the same nominal radio frequency.

Note: The frequency spread is due to the fact that each *Interrogation* is a pulsed transmission, and to the additional fact that not all transmitters in the group are exactly on the nominal frequency.

Scintillation (also *Target Glint* or *Wander*). On a *Radar Display*, a rapid apparent displacement of the *Target* from its mean *Position*.

Note: This includes but is not limited to shift of effective reflection point on the *Target*.

Scope. A cathode ray oscilloscope. (Use of this term to mean *Display* is deprecated.)

Searchlighting. The process of projecting a *Radar* beam continuously at an object.

Search Radar. A *Radar* primarily intended to display *Targets* as soon as possible after they enter the coverage area.

Sea Return. *Clutter* resulting from irregularities of the sea surface.

Secondary Radar. See *Radar*.

Second-Time-Around Echo. See *Echo, Second-Time-Around*.

Sector Display. See *Display*.

Selector Pulse. A pulse which is used to identify for selection one event in a series of events.

Sense. In *Navigation*, the relation of the change of the indication of a radio navigational facility to the change of the navigational parameter being indicated. Also the property of some navigational equipment permitting the resolution of 180° *Ambiguities*.

Note: As a specific illustrative example of the "relation" mentioned in the definition, one may assume that a particular navigational facility includes a zero-center meter. Assume further that the pilot of the vehicle observes that the pointer of this meter has deflected to the left. Shall this be interpreted as an instruction to the pilot, directing him to steer his vehicle to the *left;* or shall it be interpreted as an indication that the vehicle is already on the left-hand side of the *Course Line*, and should therefore be steered to the *right* in order to correct the navigational error? The similar *up*-and-*down* ambiguity must also be resolved.

Sensing. The process of determining the *Sense* of an indication.

Sensitivity Time Control (also called *Gain-Time Control* or *Time-Gain*). That portion of a system which varies the amplification of a radio receiver in a predetermined manner as a function of time.

Sensor. That portion of a navigational system which perceives deviations from a reference and converts these deviations into signals.

Service Area. The area within which a navigational aid is of use.

Short-Distance Navigation Aid. An aid useful primarily at distances within radio line-of-sight.

Simple Target. In *Radar*, a *Target* having a reflecting surface, such that the amplitude of the reflected signal does not vary with the aspect of the *Target;* e.g. a metal sphere.

Simultaneous Lobing. In *Radar*, a *Direction*-determining technique utilizing the received energy of two concurrent and partially-overlapped signal lobes. The relative phase or the relative power of the two signals received from a *Target* is a measure of the angular displacement of the *Target* from the equiphase or equisignal *Direction*. Compare with *Lobe Switching*.

Site Error. In *Navigation*, error due to the distortion in the radiated field by objects in the vicinity of the navigational equipment.

Skiatron. (a) A dark trace oscilloscope tube (See *Dark Trace Tube*). (b) A *Display* employing an optical system with a *Dark Trace Tube*.

Sky Error. Deprecated. See *Ionosphere Error*.

Sky-Wave Accuracy Pattern. In *Navigation*, the plot of systematic iso-error due to sky wave on a geographic co-ordinate system.

Sky-Wave Correction. In *Navigation*, a correction for sky wave propagation errors applied to measured *Position* data. The amount of the correction is established on the basis of an assumed *Position* and an assumed ionosphere height.

Sky-Wave Station-Error. In sky-wave synchronized *Loran* the error of station synchronization due to the effect of variations of the ionosphere on the time of transmission of the synchronizing signal from one station to the other.

Slant Distance. The distance between two points not at the same elevation. Used in contrast to *Ground Distance*.

Slant Range—Deprecated. See *Slant Distance*.

Slave Station. In *Navigation*, a station in which some characteristic of its emission is controlled by a *Master Station*.

Slave Sweep. A Time Base which is synchronized or triggered by a waveform from a source external to the Time Base. Used in navigational systems for displaying or utilizing the same information at different locations, or in displaying or utilizing different information with a common or related Time Base.

Slope—(In *Navigation*). See *Glide Slope*.

Slope Angle. The angle in the vertical plane between the *Flight Path* and the horizontal.

Soft Spot—Deprecated. See *Low Clearance Point*.

Sonar. A general name for sonic and ultrasonic underwater ranging, sounding and communication systems.

Specific Repetition Rate. In *Loran*, one of a set of closely-spaced *Repetition Rates* derived from the basic rate and associated with a specific set of synchronized stations.

Spherical Hyperbola. The locus of the points on the surface of a sphere having a specified constant difference in great circle distances from two fixed points on the sphere.

Spinner. Rotating part of a *Radar* antenna used to impart any subsidiary motion in addition to the primary slewing of the beam.

Squeezable Waveguide. In *Radar*, a variable width uniconductor waveguide for shifting the phase of the radio-frequency wave traveling through it.

Squint. In *Radar*, an ambiguous term, meaning either: (a) The angle between the two major lobe axes in a lobe switching antenna, or (b) The angular difference between the axis of antenna radiation and a selected geometric axis, such as the axis of the reflector.

Squitter. Random firing, intentional or otherwise, of the *Transponder* transmitter in the absence of *Interrogation*.

Stabilization. In *Navigation*, maintenance of a desired orientation independent of the motion of the *Vehicle*.

Stabilized Flight. That type of flight which obtains control information from inertia-stabilized references such as gyroscopes.

> *Example:* Flight in which the lateral, longitudinal, and vertical attitudes of an aircraft are maintained constant by a conventional *Automatic-Pilot*.

Stable Element. In *Navigation*, an instrument or device which maintains a desired orientation independently of the motion of the *Vehicle*.

Stalo. In *Radar MTI*, a highly stable local rf oscillator used for heterodyning signals to produce an intermediate frequency.

Star Chain. A radio *Navigation* transmitting system comprising a *master station* about which three (or more) slave stations are symmetrically located.

STC. See *Sensitivity Time Control*.

Suppressed Time Delay. A deliberate displacement of the zero of the time scale with respect to time of emission of a pulse in order to simulate electrically a geographical displacement of the true *Position* of a *Transponder*.

Surface of Position. Any surface defined by a constant value of some *Navigation Co-ordinate*.

Surveillance Radar, Airport. See *Airport Surveillance Radar*.

Synchronization Error. In *Navigation*, the error due to imperfect timing of two operations; this may or may not include signal transmission time.

Systematic Errors. Those errors having an orderly character and which can be corrected by calibration.

Target. In *Radar*, (1) specifically an object of *Radar* search or surveillance, (2) broadly any discrete object which reflects energy back to the *Radar* equipment.

Target Glint. See *Scintillation*.

Temporal Gain Control. See *Sensitivity Time Control*.

Terrain Echoes. See *Ground Clutter*.

Terrain Error. In *Navigation*, the error resulting from the distortion in the radiated field by the nonhomogeneous characteristic of the terrain over which the radiation in question has propagated.

Terrestrial-Reference Flight. That type of *Stabilized Flight* which obtains control information from terrestrial phenomena.

> *Example:* Flight in which basic information derived from the earth's magnetic field, atmospheric pressure, and the like is fed into a conventional *Automatic Pilot*.

Threshold Signal. In *Navigation* the smallest signal capable of effecting a recognizable change in positional information.

Tilt Angle. In *Radar*, the angle between the axis of radiation in the vertical plane and a reference axis (normally the horizontal).

Tilt Error. In *Navigation*, the component of the ionospheric error due to nonuniform height.

Time Discriminator. A circuit in which the sense and magnitude of the output is a function of the time difference of the occurrence, and relative time sequence, of two pulses.

Timer. In *Navigational* equipment, the programming unit.

Time-Varied Gain (TVG). See *Sensitivity Time Control.*

To-From Indicator. A *Sensing* device to show whether the numerical reading of an *Omnibearing* selector for an "on-course" indication of the *Course Line Deviation Indicator* and *Flight Path Deviation Indicator* represents the *Bearing* toward or away fron an *Omnirange.*

Tone Localizer. See *Equi-Signal Localizer.*

Track. The horizontal component of the *Path* actually followed by a *Vehicle.*

Note: Marine practice sometimes extends this term to include the horizontal component of intended *Path.*

Track Homing. The process of following a *Line of Position* known to pass through an objective.

Transponder. A transmitter-receiver facility the function of which is to transmit signals automatically when the proper *Interrogation* is received.

Transponder Beacon. See *Transponder.*

Transponder, Crossband. In *Navigation,* a *Transponder* which replies in a different frequency band from that of the received *Interrogation.*

Transponder Reply Efficiency. The ratio of the number of replies emitted by a *Transponder* to the number of *Interrogations* which *Transponder* recognizes as valid.

Note: The *Interrogations* recognized as valid include both those properly coded and those accidentally combined to form recognizable codes, the latter normally being computed statistically.

TR Box. See *TR Switch.*

TR Cavity (Radar). The resonant portion of a *TR Switch.*

Triad. See *Triplet.*

Trigatron. An electronic switch in which conduction is initiated by the breakdown of an auxiliary gap.

Trigger Level. In a *Transponder,* the minimum input to the receiver which is capable of causing a transmitter to emit a reply.

Triplet. In *Navigation,* three radio stations operated as a group for the determination of *Positions.*

TR Switch. A switch, frequently of the gas-discharge type, employed when a common transmitting and receiving antenna is used, which automatically decouples the receiver from the antenna during the transmitting period.

TVG (Time-Varied Gain). See *Sensitivity Time Control.*

V-Beam Radar. A *Volumetric Radar* system for the determination of distance, *Bearing* and height by the use of two *Fan Beams.*

Vehicle. That in or on which a person or thing is being or may be carried.

Video Integration. A method of utilizing the redundancy of repetitive signals to improve the output signal-to-noise ratio, by summing the successive video signals.

Video Mapping. A procedure whereby a chart of an area is electronically superimposed on a *Radar Display.*

Video Stretching. In *Navigation,* a procedure whereby the duration of a video pulse is increased.

Visibility Factor (Display Loss). The ratio of the minimum signal input power detectable by ideal instruments connected to the output of a receiver, to the minimum signal power detectable by a human operator through a *Display* connected to the same receiver.

Note: The *Visibility Factor* may include the scanning loss.

Visual Aural Range. See *VAR* (Glossary).

Volumetric Radar. A *Radar* capable of producing three-dimensional *Position* data on a multiplicity of *Targets.*

Note: This definition includes but is not limited to Volumetric Scan.

Wander. See *Scintillation.*

Way Point. A selected point on a *Course Line* having some particular significance.

Zero Time Reference. The time reference of the schedule of events in a cycle of operation of a *Radar.*

4. A GLOSSARY OF SOME COMMON ELECTRONIC NAVIGATIONAL SYSTEMS

Airport Surface Detection Equipment (ASDE). A *Radar* for observation of the *Positions* of aircraft on the surface of an airport.

Air-Position Indicator (API). An airborne computing system which presents a continuous indication of the aircraft *Position* on the basis of *Aircraft-Heading, Air Speed* and elapsed time.

A-N Radio Range. A *Radio Range* providing four radial *Lines of Position* identified aurally as a continuous tone resulting from the interlocking of equal amplitude "*A*" and "*N*" *International Morse* code letters. The sense of deviation from these lines is indicated by deterioration of the steady tone into audible A or N code signals.

API. See *Air-Position Indicator.*

ASDE. See *Airport Surface Detection Equipment.*

BABS (Blind Approach Beacon System). A *Radar* instrument low-approach system in which airborne equipment interrogates a ground *Transponder*. Distance from the *Transponder* and *Position* with respect to the *Center Line* of the runway is presented on an *"L" Type Display* in the aircraft.

Benito. A cw navigational system in which the distance to an aircraft is determined on the ground by a phase-difference measurement of an audio signal transmitted from the ground and retransmitted by the aircraft. *Bearing* information is obtained by ground direction-finding of the aircraft signals.

Boundary Marker. In an *Instrument Landing System* (*ILS*) a vhf radio marker facility which is installed near the approach end of the landing runway and on, or near, the *Localizer Course Line* to provide a fix.

Condor. A cw navigational system similar to *Benito*, which automatically measures *Bearing* and distance from a single ground station. The distance is determined by phase comparison and the *Bearing* by automatic *Direction Finding*. Distance and *Bearing* are displayed on a cathode ray indicator.

Consol. See *Sonne.*

Consolan. See *Sonne.*

Decca. A cw radio aid to *Navigation* using multiple receivers to measure and indicate the relative phase difference of cw signals received from several synchronized radio stations. The system provides differential distance information from which *Position* can be determined.

DME (Distance Measuring Equipment). A radio aid to *Navigation* which provides distance information by measuring total round-trip time of transmission from an *Interrogator* to a *Transponder* and return.

Electra. A specific *Radio Navigation* aid that provides a number (usually 24) of equi-signal zones. *Electra* is similar to *Sonne* except that in *Sonne* the equi-signal zones as a group are periodically rotated in *Bearing.*

Eureka. The ground *Transponder* of *Rebecca-Eureka*, a secondary *Radar* system.

Fan Marker. A vhf radio facility having a vertically-directed *Fan Beam* intersecting an airway to provide a fix.

GCA (Ground-Controlled Approach). A ground *Radar*-system providing information by which aircraft approaches may be directed via radio communications. A GCA system consists of a PAR and an SRE.

GCI (Ground-Controlled Interception). A *Radar* system by means of which a controller may direct an aircraft to make an interception of another aircraft.

GEE. A vhf *Radio Navigation* system transmitting synchronized pulses. Hyperbolic *Lines of Position* are determined by the measurement of the difference in the time of arrival of these pulses.

GEE-H. A combination of the *GEE* and *H* systems of *Navigation.*

GPI (Ground Position Indicator). A computer, similar to an *Air Position Indicator*, with provision for taking account of drift.

H. A *Radar* air-*Navigation*-system using an airborne *Interrogator* to measure distance from two ground *Responder-Beacons.*

(*Note:* See *Shoran*). *H* is also a name applied to certain *Aerophares.*

ILS (Instrument-Landing-System). A system of *Radio Navigation* stations providing a means of instrument-low-approach utilizing a vhf *Localizer*, a uhf *Glide-Slope* station, and marker.

LANAC (Laminar Navigation, Anti-Collision). An aircraft radio *Navigation* system consisting of airbrone *Interrogator* and ground *Transponder* equipments with height-coding of the airborne *Interrogator Pulses.*

Lodar. A *Direction Finder* with which the *Direction* of arrival of *Loran* signals is determined free of *Night Effect* by observing the separately distinguishable ground and skywave *Loran* signals on a cathode ray oscilloscope and positioning a loop antenna so as to obtain a null indication of the component selected to be most suitable.

Lorac. In a *Navigation* system which determines a *Position Fix* by the intersection of *Lines of Position* each line being defined by the phase angle between a heterodyne beat frequency wave between cw signals from two widely-spaced transmitters; and a reference wave of the same frequency that is obtained by deriving the heterodyne beat of the same two cw signals at a fixed location and transmitting it to the receiver being located via a second radio frequency channel.

Lorad. See *Lodar.*

Loran. A long distance *Radio Navigation* system utilizing synchronized pulses from widely-spaced transmitting stations in which hyperbolic *Lines of Position* are determined by the measurement of the difference in the time of arrival of these pulses.

MEW (Microwave Early Warning). A particular high-power, long-range, early-warning *Radar* with a number of indicators, giving high resolution and large traffic handling capacity.

Middle Marker. A marker facility in an *ILS* which is installed approximately 3,500 feet from the approach end of the runway on the *Localizer Course Line* to provide a fix.

MTR (Multiple Track Range). An adaptation of the *GEE* systems utilizing two closely-spaced synchronized pulse stations. The indicator in the aircraft has several pre-determined time difference settings so that by their selection a number of approximately parallel *Tracks* may be flown.

Navaglobe. A long-distance continuous-wave lf *Navigation* system of the amplitude-comparison type, providing *Bearing* information.

Navar. A co-ordinated series of *Radar* air *Navigation* and traffic-control aids utilizing transmissions at wavelengths of 10 centimeters and 60 centimeters to provide in the aircraft distance and *Bearing* from a given point, display of other aircraft in the vicinity, and commands from the ground; also providing on the ground a display of all aircraft in the vicinity, as well as their altitudes, identities, and means for transmitting certain commands.

Nava-Rho. A long distance continuous wave lf *Navigation* system providing simultaneous *Bearing* and distance information.

OBI (Omnibearing Indicator). An instrument which presents an automatic and continuous indication of an *Omnibearing*.

Oboe. A particular *Radar Navigation* system consisting of two ground stations measuring distance to an airborne *Transponder Beacon* and relaying information to the aircraft.

OBS (Omnibearing Selector). An instrument capable of being set manually to any desired *Bearing* of an *Omnirange* station and which controls a *Course Deviation Indicator*.

Outer Marker. A marker facility in an *ILS* which is installed at approximately 5 miles from the approach end of the runway on the *Localizer Course Line* to provide a fix.

PAR (Precision Approach Radar). A *Radar* system located on an airfield for observation of the *Position* of an aircraft with respect to an *Approach Path* and specifically intended to provide guidance to the aircraft in the *Approach*.

POPI (Post Office Position Indicator). A long-distance continuous-wave lf navigational system of the phase-comparison type providing *Bearing* information. In this system, phase-difference between sequential transmissions on the single frequency is measured.

Racon (an abbreviation of *Radar Beacon*). A *Transponder* for *Interrogation* by a primary *Radar*.

Radux. A long-distance continuous-wave low-frequency navigational system of the phase comparison type providing hyperbolic *Lines of Position*.

Ramark. A fixed facility which continuously emits a signal so that a *Bearing* indication appears on a *Radar Display*.

Raydist. A *Navigation* system in which a cw signal emitted from a *Vehicle* is received at three or more ground stations; the received signals are compared in phase to determine the *Position* of the *Vehicle*.

Rebecca. The airborne *Interrogator-Responder* of *Rebecca-Eureka*, a secondary *Radar* system.

SBA (Standard Beam Approach). A vhf 40 mc continuous-wave low-approach system using a *Localizer* and markers. The two main signal lobes are tone-modulated with the Morse Code Letters E and T, respectively. These modulations interlock to form a continuous "on-course" tone. The airborne equipment is instrumented for visual reference but the system may also be used aurally.

Shoran (Short Range Navigation). A precision *Position* fixing system using a pulse transmitter and receiver on the *Vehicle* with two *Transponders* at fixed points.

Sonne. A *Radio Navigation* aid that provides a number of characteristic signal zones which rotate in a time sequence. A *Bearing* may be determined by observation (by interpolation) of the instant at which transition occurs from one zone to the following zone. (Also called *Consol*.) Compare with *Electra*.

SRE (Surveillance Radar Element). The *Radar* of the *GCA* system used to direct traffic to a region where it may be observed by the *PAR Radar*.

Teleran (Television and Radar Navigation System). A *Radar Navigation* system in which the *Positions* of aircraft are determined by ground *Radar*, the *PPI* being televised, superimposed on a map, and transmitted to the aircraft.

Tricon. A *Radio Navigation* system in which the airborne receiver accepts pulses from a *Triplet* or chain of three stations pulsed in variable time sequence. The time sequences vary so that pulses arrive at the same time along *Paths* of various lengths.

VAR (VHF Aural-Visual Range). A special type of vhf ating at vhf and providing *Radial Lines of Position* in any *Direction* as determined by *Bearing* selection within the receiving equipment. This facility emits a nondirectional "reference" modulation and a rotating pattern which develops a "variable" modulation of the same frequency as the reference modulation. *Lines of Position* are determined by comparison of phase of the variable with that of the reference.

VOR (VHF Omnirange). A specific type of range operating at vhf and providing *Radial Lines of Position* in any *Direction* as determined by *Bearing* selection within the receiving equipment. This facility emits a nondirectional "reference" modulation and a rotating pattern which develops a "variable" modulation of the same frequency as the reference modulation. *Lines of Position* are determined by comparison of phase of the variable with that of the reference.

Z (Zone) Marker. A vhf radio station designed to radiate vertically and used to define a zone above a *Radio Range* station.

A Coupled Mode Description of Beam-Type Amplifiers*

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Summary—**A description of beam-type amplifiers, in particular the klystron and traveling-wave tube, is developed in which the electron stream and the circuit are treated as coupled transmission lines. The method allows the derivation of expressions for the ac power flow in both the beam and the circuit. The power flow relations are presented for the klystron and the traveling-wave tube.**

INTRODUCTION

IN THE usual small signal theory of the traveling-wave tube a description of ac power flow is never attempted. The reason lies in the manner in which the assumption of linearity is introduced. Once the differential equations have been written, the small signal condition is imposed and products of ac terms are neglected. In this manner the equations are linearized. Any subsequent description of quadratic ac quantities such as ac power may then be incomplete.

An alternative approach which does allow the description of ac power flow is possible. It relies on a slightly different method of invoking the conditions of linearity. Both the circuit and the electron stream are treated as transmission lines each one of which is capable of supporting "modes" of power flow. When these two lines are coupled together as in a klystron or traveling-wave tube, we require that the output quantities in each "mode" be a *linear* combination of the input quantities.[1] In this way the principle of linearity is introduced directly rather than through the small signal condition and no ambiguity arises in defining ac power flow.

AC POWER FLOW IN AN ELECTRON STREAM

Since the description of a modulated electron stream as a transmission line carrying ac power may not be familiar, it is perhaps desirable to present a plausibility argument which will lead to the correct relations needed.

The usual description of the propagation of a disturbance in an electron stream is in terms of two space charge waves (labeled "f" and "s") each having associated with it an ac velocity and an ac current.[2] The total ac velocity and ac current can be made up of an appropriate linear combination of the two waves. If the total ac velocity is $\tilde{v}$ and the total ac current is $\tilde{\imath}$, then

$$\tilde{v} = v_f + v_s \tag{1}$$

$$\tilde{\imath} = i_f + i_s, \tag{2}$$

where for the first space charge wave

$$i_f = i_{fm} e^{j\omega t} e^{-j(\beta_e - \beta_p)z} \tag{3}$$

$$v_f = v_{fm} e^{j\omega t} e^{-j(\beta_e - \beta_p)z} \tag{4}$$

$$\beta_e = \frac{\omega}{u_0} \tag{5}$$

$$\beta_p = \frac{\omega_p}{u_0} \tag{6}$$

$$i_f = \frac{I_0}{u_0} \frac{\omega}{\omega_p} v_f, \tag{7}$$

and for the second space charge wave

$$i_s = i_{sm} e^{j\omega t} e^{-j(\beta_e + \beta_p)z} \tag{8}$$

$$v_s = v_{sm} e^{j\omega t} e^{-j(\beta_e + \beta_p)z} \tag{9}$$

$$i_s = -\frac{I_0}{u_0} \frac{\omega}{\omega_p} v_s. \tag{10}$$

Here, u_0 is the average or dc electron velocity and ω_p is the effective plasma frequency.

The phase constant $(\beta_e - \beta_p)$ indicates that the first space charge wave (i_f, v_f) travels faster than the dc electron velocity while the second space charge wave (i_s, v_s) associated with the phase constant $(\beta_e + \beta_p)$ travels slower than the dc velocity. Let us determine the ac power flow associated with each of these waves.

Suppose an unmodulated beam is sent through an infinitesimal gap across which is applied an ac voltage, V. At the exit of the gap the beam is modulated in velocity alone. By simple kinematics the ac velocity is given in terms of the gap voltage by the relation

$$\tilde{v} = \frac{u_0}{2} \frac{V}{V_0} e^{j\omega t}, \tag{11}$$

V_0 being the dc beam voltage. Hereafter, the factor $e^{j\omega t}$ will be dropped. Taking the origin of the distance coordinate, z, at the gap, the space charge waves must then have the form

$$v_{fm} = v_{sm} = \frac{u_0}{4} \frac{V}{V_0} \tag{12}$$

$$\tilde{v} = \frac{u_0}{4} \frac{V}{V_0} e^{-j(\beta_e - \beta_p)z} + \frac{u_0}{4} \frac{V}{V_0} e^{-j(\beta_e + \beta_p)z} \tag{13}$$

$$\tilde{\imath} = \frac{1}{4} \frac{V}{V_0} \frac{\omega}{\omega_p} I_0 e^{-j(\beta_e - \beta_p)z} - \frac{1}{4} \frac{V}{V_0} \frac{\omega}{\omega_p} I_0 e^{-j(\beta_e + \beta_p)z}. \tag{14}$$

The power flowing from the gap to the beam is

$$P = \tfrac{1}{2} \operatorname{Re} V \tilde{\imath}^*, \tag{15}$$

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* Original manuscript received by the IRE, September 14, 1954; revised manuscript received November 15, 1954.

† Stanford University, Stanford, California.

[1] J. R. Pierce, "Coupling of modes of propagation," *Jour. Appl. Phys.*, vol. 25, pp. 179–183; February, 1954.

[2] S. Ramo, "Space charge and field waves in an electron beam," *Phys. Rev.*, vol. 56, p. 276; August, 1939.

where $\bar{i}$ is the current produced by the gap voltage. In terms of the ac velocity at the gap

$$P = \frac{V_0}{u_0} \operatorname{Re} \bar{v}\bar{i}^*. \tag{16}$$

Expanding the velocity and current into their individual space charge waves, we find

$$P = \frac{V_0\omega_p}{I_0\omega} i_{fm}i_{fm}^* - \frac{V_0\omega_p}{I_0\omega} i_{sm}i_{sm}^*. \tag{17}$$

This result indicates that the power associated with the fast space charge wave (i_f, v_f) is positive, which is taken to mean that it is flowing in the direction of the electron motion, while the power associated with the slow space charge wave (i_s, v_s), being negative, is taken as flowing opposite to the direction of the electrons. The fact that the waves carry power in opposite directions has been pointed out previously by Chu[3] and by Walker.[4] It arises because of the opposite signs attached to the stored energy of the two waves. Energy was supplied to the beam to initiate the fast space charge wave while energy was obtained from the beam in initiating the slow wave.

The power relation for the gap excited beam has one further implication; there is no real power carried in the cross products of the two space charge waves. The two waves can thus be considered to be power-wise independent, and we may express the total power flow as the sum of the power flow in each wave,

$$P_f = \frac{V_0}{I_0}\frac{\omega_p}{\omega} \mid i_f \mid^2 \tag{18}$$

$$P_s = -\frac{V_0}{I_0}\frac{\omega_p}{\omega} \mid i_s \mid^2. \tag{19}$$

In the case of gap modulation the two space charge waves are excited equally, and the net power flow is zero.

Since the two waves on an electron stream carry power in opposite directions and are independent, we may treat them as though they were waves on a transmission line. This transmission line has, however, two special properties not usually encountered. First, it is nonreciprocal.[5] Second, the initial or input conditions occur at the same end of the line for the two waves. In the more familiar transmission lines the wave which carries power from left to right has its input toward the left, and the wave carrying power from right to left has its input toward the right. This difference in behavior arises because, in the usual transmission lines, the opposite directions of power flow of the two waves is due to the opposite directions of their travel. In the case of the electron stream, however, it arises because their stored energies are of opposite sign. It is this fact that allows coupled transmission lines to have growing waves when one of the "transmission lines" is an electron stream, while these same waves represent decreasing waves if it is not an electron stream.

Coupled Electron Beam and Circuit

Suppose an electron beam is allowed to interact over a very small region with the fields existing on a generalized transmission line. We assume the transmission line is capable of supporting two modes, one carrying power in the positive direction and one in the negative direction. Let us describe each of these modes by a quantity, Q, such that QQ^* represents the average power flow in the mode. In terms of the voltage, V, and impedance, Z_0, of a running wave on the line carrying power in the negative z direction,

$$Q_1 = \frac{V_1 e^{j\beta_1 z}}{\sqrt{2Z_0}}, \tag{20}$$

and, for a running wave carrying power in the positive z direction,

$$Q_2 = \frac{V_2 e^{-j\beta_2 z}}{\sqrt{2Z_0}}. \tag{21}$$

Let us also describe the two space charge waves in this same way. The slow space charge wave (i_s, v_s) carries power in the negative z direction and can be described as

$$Q_3 = \sqrt{\frac{V_0}{I_0}\frac{\omega_p}{\omega}}\, i_s e^{-j(\beta_e + \beta_p)z}. \tag{22}$$

The fast space charge wave (i_f, v_f) which carries power in the positive z direction can be described as

$$Q_4 = \sqrt{\frac{V_0}{I_0}\frac{\omega_p}{\omega}}\, i_f e^{-j(\beta_e - \beta_p)z}. \tag{23}$$

If we label power flowing to the right as positive, then, in adding up total power, we must associate a positive sign with $Q_2Q_2^*$ and $Q_4Q_4^*$ and a negative sign with $Q_1Q_1^*$ and $Q_3Q_3^*$.

The values of the Q's just preceding the interaction region will be labeled with a superscript 1 and, for convenience, termed the input quantities, and the values just following the interaction region will be labeled with a superscript 2 and termed the output quantities. See Fig. 1, on the following page.

We now make the following assumptions concerning the interaction region:

1. The interaction is linear. That is, the output quantities may be expressed as a linear combination of the input quantities.
2. The interaction region is dissipationless.
3. Within the interaction region, the circuit is reflectionless.

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[3] The negative ac energy in electron streams was discussed by L. J. Chu at the 1951 Conference on Electron Tube Research.

[4] L. R. Walker, "Stored energy and power flow in electron beam," *Jour. Appl. Phys.*, vol. 25, pp. 615–618; May, 1954.

[5] The electron stream has been treated as a moving reciprocal transmission line by W. E. Mathews, "Traveling-wave amplification by means of coupled transmission lines," Proc. I.R.E., vol. 39, p. 1054; September, 1951.

Under these conditions we find (see Appendix 1) that the output quantities may be written in terms of the input quantities, as:

$$^2Q_1 = {}^1Q_1 + K\,{}^1Q_3 + K\,{}^1Q_4 \qquad (24)$$

$$^2Q_2 = {}^1Q_2 - K\,{}^1Q_3 - K\,{}^1Q_4 \qquad (25)$$

$$^2Q_3 = -\,K\,{}^1Q_1 - K\,{}^1Q_2 + {}^1Q_3 \qquad (26)$$

$$^2Q_4 = +\,K\,{}^1Q_1 + K\,{}^1Q_2 + {}^1Q_4 \qquad (27)$$

where

$$K = \frac{1}{2}\sqrt{\frac{Z_0 I_0}{2V_0}}\,\frac{\omega}{\omega_p}. \qquad (28)$$

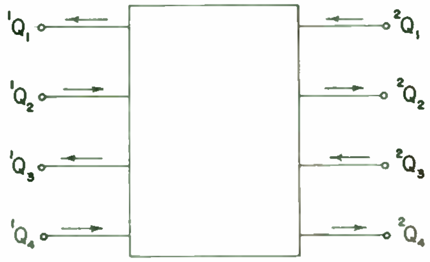

Fig. 1—Schematic representation of two coupled transmission lines. Q_1 and Q_2 represent the two waves on one of the lines and Q_3 and Q_4 the two waves of the other line.

Cavity Coupling

The relations governing the coupling of a beam with a cavity may be obtained from the preceding equations quite easily. If the transmission line is terminated in a short circuit one quarter wavelength after the interaction region, the gap behaves as a resonant cavity (Fig. 2). To generalize, we may write

$$^2Q_1 = k\,{}^2Q_2, \qquad (29)$$

where k may be complex ($k = \alpha e^{i\theta}$) to allow for both loss and phase shifts other than a quarter wavelength.

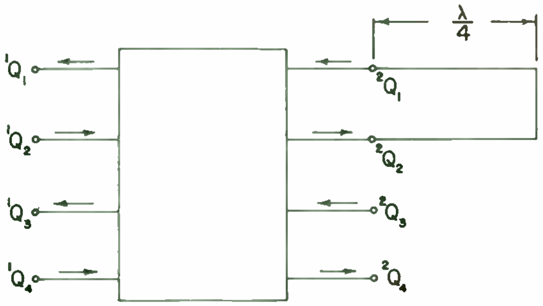

Fig. 2—The coupled transmission lines representation of an electron beam flowing through a cavity.

Under this condition interaction equations become

$$^1Q_1 = k\,{}^1Q_2 + K(1+k)\,{}^1Q_3 - K(1+k)\,{}^1Q_4 \qquad (30)$$

$$\begin{aligned} ^2Q_3 = &-K(1-k)\,{}^1Q_2 + [1 + K^2(1+k)]\,{}^1Q_3 \\ &+ K^2(1+k)\,{}^1Q_4 \end{aligned} \qquad (31)$$

$$\begin{aligned} ^2Q_4 = &\,K(1+k)\,{}^1Q_2 - K^2(1+k)\,{}^1Q_3 \\ &+ [1 - K^2(1+k)]\,{}^1Q_4. \end{aligned} \qquad (32)$$

Here, $^1Q_2\,{}^1Q_2{}^*$ represents the power applied to the cavity, and $^1Q_1\,{}^1Q_1{}^*$ represents the output power obtained from the cavity. In the absence of input modulation on the electron stream, the power lost in the cavity is $(1 - kk^*)\,{}^1Q_2\,{}^1Q_2{}^*$. The "$Q$" of the cavity is then

$$\text{“}Q\text{”} = \frac{\omega\text{ energy stored}}{\text{energy dissipated}} \qquad (33)$$

$$\cong \frac{\theta(1+\alpha^2)}{1-\alpha^2} \qquad (34)$$

and the shunt resistance is

$$R_{\text{shunt}} = \frac{(1+k)(1+k)^*}{1 - k\,k^*}\,Z_0. \qquad (35)$$

In passing it should be noted that with the proper choice of magnitude and phase of the power applied to the cavity ($^1Q_2$), either of the input space charge waves may be cancelled at the output, but not both. That is, either $^2Q_3$ or $^2Q_4$ may be made zero.

The above relations describe the interaction of an electron stream with a very narrow gap cavity. The effect of a long gap may be taken into account by considering it to be made up of a series of narrow gaps and applying the above equations successively.

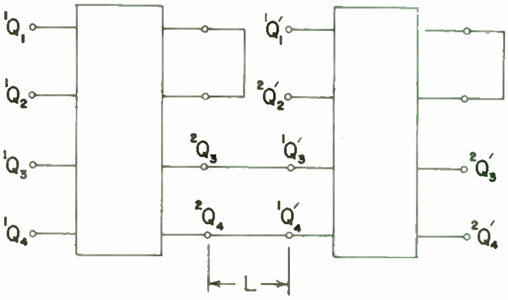

Fig. 3—The coupled transmission lines representation of the two-cavity klystron.

The Two-Cavity Klystron

With the interaction equations for a single cavity, we are now able to derive the power relations in a two-cavity klystron. For simplicity let us assume the cavities to be lossless, that is, $k = 1$. Assume the electron beam enters the first excited cavity unmodulated, ($^1Q_3 = {}^1Q_4 = 0$) then drifts a length, L, before entering the second cavity. See Fig. 3. At the exit of the drift tube,

$$^1Q_3' = e^{-i(\beta_e+\beta_p)L}\,{}^2Q_3 \qquad (36)$$

$$^1Q_4' = e^{-i(\beta_e-\beta_p)L}\,{}^2Q_4. \qquad (37)$$

Using these relations and applying the single gap equations twice, we find

$$^1Q_1' = -\,8jK^2e^{-j\beta_eL}\sin\beta_pL\,{}^1Q_2 \qquad (38)$$

$$^2Q_3' = [-\,2Ke^{-i(\beta_e+\beta_p)L} + 8jK^3e^{-j\beta_eL}\sin\beta_pL]\,{}^1Q_2 \qquad (39)$$

$$^2Q_4' = [2Ke^{-i(\beta_e-\beta_p)L} - 8jK^3e^{-j\beta_eL}\sin\beta_pL]\,{}^1Q_2. \qquad (40)$$

The power flowing out of the second cavity $({}^1Q_1')\,({}^1Q_1')^*$ is

$$({}^1Q_1')({}^1Q_1')^* = 64K^4 \sin^2 \beta_p L \; {}^1Q_2 \; {}^1Q_2^*. \qquad (41)$$

As the beam leaves the second cavity, the fast space charge wave carries power in the forward direction of the amount

$$({}^2Q_4')({}^2Q_4')^* = [4K^2 + 64K^6 \sin^2 \beta_p L - 32K^4 \sin^2 \beta_p L] \; {}^1Q_2 \; {}^1Q_2^*. \qquad (42)$$

The slow space charge wave carries power in the reverse direction.

$$({}^2Q_3')({}^2Q_3')^* = [4K^2 + 64K^6 \sin^2 \beta_p L + 32K^4 \sin^2 \beta_p L] \; {}^1Q_2 \; {}^1Q_2^*. \qquad (43)$$

The sum of these three powers with their appropriate signs is zero. The power relations in a lossless two-cavity klystron can then be described as follows. No net signal power is applied to the first cavity. At the exit of the first cavity the beam contains no net power. Individually, however, the two space charge waves do carry powers which are equal but oppositely directed. At this point the two space charge waves are 180 degrees out of phase. After drifting a suitable distance they may be made to be in phase at the second cavity. Here they give up a certain amount of power to the cavity. At the exit of the second cavity the fast space charge wave carrying forward power is smaller than the slow space charge wave which carries negative power. The difference in the two powers is exactly that given up to the cavity.

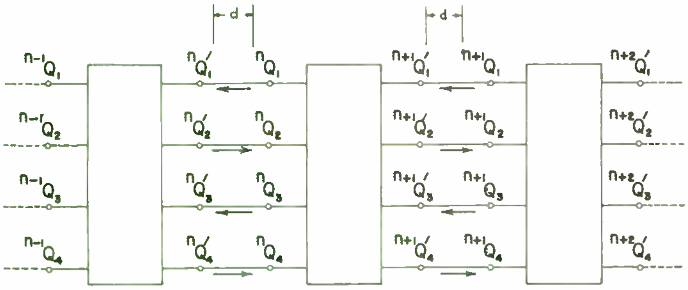

Fig. 4—A series of gap couplings to represent continuous interaction as in the traveling-wave tube.

THE TRAVELING-WAVE TUBE

The interaction equations of an electron stream passing through a gap can form the basis for a power description of the traveling-wave tube. We can replace the continuous interaction which actually takes place by interaction in a series of narrow gaps. Once the relations are derived for this form of interaction we can let the distance between gaps approach zero and reach the case of continuous interaction as a limiting condition.

Consider now the interaction of an electron stream with a series of equally spaced gaps. This situation is shown schematically in Fig. 4.

If the gaps are not actually of zero width, we must take into account the phase shift which the waves experience in crossing the gap. We can do this for small gaps by adding a small length of transmission line of length d after each gap. In the limit of infinitesimal gaps, this length, d, becomes equal to the actual gap spacing. At the output of one of these transmission lines:

$${}^{n+1}Q_1' = e^{-\Gamma_1 d} \; {}^{n+1}Q_1 \qquad (44)$$

$${}^{n+1}Q_2' = e^{+\Gamma_2 d} \; {}^{n+1}Q_2 \qquad (45)$$

$${}^{n+1}Q_3' = e^{j(\beta_e+\beta_p)d} \; {}^{n+1}Q_3 \qquad (46)$$

$${}^{n+1}Q_4' = e^{j(\beta_e-\beta_p)d} \; {}^{n+1}Q_4. \qquad (47)$$

Here Γ_1 and Γ_2 are the reverse and forward propagation constants on the circuit, and $(\beta_e \pm \beta_p)$ are the propagation constants of the two space charge waves in a drifting electron stream. $\beta_e = \omega/u_0$ and $\beta_p = \omega_p/u_0$. At a representative gap, the output quantities in terms of the input quantities are then:

$$e^{-\Gamma_1 d} \; {}^{n+1}Q_1 = {}^nQ_1 + K \; {}^nQ_3 + K \; {}^nQ_4 \qquad (48)$$

$$e^{+\Gamma_2 d} \; {}^{n+1}Q_2 = {}^nQ_2 - K \; {}^nQ_3 - K \; {}^nQ_4 \qquad (49)$$

$$e^{j(\beta_e+\beta_p)d} \; {}^{n+1}Q_3 = -K \; {}^nQ_1 - K \; {}^nQ_2 + {}^nQ_3 \qquad (50)$$

$$e^{j(\beta_e-\beta_p)d} \; {}^{n+1}Q_4 = +K \; {}^nQ_1 + K \; {}^nQ_2 + {}^nQ_4. \qquad (51)$$

Let us look for solutions of these equations of the form

$${}^{n+1}Q = e^{-\Gamma d} \; {}^nQ. \qquad (52)$$

If we assume that the circuit is reciprocal,

$$\Gamma_1 = \Gamma_2; \qquad (53)$$

and, if we let the distance, d, between the gaps become very small so that the exponentials may be approximated by the first two terms in their power series expansions, the equations become:

$$\frac{\Gamma + \Gamma_1}{K/d} \; {}^nQ_1 + {}^nQ_3 + {}^nQ_4 = 0 \qquad (54)$$

$$\frac{-\Gamma + \Gamma_1}{K/d} \; {}^nQ_2 + {}^nQ_3 + {}^nQ_4 = 0 \qquad (55)$$

$$\frac{-\Gamma + j(\beta_e + \beta_p)}{K/d} \; {}^nQ_3 + {}^nQ_1 + {}^nQ_2 = 0 \qquad (56)$$

$$\frac{-\Gamma + j(\beta_e - \beta_p)}{K/d} \; {}^nQ_4 - {}^nQ_1 - {}^nQ_2 = 0. \qquad (57)$$

The condition that these equations have a non-zero solution is that

$$(\Gamma_1^2 - \Gamma^2)[(j\beta_e - \Gamma)^2 + \beta_p^2] = -4j\Gamma_1\beta_p \frac{K^2}{d^2} \cdot \qquad (58)$$

As the cavity gap length becomes equal to the distance between the gaps, then

$$2\frac{\omega_p}{u_0}\frac{K^2}{d^2} = \frac{E^2}{2P}\frac{I_0}{4V_0}\frac{\omega}{u_0} = -\Gamma_1^2\beta_e C^3. \qquad (59)$$

Here E is the peak electric field strength in the gap, P, the power associated with this field, and C, the usual traveling-wave tube gain parameter. If, in addition, we let

$$4QC = \left(\frac{\omega_p}{\omega C}\right)^2, \tag{60}$$

then the root equation becomes

$$(j\beta_e - \Gamma)^2 = \frac{j2\beta_e\Gamma_1^3C^3}{(\Gamma_1^2 - \Gamma^2)} - 4QC^3\beta_e^2 \tag{61}$$

which is equivalent to the usual traveling-wave tube root equation.[6] Its solution shows the existence of four waves. One of these travels opposite to the direction of electron flow with velocity only slightly different from the undisturbed circuit velocity. In theory at least, the circuit may be suitably terminated so that this wave is not excited. Let us assume that this has been done and confine our attention to the other three waves.

Power Relations in the Traveling-Wave Tube

The coupled circuit description of the traveling-wave tube allows us to examine the power relations in three waves. If we adopt Pierce's notation[7] that δ_1 is the incremental propagation constant of the growing wave, δ_2 that of the decreasing wave, and δ_3 that of the unattenuated wave and confine ourselves to the case of the lossless circuit in which the fourth wave is not excited, we find that the total power flow is given by (see Appendix 2)

$$\begin{aligned} P = \{ & [1 + j2\delta_3(\delta_3 + jb)^2]A_3A_3^* \\ & + 2\,\mathrm{Re}\,[1 + j2\delta_2(\delta_2 + jb)^2]A_2A_1^*\}. \end{aligned} \tag{62}$$

Here A_1, A_2, A_3 are the amplitudes of the growing, decreasing, and unattenuated circuit waves, respectively. This relation shows that positive power is carried by the unattenuated wave, no power is carried by either the growing or decreasing wave alone, but when both are present their cross products may contribute either positive or negative power. This latter situation is very reminiscent of the power transfer in a waveguide below cutoff. The fields in such a guide are made up of two waves, one decreasing exponentially to the left and one decreasing exponentially to the right. Since both are cutoff neither carries power by itself. Power is carried by the cross products of the two and may travel either way depending upon which end is source and which is load, or what is equivalent, upon the phase relations between the two waves.

This method of approach, namely a treatment in terms of coupled circuits and ac power flow, can be used to advantage in other beam type devices such as the easitron and the space charge wave amplifier. The technique could also be applied to the double stream amplifier. The method will seldom reveal anything really new but rather serves as a different way of looking at known phenomena.

Acknowledgment

The idea of a power flow description of the traveling-wave tube in terms of coupled transmission lines originated with J. R. Pierce. The author is pleased to acknowledge his aid in the preparation of this material.

Appendix A

Consider two transmission lines each one of which can carry power in either direction to be coupled together over a certain region. Fig. 5 portrays this situation schematically. In it the r's refer to the distance along the line from some arbitrary reference plane to the position where the associated Q's are measured. As before, the superscripts refer to the side of the coupler, the subscripts to the particular wave and the Q's are defined so that QQ^* represents the power flow. Choose positive power flow to the right. Then by this convention $Q_1Q_1^*$ and $Q_3Q_3^*$ represent negative power flow while $Q_2Q_2^*$ and $Q_4Q_4^*$ represent positive power flow.

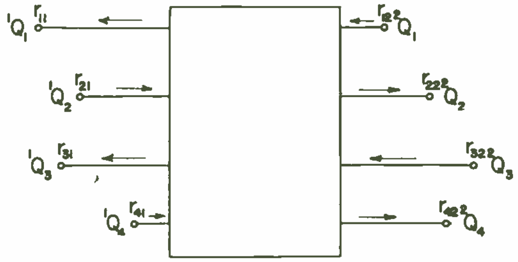

Fig. 5—The representation of a generalized coupling between two transmission lines.

The coupling is assumed to be linear and lossless. The assumption of linearity allows us to write the output quantities in this form:

$${}^2Q_1 = a_{11}\,{}^1Q_1 + a_{12}\,{}^1Q_2 + a_{13}\,{}^1Q_3 + a_{14}\,{}^1Q_4 \tag{63}$$

$${}^2Q_2 = a_{21}\,{}^1Q_1 + a_{22}\,{}^1Q_2 + a_{23}\,{}^1Q_3 + a_{24}\,{}^1Q_4 \tag{64}$$

$${}^2Q_3 = a_{31}\,{}^1Q_1 + a_{32}\,{}^1Q_2 + a_{33}\,{}^1Q_3 + a_{34}\,{}^1Q_4 \tag{65}$$

$${}^2Q_4 = a_{41}\,{}^1Q_1 + a_{42}\,{}^1Q_2 + a_{43}\,{}^1Q_3 + a_{44}\,{}^1Q_4. \tag{66}$$

The assumption of no loss allows us to equate the power flowing into the transducer with the power flowing out of it; or:

$$\begin{aligned} & {}^1Q_2\,{}^1Q_2^* + {}^1Q_4\,{}^1Q_4^* + {}^2Q_1\,{}^2Q_1^* + {}^2Q_3\,{}^2Q_3^* \\ & \qquad = {}^1Q_1\,{}^1Q_1^* + {}^1Q_3\,{}^1Q_3^* + {}^2Q_2\,{}^2Q_2^* + {}^2Q_4\,{}^2Q_4^* \end{aligned} \tag{67}$$

for any arbitrary values of Q_1, Q_2, Q_3, or Q_4. If we substitute the linearity relation into the above equation

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[6] J. R. Pierce, "Traveling-Wave Tubes," D. Van Nostrand Co., New York, 1950, Eq. 7.10, p. 113. The slight difference in the two equations arises because of differences in the definition of C. Pierce defines C in terms of the circuit impedance in the absence of the electron beam, while here it is defined in terms of the circuit impedance in the presence of the beam.

[7] *Ibid.*, p. 16.

and equate coefficients of like terms, we obtain ten equations for the sixteen coefficients.

$$a_{11}a_{11}^* - a_{21}a_{21}^* + a_{31}a_{31}^* - a_{41}a_{41}^* = 1 \tag{68}$$

$$a_{12}a_{12}^* - a_{22}a_{22}^* + a_{32}a_{32}^* - a_{42}a_{42}^* = -1 \tag{69}$$

$$a_{13}a_{13}^* - a_{23}a_{23}^* + a_{33}a_{33}^* - a_{43}a_{43}^* = 1 \tag{70}$$

$$a_{14}a_{14}^* - a_{24}a_{24}^* + a_{34}a_{34}^* - a_{44}a_{44}^* = -1 \tag{71}$$

$$a_{11}^*a_{12} - a_{21}^*a_{22} + a_{31}^*a_{32} - a_{41}^*a_{42} = 0 \tag{72}$$

$$a_{11}^*a_{13} - a_{21}^*a_{23} + a_{31}^*a_{33} - a_{41}^*a_{43} = 0 \tag{73}$$

$$a_{11}^*a_{14} - a_{21}^*a_{24} + a_{31}^*a_{34} - a_{41}^*a_{44} = 0 \tag{74}$$

$$a_{12}^*a_{13} - a_{22}^*a_{23} + a_{32}^*a_{33} - a_{42}^*a_{43} = 0 \tag{75}$$

$$a_{12}^*a_{14} - a_{22}^*a_{24} + a_{32}^*a_{34} - a_{42}^*a_{44} = 0 \tag{76}$$

$$a_{13}^*a_{14} - a_{23}^*a_{24} + a_{33}^*a_{34} - a_{43}^*a_{44} = 0. \tag{77}$$

It may be easily shown that the measurement planes ${}^1r_1{}^1r_2 \cdots {}^2r_3{}^2r_4$ can be chosen in such a way as to make all the a_{ij} coefficients real.

With this choice of reference planes, assume that the coupling section is such that if no input signal is applied to one of the lines, the excitation of the other line is unchanged in passing through the coupling region. Mathematically this implies

$$a_{11} = a_{22} = 1 \tag{78}$$

$$a_{12} = a_{21} = 0. \tag{79}$$

Stated in another way, this condition demands that one of the lines suffer no reflection in passing through the coupling section. Although this restriction simplifies the mathematics greatly, it still leaves the final results applicable to a wide range of coupling systems.

With this restriction the remaining coefficients may be expressed in terms of any three of them.[8] Choosing, for example,

$$a_{13} = p, \tag{80}$$

$$a_{41} = k, \tag{81}$$

$$a_{42} = m, \tag{82}$$

one may write the remaining coefficients in terms of these three as

$$a_{31} = \pm\, k \tag{83}$$

$$a_{32} = \pm\, m \tag{84}$$

$$a_{14} = \pm'\, p \tag{85}$$

$$a_{33} = \pm\, \frac{1}{2}\left[p\,\frac{(k^2 - m^2 - 1)}{k} - \frac{k}{p}\right] \tag{86}$$

$$a_{34} = \pm' \pm \frac{1}{2}\left[p\,\frac{(k^2 - m^2 - 1)}{k} + \frac{k}{p}\right] \tag{87}$$

$$a_{43} = \frac{1}{2}\left[p\,\frac{(k^2 - m^2 + 1)}{k} - \frac{k}{p}\right] \tag{88}$$

$$a_{44} = \pm'\, \frac{1}{2}\left[p\,\frac{(k^2 - m^2 + 1)}{k} + \frac{k}{p}\right] \tag{89}$$

$$a_{23} = -\,\frac{m}{k}\,p \tag{90}$$

$$a_{24} = \mp'\,\frac{m}{k}\,p. \tag{91}$$

Here, either the lower or the upper signs of both primed and unprimed ± signs must be taken consistently. The choice of signs arises from the fact that there are two possible positions for each of the reference planes which make the corresponding Q's real.

Note that the condition of reciprocity has not been explicitly imposed. Indeed, if the results are to be applied to electron beams, it must not be imposed.

Consider now that the two wave-carrying circuits are actually composed of a transmission line and an electron stream. Let the coupling between the two take place in a small region where the electron stream flows across a gap formed by the transmission line. See Fig. 6. Suppose Q_1 and Q_2 characterize the two waves which can exist on the transmission line and Q_3 and Q_4 those of the electron stream.

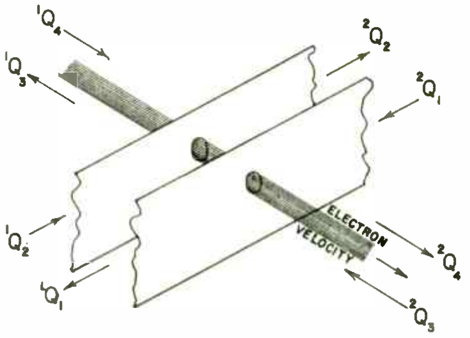

Fig. 6—An electron beam flowing across a gap formed by a transmission line.

Let us assume we apply no external power to the transmission line and allow only the fast space charge wave ${}^1Q_4$ to exist on the stream initially; that is

$${}^1Q_2 = {}^1Q_3 = {}^2Q_1 = 0. \tag{92}$$

Using (92), (78), and (79), the coupling equations (63) through (66) become

$$0 = {}^1Q_1 + a_{14}\,{}^1Q_4 \tag{93}$$

$${}^2Q_2 = a_{24}\,{}^1Q_4 \tag{94}$$

$${}^2Q_3 = a_{31}\,{}^1Q_1 + a_{34}\,{}^1Q_4 \tag{95}$$

$${}^2Q_4 = a_{41}\,{}^1Q_1 + a_{44}\,{}^1Q_4 \tag{96}$$

If the reference planes are taken at the gap, the voltage waves traveling away from the gap are equal by symmetry.

$${}^2Q_2 = {}^1Q_1. \tag{97}$$

---

[8] Eqs. (78) and (79) are not independent and hence serve as three rather than four constraints.

Combining (97) with (93), we find

$$ {}^2Q_2 = -a_{14}\,{}^1O_4, \tag{98} $$

or, from (94)

$$ a_{24} = -a_{14}. \tag{99} $$

Initially only the fast space charge wave, ${}^1Q_4$, was present. On emerging from the gap both waves will be present due to the presence of an induced voltage, V, in the gap. In terms of the Q's, the slow space charge wave will be modulated by the gap voltage so that,

$$ {}^2Q_3 = -K\,{}^1Q_1, \tag{100} $$

and the fast space charge wave will be augmented by a similar term with opposite sign,

$$ {}^2Q_4 = {}^1Q_4 + K\,{}^1Q_1. \tag{101} $$

From the relations discussed in an early section (AC Power Flow in an Electron Stream), we find

$$ K = \frac{1}{2}\sqrt{\frac{I_0}{V_0}\frac{\omega}{\omega_p}Z_0}. \tag{102} $$

These relations imply that

$$ a_{34} = 0 \tag{103} $$

$$ a_{31} = -K \tag{104} $$

$$ a_{41} = K \tag{105} $$

$$ a_{44} = 1. \tag{106} $$

In addition we know that, for the infinitesimally narrow gap,

$$ a_{33} = 1. \tag{107} $$

These relations in conjunction with the general relations which the coefficients must satisfy enable us to write the output quantities in terms of the input quantities:

$$ {}^2Q_1 = {}^1O_1 + K\,{}^1Q_3 + K\,{}^1Q_4 \tag{108} $$

$$ {}^2Q_2 = {}^1Q_2 - K\,{}^1Q_3 - K\,{}^1Q_4 \tag{109} $$

$$ {}^2Q_3 = -K\,{}^1Q_1 - K\,{}^2Q_2 + {}^1Q_3 \tag{110} $$

$$ {}^2Q_4 = K\,{}^1Q_1 + K\,{}^1Q_2 + {}^1Q_4. \tag{111} $$

APPENDIX B

In the properly terminated traveling-wave tube there is no reverse traveling wave present, so that any of the pertinent quantities may be described in terms of the remaining three waves. The amplitudes of the kth wave components at the nth section are: (see Fig. 4)

$$ {}^nQ_{2k} = A_{2k}e^{-n\Gamma_k d} \tag{112} $$

$$ {}^nQ_{3k} = A_{3k}e^{-n\Gamma_k d} \tag{113} $$

$$ {}^nQ_{4k} = A_{4k}e^{-n\Gamma_k d}. \tag{114} $$

Here the supserscript, n, indicates which interaction gap is being considered. The subscripts 2, 3, or 4 indicate circuit wave components, slow and fast space charge wave components, respectively. The subscript, k, indicates whether the contribution to these respective waves is from the increasing, decreasing or unattenuated wave. Since, for the two space charge waves,

$$ e^{j(\beta_e+\beta_p)d}\,{}^{n+1}Q_{3k} = -K\,{}^nQ_{2k} + {}^nQ_{3k}, \tag{115} $$

$$ e^{j(\beta_e-\beta_p)d}\,{}^{n+1}Q_{4k} = K\,{}^nQ_{2k} + {}^nQ_{4k}, \tag{116} $$

and

$$ \frac{K}{d} = \frac{1}{2}\sqrt{2\beta^2C^3\frac{\omega}{\omega_p}}, \tag{117} $$

then for small d we may write to first order in d

$$ \frac{{}^nQ_{2k}}{{}^nQ_{3k}} = \frac{2[\Gamma_k - j\beta_e - j\beta_p]}{\sqrt{2\beta^2C^3\frac{\omega}{\omega_p}}} \tag{118} $$

$$ \frac{Q_{2k}}{Q_{4k}} = -\frac{2[\Gamma_k - j\beta_e + j\beta_p]}{\sqrt{2\beta^2C^3\frac{\omega}{\omega_p}}}; \tag{119} $$

or in Pierce's notation

$$ \frac{{}^nQ_{2k}}{{}^nQ_{3k}} = -2(QC)^{1/4}[\delta_k + j\sqrt{4QC}] \tag{120} $$

$$ \frac{{}^nQ_{2k}}{{}^nQ_{4k}} = 2(QC)^{1/4}[\delta_k - j\sqrt{4QC}]. \tag{121} $$

In general then, we may write

$$ {}^nQ_2 = A_1e^{-\Gamma_1 nd} + A_2e^{-\Gamma_2 nd} + A_3e^{-\Gamma_3 nd} \tag{122} $$

$$ {}^nQ_3 = \frac{-1}{2(QC)^{1/4}}\left[\frac{A_1e^{-\Gamma_1 nd}}{\delta_1 + j\sqrt{4QC}} + \frac{A_2e^{-\Gamma_2 nd}}{\delta_2 + j\sqrt{4QC}} + \frac{A_3e^{-\Gamma_3 nd}}{\Gamma_3 + j\sqrt{4QC}}\right] \tag{123} $$

$$ {}^nQ_4 = \frac{1}{2(QC)^{1/4}}\left[\frac{A_1e^{-\Gamma_1 nd}}{\delta_1 - j\sqrt{4QC}} + \frac{A_2e^{-\Gamma_2 nd}}{\delta_2 - j\sqrt{4QC}} + \frac{A_3e^{-\Gamma_3 nd}}{\delta_3 - j\sqrt{4QC}}\right] \tag{124} $$

According to the usual convention we shall designate A_1, δ_1, Γ_1, etc. as being associated with the increasing wave; A_2, δ_2, Γ_2, etc. with the decreasing wave; and A_3, δ_3, Γ_3, etc. with the unattenuated wave. We assume no circuit attenuation.

We desire to determine the total ac power flow which is

$$ P = {}^nQ_2\,{}^nQ_2^* + {}^nQ_4\,{}^nQ_4^* - {}^nQ_3\,{}^nQ_3^*. \tag{125} $$

The algebraic labor involved may be lightened when it is realized that no cross terms which have a distance variation can be present. This implies that the only non-zero cross terms are products of the increasing and decreasing waves. These two waves have incremental propagation constants which in the lossless case are complex conjugates. There will then be two types of terms, products of waves of like subscript and products of the increasing and decreasing wave. The terms of like subscripts are:

$$P_{kk} = \frac{A_k A_k^*}{(\delta_k^* + j\sqrt{4QC})(\delta_k^* - j\sqrt{4QC})} \cdot [x_k^2 - 3y_k^2 - 2y_k b + 4QC], \qquad (126)$$

where, as is customary, x_k and y_k are the real and imaginary parts of the *k*th incremental propagation constant. The quantity within brackets in the numerator is zero for $x \neq 0$.[8,9] For the unattenuated wave, $x=0$ and the power contribution is

$$P_{33} = [1 + j2\delta_3(\delta_3 + jb^2]A_3A_3^*. \qquad (127)$$

The contribution to the power from the two terms involving the products of the increasing and decreasing wave reduces to

$$P_{12} = 2 \operatorname{Re} [1 + j2\delta_2(\delta_2 + jb)^2]A_2A_1^* \qquad (128)$$

The entire power carried in terms of the amplitudes of the three circuit waves is then

$$P = [(1 + j2\delta_3(\delta_3 + jb)^2]A_3A_3^* + 2 \operatorname{Re} [1 + j2\delta_2(\delta_2 + jb)A_2A_1^*. \qquad (129)$$

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[9] J. R. Pierce, *op. cit.*, eq. 8.27, p. 124.

Investigations of Noise in Audio Frequency Amplifiers Using Junction Transistors*

P. M. BARGELLINI† AND M. B. HERSCHER‡

***Summary*—An investigation of noise from modern junction transistors in audio frequency amplifiers is presented. Different circuit configurations are examined and the effects on noise factor of the input termination and operating point are discussed. At least three distinct sources of noise corresponding to different physical phenomena contributing to total noise are identified. In modern junction transistors shot noise and thermal noise set the ultimate limit of noise in transistor amplifiers, and are frequency-independent over the audio spectrum. Semiconductor noise which follows approximately the 1/f law has been found to be just one contributor to total transistor noise. The concept of equivalent input noise resistance is applied to transistor circuits and a comparison is drawn between noise of transistor and vacuum-tube amplifiers.**

INTRODUCTION

A WELL-KNOWN and convenient method of expressing the noisiness of a four-terminal electrical network is to use the basic concept of noise factor,[1] a quantity defined as

$$NF_{\text{db}} = 10 \log \frac{(S/N)_i}{(S/N)_o} = 10 \log \frac{N_o}{N_o'} \qquad (1)$$

where S and N are respectively signal and noise powers. The suffixes i and o refer to input and output, and the index of N_o' in the denominator indicates that part of N_o which is due to amplification of noise from source.

Amplifiers using the early point contact type transistors were found to be very poor because of their noisiness and, as such, they could not be used in very low level applications. Noise factors of 50–70 db (measured at 1000 cps)were reported in literature[2] for amplifiers using these early point contact transistors. Clearly any device having such a large noise factor is of little or no use unless the signals to be amplified by it originate from sources characterized by large value of signal-to-noise ratio. With junction transistors it was discovered that much better noise performance could be obtained; noise factors (at 1000 cps) in the range from 10 to 35 db were measured. It was conceivable to hope, therefore, that even lower noise factors could be obtained as the art progressed so that transistor noise factors comparable with good vacuum tube amplifiers would be available. When noise at frequencies other than 1000 cps is considered, most previously available information was of such a character that it emphasized the so-called $1/f$ law, (the decrease of noise with increasing frequency).[2–9]

POSSIBLE METHODS OF ATTACK

Once the noise factor is taken as the fundamental quantity of interest to electrical engineers, there are clearly two possible ways of attacking the problem.

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When the physical phenomena active in the noise generation are known it is possible to obtain directly the values of the quantities of (1) under different operating conditions and with various circuit configurations. It will then be the purpose of experiments and measurements to check the values of the noise factor obtained theoretically.

On the other hand, when the mechanism of some of the noise generators is totally or partially unknown it is advisable to proceed with direct experimental techniques by measuring the noise factor of amplifiers operated under different conditions; such an approach yields direct information on the usefulness of the device as an amplifier and offers the possibility of some later understanding of the physics of noise generation.

Transistor amplifiers have been investigated by the latter type of approach since no generally acceptable model for the noise-generating mechanisms active in the transistor itself was available at the time this investigation was started. Theories of noise in semiconductor devices had been advanced[10,11] but they appeared insufficient to predict the noise behavior of a transistor amplifier. The 1/f law itself was questioned with respect to its general application and it was decided to investigate carefully the limits of its validity; its correction was the conclusive element leading to a formulation of a novel transistor noise equivalent circuit.

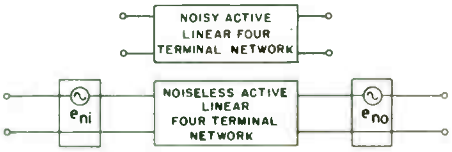

Fig. 1—General representation of a noisy four-terminal network.

THE FORMULATION OF THE NOISE PROBLEM FROM FOUR-TERMINAL NETWORK POINT OF VIEW

It has been shown[12] that in order to describe a noisy four-terminal network of the active type, six parameters are required, four of them being the usual Z, Y or H parameters[13] and the additional two representing two fictitious noise generators such as open circuit input and output voltage generators, or an open-circuit voltage generator and another short-circuit current generator. When, for example, voltage generators are used for the noise sources, the noisy four-terminal network can be replaced by the cascade arrangement of three four-terminal networks as in Fig. 1. When the network is connected to a generator on one side and to a load on the other, the noise factor of the amplifier resulting from the combination can be found.

In the general case the single frequency noise factor F_o is given in terms of the Z parameters by

$$F_o = 1 + \frac{1}{4KTR_g}\left[N_i + N_o\left|\frac{Z_{11}+Z_g}{Z_{21}}\right|^2 - 2\mathrm{Re}\left(N_{io}\frac{Z_{11}+Z_g}{Z_{21}}\right)\right], \tag{2}$$

in terms of the Y parameters by

$$F_o = 1 + \frac{1}{4KTG_g}\left[N_i' + N_o'\left|\frac{Y_{11}+Y_G}{Y_{21}}\right|^2 - 2\mathrm{Re}\left(N_{io}'\frac{Y_{11}+Y_G}{Y_{21}}\right)\right], \tag{3}$$

or, in terms of the H parameters,

$$F_o = 1 + \frac{1}{4KTR_g}\left[N_i + N_o'\left|\frac{H_{11}+Z_g}{H_{21}}\right|^2 + 2\mathrm{Re}\left(N_{io}''\frac{H_{11}+Z_g}{H_{21}}\right)\right]; \tag{4}$$

where

$$\left.\begin{matrix} R_g \\ G_g \end{matrix}\right\} = \text{generator}\left\{\begin{matrix} \text{resistance} \\ \text{conductance} \end{matrix}\right.$$

N_i = power spectrum of e_{ni}, N_o = power spectrum of e_{no}, N_{io} = cross power spectrum of e_{ni} and e_{no}; N_i' = power spectrum of i_{ni}, N_o' = power spectrum of i_{no}, N_{io}' = cross power spectrum of i_{ni} and i_{no}, N_i = power spectrum of e_{ni}, N_o' = power spectrum of i_{no}, N_{io}'' = cross power spectrum of e_{ni} and i_{no}.

The influence of the third term, which is descriptive of correlation between the noise generators, has been the object of previous studies[3,8]. Although it seems to have a certain importance in the case of very noisy transistors it appears that in low-noise units its importance decreases because the noise levels are close enough to values which can be ascribed, as will be shown later, to uncorrelated thermal and shot noise sources.

By eliminating the third term the noise factor can be written, when Z parameters are used, in the smplified form

$$F_o = 1 + \frac{1}{4KTR_g}\left[\overline{e_{ni}^2} + \overline{e_{no}^2}\left|\frac{Z_{11}+Z_g}{Z_{21}}\right|^2\right], \tag{5}$$

and with a further simplification (whereby all Z's reduce to R's),

$$F_o = 1 + \frac{1}{4KTR_g}\left[\overline{e_{ni}^2} + \overline{e_{no}^2}\left(\frac{R_{11}+R_g}{R_{21}}\right)^2\right]; \tag{6}$$

with

$\overline{e_{ni}^2}$ = open circuit input generator mean squared volts,

$\overline{e_{no}^2}$ = open circuit output generator mean squared volts.

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[10] W. Shockley, *op. cit.*, pp. 342–346.

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Similar expressions can be written in terms of Y or H parameters.

Developing (6) for the three basic transistor amplifier configurations; common-base, common-emitter, and common-collector, gives the following:

common-base

$$F_o = 1 + \frac{1}{4KTR_g}\left[\overline{e_{ne}^2} + \overline{e_{nc}^2}\left(\frac{r_e + r_b + R_g}{r_m + r_b}\right)^2\right], \tag{7}$$

common-emitter

$$F_o = 1 + \frac{1}{4KTR_g}\left[\overline{e_{ne}^2}\left(\frac{r_m + r_b + R_g}{r_m - r_e}\right)^2 + \overline{e_{nc}^2}\left(\frac{r_e + r_b + R_g}{r_m - r_e}\right)^2\right]. \tag{8}$$

common-collector

$$F_o = 1 + \frac{1}{4KTR_g}\left[\overline{e_{ne}^2}\left(\frac{r_b + r_c + R_g}{r_c}\right)^2 + \overline{e_{nc}^2}\left(\frac{r_b + R_g}{r_c}\right)^2\right]. \tag{9}$$

The above expressions correspond respectively to the three arrangements of the noise generators of Fig. 2. If the short circuit current amplification factor

$$\alpha = \frac{r_m + r_b}{r_e + r_b} \cong \frac{r_m}{r_c}$$

is introduced in (7), (8) and (9) one finds further equivalent expressions for the noise factor

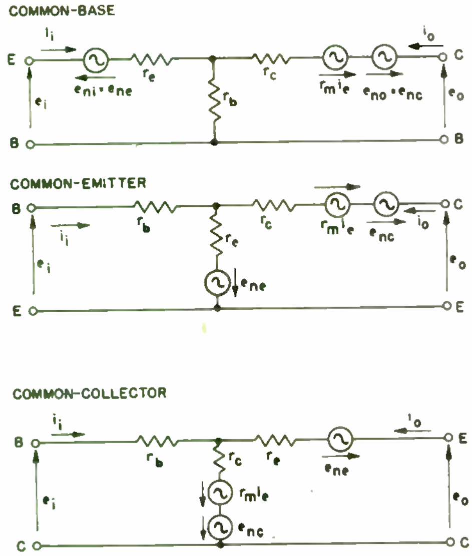

Fig. 2—Basic transistor equivalent circuits with noise generators.

CONSIDERATIONS ON e_{ni} AND e_{no}, THEIR MEASUREMENT AND NATURE

In (7), (8), and (9), the noise mean-squared voltages must be defined over a one cycle bandwidth at any point of the frequency spectrum for which it is desired to obtain the value of F_o. However, F_o cannot be determined from these equations unless e_{ne} and e_{nc} are known. Direct measurements have been reported[3–6,13] and some indicative values at 1000 cps are available for point-contact transistors ($e_{ne} = 10^{-6}$ volts, $e_{no} = 10^{-4}$ volts). Both noise voltages are functions of the operating conditions, particularly of the d-c voltages and currents in the input and output junctions. Since the generator impedance enters in the expressions of noise factor the functions $F_o = f(R_g)$ are obtained experimentally for any of the three different configurations and for a given transistor. Taking then two values of R_g so as to yield two values of F_o, two equations in two unknowns, e_{ni} and e_{no}, can be obtained.

In the case of the common-base connection, (7) can thus be written twice:

$$\begin{aligned} F_{o1} &= 1 + a_1\left[\overline{e_{ne}^2} + \overline{e_{nc}^2}(b_1)^2\right] \\ F_{o2} &= 1 + a_2\left[\overline{e_{ne}^2} + \overline{e_{nc}^2}(b_2)^2\right], \end{aligned} \tag{10}$$

where

$$a = \frac{1}{4KTR_g},$$

and

$$b = \frac{r_e + r_b + R_g}{r_m + r_b}.$$

Solving (10), produces

$$\overline{e_{ne}^2} = \frac{a_1 b_1^2(F_{o1} - 1) - a_2 b_2^2(F_{o2} - 1)}{a_1 a_2(b_1^2 - b_2^2)} \tag{11}$$

$$\overline{e_{nc}^2} = \frac{a_2(F_{o1} - 1) - a_1(F_{o1} - 1)}{a_1 a_2(b_1^2 - b_2^2)}. \tag{12}$$

In any problem of this kind the knowledge of the optimum source resistance R_g yielding minimum noise factor is of importance. Thus by setting

$$\frac{\partial F_o}{\partial R_g} = 0$$

and solving for R_g, it is found in the general case that

$$R_{g\,\text{optimum}} = \sqrt{r_{21}\left(\frac{e_{n1}}{e_{n2}}\right)^2 + r_{11}^2}. \tag{13}$$

For the three different configurations the following expressions are found:

common-base

$$R_{g\,\text{optimum}} = \sqrt{\left(\frac{e_{ne}}{e_{nc}}\right)^2(r_b + r_m)^2 + (r_e + r_b)^2}, \tag{14}$$

common-emitter

$$R_{g\,\text{optimum}} = \sqrt{\frac{r_b^2 + r_m^2(e_{ne}/e_{nc})^2}{1 + (e_{ne}/E_{nc})^2}}, \tag{15}$$

common-collector

$$R_{g\,\text{optimum}} = \sqrt{\frac{\left(\frac{e_{ne}}{e_{nc}}\right)^2 r_c^2 + r_b^2}{1 + \left(\frac{e_{ne}}{e_{nc}}\right)^2}}. \tag{16}$$

Previously available information concerning e_{ne} and e_{nc} indicated that these noise voltages are frequency-dependent, the type of dependence being described by the already mentioned inverse-frequency law. Since, as has already been mentioned, it was necessary to reconsider the 1/f law, the dependence of noise sources and consequently of noise factor on frequency is of extreme importance. Notice that (1), in yielding noise factor, leads to different values of this quantity which are usually indicated as:

1. Single frequency or spot noise factor,
2. Integrated noise factor, which are respectively:

$$NF(f) = 10 \log \frac{N_o(f)}{N_o'(f)} \tag{17}$$

and

$$NF_{\text{int}} = \frac{1}{f_2 - f_1} \int_{f_1}^{f_2} NF(f) df, \tag{18}$$

where $N_o(f)$ and $N_o'(f)$ are the output noise-power densities (watts/cycle) of the thermal and total noise.

Since $N_o'(f)$ is frequency-dependent only through the amplitude squared function of the device, while $N_o(f)$ is a function of the location and mechanism of the various noise generators, a difference may result between spot and integrated noise factors.

Description of Noise Factor Measurements—Methods, Techniques, and Precautions

Several methods and techniques are available for measuring the noise factor of an amplifier. However, these might be classified into two main categories:

1. Methods employing a noise source such as a noise diode.
2. Methods using a sinusoidal signal generator.

The noise-diode method of measuring noise factor is quite fundamental; it permits simplification in the procedure and, in general, a greater accuracy than other methods. Techniques employing a sinusoidal signal generator become easily subject to error in the measurement of the extremely small power levels employed, especially at higher frequencies; furthermore, a separate measurement of amplifier bandwidth is required and the response to signal and noise of the indicator has to be carefully considered.

A block diagram of the noise-diode set-up used is shown in Fig. 3. In order to reduce stray and hum fields which would introduce errors, the amplifier is shielded and the noise-diode filament and plate supplies are obtained from batteries. The signal from the transistor amplifier is fed directly to a low-noise tube amplifier using a 1620 tube in the input stage; the noise power output may be read at its output or may be channeled to a General Radio Wave Analyzer, Model 736-A.

Measurements taken with the wave analyzer yield essentially spot noise-factor values since the analyzer has a constant noise bandwidth of 5.3 cps over the audio band. When the analyzer is not employed, and since the noise bandwidth of 1620 set is 12 kc, noise-factor values integrated throughout the audio band are obtained. Integrated noise-factor measurements are usually desirable since they describe more accurately the device under investigation; several spot noise-factor measurements at different frequencies should be taken to obtain a comparable result.

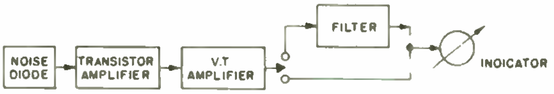

Fig. 3—Block diagram of noise-factor measurement set-up with random noise generator.

In the experimental results to be found in the next section, it should be noted that the greater percentage of noise measurements were taken using the noise-diode set-up. The narrow-band results obtained were also compared with various signal generator methods of measurement and were found to be in close agreement. Fig. 4 gives the block diagram of the single signal noise-factor measurement set-up.

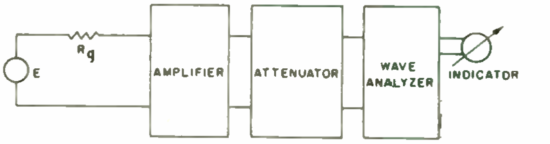

Fig. 4—Block diagram of noise-factor measurement set-up with single frequency-signal generator.

Experimental Results

Noise factor measurements of *p-n-p* and *n-p-n* junction transistors were conducted. Almost all the different types of transistors manufactured were investigated although the RCA type 2N34 transistor was given preference due to the importance of this type for low-level audio work.

It was recognized at an early stage of the experimental program that the 1/f law is not always verified in junction transistors throughout the whole audio range; as a consequence it was decided to adopt as a possible measure of the noise quality of a transistor the integrated (over the audio band) value of its noise factor rather than the spot or single-frequency noise factor usually given at 1 kc. In assigning the limits to the above mentioned band of frequencies it was kept in mind that (a) the lower limit should be set considerably below the lowest audible frequency because it is usually in this region that the 1/f law holds as the result of the predominant "semiconductor noise" (adopted value, 20 cps); (b) the higher limit should be set around the highest audible frequency, the exact value being immaterial. The 12 kc noise bandwidth of the tube noise set was thereby acceptable and use of the set was made for experimental convenience.

The 2N34 transistors tested were generally found to have relatively low noise factors. From a random sample of 50 units tested the average integrated noise factor was found to be about 13 or 14 db. The measurements of integrated noise factor gave the results in Fig. 5 for the specified conditions.

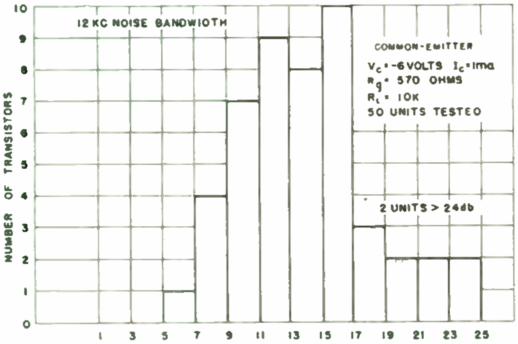

Fig. 5—Integrated noise-factor distribution (RCA-2N34).

Measurements of single frequency noise factors are given in Fig. 6 for the specified conditions. The most important conclusions on the basis of this experimental evidence is that the noise behavior of transistors is not unique; there are not only quiet and noisy transistors, but each type exhibits a different behavior, as is clearly indicated in the figure.

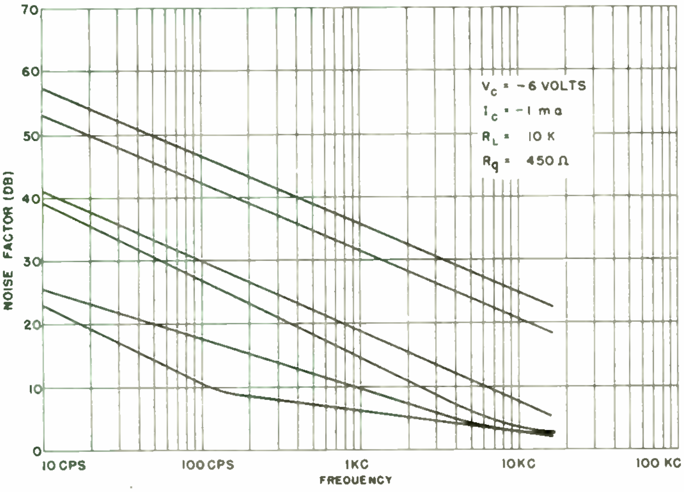

Fig. 6—Noise factor vs frequency (RCA-2N34; common-emitter).

The change in the spot noise-factor value over a decade frequency interval ranges from 12 db to 3 db depending on a given transistor and on the position in the spectrum of the frequency interval.

In general the experimental evidence indicates that noisy units approximately follow the 1/f law throughout the whole audio-frequency range and above, while quiet units exhibit different slopes in different regions, eventually exhibiting a somewhat flat spectrum. Theorectically, whether the transistor is connected common-emitter, common-base, or common-collector, its noise factor should be approximately the same. This has been substantiated experimentally for several transistors as shown in Fig. 7. It may be noted that measurements for the various connections are within 2 db of each other.

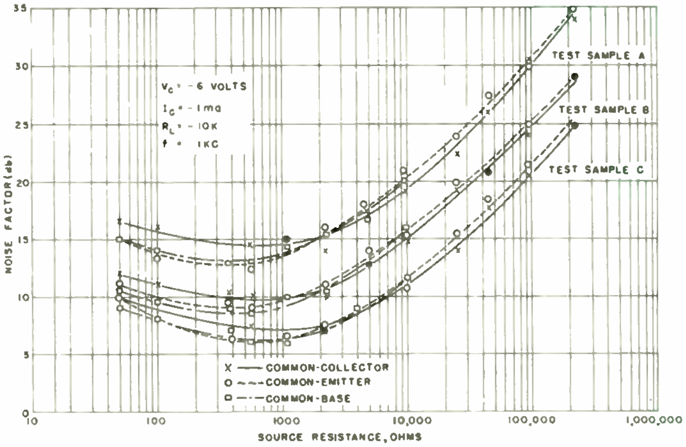

Fig. 7—Noise factor vs source resistance (RCA-2N34).

From the designer's point of view, it is of interest to know the value of source impedance which will yield optimum noise factors. Fig. 7 shows a broad minimum value of noise factor, from which it may be concluded that source impedance is not a critical value; however, for best results, the device should be operated from a source having an impedance in the range between 400 and 1000 ohms. The results shown are spot noise-factor measurements taken at a frequency of 1 kc. If integrated noise factor measurements are made, Fig. 8 shows that the results are quite similar, with the integrated noise being lower than the spot noise measurements; the exact value depends on the transistor spot noise-factor vs frequency characteristic.

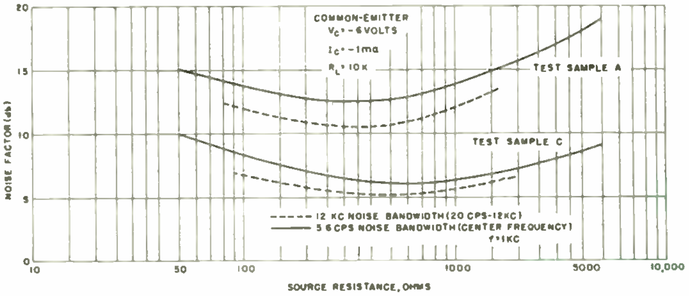

Fig. 8—Noise factor vs source resistance (RCA-2N34).

The effect on noise of collector current I_c, and voltage V_c are illustrated on following page in Figs. 9, 10 and 11. Fig. 9 refers to the typical behavior of an RCA 2N34 transistor operated at a constant-collector voltage with different values of collector current. The change in level and shape of the noise-factor vs frequency curves is significant. Fig. 10 gives noise factor at 1 kc vs collector current I_c, with collector voltage V_c as a parameter, while Fig. 11 shows noise factor at 1 kc vs collector voltage with collector current taken as a parameter.

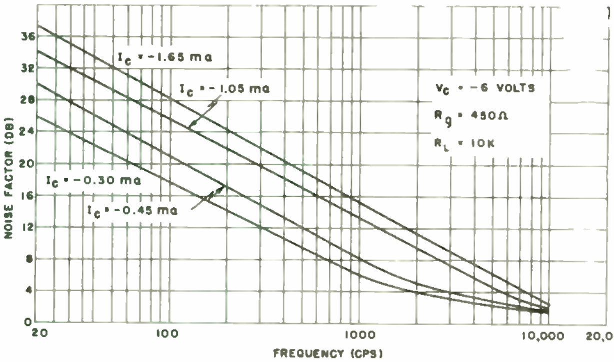

Fig. 9—Noise factor vs frequency (collector current as a parameter; RCA-2N34, common-emitter).

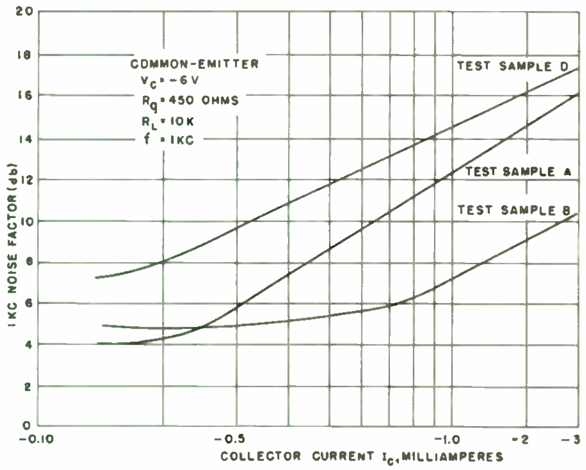

Fig. 10—Noise factor vs operating point (collector current).

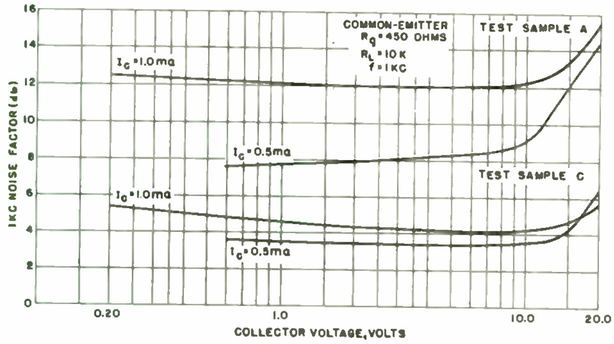

Fig. 11—Noise factor vs operating voltage (collector voltage; RCA-2N34).

These three figures refer to amplifiers in the common-emitter connection; further tests have constantly revealed no appreciable difference for the two other connections as far as dependence upon dc bias is concerned. The conclusions to be drawn from the above experimental evidence are:

1. Noise factors around 12 db are frequently encountered in modern junction transistors.
2. Remarkably quiet units were found with minimum values of noise factor around 4 db.
3. All three connections, common-base, common-emitter, or common-collector are capable of resulting in essentially identical values of noise factor. The lower power gain of the common-collector connection advises against its use whenever second-stage noise would be objectionable.
4. Source resistance has an influence on minimum noise factor. Optimum values are not critical, however, and typical values have been reported for the three different connections.
5. The 1/f law is observed only through part of the spectrum and the frequency dependence of noise factor or the applied dc bias is indicative of the superposition of various noise sources having different spectral distributions.
6. No appreciable reduction of noise is obtained below $V_c = 10$ volts. But above this range the noise increases sharply with increasing collector voltage.
7. Reduction of collector current results generally in more quiet operation.

SEPARATION OF NOISE SOURCES, PHYSICAL EQUIVALENT CIRCUITS FOR NOISY TRANSISTORS

Experimental evidence has indicated that the noise behavior of a transistor amplifier expressed in terms of noise factor can be described as follows:

1. At very low frequencies the noise decreases with increasing frequency (region I).
2. In an intermediate range of frequencies the noise remains relatively constant (region II).
3. At higher frequencies the noise increases with frequency (region III).

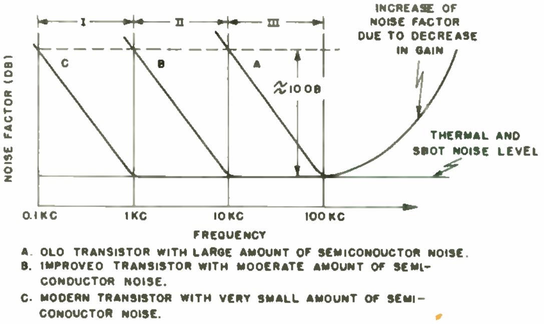

Fig. 12—Generalized behavior of transistor noise.

The definition of these three regions is a function of many variables and, as indicated by the idealized curves of Fig. 12, their interval of existence is different for various transistors operated under different conditions. The general trend on the curves of Fig. 12 has been inferred not only from the measurement at audio frequencies but also correlates well with radio-frequency measurements in the range from 500 kc to 8 mc. It must be added that the noise levels effectively measured for region II are not equal but depend on the particular transistor and circuit used.

At present one can only hypothesize as to the exact nature of transistor noise-generating mechanisms. Based upon available information in the literature and upon the measurements considered the following analysis seems plausible with the possible active noise sources being those due to (a) thermal agitation, (b) shot effect in the current carriers, (c) semiconductor (or excess) noise, and (d) leakage. All these sources contribute to form the e_{ne} and/or e_{nc} noise voltages at any given frequency; therefore, they must be investigated separately to correctly interpret the noise from transistors.

Leakage noise, characterized by abnormally large bursts (pops), has been observed in the course of this work, especially on poor and unreliable units. It was decided, however, to reject units with excessive leakage since this type of noise is due to manufacturing techniques and is not necessarily inherent in the device. Semiconductor noise is that component of noise (considered in the past as the only transistor noise) which is observed in nonmetallic resistors, carbon microphones, and semiconductor devices when a circuit current is made to flow through them; mean square noise voltage from a semiconductor has been hypothesized[14] as

$$\overline{de^2} = kV^{\alpha}R^{\beta}f^{-\gamma}\cdot df; \qquad (19)$$

where k = a factor dependent on the material used, V = applied dc voltage, R = dc resistance, f = frequency, α = a factor from 1.2 to 1.8, β = a factor from 1.2 to 1.8, and γ = a factor from 0.9 to 1.2. From equation (19) it may be inferred that noise is dependent on dc voltage and dc resistance; therefore noise will be many times higher in a reverse- than in a forward-biased junction. In a transistor considered as two adjacent semiconductor junctions displaying a mutual interaction there are two semiconductor noise sources; one in the emitter-to-base and one in the collector-to-base junctions. Mention will be made later of their relative importance. Shot noise from a rectifying junction can be expressed as

$$\overline{di_{\text{shot}}^2} = 2eIdf; \qquad (20)$$

where e = electron charge and I = dc current through the junction. The above current source is in parallel with the junction dynamic resistance r_d so that the mean square voltage across it is

$$\overline{de_{\text{shot}}^2} = \overline{di^2}\cdot r_d^2. \qquad (21)$$

As in the case of semiconductor noise, two shot-noise sources have to be considered in a transistor; one in the emitter-to-base junction and another in the collector-to-base junction. Since the output (collector) direct current is the sum of the thermal equilibrium current I_{co} and the current injected from the input circuit, care must be exercised to use the correct values of the dc components of the current and of the dynamic resistances in (20) and (21). The extension to transistors of (20) was recently discussed[15] in the literature in an attempt to investigate the lower noise limits of transistors. Substantial agreement has been found between the results of the above reference and the work reported here, which was carried out independently.

Finally, thermal noise from resistive components in the transistor not otherwise considered must be taken into account yielding voltages of the form

$$\overline{de_{th}^2} = 4KTRdf.$$

In a transistor there are three resistances of the above type associated with each of the three terminals: base, emitter and collector. The intrinsic base resistance (sometimes called spread base resistor or $r_{bb'}$) is the only term of importance, however, and the other two (lead emitter and collector resistances) can be neglected. It can therefore be concluded that the effective noise sources in a transistor are:

1. One thermal source in the base resistance.
2. Two shot noise sources in the input and output junctions.
3. Two semiconductor noise sources in the input and output junctions.

Notice that while sources 1 and 2 can be considered as frequency independent (at least within the audio frequency range) and those of the source 3 are frequency dependent, yet some of the above contributions may result in quantities small enough to make it permissible to neglect them. Such is the case, as indicated by experimental evidence, with semiconductor noise which is originated for its greater part in the collector junction. With reference to Fig. 12, while region I is ascribed to semiconductor noise, and regions II and III to shot and thermal noise, the increase of noise factor of the latter is explained as due to the effect of the decrease in the power gain of the amplifier (and possible intervention of additional noise sources) at high frequencies and the presence of shot noise from the output junction. The physical equivalent circuits for noisy transistors in the three basic circuit configurations can therefore be drawn as in Fig. 13, on the following page.

When a generator of internal resistance R_g and a load R_L are connected to the equivalent circuits the resultant expressions for the single frequency noise factors are:

common-base,

$$F = 1 + \frac{1}{4KTR_g}\left[\overline{e_{she}^2} + \overline{e_{thb}^2}\left(\frac{\alpha r_c + r_e + R_g}{\alpha r_c + r_b}\right)^2 + \overline{e_{shc}^2}\left(\frac{r_e + r_b + R_g}{\alpha r_c + r_b}\right)^2 + \overline{e_{scc}^2}\left(\frac{r_e + r_b + R_g}{\alpha r_c + r_b}\right)^2\right]; \qquad (23)$$

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[14] C. J. Christensen and G. L. Pearson, "Spontaneous fluctuations in carbon microphones and other granular resistances," *Bell. Sys. Tech. Jour.*, vol. 15, pp. 197–223; April, 1936.

[15] H. C. Montgomery and M. A. Clark, "Shot noise in junction transistors," *Jour. Appl. Phys.*, vol. 24, pp. 1357–1358; October, 1953.

common-emitter,

$$F = 1 + \frac{1}{4KTR_g}\left[\overline{e_{thb}^2} + \overline{e_{she}^2}\left(\frac{ar_c + r_b + R_g}{ar_c - r_c}\right)^2 + \overline{e_{shc}^2}\left(\frac{r_e + r_b + R_g}{ar_c - r_e}\right)^2 + \overline{e_{shc}^2}\left(\frac{r_c + r_b + R_g}{ar_c - r_e}\right)^2\right]; \qquad (24)$$

common-collector,

$$F = 1 + \frac{1}{4KTR_g}\left[\overline{e_{thb}^2} + \overline{e_{she}^2}\left(\frac{r_e + r_b + R_g}{r_c}\right)^2 + \overline{e_{shc}^2}\left(\frac{r_b + R_g}{r_c}\right)^2 + \overline{e_{scc}^2}\left(\frac{r_b + R_g}{r_c}\right)^2\right]. \qquad (25)$$

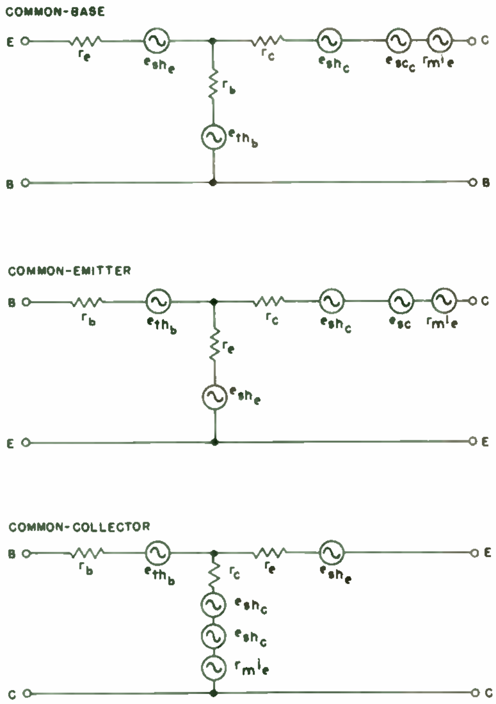

Fig. 13—Basic transistor equivalent circuits with separation of noise generators.

Comparing (30), (31), and (32) with (5) it is noted that they are respectively:

common-base,

$$\left[\begin{aligned}\overline{e_{ni}^2} &= \overline{e_{she}^2} + \overline{e_{thb}^2}\\ \overline{e_{no}^2} &= \overline{e_{thb}^2} + \overline{e_{shc}^2} + \overline{e_{scc}^2};\end{aligned}\right. \qquad (26)$$

common-emitter,

$$\left[\begin{aligned}\overline{e_{ni}^2} &= \overline{e_{thb}^2} + \overline{e_{she}^2}\\ \overline{e_{no}^2} &= \overline{e_{she}^2} + \overline{e_{shc}^2} + \overline{e_{scc}^2}\end{aligned}\right. \qquad (27)$$

common-collector,

$$\left[\begin{aligned}e_{ni} &= \overline{e_{thb}^2} + \overline{e_{shc}^2} + \overline{e_{scc}^2}\\ \overline{e_{no}^2} &= \overline{e_{sce}^2} + \overline{e_{shc}^2} + \overline{e_{she}^2}.\end{aligned}\right. \qquad (28)$$

To obtain numerical values from (23), (24), and (25), it is necessary to write all the noise voltages explicitly following (22) and (21), yielding:

$$e_{th_b}^2 = 4KTr_{bb'}, \qquad (29)$$

$$\overline{e_{she}^2} = 2eI_er_e^2, \qquad (30)$$

$$\overline{e_{shc}^2} = 2eI_{co}r_c^2, \qquad (31)$$

$$\overline{e_{scc}^2} = k_cV^\alpha R_c^\beta f_{-j}. \qquad (32)$$

Note that in (31) the thermal equilibrium current I_{co} is used instead of I_c in order to correctly separate the shot-noise components from the two junctions, and that the intrinsic base resistance $r_{bb'}$ is used.

The above results could have been obtained also starting from the basic equation, (5) which is rewritten below in a slightly different form.

$$F = 1 + \frac{1}{4KTR_g}\left|\overline{e_{ni}^2} + \overline{e_{no}^2}/\mu^2\right|, \qquad (33)$$

where

$$\mu = \frac{r_{21}}{r_{11} + R_g}$$

is the open circuit voltage gain. To express separately the three contributions to F one can write three noise factors:

Thermal noise factor

$$F_{th} = 1 + \frac{r_{11}^*}{R_g} + \frac{r_{22}^*}{\mu^2R_g}, \qquad (34)$$

equivalent shot noise factor

$$F_{sh} = 1 + \frac{er_{11}^{2*}}{2KTR_g}I_1 + \frac{er_{22}^{2*}}{2KTR_g\mu^2}I_2, \qquad (35)$$

semiconductor noise factor

$$F_{sc} = 1 + \frac{1}{4KTR_g}\left[k_1V_1^aR_1^\beta f^{-\gamma} + \frac{k_2V_2^aR_2^\beta f^{-\gamma}}{\mu^2}\right]; \qquad (36)$$

where $e = 1.6\times10^{-19}$ coulombs, $K = 1.38\times10^{-23}$ joules/degree Kelvin, T = degrees Kelvin, R_g = generator resistance, ohms, V_1, I_1 = dc input voltage and current, V_2, V_2 = dc output voltage and current α, β, γ = semiconductor noise coefficients, refer to (19).

The symbol * indicates that part of the resistance which is involved in the noise generation. Considering the combined effect of (34), (35) and (36) the total noise figure is

$$F = 1 + (F_{th} - 1) + (F_{sh} - 1) + (F_{sc} - 1), \qquad (37)$$

which checks with equations (23, (24), and (25) if $r_{11}^* = r_{bb'}$ in (34), $r_{22}^* = 0$, $r_{11}^* = r_e$ in (35), $r_{22}^* = r_c$, $I_1 = I_e$, $I_2 = I_{co}$, and the first term in the bracket of (36) is set equal to zero.

When the equations for the noise voltages (29), (30), (31), and (32) are substituted in (23), (24) and (25), the equations for noise factor may be put in a more usable form. Further, if certain assumptions are made, for example, $r_c \gg R_g$, $r_c \gg r_b$, $r_c \gg r_e$, the equations may be simplified and become

common-base

$$F = 1 + \frac{r_{bb}'}{R_g} + \frac{r_e}{2R_g}\left[1 + \frac{I_{co}}{I_e}\left(\frac{r_e + r_b + R_g}{ar_e}\right)^2\right] + \frac{k_c V_c^{\,a} R_c^{\,\beta} f^{-\gamma}}{4KTR_g}\left(\frac{r_c + r_b + R_g}{ar_c + r_b}\right)^2. \tag{38}$$

common-emitter

$$F = 1 + \frac{r_{bb}'}{R_g} + \frac{r_e}{2R_g}\left[1 + \frac{I_{co}}{I_e}\left(\frac{r_e + r_b + R_g}{r_e}\right)^2\right] + \frac{k_c V_c^{\,a} R_c^{\,\beta} f^{-\gamma}}{4KTR_g}\left(\frac{r_e + r_b + R_g}{ar_c - r_e}\right)^2. \tag{39}$$

common-collector

$$F = 1 + \frac{r_{bb}'}{R_g} + \frac{r_e}{2R_g}\left[1 + \frac{I_{co}}{I_e}\left(\frac{r_b + R_g}{r_e}\right)^2\right] + \frac{k_c V_c^{\,a} R_c^{\,\beta} f^{-\gamma}}{4KTR_g}\left(\frac{r_b + R_g}{r_c}\right)^2. \tag{40}$$

The usefulness of the above expressions resides mainly in the fact that it is possible to obtain from them minimum values of noise factor when the last term expressing semiconductor noise in the output junction is dropped; then the lower limits are dictated only by thermal noise from the base-spread resistance and by shot noise from the input and output junctions.

Substituting typical values for the other quantities: $I_e = 10^{-3}$ amperes, $r_e = 26$ ohms, $r_{bb'} = 300$ ohms, $r_b = 350$ ohms, $\alpha = 0.98$, $I_{co} = 4 \times 10^{-6}$ amperes, and $R_g = 500$ ohms; it is found that the noise factor should be about 2.4 db. This minimum value for noise factor could further be reduced for transistors with lower values of I_{co} and $r_{bb'}$.

Identical results are obtained when using (7), (8), and (9) by substituting values of e_{ne} and e_{nc}; typical values in quiet RCA-2N34 transistors are

$$e_{ne} = (5 \text{ to } 40) \times 10^{-9} \text{ volts},$$

and

$$e_{nc} = (10 \text{ to } 40) \times 10^{-9} \text{ volts},$$

for normal operating conditions at $V_c = -6$ V, $I_e = -1$ ma at 1 kc over a 1 cycle noise bandwidth.

The agreement between theoretical and measured values of noise factor is satisfactory for transistors operating under conditions where the contribution of semiconductor noise is negligible. Observed discrepancies from 1 to 2 db may be attributed to two factors: (a) the neglect of correlation among the various noise sources, and (b) the omission of other noise mechanisms.

The latter point seems to be worthy of particular attention since it was recently disclosed[16] that a mechanism of partition noise may be active in transistors. When this additional source is taken into account, a closer agreement between theory and experiment may be obtained.

Equivalent Input Noise Resistance

An equivalent input noise resistance for a transistor may be deduced. This resistance, in effect, would be the series combination of equivalent noise resistance for thermal, shot, and semiconductor noise. In the case of the common-base connection the following is found:

thermal noise equivalent resistance

$$R_{th} = r_{bb}' \tag{41}$$

emitter shot-noise equivalent resistance

$$R_{she} = \frac{r_e}{2} = \frac{e}{2}\,\frac{KT}{eI_e} \tag{42}$$

collector shot-noise equivalent resistance

$$R_{shc} = \frac{r_e}{2}\,\frac{I_{co}}{I_e}\left(\frac{r_e + r_b + R_g}{\alpha r_e}\right)^2 \tag{43}$$

collector semiconductor equivalent resistance

$$R_{scc} = k_c V_c^{\,a} R_c^{\,\beta} f^{-\gamma}\left(\frac{r_e + r_b + R_g}{\alpha r_e}\right)^2. \tag{44}$$

A transistor amplifier can then be represented in the manner illustrated in Fig. 14, where the emitter and collector junction equivalent shot noise resistance are combined into $R_{sh} = R_{she} + R_{shc}$. Only the semiconductor noise equivalent resistance is frequency dependent; of the other two R_{th} is by its nature frequency independent, while R_{sh} can be considered constant within the audio range, although its behavior at high frequencies needs further investigation.

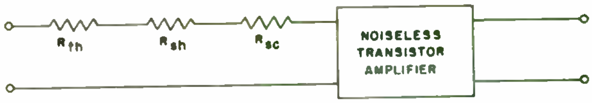

Fig. 14—Equivalent noise input resistance in a transistor amplifier.

Using the same values for the transistor parameters given in a previous example, and again neglecting semiconductor noise, typical values for the equivalent noise resistances are:

R_{th} = 300 ohms
R_{she} = 13 ohms
R_{shc} = 52 ohms

R equivalent noise = 365 ohms

It may be seen that the major contribution to noise is introduced by the thermal resistance $r_{bb'}$. An equivalent resistance for semiconductor noise is not calculated due to the lack of information concerning the value of some of the quantities appearing in (44). Once the

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[16] A. van der Ziel, "Partition noise in transistors," *Jour. Appl. Phys.*, vol. 25, pp. 815–816; June, 1954.

equivalent input noise resistance is known, noise factor may be calculated as

$$F = 1 + \frac{R \text{ equivalent noise}}{R_g}. \tag{45}$$

It should be pointed out that the use of the preceding equations for the equivalent input noise resistance may lead to more expeditious calculations to be used by application engineers. However, it must be noted that R_{sh_c} is also a function of R_g and therefore a mere increase of R_g in (45) will not minimize noise factor.

COMPARISON WITH VACUUM TUBES

A noticeable similarity is found in the general trend of the noise characteristics of vacuum tubes and transistors. The noise spectrum of a typical low-noise triode (1620-triode connected) with an oxide-coated cathode is shown in Fig. 15. It may be observed that tube noise decreases at approximately 10 db per decade at lower frequencies (1/f law) and then tends to approach an asymptotic value determined by shot noise.

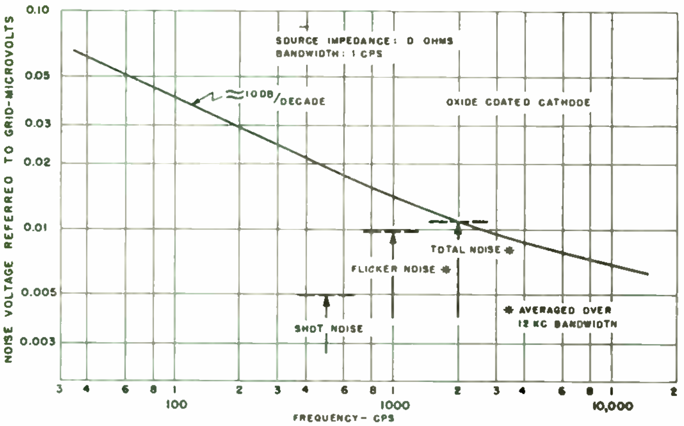

Fig. 15—Triode tube noise vs frequency.

That portion of the curve which is consistent with the 1/f law is due to flicker effect in the cathode and produces a noise spectrum remarkably similar to that of semiconductor noise in transistors. Because of this flicker effect, results would certainly be in error if the noise formulas generally used for vacuum tubes at radio frequencies were extended down to the low-frequency range. With certain oxide-coated cathodes, flicker noise produces in effect appreciable components extending up to 20 kc.

The similarity in the trend of vacuum tube and transistor noise in the audio frequency region is apparent when Fig. 15 and Fig. 16 are compared. The similarity extends itself further into those respective frequency ranges where the contributions of shot noise remain constant. Eventually the noise factor increases with increasing frequency because of gain reduction.

For a vacuum tube, noise factor improves as the source impedance increases and zero db noise factor can be approached in practice. As a result, efficient input transformers greatly improve the noise factor of a system with a low source impedance such as offered by magnetic pickups and microphones. On the other hand, as shown in Figs. 7 and 8, transistor noise factor is a minimum when working from a source impedance of about 500 ohms.

The similarity is summarized in Table I:

TABLE I

Frequency Range	Noise Factor vs Frequency	Tube Noise	Transistor Noise
Very low	inversely proportional	flicker	semiconductor
Intermediate	constant	shot	shot and thermal
High	constant within certain limits, beyond which it increases indefinitely	shot, input conductance, transit time, reduced gain	shot and thermal transit time, reduced gain

Fig. 16 shows a direct comparison of transistor and tube noise plotted versus source resistance. It may be seen that transistors behave favorably in those cases where the generator impedance is low, thus it might be desirable to use transistors thereby eliminating an expensive input transformer.

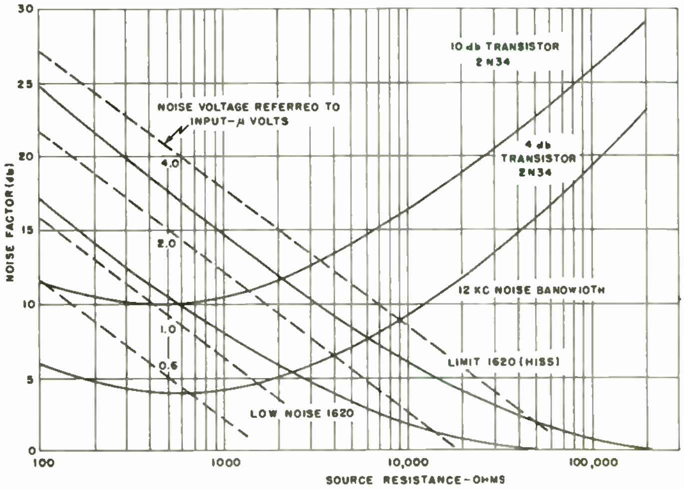

Fig. 16—Comparison of transistor and tube noise characteristics; noise factor vs source resistance.

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Correspondence

On the Minimum Noise Figure of Traveling-Wave Tubes*

The most recently advanced theories for the minimum obtainable noise figure for traveling-wave tubes consider that there is both an initial velocity and an initial current fluctuation on the electron beam, and that these two noise quantities are uncorrelated.[1,2] A general proof is given here to show that, under these conditions, the minimum noise figure is attained simultaneously with maximum gain.

If a potential minimum exists in the diode region of the electron gun, various assumptions can be made about the initial fluctuations. According to Watkins,[3] the current fluctuation at the potential minimum is given by

$$\overline{i_a^2} = R^2 2eI_D\Delta f,$$

and the velocity fluctuation is equal to that calculated by Rack[4] for the temperature-limited case,

$$\overline{v_a^2} = (4-\pi)\frac{e}{m}\frac{kT_c}{I_D}\Delta f.$$

The current density I_D is the net dc current density through the diode, R^2 is a reduction factor (different from Γ^2) which for complete space-charge conditions is approximately one-half, T_c the cathode temperature in degrees K, and Δf the bandwidth.

With these assumptions, the expression for the minimum obtainable noise figure of a traveling-wave tube in which the gun consists entirely of regions for which the external circuit has no ac influence,[5] can be written

$$F = 1 + 2\alpha R\frac{T_c}{T}[4QCf_{\max}f_{\min}]^{1/2}; \qquad (1)$$

where T is ambient temperature, QC space-charge factor,[6] and α a factor near unity.[7]

The quantities $f_{\max}$ and $f_{\min}$ are functions of the space-charge parameter QC, the loss parameter d, and the electron speed b, and can be written

$$\begin{aligned} 2f_{\max} &= |\alpha|^2 + |\beta|^2 + |\alpha^2+\beta^2|, \\ 2f_{\min} &= |\alpha|^2 + |\beta|^2 - |\alpha^2+\beta^2|; \end{aligned} \qquad (2)$$

where

$$\begin{aligned} \alpha &= \delta_2 + \delta_3, \\ \beta &= (\delta_2\delta_3 - 4QC)/\sqrt{4QC}, \end{aligned}$$

and δ_2 and δ_2 are two of the three roots, $\delta_i = x_i + jy_i$, of the equation for the propagation constants of a TW tube,

$$\delta^2 = (-b + jd + j\delta)^{-1} - 4QC. \qquad (3)$$

By making use of the relationship between the roots and the coefficients of (3), it can be shown that

$$\begin{aligned} &2(4QCf_{\max}f_{\min})^{1/2} \\ &\qquad = -2y_1[(x_1+d)^2 + (y_1+b)^2]. \end{aligned} \qquad (4)$$

The subscript 1 refers, by convention, to that root of (3) which corresponds to the gaining wave. For any given d and QC, x_1 is a function of b, through (3), and the maximum gain in a traveling-wave tube is attained when the electron speed is adjusted so that b has that value for which x_1 is maximum.

From the two simultaneous equations obtained from the real and imaginary parts of (3), it can be shown that, in general,

$$-2y[(x+d)^2 + (y+b)^2] = \frac{d+x}{x}; \qquad (5)$$

so that the minimum obtainable noise figure can be written

$$F = 1 + \alpha R\frac{T_c}{T}\left(\frac{d+x_1}{x_1}\right). \qquad (6)$$

The quantity $(d+x_1)/x_1$ is obviously a minimum when x_1 is a maximum. Thus for given values of QC and d, the maximum gain and minimum noise figure are attained at the same value of the electron-speed parameter b. If the loss parameter d is zero, the minimum noise figure is independent of the value of QC.

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* Reprinted from *Sylv. Tech.*, vol. VII, p. 123; October, 1954.

[1] S. Bloom and R. W. Peters, "A minimum noise figure for the traveling-wave tube," *RCA Review*, vol. 15, pp. 252–267; June, 1954.

[2] J. R. Pierce and W. E. Danielson, "Minimum noise figure of TWT with uniform helices," *Jour. Appl. Phys.*, vol. 25, pp. 1163–1165; September, 1954.

[3] D. A. Watkins, "Noise at the potential minimum in the high-frequency diode," private communication.

[4] A. J. Rack, "Effect of space charge and transit time on shot noise in diodes," *Bell Sys. Tech. Jour.*, vol. 17, pp. 592–619; October, 1938.

[5] R. G. E. Hutter, "Space-charge-wave amplifier tubes, basic principles of operation," *Sylv. Tech.*, vol. VI, pp. 6–12; January, 1953.

[6] J. R. Pierce, "Traveling-Wave Tubes," D. Van Nostrand Company, Inc., New York, N. Y.; 1950.

[7] J. R. Pierce, "A theorem concerning noise in electron streams," *Jour. Appl. Phys.*, vol. 25, pp. 931–933; August, 1954.

Comment on "Low-Temperature Electronics,"* C. A. Swenson and A. G. Emslie[1]

In their paper I believe that Dr. Swenson and Dr. Emslie drew an incorrect and misleading conclusion regarding noise in a carbon resistor. In their second paragraph they drew the immediate conclusion that a reduction in temperature reduces the noise from a metallic resistor and leaves constant the noise from a carbon resistor. In connection with this conclusion there is no reservation regarding frequency or direct current.

In the absence of excitation other than thermal, any conductor, whether it be a metal or a semiconductor, will exhibit only thermal noise as defined by the expression

$$N = kTB, \qquad (1)$$

where N is the available noise power, k is Boltzmann's constant, T is the absolute temperature, and B is the bandwidth of the system used to observe the noise. This thermal noise in a semiconductor results directly from thermal agitation of the electrons in the conduction band, in the same manner as in a metallic conductor. It should be observed that the noise power as defined by (1) has no dependence on resistance. In the second sentence of the second paragraph the authors state that "... thermal noise, follows a simple law which shows it to ... increase with the value of the resistance used." Implicit in this statement must be the fact that the authors are discussing noise voltage only, because the available power is independent of resistance and the noise current is decreased by an increase in resistance. That is,

$$\overline{e^2} = 4R(kTB) \qquad (2)$$

and

$$\overline{i^2} = 4G(kTB), \qquad (3)$$

where $\overline{e^2}$ is the mean-square open-circuit noise voltage, R is the resistance, $\overline{i^2}$ is the mean-square short-circuit noise current, and G is the conductance.

When an electric field is applied, conductors and semiconductors tend to behave differently. Semiconductors exhibit an excess noise power which is inversely proportional to frequency from very low frequencies to super-high frequencies, and is approximately proportional to the square of the instantaneous direct current. Therefore, depending upon the frequency and the applied current, the excess noise may be quite large or may be entirely negligible.

With respect to the particular examples given, it is probable that the conclusion regarding transistors is valid, but the one regarding a grid resistor requires qualification. If excess noise generated by current through the resistor is predominant, the conclusions as stated are correct; however, if thermal noise predominates, the conclusions are incorrect.

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* Received by the IRE, October 1, 1954.

[1] Proc. I.R.E., vol. 42, pp. 408–413; February, 1954.

Rebuttal[2]

We wish to thank Mr. Strum for calling to our attention the possibilities for misinterpretation of the noise discussion in our paper as it applies to semiconductors. Perhaps the third paragraph should have read (in part): "Other sources of noise *can be* more

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[2] Received by the IRE, October 19, 1954.

important in carbon resistors," for, as Mr. Strum points out, ordinary thermal or Johnson noise must always be present in any conductor, and, in fact, predominates in moderate-valued carbon-grid resistors which carry very little current. Thus, one does gain in general by cooling a grid resistor. As soon as the current drawn is appreciable, or low frequency noise becomes important, the relative magnitude of the current noise is greatly increased and the advantages gained by cooling are slight. In any case, in contrast with a metallic resistor, there will always be a definite temperature below which the current-dependent noise predominates and further cooling would be unprofitable.

It is worth pointing out that there exists relatively little experimental data about the properties of noise in semiconductors, and that further work is needed to determine its true mechanism and behavior. For instance, van der Ziel and his co-workers have shown that this excess noise in germanium is not strictly proportional to $1/f$, but falls off less rapidly at high frequencies.[3] No data exists in the temperature region below 80 degrees K where the resistance is changing very rapidly due to the rapid decrease of conduction electrons or holes.

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[3] "Low temperature electronics," Ref. 1.
R. H. Mattson and A. van der Ziel, "Shot noise in Germanium filaments," *Phys. Rev.*, vol. 89, p. 899; 1953.

Circuits for Producing High Negative Conductance*

The circuits of Figs. 1–3 are of interest because of the very large values of negative conductance that they are capable of producing. Analysis of the equivalent plate circuit for the circuit of Fig. 1 shows that, if $r_1+r_2 \gg r_b$ and the frequency is sufficiently low so that the effects of interelectrode and stray capacitances can be neglected, the admittance between terminals A and B is a conductance of value

$$G=\frac{1}{r_{p1}}+g_{m1}+\frac{1+\mu_2}{r_{p2}+r_b}\left(1-g_{m1}r_b\frac{r_1}{r_1+r_2}\right) \quad (1)$$

in which the subscript numbers in the tube factors refer to tubes 1 and 2. Eq. (1) also holds approximately for the circuit of Fig. 2, in which the biasing resistance R_c is small in comparison with r_b. If $g_{m1}r_br_1/(r_1+r_2)\gg 1$. (1) reduces to the approximate form

$$G \cong g_{m1}\left(1 - A_2\frac{r_1}{r_1+r_2}\right), \quad (2)$$

in which A_2 is the magnitude of the voltage amplification of tube 2.

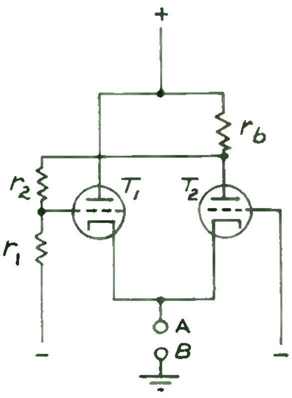

Fig. 1—One form of neganho high-negative-conductance circuit.

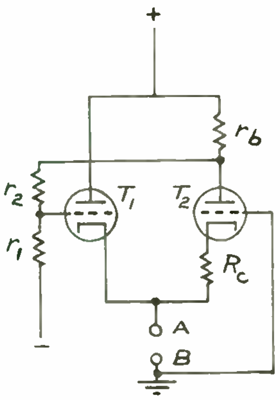

Fig. 2—Circuit incorporating biasing resistor.

Similarly, in the circuit of Fig. 3, if $r-j/\omega C\gg r_b$, and $g_{m1}r_b\omega^2r^2C^2/(1+\omega^2r^2C^2)\gg 1$, the admittance between terminals A and B has the approximate value

$$Y \cong g_{m1}\left(1 - A_2\frac{\omega^2r^2C^2}{1+\omega^2r^2C^2}\right) - jg_{m1}A_2\frac{\omega rC}{1+\omega^2r^2C^2}. \quad (3)$$

The conductive component of this admittance approximates $g_{m1}(1-A_2)$ at frequencies such that $\omega^2r^2C^2\gg 1$. The susceptive component is inductive.

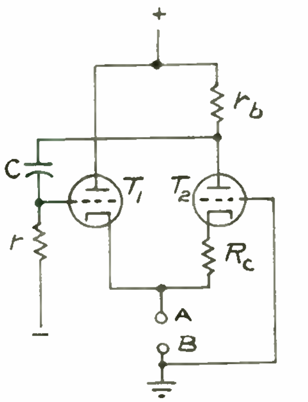

Fig. 3—Capacitance-coupled circuit.

Because values of g_{m1} of several thousand micromhos and values of A_2 of several hundred are attainable, negative conductances of the order of magnitude of 10 mhos can be produced by these circuits. These large values of negative conductance are attained at the expense of allowable input voltage, which is in general only a fraction of a volt. The small voltage range over which negative conductance is obtained is usually no handicap when the circuit is used as the basis of a negative-conductance oscillator, since the amplitude of oscillation may be kept small and ample output voltage obtained from the plate of tube 2.

The voltage range in which the slope of the current-voltage characteristic between terminals A and B has a negative slope is limited at the low-current end by cutoff of tube 1, and at the high-current end by the flow of grid current in tube 1 and consequent reduction of amplification of tube 2. The amplification of tube 2 is essentially linear in the useful input-voltage range of the circuit. The negative-conductance portion of the current-voltage characteristic is, therefore, of the same general shape as the transfer characteristic of tube 1 at currents below that at which the grid of the tube 1 starts to conduct.

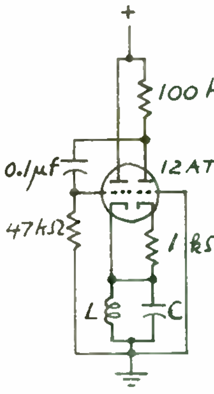

Fig. 4—Oscillator based on the circuit of Fig. 3.

The negative-conductance oscillator of Fig. 4 has been made to oscillate with a supply voltage of only 10 volts. Stable oscillation at considerably lower voltages should be attainable by proper selection of tubes and circuit parameters.

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* Received by the IRE, October 21, 1954.

Frequency Analysis of Computer Systems*

It has been shown in the literature that sampled data feedback systems and digital computer programs can be analyzed in the frequency domain.[1–3] The transfer functions of the difference equations characteristic of such analyses are rational polynomials of

* Received by the IRE, November 12, 1954.

[1] J. R. Ragazzini and L. A. Zadeh, "The analysis of sampled data systems," *A.I.E.E. Trans.*, vol. 71, pp. 232–252; November, 1952.

[2] William K. Linvill and J. M. Salzer, "Analysis of control systems involving digital computers," Proc. I.R.E., pp. 901–906; July, 1953.

[3] John M. Salzer, "Frequency analysis of digital computers operating in real time," Proc. I.R.E., pp. 457–466; February, 1954.

the variable z which may be defined by

$$Z = \exp ST \tag{1}$$

where:

S = complex frequency variable
T = period between successive samples.

In references 1, 2 and 3 a continuous function, $f(t)$, which is sampled is changed to an impulse function. The area of the impulse is made equal to the amplitude of the continuous function at the corresponding sampling instant. The resulting impulse function is defined by:

$$f^*(t) = \sum_{n=0}^{\infty} f(nT)\delta(t - nT) \tag{2}$$

where $\delta(t-nT)$ is the shifted unit impulse. The Laplace transform is given by:

$$F^*(S) = \sum_{n=0}^{\infty} [f(nT)][\exp(-nTS)]. \tag{3}$$

The z-transform of $f^*(t)$ is defined by substituting relation (1) into relation (3). Thus

$$z[f^*(t)] = F(Z) = \sum_{n=0}^{\infty} f(nT)Z^{-n}. \tag{4}$$

To obtain particular z-transforms the approach has been to expand relation (4) into an infinite series and then recognize the closed form of the series.

It is suggested here that an alternate approach yields z-transforms in closed form directly. The method of accomplishing this is to deal with the impulse functions in a manner similar to the methods of Gardner and Barnes when manipulating jump functions.[4] The jump function definition of Gardner and Barnes may be written:

$$J[f(t)] = \sum_{n=0}^{\infty} f(nT)P(t - nT) \tag{5}$$

where $P(t-nT)$ is the unit pulse given by:

$$P(t - nT) = u(t - nT) - u(t - nT - 1) \tag{6}$$

in which $u(t)$ is the unit step function.

Taking the Laplace transform of (5)

$$L[Jf(t)] = \sum_{n=0}^{\infty} f(nT)P(S) \exp(-nTS) \tag{7}$$

where $P(S)\exp(-nTS)$ is the Laplace transform of the shifted unit pulse and $P(S) = 1/S[1 - \exp(-ST)]$.

Since $P(S)$ is independent of n in relation (7) it can be taken outside the summation sign:

$$L[Jf(t)] = P(S)\left[\sum_{n=0}^{\infty} f(nT) \exp(-nTS)\right]. \tag{8}$$

Letting $Z = \exp ST$:

$$L[Jf(t)] = P(S)\left[\sum_{n=0}^{\infty} f(nT)Z^{-n}\right]. \tag{9}$$

The expression in brackets in (9) is identical with the definition of z-transform given by (4). The following relation may therefore be written:

$$F(Z) = L[Jf(t)]/P(S) \tag{10}$$

with $Z = \exp ST$.

Eq. (10) illustrates that the tables of transforms derived for jump functions can be used to obtain z-transforms by dividing the jump function transform by $P(S)$.

To illustrate the manner in which z-transforms may be derived in closed form directly, the z-transform of $f(t) = t$ will be derived.

$$\Delta t = \frac{(t + T) - t}{T} = 1 \tag{11}$$

where Δt is the first difference of the sampled function $f^*(t) = t$. It can be shown that the z-transform of the first difference is given by:

$$z[\Delta f^*(t)] = (Z - 1)F(Z) - f(0)Z/T \tag{12}$$

where $f(0)$ is the initial value of the function. Applying relations (11) and (12)

$$\frac{1}{T}[(Z - 1)z(t)] - 0 = z[1]. \tag{13}$$

Since:

$$z[1] = \frac{Z}{Z - 1}, \tag{14}$$

one has the required result

$$z[t] = T\frac{Z}{(Z - 1)^2}. \tag{15}$$

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[4] M. F. Gardner and J. L. Barnes, "Transients in Linear Systems," pp. 286–287, John Wiley & Sons, Inc., New York, 1942.

Cathode-Follower-Coupled Phase-Shift Oscillator*

The literature on phase-shift oscillators appears to contain no mention of the desirability of using cathode-follower amplifiers between the sections of the phase-shifting network, as shown in Fig. 1. This circuit has the following desirable features:

1. Because of the high input impedance of the amplifiers, each section of the phase-shifting network is essentially unloaded. Since voltage amplification approaching unity may be obtained in cathode-follower amplifiers, the total attenuation of the phase-shifting network approaches the theoretical minimum of tapered networks having an infinite ratio of input impedance of adjacent sections (8 in the circuit of Fig. 1).[1,2] As pointed out by Johnson and by Sulzer, low network attenuation is desirable in oscillators designed to cover wide frequency ranges, since the correspondingly small amplification required may be obtained over a wide frequency range. Furthermore, the low amplification required makes possible the use of a higher degree of inverse feedback in the amplifier, and is consequently favorable to low distortion.

An advantage of the cathode-follower-coupled circuit over a tapered-network circuit is a consequence of the fact that maximum allowable amplifier grid-circuit resistance imposes an upper limit upon the impedance ratio between adjacent stages of a tapered network, and therefore limits the extent to which the attenuation of the network may be reduced.[1,2] A second advantage of the cathode-coupled circuit is that all sections of the phase-shifting network are alike, and the tuning elements are therefore more easily ganged than in a tapered-network oscillator.

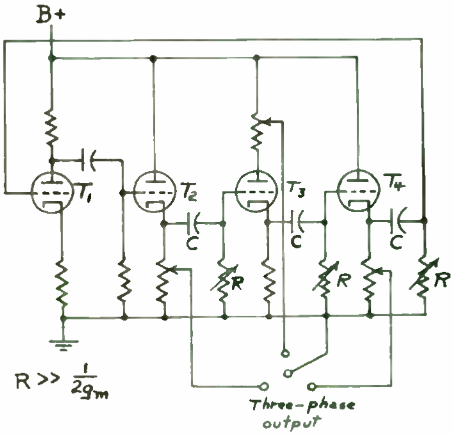

Fig. 1—Basic circuit of cathode-follower-coupled phase-shift oscillator.

2. The cathode-follower-coupled circuit is capable of delivering N-phase output, where N is any integer greater than 2. Unlike the Barrett polyphase oscillator, in which the adjacent sections of the phase-shifting network are separated by phase-inverting amplifiers,[3] this circuit functions when the phase-shifting network has four sections. The differences in the output voltages of the various stages are readily compensated by tapping the output resistors, as in the circuit of Fig. 1. Six-phase output may be obtained from the circuit of Fig. 1 by adding resistors in the plate circuits of tubes T_1 and T_4 and taking outputs from both the plate circuits and the cathode circuits.

The amplitude of oscillation of the circuit of Fig. 1 may be limited by using a thermistor in place of the cathode resistor of T_1, adding a resistor in the plate circuit of T_2, and providing a feedback path from the plate of T_2 to the cathode of T_1.

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* Received by the IRE, October 19, 1954.

[1] R. W. Johnson, "Extending the frequency range of the phase-shift oscillator," PROC. I.R.E., vol. 33, pp. 597–603; September, 1945.

[2] P. G. Sulzer, "The tapered phase-shift oscillator." PROC. I.R.E., vol. 36, pp. 1302–1305; October, 1948.

[3] R. M. Barrett, "N-phase resistance-capacitance oscillators," PROC. I.R.E., vol. 33, pp. 541–545; August, 1945.

Maximum Efficiency of Four-Terminal Networks*

In a recent paper, Mathis presented some experimental procedures for determining the efficiency of four-terminal networks.[1] The first of these procedures can be extended to provide a mathod for determining the condition for maximum efficiency.

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* Received by the IRE, November 3, 1954.

[1] H. F. Mathis, "Experimental procedures for determining the efficiency of four-terminal networks," *Jour. Appl. Phys.*, vol. 25, pp. 982–986; August, 1954.

The efficiency of a four-terminal network is a function of the input impedance Z_A. In general, the terminating impedance Z_L is uniquely determined by Z_A. (This is not true if the efficiency of the network is zero.) The problem is to determine the value of Z_A that gives the maximum efficiency, and then to determine the corresponding value of Z_L. A procedure for doing this is given here.

First, the four-terminal network is terminated in a pure reactance, the input impedance Z_x is measured, and Z_x is plotted on a Smith chart, or $Z-\theta$ chart, as shown in Fig. 1. This process is continued until at least three different values of Z_x are plotted on the Smith chart. The circle K is drawn through the points Z_x. The line Ob is drawn through the center of the Smith chart and the center of circle K. This line intersects circle K at points a and b. The lines ac and bd are drawn from points a and b perpendicular to the line Ob. These lines intersect the $R=O$ circle of the Smith chart at points c and d. The intersection of lines Oa and cd is the value of Z_A that gives maximum efficiency.

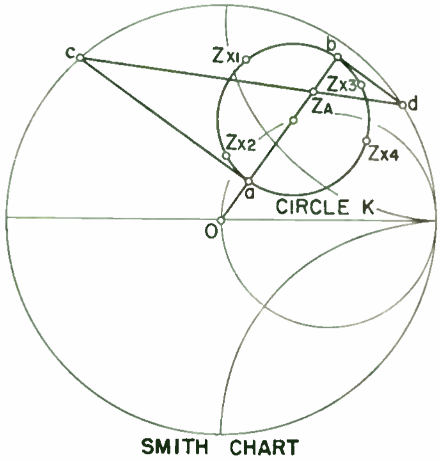

Fig. 1—Diagram for determining maximum efficiency.

The value of Z_L corresponding to Z_A can be determined by connecting an impedance the value of which is the conjugate of Z_A to the input of the four-terminal network. Then Z_A is the conjugate of the impedance measured at the output terminals.

It is easily seen that the value of Z_A for the maximum value of the efficiency, as given by equation (1) in Mathis' paper,[1] must lie on line Ob. In this case, (1) can be written

$$\eta = \frac{(D_3 - k)(k + 2r - D_3)}{r(1 - D_3^2)},$$

where k is the distance between points O and a, and r is the radius of circle K. The value of D_3 that maximizes η is found by the usual method to be

$$D_3 = \frac{1+2kr+k^2-\sqrt{(1+2kr+k^2)^2-4(r+k)^2}}{2(k+r)}.$$

This value of D_3 can be obtained by the graphical procedure described above.

If it is assumed that the network is fed by a generator the internal impedance of which is the conjugate of Z_A, the conditions for maximum efficiency are the same as those for maximum power transfer. Consequently, Z_L can be determined by the above procedure.

This subject has been discussed by Wheeler and Dettinger.[2] The graphical procedure presented here is simpler than the one given by Wheeler and Dettinger.

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[2] H. A. Wheeler and D. Dettinger, "Measuring the efficiency of a superheterodyne converter by the input impedance circle diagram," Wheeler Monograph No. 9, Wheeler Labs., Inc., Great Neck, Long Island, N. Y.; 1949.

Comment on "The Transistor as a Mixer,"* Jakob Zawels

In this paper,[1] Jakob Zawels seems to have omitted a component from his Fig. 7 entitled "Five-pole equivalent circuit for diode mixer including image and sum frequency impedances." To complete his equivalent circuit, there should be a conductance connecting terminals E_4 and E_K, and this conductance should be subtracted from γ_4 and γ_K.

It was pointed out in Mr. Zawels' footnote[5] that the derivation of his equivalent circuit would be forthcoming. It is believed that, if it does not show the conductance between terminals E_4 and E_K, the derivation will be incomplete.

Perhaps the simplest representation of such a multi-terminal mixer is given by a matrix of admittances:

$$\begin{bmatrix} y_{11} & y_{12} & y_{13} & \cdots & y_{1k} \\ y_{21} & y_{22} & y_{23} & \cdots & y_{2k} \\ y_{31} & y_{32} & y_{33} & \cdots & y_{3k} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ y_{i1} & y_{i2} & y_{i3} & & y_{ik} \end{bmatrix}$$

$$y_{ik} = G_n/2 = \text{conversion admittance}, \; i \neq k$$
$$= G_0 = \text{short-circuit input admittance}, \; i = k.$$

For any arbitrary nonlinear conductance such as a transistor or crystal diode, none of the elements in the matrix will in general be zero. This matrix is seen to represent a multi-pole circuit in which one terminal of each pair is grounded, short-circuit input admittance at any pair of terminals is the average admittance over an excitation cycle, and the series admittance connecting each ungrounded terminal with each other ungrounded terminal is a conversion admittance of the lowest order that will convert the frequency of the signal at one terminal to the frequency of the signal at the other terminal.

It is possible that, since the omitted conductance is the third harmonic-conversion conductance, the magnitude was considered so small as to be negligible. If so, this is a special case, not the general case.

In connection with a recent paper, I utilized the equivalent circuit given in Fig. 7 for the case in which the omitted conductance was found to be zero for the particular methematical model of the nonlinear element.[2] In that case, the omission of the single element from the over-all network simplified the calculations to such an extent that a computation could be easily made. Without this simplification the network expressions were unwieldy.

It is believed that the omission that has been cited will cause no serious increase of the error in computed results because of the limited accuracy with which the functional form of the conductance wave is known.

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* Received by the IRE, October 1, 1954.

[1] Proc. I.R.E., vol. 42, pp. 542–548; March, 1954.

[2] The single points in Figure 3(c) of P. D. Strum, "Some aspects of mixer crystal performance," Proc. I.R.E., vol. 41, pp. 875–889; July, 1953, were calculated from such an equivalent circuit.

Rebuttal[3]

The small signal equivalent circuit of a diode mixer has in general an infinite number of poles, unless the driving point impedance of the linear circuit, as viewed from the diode terminals, is zero at all but a finite number of sum and/or difference frequencies (such as $\pm(n\omega_0 \pm \omega_s)$ where n is an integer which may vary from 0 to infinity). In the case of the diode mixer circuit which results from an approximation of the transistor mixer circuit described in the paper under discussion [Fig. 2(b)], it is easily seen that none of the aforementioned impedances is zero. Thus, for practical reasons it is obvious that an approximate circuit which is a compromise between accuracy and ease of computation is here called for. The circuit of Fig. 7, mentioned above, has accordingly been found to be a satisfactory approximation.

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[3] Received by the IRE, November 1, 1954.

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◆

W. P. Dyke was born on December 9, 1914, in Forest Grove, Oregon. He received the B.A. degree with a major in physics at Linfield College, McMinnville, Oregon, in 1938, and in 1946 completed the Ph.D. degree, also with a major in physics, at the University of Washington, Seattle, Washington.

From 1942 to 1945, Professor Dyke was a staff member of the Radiation Laboratory at M.I.T. From there he went to Linfield College as professor of physics and director of research. At present he is a staff member in the Division of Defense Laboratories at M.I.T., and plans to return to Linfield College early in 1955.

L. D. Hanley (A'54) was born in Whitinsville, Mass., on August 13, 1927. He received his B.S. degree in physics at Rensselaer Polytechnic Institute in 1952. From 1946 to 1947 he served with the U. S. Army Signal Corps.

From 1952 to 1954 he was a member of the Ipswich Electronics Division of Sylvania Electric Products Inc., where he was engaged in research and development on semiconductors. At present he is a staff member of the M.I.T. Instrumentation Laboratory and is working for an advanced degree at M.I.T.

◆

H. Heffner

Hubert Heffner (S'49–A'52) was born in Lincolnton, N. C., on December 26, 1924. He received the B.S. degree in physics in 1947 and the M.S. and Ph.D. degrees in electrical engineering in 1949 and 1952, respectively, from Stanford University. From 1949 to 1951 he was a pre-doctoral fellow of the Atomic Energy Commission.

During the war he served in the Army Signal Corps where for a time he was in charge of several microwave relay stations in Germany. Between 1952 and 1954 Dr. Heffner was a member of the technical staff of the Bell Telephone Laboratories where he was engaged in vacuum-tube research. Since 1954 he has been assistant professor of electrical engineering at Stanford.

Dr. Heffner is a member of Phi Beta Kappa, Sigma Xi, and the American Physical Society.

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M. B. Herscher

M. B. Herscher (A'54) was born on November 16, 1930, in Philadelphia, Pennsylvania. He attended Drexel Institute of Technology and received his B.S. degree in electrical engineering in 1953. While attending college he was employed by the Frankford Arsenal under a cooperative training program. There he was engaged in development work on electronic fuses.

He joined the Circuit and Component Development Group of the RCA Engineering Products Division in August, 1953. There he worked primarily on transistor noise studies. At present he is working in the Signal Corps Engineering Laboratories at Fort Monmouth, New Jersey.

Mr. Herscher is a member of Eta Kappa Nu, Tau Beta Pi, and the AIEE.

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L. J. Johnson was born in Lyons, Neb., on June 25, 1920. He attended Tri-State College from 1940 to 1943, where he received a B.S. degree in electrical engineering. Further study at Union College, Schenectady, N. Y., and the University of Maryland was directed towards a M.S. degree in electrical engineering. He is a Registered Professional Engineer in the District of Columbia.


L. J. JOHNSON

From 1942 to 1946 Mr. Johnson was employed by the General Electric Company. As a staff member of the Naval Research Laboratory, Electricity Division from 1946–1952, Mr. Johnson specialized in servo systems for computer and automatic controls. He was a member of the original Magnetic Amplifier Research Group under the direction of Dr. R. A. Ramey at the Naval Research Laboratory. In 1952–1953 he was employed at D & R, Limited, Santa Barbara, California, and since 1953 has been a staff member of the Electronics Division, Hufford Machine Works, Los Angeles, California.

Mr. Johnson is an associate member of AIEE.

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S. E. Rauch was born in Portland, Oregon, on April 22, 1916. He attended Reed College from 1933–1937, receiving the B.A. degree in mathematics. Graduate study at the University of Washington and Stanford University resulted in the awarding of the M.S. degree in 1939 and the Ph.D. in 1941 in the field of mathematics-physics.

Following the doctoral studies, Mr. Rauch joined the staff of the University of Oregon as an assistant professor of mathematics-physics. In 1943 he became a research physicist in the Theoretical Division, Radiation Laboratory, University of California. Later duties included that of research engineer in the Division of Mechanical Engineering. In 1945 Dr. Rauch transferred to the University of California, Santa Barbara campus, where he became chairman of the department of mathematics, and professor of mathematics. For the past three years he has been doing research in components and systems in the fields of guidance controls.


S. E. RAUCH

Dr. Rauch is a member of Mathematical Association of America and Sigma Xi.

◆

H. M. Schlicke (M'49–SM'54) was born in Germany, on December 13, 1912. After graduation from the Staatsrealgymnasium in Annaberg, he studied at the Institute of Technology in Dresden, majoring in electronics. In 1938 he received the degree of Dr. of Engineering Sciences with Professor Barkhausen as referent.


H. M. SCHLICKE

After several years as research engineer at the laboratories for large transmitters at Telefunken, Dr. Schlicke became head of the Naval Test Fields for communications, radar and infrared devices in Kiel, Germany. Later he originated, organized and supervised large-scale countermeasures projects. After the war, he was brought to this country by the U. S. Navy as a "paper clip" scientist. He worked as project engineer and special consultant on classified projects for the Office of Naval Research at Port Washington, Long Island, New York.

Since 1950 Dr. Schlicke has been consultant engineer with the Allen-Bradley Company in Milwaukee, Wisconsin, where he is specializing in the evaluation and application of ferrites and high-K dielectrics.

◆

S. Sensiper (S'39–A'42–SM'47) was born in Elmira, N. Y., on April 26, 1919. He received the S.B. degree in electrical engineering from the Massachusetts Institute of Technology in 1939, the E.E. degree from Stanford University in 1941, and the Sc.D. in electrical engineering from M.I.T. in 1951.

From 1939 to 1941 he was a research and teaching assistant at Stanford. From 1941 to 1948 he was employed by the Sperry Gyroscope Company, where he held the position of senior project engineer and head of the research section in the Microwave Development Department. From 1949 to 1951 he was a staff member of the Research Laboratory of Electronics at M.I.T. Since 1951 he has been a research physicist at the Hughes Aircraft Company, Culver City, Calif. He was head of the antenna section in the Microwave Laboratory during 1952 and 1953, and since 1953 has been a staff member of the Electron Tube Laboratory.


S. SENSIPER

Dr. Sensiper was an Industrial Electronics Fellow at M.I.T. from 1947 to 1948. He is member of Sigma Xi, RESA, and Eta Kappa Nu.

◆

C. G. Thornton (SM'54)was born in Detroit, Mich., on August 3, 1925. He obtained the B.S., M.S., and Ph.D. degrees in physical chemistry at the University of Michigan. He taught at the University of Michigan and was associated with a classified research program conducted by the Engineering Research Institute for the United States Army. In addition, he spent a year setting up high-speed computing methods for the Fourier synthesis and harmonic analysis of sinusoidal functions.


C. G. THORNTON

He joined the engineering staff of Sylvania Electric Products Inc., in 1951. He is now a section head in the Semiconductor Engineering Laboratory.

Dr. Thornton is a member of the American Crystallographic Association, the American Association for the Advancement of Science, Alpha Chi Sigma, Sigma Xi, Phi Lambda Upsilon, and Phi Kappa Phi.

IRE News and Radio Notes

Order Your Banquet Tickets Now. Gen. Ridgway to Address IRE Members

General Matthew B. Ridgway, U. S. Army Chief of Staff, will make the principal address at the Annual IRE Banquet to be held March 23, during the National Convention, at the Waldorf-Astoria Hotel. Since a packed house is expected, members should make their banquet reservations immediately. Tickets, $14.00 each, may be ordered from the Institute of Radio Engineers, 1 East 79 Street, New York 21, N. Y.

Attendance Sets Record at Eastern Joint Computer Conference

The 1954 Eastern Joint Computer Conference and Exhibition was held December 8–10 at the Bellevue Stratford Hotel in Philadelphia. Attracting over 1,750 engineers and workers in the computer field, attendance set a record for the conference. The three day meeting was sponsored jointly by the IRE, the AIEE, and the Association for Computing Machinery.

"Design and Application of Small Digital Computers" was the theme of the conference and each of the technical papers discussed some aspect of the subject. In addition to the papers, there were inspection trips to local computer installations and exhibits, many of new products shown for the first time, by nearly forty companies.

Conference proceedings, including the complete text of all papers and discussion from the floor, may be ordered from any of the sponsoring organizations at $2.00 a copy.

Over 900 Attend First IRE East Coast Conference on Airborne and Navigational Electronics

More than 900 engineers and industrial representatives were on hand to inaugurate the first East Coast Conference on Airborne and Navigational Electronics which was held November 4 and 5 in Baltimore. Twenty-eight technical papers were presented by authors from fifteen industrial and government organizations. At the Sheraton-Belvedere Hotel, over thirty development and manufacturing companies displayed their products. The two-day program also featured a Thursday evening banquet.

Serving on the conference committees were: C. D. Pierson, Jr., General Chairman; G. R. White, Arrangements; Sanford Hershfield, Publicity; N. Caplan, Technical Program; C. F. Miller, Finances; C. E. McClellan, Exhibits; J. General, Member-at-large; and N. V. Petrou, 1954 Chairman of the Baltimore Section of PGANE.

Technical session moderators included: Harry Davis, E. C. McClellan, N. V. Petrou, W. W. Bender, and H. Schutz.

Conference on High-Speed Computers To Be Held

The 1955 Conference on High-Speed Computers will be held at Louisiana State University, February 14 through 16.

The conference will be open to businessmen, office managers, accountants, engineers, chemists, physicists and other potential computer users from all sections of the country. A wide selection of topics has been scheduled for discussion. These topics include office procedures, statistical operations, and numerical methods designed for the adaptation of problems to machine solution. Several manufacturers of computing equipment will be represented through exhibits and demonstrations of computers in operation.

Los Angeles To Be Host for Computer Conference

The Joint Western Computer Conference and Exhibit will be held at the Statler Hotel in Los Angeles, March 1 to 3. The conference will be sponsored by the IRE, AIEE, and Association for Computing Machinery. The pre-registration fee is $2.50 and covers admittance to lectures and exhibits and a copy of the transactions.

The theme of the conference is "Functions and Techniques in Analog and Digital Computers." Technical papers and discussions will include: descriptions of existing systems and techniques, methods of matching digital tapes and cards, language and communication problems between machines, the possibilities of managerial and computer systems revision to achieve rapid and lasting marriage, and new developments in analog computers and computing methods.

(Cont'd on page 234)

Calender of Coming Events

AIEE Winter General Meeting, Hotel Statler, New York, N. Y., January 31–February 4

1955 Southwestern IRE Conference and Electronics Show, Baker Hotel, Dallas, Tex., February 10–12

IRE-AIEE Conference on Transistor Circuits, Philadelphia, Pa., February 17–18

IRE-AIEE-ACM Western Computer Conference, Hotel Statler, Los Angeles, Calif., March 1–3

IRE Philadelphia Section Color TV Symposium, Physics Building, University of Pennsylvania, March 8, 15, 22, 29, and April 5

IRE National Convention, Waldorf-Astoria Hotel and Kingsbridge Armory, New York, N. Y., March 21–24

IRE-PIB Symposium on Modern Network Synthesis, Engineering Societies Building, New York, N. Y., April 12–15

IRE Seventh Region Technical Conference and Trade Show, Hotel Westward Ho, Phoenix, Ariz., April 27–29

National Aeronautical Electronics Conference, Biltmore Hotel, Dayton, Ohio, May 9–11

IRE-AIEE-IAS-ISA National Telemetering Conference, Hotel Morrison, Chicago, Ill., May 18–20

IRE-AIEE-RETMA-WCEMA Electronic Components Conference, Hotel Ambassador, Los Angeles, Calif., May 26–27

Chairmen for PGANE Conference. (From left to right) N. Caplan, Technical Program; G. R. White, Arrangements; J. General, Member-at-Large; C. D. Pierson, General Conference Chairman; S. Hershfield, Publicity; C. E. McClellan, Exhibits; C. F. Miller, Finances; N. V. Petrou, 1954 Chairman, Baltimore Section PGANE.

LOS ANGELES TO BE HOST FOR COMPUTER CONFERENCE

(Cont'd from page 233)

The exhibit will be limited to the products of manufacturers who make computers or major computer sub-assemblies and will be open during the day and evening so that all may visit.

In addition to the technical sessions and the exhibit, there will be evening field trips to Los Angeles electronics firms, a cocktail party, and luncheons. Those interested in attending should write to: William Gunning. International Telemetering Corp., 2000 Stoner Avenue, Los Angeles 25, California,

PAPERS INVITED NOW FOR AUGUST WESCON

The annual Western Electronics Show and Convention (WESCON) will be held this year from August 24 to 26 in San Francisco. The Technical Program Committee is now inviting papers for presentation at that time.

In addition to the title of a proposed paper, prospective authors should submit a 200 word abstract and either the full text or a comprehensive summary of approximately 2,000 words of the paper itself. The abstract will be used for reproduction in the convention program, while the summary will serve as a means of judging the scope and level of the material. The complete text of accepted papers may be submitted at a somewhat later date for consideration for publication in THE PROCEEDINGS or in *the transactions* of one of the professional groups.

Joint Chairmen of the Technical Program Committee are Dr. S. Silver of the University of California at Berkeley and Dr. W. A. Edson of the Applied Electronics Laboratory, Stanford University, Stanford, California. All papers should be directed as soon as possible to Dr. Edson.

COLOR TV SYMPOSIUM TO MEET IN PHILADELPHIA

The second annual Color Television Symposium, sponsored by the Philadelphia Section, will be held this year at the University of Pennsylvania. The group will meet on six successive Tuesdays beginning March first. Subject matter will be arranged to emphasize practical problems related to the transition from monochrome to color television; receiver problems will be given special attention.

The program for the six meetings of the symposium is: March 1, "Fundamentals of Color Television," J. W. Wentworth; March 8, "Color Signal Generating Equipment," Richard O'Brien; March 15, "Color Reproducing Tubes and Associated Components," B. Loughlin; March 22, "Color Decoding Circuits," Jack Avins; March 29, "Measurement and Equalization of Amplifiers and Transmission Systems for Color TV Service," Hugh Kelly; April 5, "Colorimetry Problems in Color TV and the Effect of Transmission Errors on Color Reproduction," Harold Weiss.

Registration blanks and information about the symposium may be obtained by writing to R. Bowley, WPTZ, 1619 Walnut Street, Philadelphia 3, Pennsylvania.

MANUAL OF STANDARDIZATION NOW AVAILABLE

At its December meeting the Standards Committee gave final approval to the new version of the *Manual of Standardization.* The volume, which describes procedure of IRE Technical Committees, is available to IRE members upon request. Copies may be obtained by writing: Technical Secretary, IRE, 1 East 79 Street, New York 21, N. Y.

OBITUARIES

L. R. Mead, the technical assistant to the chief engineer of the Hallicrafters company, radio, television and communications manufacturer, died recently.

Mr. Mead had been an engineer with Hallicrafters since 1950, serving as chief of research until February of this year when he was promoted to the position he held at the time of his death. Prior to joining Hallicrafters, he was affiliated with the Sentinel Radio company for eight years and before that with the Wells Gardner company.

A graduate of Knox College, Galesburg, Illinois, he was a member of the Illinois Society of Professional Engineers.

PROFESSIONAL GROUP NEWS

NEW CHAPTERS APPROVED

The Executive Committee approved three new chapters at its meeting of November 9. These were: Microwave Theory and Techniques, Baltimore Chapter; Medical Electronics, Los Angeles Chapter; Reliability and Quality Control, Washington Chapter.

On December 8 the Executive Committee approved five other chapters. These included: Production Techniques, Los Angeles Chapter; Component Parts, New York Chapter; Automatic Control, Dallas-Fort Worth Chapter; Antennas and Propagation, Orange Belt Chapter; Antennas and Propagation, Washington Chapter.

TECHNICAL COMMITTEE NOTES

The **Electron Devices** Committee met on November 5 at IRE Headquarters with G. D. O'Neill, past Chairman, presiding in absence of W. J. Dodds. Methods of coordination of IRE and AIEE work on phototube definitions were discussed. It was noted that a new IRE task group on photosensitive semiconductor devices was being formed. Comments received on Grand Tour on the proposed *Methods of Testing Microwave Tubes—Non-Operating Characteristics* and the proposed *Test Methods for Microwave Amplifiers* were referred to Dr. Boone and his subcommittee with the request that these proposed Standards be submitted in final form by the first of the year. The proposed *Microwave Tube Definitions (Klystrons, Magnetrons and Traveling Wave Tubes)* were approved for submittal to the Standards Committee. The proposed *Methods of Testing Transistors* were also approved by this committee, subject to editorial changes.

On October 14th the **Standards** Committee convened under the chairmanship of Ernst Weber. A request to ASA concerning sponsorship of ASA C85 was discussed. Mr. Baldwin reported on Mr. Jensen's discussion with Mr. McNair of ASA on adequate recognition for those IRE committees the standards of which were processed through ASA committees sponsored by other organizations, since only the sponsoring organization is recognized on the printed American Standard. Mr. McNair requested the IRE Executive Committee to make suggestions for a new arrangement to the Managing Director of ASA.

Mr. Cumming was directed to work with Mr. McNair on a format for the front page of future ASA Standards which will give due recognition to the organizations providing the technical work. It was agreed to submit it to Dr. Brainerd for comment, and, when a satisfactory one has been developed, the Standards Committee will turn it over to the Executive Committee for presentation to ASA.

In considering the Symbols Committee report on "decilog," the use of "dg" (either in lower case or capital letters) was unanimously approved. The Symbols Committee's suggestion, "decilor," was rejected, in the interest of cooperating with ASA in its choice of "decilog."

R. F. Shea, Chairman of the *ad hoc* committee on Spurious Radiation, sent the Committee a request that the action of committee chairmen on this subject be included in the minutes. Dr. Weber stated that RETMA was depending on the IRE Technical Committees for standards on this subject, and asked chairmen to act immediately on requests from this group. Appointments were requested for Subcommittee 25.8 on Interference Measurements, and for the RETMA Task Groups. Finally, the list of Navigation Aids terms was further considered by the group.

The Standards Committee met on November 18 at IRE Headquarters with Ernst Weber presiding. The committee approved the *Manual of Standardization* which will be made available to committee and subcommittee personnel at the beginning of the new committee term. The *Standards on Radio Aids to Navigation; Definitions of Terms, 1954* were given final approval, and will be published in the February issue of THE PROCEEDINGS.

The Standards Committee met again December 9 at IRE Headquarters. The committee discussed the formation of two technical committees, one on Nuclear Science, and one on Interference. The previous affirmative vote on the proposed separation of ASA Y32 into two committees, Mechanical Graphical Symbols and Electrical Graphical Symbols, was changed to a negative vote by the committee. The change was made after additional information against the separation was presented by the Chairman of ASA Y32, A. Pomeroy, and discussed by members present.

Books

Electroacoustics by F. V. Hunt

Published (1954) by John Wiley and Sons, Inc., New York, N.Y. 245 pages+13 page index+viii pages. 41 figures. 8¾×5¾. $6.00.

If publishers did not prefer short titles, this excellent monograph might well have been named "The Principles of Electroacoustic Transduction from an Advanced Viewpoint." Transduction is the main theme of the text and the author assumes that the reader possesses both a thorough understanding of electrical network theory and of the mechanism of sound radiation. The area between is treated in an interesting and scholarly manner.

Professor Hunt unfolds the story of transduction, commencing with Stephen Gray's discovery in 1729 that some substances "would carry the electrical virtue" while others would not. Over one third of the text that follows deals with the historical background. This part is an instructive collection of incidents from widely scattered writings, personal accounts, and the patent literature. Time and again, workers in acoustics discovered that their work had been anticipated by previous investigators, causing Rice's classic complaint, "the ancients have stolen our inventions!" Professor Hunt finds prophecy of modern pulse-time modulation in Cavallo's remark of 1795 that "by sending a number of sparks at different intervals of time according to a settled plan, any sort of intelligence might be conveyed instantaneously;" and he goes on to comment elsewhere on "the surprise with which one worker in this field after another tardily discovered Rayleigh's (1877) analysis of the baffle problem. . . . " It would seem that aside from its cultural value, the obvious economic importance of the history of transduction should prompt every director of research to place this chapter on the "must" reading list for all research workers in electroacoustics.

In analyzing dynamic, magnetic, and magnetostrictive transducers, Professor Hunt proposes the use of space operator "k," which is so defined as to provide the correct space relationship between the electrical, magnetic, and mechanical vectors. Thus, for a conductor of length l in a magnetic field of density B, the force is defined as $F=BlkI$ and the voltage as $E=Blkv$, where the operator k, signifies a 90 degree counterclockwise rotation in space of the vector which follows it around the vector which precedes it. k is subject to specific rules of mathematical manipulations, and in the electrical circuit analysis it turns out to have a function parallel to that of the phase-operator, j, which appears in the analysis of electrostatic and piezoelectric systems. In this manner, a unified theory of transducer analysis by electrical network theory developed.

There is a chapter describing in detail the use of electrical impedance measurements in the analysis of transducer performance. The balance of the book is devoted to the theory of the dynamic, electrostatic, and electromagnetic transducer systems. The discussion of the electrostatic loudspeakers is especially noteworthy. Two appendixes provide useful conversion charts. Indexes of names and subjects conclude the text.

This monograph is a refreshing and welcome addition to the list of acoustical texts and should be required reading for advanced students and acoustical research people.

B. B. Bauer
Shure Brothers, Inc.
Chicago 10, Illinois

Yagi-Uda Antenna by S. Uda and Y. Mushiake

Published (1954) by Maruzen Company, Ltd., 2-chome, Mihombashi-dori, Chuc-ku, Tokyo, Japan. 176 pages+3 page index+4 page reference+ix pages. Illustrated. 6×8½. $4.00.

S. Uda and Y. Mushiake are professors at Tohoku University, Japan.

"The object of the authors' research, described in this work, was to establish a rigorous but practical method of design of Yagi-Uda antennas, based upon theoretical considerations, and without resorting to cut and try methods. Although this objective, in the strict sense, may not have been completely attained for all possible cases of specifications, the authors believe that this text will be of great assistance in designing antennas with multi-elements, such as Yagi-Uda antennas."

This extract from the authors' preface accurately summarizes both the objectives of the book and the degree of attainment of those objectives. A foreword by Dr. Yagi points out the complexities of analysis that are encountered with such antenna systems and commends the authors for their efforts.

Yagi-Uda antennas (or Yagi antennas as they are more often called), consisting of a driven element and one or more parasitic reflector or director elements, have been used extensively for many years in a multitude of applications because they combine good directivity with reasonably small antenna dimensions. This book provides complete information for the design of two- or three-element Yagi antennas. The methods of analysis employed are sufficiently general to treat antennas with a greater number of elements, but such antennas are not considered because of the large number of variables involved. The book summarizes the extensive theoretical and experimental antenna investigations which have been carried out by the authors and their associates during the past several years. An introductory chapter covers some fundamental theory, including the application of the reciprocity theorem in regions where the media are discontinuous. This is followed by a discussion of Hallen's antenna theory which is then applied to the calculations of the input impedances of parallel antennas. A chapter on the theory of antennas of nonuniform thickness (such as Yagi antennas with tunable elements) is followed by four chapters on the general theory and design of Yagi antennas. Rather complete charts and design curves, along with practical examples, are included to facilitate the design of actual antennas. Because folded dipoles are commonly used as the driven elements of these arrays, the input impedances of various types of folded dipole antennas are calculated by methods more accurate than those in common use.

Aside from an unusual number of typographical errors, the book is easy to read and has a large amount of information presented accurately and effectively. The book can be strongly recommended to all those interested in the theory or design of Yagi antennas.

E. C. Jordan
University of Illinois
Urbana, Illinois

Dielectric Materials and Applications Edited by A. R. von Hippel

Published (1954) by Technology Press of M.I.T., John Wiley and Sons, Inc., N.Y. 425 pages+12 page index+xii pages. Illustrated. 8¾×11¼. $17.50.

The stated purpose of this book is to coordinate the properties and processes of dielectrics so that the physicist, chemist, and electrical engineer can each speak the other's language. In this purpose, the reviewer feels that the book has succeeded admirably. Defining dielectrics as nonmetal substances and considering their interaction with electric, magnetic, and electromagnetic fields, a number of authorities have collaborated to describe properties, methods of measurement, and applications.

Starting with a review chapter on the theory of dielectrics—a much longer and complete account of the theory of dielectrics is given in a companion volume, "Dielectrics and Waves," by Professor Von Hippel—there are sections on measuring techniques, dielectric materials and applications, dielectric requirements of the armed forces, and the MIT table of dielectric materials. Each section is divided into a number of chapters and these are written by experts in their field. Due to skillful editing, the book shows no overlapping between chapters. Each chapter is complete in itself and describes fully the techniques used in measurements; the uses of high pressure gases, liquids, plastics and ceramics as voltage insulating devices; dielectric magnetic materials; and semiconductors. The use of dielectrics as rectifiers, transducers, amplifiers, and memory devices constitutes a unique section. An especially valuable part of the book presents the MIT tables of dielectric materials. This section, covering over a quarter of the book, gives tables and curves of the dielectric constant and associated power factors of 600 materials measured in the frequency range for 100 cycles to 10^{10} cycles. A number of these materials have been measured over temperature ranges from 0 to 500 degrees C.

This book contains the most complete account yet published on dielectric materials and their applications and should find its way into the libraries of engineers, physicists and chemists. It appears certain to be the standard book for dielectrics for many years to come.

W. P. Mason
Bell Telephone Labs.
Murray Hill, N.J.

Dielectrics and Waves by A. R. von Hippel

Published (1954) by John Wiley and Sons, Inc., New York, N. Y. 277 pages +6 page index +xii pages. Illustrated. 8 7/8×11 5/16. $16.00

This book, written for electrical engineers, physicists, and chemists, is an excellent survey of a wide field of electromagnetic phenomena. In Part I, entitled "Macroscopic Approach," the classic electromagnetic theory is developed rapidly after the introduction of complex permittivity and permeability as the fundamental parameters of a dielectric. ("Dielectric" is used in a broad sense.) In a section entitled "Description of a Dielectric by Various Sets of Parameters," several nomographic charts are given for rapid conversion between various sets of the parameters. The usefulness of these charts is enhanced by the large page size used. Among the many topics on waves is one on the measurement of dielectric by standing waves and another on their measurement in wave guides. The first part closes with a treatment of field phenomena by equivalent circuits and representation of dielectric by lumped circuit equivalents.

The second part of the book, "Molecular Approach," begins with the theory of polarization on the atomic basis and develops structural and spectroscopic theories for atoms and molecules. There are sections on microwave spectroscopy, piezoelectricity and crystal structure, ferroelectricity, ferromagnetic metals, and semiconductors to mention a few of the important topics of wide interest. The last section of Part II is on conduction and breakdown. There are two appendices, one containing problems and illustrative examples and the other a brief account of vector analysis.

This book is outstanding for its exceptionally clear and interesting presentation of so much important material in a smoothly connected way. The exposition is materially aided by many diagrams, which are especially well done in cases where fundamental ideas are being developed. There are many references to more specialized books and to original papers.

To sum up, "Dielectrics and Waves" is an important contribution. It is a book which once seen will be read.

R. F. Wick
Bell Telephone Labs.
Murray Hill, N. J.

Modern Physics for the Engineer Edited by Louis N. Ridenour

Published (1954) by McGraw-Hill Book Co., Inc., Inc., 330 W. 42 St. New York 36. N. Y. 490 pages +8 page index +xix pages. Illustrated. 9¼×6¼. $7.50.

Perhaps the best way to give potential readers of this book an insight into its contents is first to list the contributing authors, each of whom writes on a subject to which he has in years past made noteworthy contributions. The authors are: Royal Weller, H. P. Robertson, Leonard I. Schiff, Frederick Seitz, Charles Kittel, W. D. Hershberger, William A. Fowler, R. V. Langmuir, Glenn T. Seaborg, W. K. H. Panofsky, Jesse Greenstein, David T. Griggs, Roger Revelle, Leonard B. Loeb, Walker Bleakney, Simon Ramo, John Bardeen, J. B. Wiesner and Louis N. Ridenour.

Started as a collection of lectures delivered to an extension class at the University of California at Los Angeles during 1952–53, several of the series were repeated at the Naval Ordnance Test Station, the Naval Electronics Laboratory, and also at the University of California, Berkeley. The popularity of the lectures precipitated the present compilation, and Editor Ridenour is to be congratulated in bringing forth a book of great interest for a broad cross-section of engineers and scientists.

The contents of the book are broken into three major parts: the first on the *Laws of Nature* includes chapters on Relativity and the Foundations of Mechanics, Atomic Structure, Physics of the Solid State, Magnetism, Microwave Spectroscopy, Nuclear Structure and Transmutation, Electronuclear Machines, The Actinide Elements and Nuclear Power, Elementary Particles. The second part is called *Man's Physical Environment*, with chapters on Astrophysics, High-pressure Phenomena with Applications to Geophysics, The Earth Beneath the Sea, Thunderstorms and Lightning Strokes, Transient Phenomena in Supersonic Flow. The concluding third part, *Information and Its Communication*, has chapters on Electrons and Waves, Semiconductor Electronics, Communications Theory and Transmission of Information, and Computing Machines and the Processing of Information.

I cannot resist showing enthusiasm for this stimulating collection of authoritative and instructive writings. The style of writing suggests that each author carefully dedicated himself to imparting nonmathematically to the reader a maximum of information as interestingly as possible. The reader is aided by clear illustrations and references to more detailed recent research in the field. Accordingly, this is a book of great value for broad instruction and enjoyable reading. The scope of this work should appeal to all categories of technical personnel who seek to learn more—be it for the sake of knowledge or for control and/or utilization—about the areas in which present-day research, in engineering and in many of the physical sciences, is rapidly expanding man's understanding.

Editor Ridenour and his associates have in this book made a fine contribution to contemporary scientific literature.

Harold A. Zahl
Signal Corps Engrg. Labs.
Fort Monmouth, N. J.

Linear Transient Analysis Volume I by Ernst Weber

Published (1954) by John Wiley and Sons, Inc., 440 Fourth Avenue, New York 16, N. Y. 342 pages +6 page index +xiv pages. Illustrated. 9¼×6¼. $7.50.

This new book by Prof. Weber "represents in essence the subject matter taught in the basic graduate course on transient analysis required of all graduate students in electrical engineering at the Polytechnic Institute of Brooklyn." The book is competently written, although there are not many signs of originality in the development. There is no doubt, however, that the student who studies the book diligently and who carries out most of the problems included in the text will acquire a total experience that will provide him with the techniques for solving for the transient response of almost any reasonable lumped parameter network subject to any specified driving point source. Some comments on each chapter follow.

"The Concepts of Electric Circuits and Networks," Chapter One, examines the circuit concept and its relation to the electromagnetic field phenomena. This chapter leaves much to be desired. For the students to whom the book is directed, much of the elegance is lost. Such fundamental concepts as reference conditions in networks; for example, reference positive polarity, reference current direction, and reference direction for flux receive only partial treatment. Reference current directions are generally noted on the circuit diagrams, but little, if anything, is said about the others. With an explicit reference polarity notation, the Kirchhoff relations on page 18 could be stated in better form. Also, the statement on page 22 that the sign of M is "included in the statement of the network problem" is far from satisfying. Some indication of how this information is included in the statement of a problem would be most desirable. On page 25 reference is made to dual relationships, with no previous explanation of the meaning of the term.

"Classical Solution of Network Response" seems generally adequate. Section 2.3 might well have been amplified to examine the conditions that arise due to the switching of circuit parameters, as well as the switching of sources. In particular, a discussion of the conservation of flux linkages, and the conservation of charge, in its broader aspects, would permit the discussion of a class of problem not now included in the text. The introduction of the set of system equations in matrix form with no prior discussion of matrices may be quite confusing to the uninitiated.

Chapter Three, entitled "Analogues," contains an interesting discussion, although it is felt that further amplification would have been desirable. It is questioned whether, on the basis of the discussion in Section 3.2, a student could draw the dual of any given network; could cope with a network containing magnetically coupled elements; or would understand the real significance of inverse networks. Also, a discussion would have been in order in connection with Fig. 3.7 to allow proceeding from (a) to (c) by inspection, without reference to the equations of motion, and without proceeding from (a) to (b) to (c). Some word concerning the drawing of electrical analogues from considerations of the energy equations might also have been desirable.

"Operational Calculus (Heaviside-Jeffreys)" is a development about which the author has certain strong feelings, as noted in the Preface and in Chapter Five on page 182. To this reviewer, the Heaviside method and the Laplace Transform method are substantially equivalent, and Chapter Four as such could well have been omitted without in any way detracting from the book, or from the educational objectives of a course in transients. However, as it stands, this is a very lucid account of the Heaviside operational methods.

"The Laplace Transform Method" appears to be an adequate treatment of this broad field, and seems to cover all of the salient features of the method. It is noted that the convolution integral, introduced on page 226 can be deduced quite directly from the Inversion Integral, and such a proof would be quite feasible and appropriate.

Chapter Six, "The Spectrum Concept, Fourier Integrals," seems quite satisfactory. Special note is made of the care with which the relationship between the Fourier and the Laplace Transforms is discussed.

The book should receive a ready acceptance among those who seek a single book covering the important practical methods of transient analysis.

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Active Network by Vincent C. Rideout

Published (1954) by Prentice-Hall Inc., 70 Fifth Avenue, New York 11, N. Y. 480 pages+5 page index+xvi pages. Illustrated. 5⅞×8⅞. $10.65.

Under the term "active network" the author includes all networks, in general, capable of amplification. Principal emphasis is placed on vacuum tube circuits, used for communication and control engineering, but attention is paid also to transistors and thyratrons.

The book is intended for readers who have studied the physics of vacuum tubes and who are familiar with the fundamentals of passive linear network theory. The introductory chapter gives a summary of the usual methods of network analysis, with special reference to the equations for four-terminal networks.

The main portion of the book deals with all sorts of amplifiers, low-pass, band-pass, power, and feed-back amplifiers. These are analyzed systematically by applying the equations of four-terminal network theory to their equivalent circuits. The diagrams are well drawn and their notation aids materially in following the analysis.

The author examined the transient response of amplifiers, introducing the elements of Laplace transform theory for the purpose of this study.

Considerable attention is paid to various types of oscillators, relaxation oscillators, and trigger circuits. The subjects of detection, demodulation, and the various types of modulation, amplitude, frequency and phase modulation, are extensively treated. The author devotes a final chapter to noise and information theory.

It is, of course, impossible to treat exhaustively each and every one of such a vast range of subjects, but the author has succeeded very well in producing a concise, valuable reference book for the communication engineer. The ample bibliographies, which follow each chapter, make possible further and more intensive study of a selected subject.

The book represents the results of the author's teaching experience and is suggested as a text for senior electrical engineering students. Employed as a basic textbook, it should allow the instructor considerable freedom in selection of subjects for more intensive study.

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Theory and Design of Electron Beams: Second Edition by John R. Pierce

Published (1954) by D. Van Nostrand Company, Inc., 250 4th Avenue, New York, N. Y., and D. Van Nostrand Company, Ltd., 25 Hollinger Road, Toronto, Ontario, Canada. 215 pages+4 page index+3 page appendix+xiv pages. 114 figures. 6⅛×9¼. $4.50.

John R. Pierce is a member of the technical staff, Bell Telephone Laboratories, Inc.

This is a new edition of a highly valuable book on electron beams, first published in 1949. Its primary difference from other electron optics books is its concern with the principles of electron beams useful for amplifier and oscillator tubes, especially in the microwave region, in contrast to beams used in electron microscopes and image tubes.

The first half of the book presents the fundamental laws and principles governing electron flow, with the selection of principles and examples slanted strongly toward electron tubes. In the later portions, rather than consider such subjects as aberrations, the book treats of the effects of thermal velocities and space charge, and the principles of high-beam density guns and focusing fields which can maintain very dense beams at a constant diameter over long distances.

The book is valuable as a text for teaching these materials, but perhaps even more valuable to the practicing engineer or physicist. It is essentially a theoretical work and makes no attempt to discuss experimental technique, although the analyses are illustrated with many of the design problems which face the experimenter.

This edition differs from the earlier one principally in material added on focusing in the presence of space charge. Injection problems and thermal velocity effects are considered in Brillouin flow, and Harris flow is also treated. A whole new chapter on the important topic of focusing by means of periodic fields has been added, which brings the book up-to-date.

One might wish for a few minor additions for the sake of completeness, such as a treatment of beam edge perturbations in confined flow to parallel that given for Brillouin flow, the Mathieu equation solutions for periodic focusing, and the slipping stream solutions in crossed fields. On the whole, however, the book is remarkable for its authoritative treatment and excellent selection of the important principles and problems of dense electron beam flow.

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Magnetic-Amplifier Circuits by William A. Geyger

Published (1954) by McGraw-Hill Book Company Inc., 330 West 42 Street, New York 36, N. Y. 259 pages+16 page index+ix pages. 136 figures. 6⅛×9¼. $6.00.

William A. Geyger is with the Magnetics Division, U. S. Naval Ordnance Laboratory, White Oak, Silver Spring, Maryland.

This book presents an elementary treatment of the various magnetic-amplifier circuits developed up to the present time. The author states in the preface, "This book, designed to be as simple as possible in treatment, is intended as a practical exposition of the fundamental principles and applications of magnetic amplifiers with special reference to magnetic servo amplifiers." The treatment emphasizes graphical and descriptive methods; mathematics is employed in only the simplest and most fundamental cases.

The first chapter presents a very interesting history of the development of magnetic-amplifier circuits, in both the United States and Europe. Chapter Two is a brief description of magnetic-amplifier elements and touches lightly on magnetic materials, core arrangements, and rectifiers. The remaining thirteen chapters are devoted to description of the operation and development of all of the conventional magnetic-amplifier circuits. These are classified as follows: nonfeedback circuits including the basic nonpolarized, polarized, and duodirectional types; external feedback circuits including the basic types, and duodirectional types with two- and four-reactor elements; internal feedback circuits including the basic single- and two-core circuits, half-wave and full wave duodirectional types with two reactor elements, and duodirectional types with four reactor elements. A chapter on the second-harmonic-type circuit and a short chapter on typical applications of magnetic amplifiers are also presented.

In an effort to concentrate entirely on the basic principles of operation, the author has excluded more involved mathematical treatments which, due to the severe nonlinear nature of the problem, require special assumptions or approximations, depending upon the point of view taken, and may lead to somewhat different results. For the most part, the author has used the "case-history" method in describing the various circuits, has traced each circuit to the original inventor or first source, and has given credit to all contributors to its subsequent development. Actual measured performance characteristics are given for some of the circuits described, together with complete information for the corresponding experimental circuits. Complete references are given in every case. Of particular interest is the author's knowledge of European developments.

This book satisfies a definite need in the fast-growing field of magnetic amplifiers. In general, the author accomplishes the objective previously quoted. A significant contribution is the logical classification of circuits which permits a ready comparison of the operating characteristics of the various circuits. This volume should be of value to the engineer as a source book for magnetic-amplifier circuits and literature, and to the engineer or student who wishes to obtain an unbiased introduction to the subject.

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Acoustics by Leo L. Beranek

Published (1954) by McGraw-Hill Book Co., Inc., 330 West 42 Street, New York 36, New York. 467 pages+12 page index+x pages. Illustrated. 6⅛×9¼. $9.00.

The average radio engineer is interested in applications of acoustics such as loudspeaker cabinets, acoustic treatment of rooms, microphones and phono pickups, noise control, etc. He would like to know more about the theory, operation, and design of such devices, but if he surveys the literature, he is apt to get lost in a maze of mathematics and widely scattered references. A book that explains modern theory and practice in understandable terms, consequently, is welcome.

Acoustics by Leo L. Beranek is an outgrowth of the author's course at M.I.T. to seniors and first year graduate students. It is designed especially for those with a background of electrical engineering or communication physics useful as a textbook for classroom work, it has a section at the end of the book with problems corresponding to each of the thirteen chapters. For self-study it is rich in worked out examples of design problems commonly met in practice.

For reference there are over 300 comprehensive and up-to-date illustrations and tables, concerning acoustic properties of building materials, optimum reverberation time of rooms, speech articulation indexes, audibility thresholds, spectra of voice and music, and directivity of sound sources.

Some interesting new subjects are presented on: detailed procedure for bass reflex cabinet design, an improved method of treating electro-mechanical-acoustical analogies, latest data on noise reduction, architectural design, and acoustic measurements.

The book begins with fundamentals and theory of sound and its propagation. It treats, in turn, equivalent circuits, radiation, microphones, speakers, horns, enclosures, room acoustics, noise control, measurements, hearing, intelligibility, and psychoacoustic criteria. The treatment of each subject is quite complete, down to earth, and readable.

The practicing radio or acoustical engineer, the student, and the scientist interested in modern acoustics will find his copy of this book well worn in a short time.

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RECENT BOOKS

Erdelyi, A., Ed., *Tables of Integral Transforms: Volume II*, McGraw-Hill, 330 W. 42 St., N. Y. 36, N. Y.; $8.00. (Based, in part, on notes left by Harry Bateman.)

Grob, Bernard, *Basic Television: Principles and Servicing*, McGraw-Hill, 330 W. 42 St., N. Y. 36, N. Y.; $6.00.

Hadamard, Jacques, *The Psychology of Invention in the Mathematical Field*, Dover Publication, 1780 Broadway, N. Y. 19, N. Y.; $1.25.

Maxwell, James Clerk, *A Treatise on Electricity and Magnetism*, Dover Publications, 1780 Broadway, N. Y. 19, N. Y.; $4.95. (Unabridged republication of the 1891 third edition, vols. I and II.)

Rodenhuis, E., *Valves for A.F. Amplifiers*, Philips' Technical Library, Elsevier Press Inc., 155 East 82 St., N. Y. 28, N. Y.; $2.25.

Proceedings of the First Conference on Training Personnel for the Computing Machine Field, Wayne University Press, Detroit, Mich.; $5.00.

Proceedings Symposium on Operations Research in Business and Industry, sponsored by the Midwest Research Institute, 4049 Pennsylvania Ave., Kansas City, Mo.; $5.00. (Symposium held in Kansas City, Mo., April 8 and 9, 1954.)

Abstracts of Transactions of the I.R.E.

The following issues of *Transactions* have recently been published, and are now available from the Institute of Radio Engineers, Inc., 1 East 79 Street, New York 21, N. Y. at the following prices. The contents of each issue and, where available, abstracts of technical papers are given below.

Sponsoring Group	Publication	Group Members	IRE Members	Non-Members*
Aeronautical and Navigational Electronics	Vol. ANE-1, No. 3	$1.00	$1.50	$3.00
Audio	Vol. AU-2, No. 6	$ .80	$1.20	$2.40
Audio	Vol. AU-3, No. 1	$ .60	$ .90	$1.80
Broadcast and Television Receivers	PGBTR-8	$ .90	$1.35	$2.70
Communications Systems	Vol. CS-2, No. 3	$3.00	$4.50	$9.00
Electronic Computers	Vol. EC-3, No. 4	$1.10	$1.65	$3.30
Engineering Management	PGEM-2	$1.30	$1.95	$3.90
Microwave Theory and Techniques	Vol. MTT-3, No. 1	$1.50	$2.25	$4.50

* Public libraries and colleges may purchase copies at IRE Member rates.

AERONAUTICAL AND NAVIGATIONAL ELECTRONICS

VOL. ANE-1, NO. 3, SEPTEMBER, 1954

East Coast Conference

A Maintenance Plan for Airborne Radio Equipment—T. R. W. Bushby

This paper briefly outlines the Australian system of maintenance for airborne radio equipment, and gives in more detail results of a recent investigation into the reasons for, and incidence of, unscheduled removals of units. The probability of unscheduled removal, derived from the investigation data, was used as a criterion for the assessment of the optimum period between scheduled overhauls. It was found that, in many instances, the probability of failure is greatest immediately after overhaul and decreases with time. Comparisons of the performance of various types of units are given.

A Thunderstorm Avoidance Radar for Civil Aircraft—C. L. Greenslit

The Operational Applications of Airborne Radar—E. A. Post

Feedback Relations in Military Weapons Systems—R. C. Newhouse

AUDIO

VOL. AU-2, NO. 6, NOVEMBER-DECEMBER, 1954

PGA News

A System for Recording and Reproducing Television Signals—H. F. Olson, W. D. Houghton, A. R. Morgan, J. Zenel, M. Artzt, J. G. Woodward, and J. F. Fischer

A system for recording and reproducing television signals by means of magnetic tape has been developed. This system will accommodate both monochrome and color pictures. For monochrome pictures, two channels are used, one for the video signal and one for the sound signal. These signals are recorded as two tracks on ¼-inch magnetic tape. For color pictures, five channels are used: video channels for the color signals red, green and blue, the synchronizing channel, and an audio channel. These signals are recorded as five tracks on ½-inch magnetic tape. An electronic servo-mechanism provides the speed constancy required for the reproduction of television signals from magnetic tape. The present tape speed is 30 feet per second. The recorded and reproduced frequency band is over 3 megacyclces. There is a description of a demonstration which included side-by-side showing of a direct picture, and the same picture recorded and immediately played back.

A Miniature High-Gain Audio Amplifier—R. L. Libbey

A three-stage miniature transistor amplifier is described which is built into the space behind the cone of a 2¾-inch diameter loudspeaker. It has a power gain of 90 decibels.

The "Lipstik" Miniature Condenser Microphone—J. K. Hilliard and J. J. Noble

The details of construction of a miniature condenser microphone and the associated cathode-follower amplifier are given. Factors contributing to the inherent electrical noise level of the system are analyzed theoretically and experimentally. Relative qualities of various subminiature tubes for use in the "free grid" amplifier circuit are tabulated, and related to tube construction features. Microphone sensitivity, frequency response, polar patterns, and temperature coefficient are given.

Correction: "Equivalent Circuit Analysis of Mechano-Acoustic Structures"—B. B. Bauer

Cumulative Index for 1954

Vol. AU-3, No. 1, January-February, 1955

Editorial—D. W. Martin

IRE-PGA News

Equalization and Tone Controls on Phonograph Amplifiers—F. H. Slaymaker

The necessity for equalization in phonograph amplifiers is explained, and numerous examples are given.The difference between the action of equalization controls and tone controls is explained. Examples are shown in terms of response curves for a particular amplifier.

The Manufacture of High Fidelity Magnetic Tape Records—R. C. Moyer

The equipment used in the manufacture of magnetic tape records by RCA is described. The choice of tape speed, track width, and preemphasis used is explained, and the desirability of standardization on these possible variables is emphasized.

Loudspeakers and Microphones—L. L. Beranek

This paper covers the development of loudspeakers and microphones and gives many illustrations of commercially available units dating from 1915 to the present time.

BROADCAST AND TELEVISION RECEIVERS

PGBTR-8, October, 1954

The Vectorscope and Its Applications in Color TV, FM and Radio Navigation—K. Schlesinger

A Method for Determining *Q* and Selectivity of Low-Loss Parallel Resonant Circuits—R. C. Skar

COMMUNICATIONS SYSTEMS

Vol. CS-2, No. 3, November, 1954

(*Papers presented at the Global Communications Symposium, Washington, D.C., June 23–25, 1954*)

Administrative Aspects of Telecommunications—W. A. Porter

The author in speaking on some administrative aspects of global communications, presents the function of the Office of Defense Mobilization in the telecommunications area. He outlines several categories of presidential staff responsibility which are performed under his direction as Assistant Director for Telecommunications, Office of Defense Mobilization. He describes the organization and operation of the Telecommunications Planning Committee and the Interdepartment Radio Advisory Committee and indicates the role of each in this field. The need for a clear, comprehensive and up-to-date statement of U. S. Telecommunications policy is presented. Finally, the limits in the exercise of these functions are defined together with a statement of the aims for future action.

The International Telecommunication Union and Global Communications—F. Colt de Wolf

A survey is made of the effects which the ITU has had on the development of global communications systems through facilitation of intercommunication between systems in different countries, protection of radio frequency use from interference, exchange of technical information and agreement concerning manner of operation of the systems. Current problems are reviewed involving the reorganization of the system of frequency registration, collection of dependable information on frequency utilization, and the shifting of operating frequencies so that they are in-band according to international agreements.

International Radio Frequency Management—P. D. Miles.

A modest beginning in international radio frequency management was made on March 1, 1952, when the International Frequency Registration Board, which had been created by the International Telecommunications Conferences of Atlantic City, 1947, took up its substantive functions in accordance with the provisions of an agreement adopted by the Extraordinary Administrative Radio Conference, Geneva, 1951. The composition and organization of the board are described, together with an outline of its operating methods. Statistics concerning the work thus far accomplished are given, as well as an indication of the backlog that has been developed. The paper concludes with some suggestions as to the board's needs in order to be more effective.

The Organization and Function of the C.C.I.R.—E. W. Allen, Jr.

The C.C.I.R. (International Radio Consultative Committee) is one of three committees provided in the Atlantic City Convention of 1947 as technical consulting bodies to the International Telecommunication Union and the signatory countries. The other two are the C.C.I.F. (Telephony) and the C.C.I.T. (Telegraphy). The technical work is done through fourteen Study Groups, each with specific fields of interest. Each has an international chairman and vice chairman as well as national chairmen in each country. A Director and a Secretariat at Geneva centralize and coordinate the work internationally, while an Executive Committee serves to centralize the work at the national level. International Plenary Assemblies are held once every three years to review and to formalize the work of the study groups and to adopt such rules, resolutions and recommendations as will further the work of the C.C.I.R., and provide information for the I.T.U. and the participating nations.

Improving Frequency Management to Facilitate Global Communications—D. R. MacQuivey

A survey is made of the problems encountered in the U. S. in assignment of radio frequencies and the reasons for such problems—such as frequency shifts required as a result of the Extraordinary Administrative Radio Conference (EARC). Some proposed solutions are discussed and the impact of such solutions upon the solution of related problems in the field of international telecommunications policy and operations. Some of the administrative requirements peculiar to operations of particular agencies and services are reviewed. Factors common to the operation of several agencies are noted and some views expressed as to how the handling of these common factors might be facilitated through improvement in central administrative procedures, including agreed rules. Finally, some consideration is given to how adequate the U. S. solutions to these problems may prove to be if they were to be adapted to international frequency management.

British Global Communications—Col. A. H. Read

The author is Telecommunications Attache designate at the British Embassy in Washington. The British beamed wireless was one of the first global communications systems. As Director of Overseas Telecommunications in the General Post Office since 1951 and through association with British wireless telegraphy for more than 25 years, he will bring a comprehensive appreciation of the growth and present organization of the British system when he discusses British telecommunications at the symposium.

Global Marine Communications—E. M. Webster

The marine global radio communication system dates from the earliest practical use of radio, and over the years has assumed an increasingly important role in the advancement of safety of life at sea. The joint efforts of the maritime nations to develop a uniform worldwide communications system, which the mobility of ship stations requires to insure efficient ship-to-ship and ship-to-shore communications, are discussed along with the basic concepts of a global safety radio communications system and the pertinent international treaties embracing those concepts.

Department of the Army Command Communications—W. F. Spanke

Army communications are the voice of Army command. Each commander's effectiveness is related directly to the quality and quantity of channels of communications he has available in relation to those he needs to control his segment of the Army's missions. The commander speaks in many electrical languages. The facilities which convey the commander's electrical words between the various echelons of the Army Establishment comprise the Army Command and Administrative Network. Engineering, operation, and maintenance of this complex world-wide system at reasonable cost imposes unusual technical and operational problems and obligations upon the United States Army Signal Corps.

Organization and Operation of the Naval Communication System.—Cdr. G. M. Neely, USN (Ret)

The paper outlines the mission, policy, and certain doctrines of U. S. Naval Communications and describes the organization and operation of the Naval Communication System to meet the requirements deriving therefrom. Emphasis is placed on the component structure of the typical communication center and certain phases of communications unique to the provision of communication service to United States Naval Forces deployed throughout the world.

USAF Strategic Communications System—Col. G. M. Higginson

This paper describes the concept and operations of the USAF world-wide integrated communications system. The mission of the USAF, its relation to the other military services, and the development of GLOBECOM system to meet the USAF requirements are also described. This includes the planning, accomplishment, and the capabilities of the system. The paper also deals with technical problems encountered during development of the system and also identifies other technical difficulties associated with the system which are not yet solved.

Overseas Air Traffic Control and Meteorological Circuits of the Civil Aeronautics Administration—F. J. Cervenka

Safety of transoceanic flight is dependent on meteorological and traffic control information transmitted between fixed stations of a global aeronautical communications network. CAA stations form part of this network, providing 43,000 miles of connecting links between the domestic communications network and overseas air terminals in U. S. territories and in foreign countries to which flights operate from U. S. terminals. Approximately 680 million five-letter groups of message traffic, including 172,327 flight plans, were handled by CAA stations on overseas circuits during 1953. During this period these CAA stations also handled 1,124,906 contacts with aircraft in overseas flight. Transmissions are point-to-point voice and frequency-shift radioteletypewriter signals with time-division multiplex on trunk circuits.

International Planning of Global Communications for Aviation—H. R. Adam

The underlying concepts of planning for international civil aviation as derived from the International Convention of Civil Aviation are discussed, followed by an outline of the methods employed in developing the plans. These methods include the establishment of standards and principles for world-wide application, the regional planning of air traffic control, meteorological and search and rescue services and organization together with associated telecommunication services, the planning of radionavigation aids and radiofrequency utilization. The problems of implementation and follow-up are discussed with particular reference to ICAO participation and a general review of the results obtained to date is given. Arising from the foregoing, some problems inherent in global planning are outlined with particular reference to the difficulties in establishing facilities and services on a world-wide basis while at the same time maintaining sufficient flexibility to meet the rapidly changing developments of civil aviation. Finally, suggestions on future developments together with some of the conditions these developments will need to satisfy is given.

Global Air/Ground Radiotelephone Communications—W. W. Lynch

Development of the existing world-wide air/ground radio-telephone network from an operational and functional point of view. Development of airborne equipment, the network principle, the frequency family planning, training of personnel, and the geographic deployment of ground facilities to obtain global coverage. Description of some of the many technical difficulties which were experienced particularly in the Northern latitudes, in Alaska, and in the North Atlantic and some of the means which were devised and which are continually being employed to improve air/ground radio-telephone communications including the Selective Calling System being installed in the Pacific area to eliminate the necessity of continuous monitoring by the pilots.

Frequency Propagation Forecasting for World Air Route Operations—C. A. Petry and L. S. Meaker

This paper describes the application of recognized frequency prediction data in specialized propagation forecast charts for use by aircraft crews, ground communications personnel and flight dispatches in the planning and routine communications with long over-water and world air route flights. Reference also is made to frequency propagation forecasting for the guidance of communicators in the operation of aviation point-to-point circuits. The subject is treated in two parts, covering both the civil and military applications.

Recent Advances in International Radio Communication—I. K. Given

An agenda for communications engineers has been presented in an editorial in the PROCEEDINGS OF THE I.R.E. dated February, 1954. RCA Communications, Inc., has been actively engaged in answering the questions raised with regard to increasing the potential of the frequency spectrum by making more efficient use of it; acquiring a better and more widespread understanding of the principles of detecting signals in the presence of noise, and further making use of these changes to plan automatic routing and switching systems in the future. A semi-technical treatment is presented using methods such as simulated Single-Sideband transmission, true Single-Sideband transmission, use of ARQ mutilation reduction equipment, and other ingenious operating practices.

Global Public Telephone Communications—D. D. Donald

Telephone service is available from telephone customers in the United States to about 96 per cent of the world's telephones. Service is provided over direct wire and radio links to most of the major countries. Others are interconnected to these by wire and radio circuits. The reliability and quality of transmission of the interconnected link affect the over-all service. Alternate routes have been set up in a number of cases to improve reliability. The post-war expansion of international telephone service by radio has severely congested the radio spectrum available for such services. A transatlantic cable is now being engineered to provide additional facilities between New York and London.

Impact of Submerged Repeaters on Global Telegraphy—C. S. Lawton

Not only has this development infused new blood into existing transoceanic cables, it has made the laying of new cables much more attractive. Types of repeaters, their use singly and in tandem, installations and replacements at sea, and the mechanical design of casings are variants. New equipment is required to handle extra channels derived from existing plant, together with extension of these channels to landline facilities and to subscribers. Several new types of service have been stimulated, and methods are visualized for accommodating further expansion, making possible complete integration of landline and ocean cable facilities if desired.

(Papers presented at the Military Communications symposium, New York, N. Y., April 28, 1954)

A Private Microwave Radio System for Power Company Use—D. F. Hazen, J. W. Danser, and G. S. Zilis

Simplified Transmission Engineering in Exchange Cable Plant Design—L. B. Bogan and K. D. Young

Considerations for Development of New Military Carrier Telephone Systems—R. S. Boykin, J. H. Johnston, and S. D. Bedrosian

A New Cable Design for Military Carrier Telephone Systems.—H. F. X. Kingsley

New Military Carrier Telephone Systems Equipment Features—J. P. Hoffmann

New Military Carrier Telephone Systems—G. H. Huber, W. F. Miller, and C. W. Schramm

A New Ultrahigh-Frequency Multichannel Military Radio Relay System—J. G. Nordahl

Telegraph Terminal AN/FGC-29 Circuit Design Aspects—J. E. Boughtwood

Telegraph Terminal AN/FGC-29 Equipment Features—F. H. Cusack

A New Multichannel Teletype Terminal for Use on Long-Range High-Frequency Radio Systems—A. Mack and R. H. Levine

Equipment and Mechanical Features of the AN/TRC-24 Radio Set—V. I. Cruser

Considerations for a New Military Radio Relay System—M. L. Ribe and S. P. Brown *(Contributed paper)*

Steerable Directional High Frequency Antenna—H. Brueckmann

ELECTRONIC COMPUTERS

VOL. EC-3, NO. 4,
DECEMBER, 1954

The Use of a Reflected Code in Digital Control Systems—F. A. Foss

The reflected (Gray) binary code has previously been used primarily in analog-to-digital conversion applications. However, the reflected binary code has, in addition, characteristics which strongly recommend it as a design factor in the synthesis of digital elements within closed-loop control systems. This paper describes several designs of typical reflected binary switching circuits. These switching circuits are, specifically, a reflected-to-conventional binary translator, reflected binary-to-analog converters, and a reflected binary contactor comparator. All of the circuit designs are logically related to the form of the reflected-to-conventional binary translator. These switching circuits can be used as digital control elements in the described original types of digital positional servomechanisms and digital accumulators.

A Transistorized Pulse Code Modulator—G. R. Partridge

A pulse code modulator is described in which transistors are the only active circuit components. The functions of quantizing and encoding the signal are performed entirely by semi-conductor diodes, using transistor amplifiers where necessary to increase the signal level. The readout is obtained from a set of "and" gates, each gate having as one of its inputs an output from the encoding system, and as the other input, a pulse obtained from a time delay circuit to assure sequential operation. The system produces a three-digit binary code at a sampling rate of 5,000 cps.

A Radio-Frequency Nondestructive Readout for Magnetic-Core Memories—Bernard Widrow

It is possible to read information nondestructively from two- and three-dimensional magnetic-core digital computer memories in several microseconds by exciting selected cores with rf currents. If two co-ordinate lines of a core in a memory array plane are driven at slightly different frequencies, a beat-frequency signal is generated whose phase may take on one of two values which are separated by 180 electrical degrees. These two possible phases correspond to the 0 and 1 information states of the core. The beat-frequency signal, separated from the inevitable noises by tuned linear filters, may be phase detected to yield the desired information.

Time-Delay Networks for an Analog Computer—W. J. Cunningham

Time-delay networks suitable for an analog computer are designed by considering the location of poles and zeros in their transfer functions. The curve of phase shift against frequency should be a straight line. The negative slope of this curve is the time delay. Even-order derivatives of the curve automatically vanish at zero frequency. Roots of the transfer function are chosen to make vanish similarly as many as possible of the derivatives of odd order, higher than the first. Data are given for networks with one, two, three, and four pairs of roots.

A Stabilized Driftless Analog Integrator—Howard Hamer

A new chopper-stabilized analog integrator circuit has been developed which, at the cost of two passive elements, enables the stabilizer amplifier to operate on output drift due to input current as well as drift due to unbalance.

A Desk-Model Electronic Analog Computer—H. A. Rosen and M. W. Fossier

A description is given of an analog computer comparable in size to an automatic desk calculator. By combining the techniques of electronic and electric analogs, a high problem-solving capacity is achieved in a minimum of space. Nine stable high-gain dc amplifiers are provided, each of which can be made to produce a variety of functional responses. This is accomplished by allowing the operator to build up the input and feedback networks of each amplifier on a plug board, on which space is provided for additional networks involving resistors, capacitors, and crystal diodes. The plug board containing all the components and interconnections involved in a given problem can be stored in a filing cabinet when not in use. The low cost and small size of the computer make it suited for use in many situations in which an analog computer would not otherwise be used.

IRE National Convention Electronic Computer Session III *(discussion)*

Contributors

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ENGINEERING MANAGEMENT

PGEM-2, NOVEMBER, 1954

Control of Cost of Research and Development Projects—H. J. Finison

The control of cost of research and development projects is intimately related to all factors of technical supervision. The methods must be developed to fit the needs of the particular types of research and development programs and of the organization in which the programs are carried out. Some general principles and specific practices in use at one industrial research laboratory may find general usefulness in many organizations. For example, the concept that adequate control of any business or technical problem requires, first, a plan or standard and, finally, a review or measurement to determine conformance to the plan, will be of use for all control problems. The degree of formality with which such a principle is applied requires careful consideration in order that adequate control will be obtained without inhibiting imaginative approaches to problems. This paper discusses particular principles and methods of project planning and review and the relationship of these methods to personnel and to organization. These factors are discussed from the viewpoint of the project leader, the research supervisor, and the technical manager. Specific examples are used to illustrate approaches.

Human Relations in Engineering Management—Melville Hopkins

Engineers Can Be Managers—Douglas Watson

Management Can Be Taught—L. H. Hattery

The Responsibility of Engineering Management—A. F. Coleman

Some Views on Executive Management—T. M. Linville

The Selection and Development of Laboratory Executives—O. G. Tallman

Biographical Notes on the Authors

MICROWAVE THEORY AND TECHNIQUES

VOL. MTT-3, NO. 1

JANUARY, 1955

Publication Plans of the PGMTT—T. S. Saad

George C. Southworth

The Challenge—G. C. Southworth (*editorial*)

A Method of Forming a Broad Band Microwave Frequency Spectrum—R. E. Wall, Jr., and A. E. Harrison

A method of generating a wide spectrum of evenly spaced sidebands in the microwave region, suitable for use as a frequency standard, is presented and discussed. The frequency spectrum is produced by modulating the beam acceleration voltage of a klystron with two high-frequency voltages. The frequency of one of these modulation voltages is an integral multiple of the frequency of the other voltage so that certain sidebands of the lower frequency coincide with the sidebands of the higher frequency. The output of the klystron then consists of a frequency spectrum about the microwave carrier frequency with the spacing between sidebands equal to the lowest of the two modulating frequencies.

The method is examined analytically and experimentally. The operation of a klystron is ordinarily expressed with time as the variable. An analysis making use of the Laplace transform to convert the function of time into a function of frequency has been found convenient. The result gives the magnitude of the sidebands as a function of the operating parameters of the klystron.

A Turnstile Polarizer for Rain Cancellation—P. A. Crandell

This paper describes a rain canceller using a turnstile junction to provide the necessary polarization of the fields. It discusses the system from the point of view of adapting an existing radar feed system to one which will permit the reduction of rain return. The turnstile junction will be described, and it will be shown that it has properties which meet the requirements for obtaining circular or elliptical polarizations. Along with this description, there will be discussed in detail the theory behind the effect of elliptical and circular polarization on rain return and the practical limits such a theory can be put to. Other considerations such as aspect ratio of antennas and screening for the antenna surfaces will be touched upon.

Graphical Filter Analysis—H. N. Dawirs

Some well known principles of filters and transmission lines are recalled and used to develop graphical methods of analyzing lossless transmission line filters consisting of a series of symmetrical and identical sections. The results of this development are used to construct a special filter analysis chart by means of which a filter may be completely analyzed from a Smith Chart plot of the input impedance characteristics.

A Waveguide Impedance Meter for the Automatic Display of Complex Reflection Coefficient—H. L. Bachman

A Waveguide Impedance Meter has been developed, comprising some specially designed components and some components previously designed for other applications. When this circuit is used in conjunction with the X-Band Rapid Sweep Oscillator and suitable Display and Control Circuits, the impedance locus of a waveguide component is automatically and rapidly measured and oscillographically displayed in the reflection coefficient plane. A waveguide component having a $1\frac{1}{4}$ inch$\times\frac{5}{8}$ inch (large X-band) waveguide input port can be continuously measured throughout the frequency range extending from 8.5 to 9.6 KMc (12 per cent X-band):

The bandwidth of the system is limited by the design bandwidth of the waveguide components. The plane of the impedance measurement may be referred to a plane internal to or external to the input port of the component under test. An expanded portion of the reflection coefficient plane may be displayed on the CRT when small reflections are measured. The measurements of several representative impedances by the waveguide circuit were compared with slotted line measurements of these same components. For measurements of large reflections, standard ∞ db SWR full scale display, the maximum observed errors of the magnitude and phase of the reflection coefficient as measured by the waveguide circuit were 10 per cent and 5 degrees respectively. These maximum errors occurred for measurements performed at the ends of the 12 per cent frequency band.

The average errors of the magnitude and phase of the reflection coefficient were 2.5 per cent and 2 degrees respectively. For measurements of small reflections, with the CRT display of reflection coefficient plane expanded to 6 db SWR full scale, the maximum observed deviation of the waveguide circuit measurements from slotted line measurements was .5 db SWR, and the average deviation was .2 db SWR. The maximum errors again occurred at the ends of the 12 per cent frequency band.

A Method of Measuring Dissipative Four-Poles Based on a Modified Wheeler Network—H. M. Atlschuler

A method of abstracting the parameters of dissipative four-poles from measured data is presented here. This semi-precision method is applicable to symmetric four-poles and results directly in a conveniently symmetric network representation. It is based on the Modified Wheeler representation, a new and completely general network, which is introduced in this paper. In addition to the derivation of the network and of the analysis, the relationship that the network bears to its dual, to the impedance Tee and to the admittance P_i is presented.

Notes on Crystal Mixer Performance—W. L. Pritchard

A simple relation between optimum RF source impedance for minimum noise figure and the nominal conversion loss of a mixer is derived. This impedance is related to the input mismatch and its dependence on the type of IF amplifier input circuit is discussed. Relations between the crystal noise temperature and mixer noise temperature as a function of conversion loss are derived for different load conditions at the image frequency terminals.

Intrinsic Insertion Loss of a Mismatched Microwave Network—Kiyo Tomiyasu

A brief review is presented of the absolute minimum loss of a two-port, mismatched lossy microwave network. This minimum loss, called the "intrinsic insertion loss" can be attained by adding suitable susceptances at the ports that will yield simultaneous bilateral network match. A measurement procedure is described and convenient graphs are presented.

A Practical Method of Locating Waveguide Discontinuities—O. T. Neau

Description of a method of isolating standing wave troubles to the antenna or to a specific section of waveguide. A measurement of the frequencies required to produce two successive maxima or minima of the standing wave at a fixed sampling probe location enables the operator to determine, mathematically, the approximate distance from the probe to the discontinuity. The simple mathematical solution is described and a brief discussion of equipment and technique is given.

Klystron Noise—P. D. Strum (*Correspondence*)

Abstracts and References

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NOTE: The Institute of Radio Engineers does not have available copies of the publications mentioned in these pages, 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 and is not to be confused with the Decimal Classification used by the United States National Bureau of Standards. 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.

U.D.C. CHANGES

In anticipation of a new edition of the Universal Decimal Classification Abridged English Edition (BS 1000 A), certain changes in U.D.C. numbers will be made in this and subsequent issues. The new numbers used will be:

Radio astronomy: 523.16
Ultrasonics: 534 subdivisions with the special analytical subdivision -8 attached
Sound recording and reproducing: 534.85
Electroacoustic problems, transduction, etc.: 534.86

The Index to the Abstracts and References published in the PROC. I.R.E. from February 1954 through January 1955 is published by *Wireless Engineer* and included in the March 1955 issue of that journal. Copies of this issue may be purchased for $1 (including postage) from the Institute of Radio Engineers, 1 East 79th Street, New York 21, N.Y. As supplies are limited, the publishers ask us to stress the need for early application for copies. Included with the Index is a selected list of journals scanned for abstracting with publishers' addresses.

ACOUSTICS AND AUDIO FREQUENCIES

534.1 **1**

Transverse Vibrations of a Symmetric Tapered Reed—A. Leitner and E. A. Hiedemann. (*Jour. Acoust. Soc. Amer.*, vol. 26, pp. 509–510; July, 1954.) Frequencies and node positions are calculated for double-tapered bars of a type used for ultrasonic generators, by combining the exact methods of Rayleigh and Kirchhoff for uniform and tapered bars respectively.

534.1–8:621.317.755 **2**

Analyzing Ultrasonic Pulses by the Split-Reflector Method—R. A. McConnell. (*Jour. Acoust. Soc. Amer.*, vol. 26, pp. 563–565; July, 1954.) Frequency modulation within the pulses from a pulsed ultrasonic oscillator is analyzed by directing the beam on to a plane reflector which is split into a fixed and a moving part, and observing on a cro the amplitude fluctuations of the middle portion of the reflected pulse as the position of the movable reflector is varied. The method is applicable at frequencies > 5 mc and is specially suitable for modulation in the range 0.1–5 per cent.

534.2 **3**

Transmission of Sound through Thin Elastic Plates—J. E. Young. (*Jour. Acoust. Soc. Amer.*, vol. 26, pp. 485–492; July, 1954.) An investigation is made of transmission through the plate when mounted (a) in a plane infinite baffle, and (b) in a duct of infinite length. The effect of boundary conditions is examined; the concept of bending impedance is introduced as a criterion of the mounting conditions. Experiments made with a circular plate in a 3-inch-diameter tube are reported; the plate holder was designed to provide a choice of boundary conditions. Reasonable agreement was obtained between theoretical and experimental results.

534.231.3:621.395.616 **4**

Acoustic Impedance of a Right Circular Cylindrical Enclosure—F. Biagi and R. K. Cook. (*Jour. Acoust. Soc. Amer.*, vol. 26, pp. 506–509; July, 1954.) "At low frequencies, the acoustic impedance of a right circular cylindrical enclosure (containing air, or other gases) is affected by the cooling effects of the walls. Analytical expressions for the temperature distribution have been obtained, and computations of the effect on the impedance are given in the form of plotted correction factors. These corrections are used in making absolute pressure calibrations of condenser microphones at low frequencies."

534.3/.4 **5**

Tentative Classification of Methods of Processing Musical Signals—A. Moles. (*Ann. Télécommun.*, vol. 9, pp. 201–204; July/August, 1954.) Discussion is presented in terms of the representation of the musical sound in the three dimensions level, pitch and duration. Elementary entities are distinguished from complex musical signals of indefinite duration. Processing methods include limiting (of frequency, level or duration), inversion, transposition and repetition.

534.373:534.414 **6**

A Study of the Factors influencing the Damping of an Acoustical Cavity Resonator—R. F. Lambert. (*Jour. Acoust. Soc. Amer.*, vol. 26, p. 583; July, 1954.) Correction to paper abstracted in 1643 of 1954.

534.64 **7**

The Horn as a Coupling Element for Acoustic Impedance Measurements—T. D. Northwood and H. C. Pettigrew. (*Jour. Acoust. Soc. Amer.*, vol. 26, pp. 503–506; July, 1954.) A modified impedance-tube method is described for determining the absorption of acoustic materials, suitable for measurements over a wide frequency range with samples of size 12-inch-square or greater. The sample is mounted at the mouth of a horn and the measurement is made at the throat of the horn, using a conventional impedance tube. A comparison of results obtained by this method and by the ordinary impedance-tube method (with small samples) indicates that with certain modifications of the horn the method should be satisfactory at frequencies up to 3 kc.

534.7 **8**

The Measurement of Human Channel Transmission Characteristics—W. A. Munson and J. E. Karlin. (*Jour. Acoust. Soc. Amer.*, vol. 26, pp. 542–553; July, 1954.) Information-theory concepts are used in an investigation of the human being as a communication channel. Techniques using binary signals are discussed for measurement of the transmitted information. A model proposed to represent the channel involves as parameters the noise level and the discriminator sensitivity of the human circuits. Psychophysical tests illustrating the usefulness of these concepts are described.

534.78 **9**

Some Further Experiments upon the Recognition of Speech, with One and with Two Ears—E. C. Cherry and W. K. Taylor. (*Jour. Acoust. Soc. Amer.*, vol. 26, pp. 554–559; July, 1954.) Continuation of investigation noted previously [947 of 1954 (Cherry)].

534.78 **10**

Intelligibility of Different Speech Materials—I. J. Hirsh, E. G. Reynolds and M. Joseph. (*Jour. Acoust. Soc. Amer.*, vol. 26, pp. 530–538; July, 1954.) Investigations are reported of the recognizability of nonsense syllables and of words with various numbers of syllables, as a function of the cut-off frequency of low-pass and high-pass filters and of signal/noise ratio at different noise levels. Results indicate that the elimination of all frequencies above or below 1600 cps does not seriously affect the intelligibility of words.

534.78:519.272.1 **11**

Short-Term Autocorrelation Analysis and Correlatograms of Spoken Digits—R. Biddulph. (*Jour. Acoust. Soc. Amer.*, vol. 26, pp. 539–541; July, 1954.)

ANTENNAS AND TRANSMISSION LINES

621.372.2 **12**

A Series-Laminated Conductor for High Frequencies—H. Ataka. (PROC. I.R.E., vol. 42, pp. 1527–1529; October, 1954.) Skin effect is reduced in a hf line by use of alternate lengths of conducting and insulating material; the arrangement is contrasted with that of Clogston (2908 of 1951) where the conducting and insulating materials alternate in the transverse direction. The uniformity of the current distribution over the cross section improves as the length of the sections decreases; in practice an optimum length exists.

621.372.2 13

A Coaxial Line filled with Two Non-Concentric Dielectrics—D. J. Angelakos. (*Trans. I.R.E.*, vol. MTT-2, pp. 39–44; July, 1954.) Analysis is presented for a coaxial line with different dielectrics occupying separate cross-sectional sectors of the interspace; the system is considered as a bent waveguide of width determined by the guide wavelength and length given by the average circumference. The modal structure of the fields was examined experimentally.

621.372.2:621.3.018.75 14

Propagation of a Voltage Pulse in a Perfectly Uniform Cable—M. Cotte. (*Câbles & Trans.* vol. 8, pp. 258–265; July, 1954.) The distortion of a pulse of finite duration propagated along a uniform cable is determined by evaluating a convolution integral involving the response to a unit-pulse input, and the time-function representing the successive instantaneous amplitudes corresponding to the applied input pulse at the distant point. The method is applied to the case of a sine-squared pulse and typical pulse shapes are shown which have been determined by numerical calculation and correspond to propagation of 0.15-, and 0.1- and 0.25-μs pulses over different lengths of cable.

621.372.2.029.64 15

Step Discontinuities in Disk Transmission Lines—R. N. Bracewell. (Proc. I.R.E., vol. 42, pp. 1543–1547; October, 1954.) Analysis developed by Whinnery et al. (736 of 1945) for parallel plane and coaxial lines with step discontinuities is adapted to deal with lines comprising parallel disks with radial propagation. Correction factors involving Bessel functions are derived. Charts are presented for determining the values of the correction factors from simple shape parameters.

621.372.21:621.315.213 16

Characteristic Impedance of the Shielded-Strip Transmission Line—S. B. Cohn. (*Trans. I.R.E.*, vol. MTT-2, pp. 52–57; July, 1954.) Simple design formulas and charts are presented for transmission lines of the type comprising a conducting strip centered between parallel ground plates.

621.372.8+[535.42:538.56 17

Electrodynamics Problems of Non-ideally Conducting Bodies having Angularities—V. A. Il'in. [*Compt. Rend. Acad. Sci.* (*URSS*), vol. 97, pp. 213–216; July 11, 1954. In Russian.] The two boundary-potential problems considered are the diffraction of em waves by a nonideally conducting cylinder and the excitation of a non-ideal waveguide. A method is shown of solving the problems provided that the solutions for the case of ideal conductors are known. The effect of the angularities is to introduce an additional term, the "zone of action" of which depends on the conductivity; for metals the region is negligibly small, for sea-water it is of the order of a wavelength in air. The method may be applied also in the case of a conductivity discontinuity at an angle.

621.372.8 18

An Introduction to the Principles of Waveguide Transmission: Part 1—Fundamental Concepts; Generation of Microwave Energy—C. F. Floyd and W. A. Rawlinson. (*P.O. Elec. Eng. Jour.*, vol. 47, pp. 63–67; July, 1954.) Fundamental principles are presented in nonmathematical terms.

621.372.8 19

Circular Waveguide Chart—A. C. Hudson. (*Electronics*, vol. 27, p. 194; October, 1954.) The chart presented facilitates determination of (a) the modes that will propagate at a given frequency, (b) the cut-off wavelength for these modes, and (c) the guide wavelength at this frequency for each mode.

621.372.8 20

H_{01} Mode Circular Waveguide Components—D. A. Lanciani. (*Trans. I.R.E.*, vol. MTT-2, pp. 45–51; July, 1954.) Three components for mm-λ operation are discussed, (a) a transition from rectangular to round waveguide, (b) a mode absorber, and (c) a 90-degree bend.

621.372.8 21

An Improved Squeeze Section with Constant-Width Region—H. Severin. (*Z. angew. Phys.*, vol. 6, pp. 262–264; June, 1954.) Analysis shows that for a squeeze section of length l_1+l_2 with constant-width middle portion (length l_2), the associated change in electrical length is equal to that obtained with a normal squeeze section of length l_1+2l_2. This is substantiated experimentally using a 3-cm waveguide with a longitudinal slit in the broad faces measuring 1 m × 1 mm and tapered at the ends; by means of a screw adjustment the guide width is varied by ±1 mm over a middle region of length 22 cm.

621.372.8 22

The Excitation of Plane Surface Waves—A. L. Cullen. (*Proc. IEE.*, Part IV, vol. 101, pp. 225–234; August, 1954. Digest, *ibid.*, Part III, vol. 101, pp. 276–277; July, 1954.) The problem is discussed in relation to low-loss microwave transmission systems. Launching efficiency is defined as the fraction of the total power input from the source which is propagated as a surface wave. Launching of an *E*-type plane surface wave from a slot source above a corrugated or dielectric coated metal plate is considered; high efficiencies are attained for a critical value of source height, the value of which is calculated for two special cases. Possible use of arrangements of this type as end-fire antennas is discussed.

621.372.8:537.226 23

Analysis of Propagating Modes in Dielectric Sheets—L. Hatkin. (Proc. I.R.E., vol. 42, pp. 1565–1568; October, 1954.) Procedure is described for calculating the free-space wavelength and thickness of dielectric to give a required wavelength in the dielectric. The method is based on a combination of geometrical optics and transmission-line analysis.

621.372.8:[537.562+621.318.134 24

Topics in Guided Wave Propagation through Gyromagnetic Media: Part 3—Perturbation Theory and Miscellaneous Results—H. Suhl and L. R. Walker. (*Bell Sys. Tech. Jour.*, vol. 33, pp. 1133–1194; September, 1954.) Perturbation theory is used to solve some problems whose treatment is particularly difficult by other methods. These include various cases of cylindrical waveguides enclosing long or short ferrite specimens which partially or completely fill the waveguide section. A numerical study of field patterns of the TE_{11}-limit and TM_{11}-limit mode for various dc magnetic fields is given as an addendum to part 1 (2563 of 1954). Part 2: 3129 of 1954.

621.372.8:621.372.2 25

Circular Polarization in Waveguides and Cavities—R. W. Klopfenstein. (*RCA Rev.*, vol. 15, pp. 291–311; September, 1954.) Design formulas are given for radial transmission lines excited in rotating phase and for an element consisting of a circular waveguide series loaded with a radial line.

621.372.8:621.385.029.6 26

Problems in the Coupling of the Magnetron to a Waveguide—M. L. Toppinga and J. Schuytemaker. (*Tijdschr. ned. Radiogenoot.*, vol. 19, pp. 157–178; July, 1954.) Equivalent-circuit analysis is used to determine the dimensions of the coupling system. The input admittance of the "cold" magnetron in a specified reference plane is determined for frequencies in the neighborhood of the π mode. The conditions for oscillation and the Rieke diagram are discussed. The theoretical results are compared with measurements on a Type-CV76 magnetron. A detailed indication of the output circuit to be used should be given by the magnetron designer.

621.396.67 27

Multipoles and Schelkunoff Waves—I. Ferrari. (*R. C. Accad. naz. Lincei*, vol. 17, pp. 32–37; July/August, 1954.) Analysis for the harmonic fields of antennas presented by Schelkunoff (*Electromagnetic Waves*, Chapter 10) is discussed. It is shown that the field of a multipole of order n is a linear combination of the fields of the first n terms of Schelkunoff's solution, and is of even or odd order according as n is even or odd.

621.396.676.029.62 28

Recessed Metre-Wave Aerials for Aircraft—S. Zisler. (*Ann. Télécommun.*, vol. 9, pp. 205–214; July/August, 1954.) The dependence of the properties of an antenna on its dimensions and its distance from a reflector are investigated. An account is given of experiments with cylindrical recessed antennas for the frequency range 115–130 mc with a polar diagram suitable for homing. The antenna conductor is of silvered brass, and the reflector, constituted by the recess wall, is of duralumin. Calculations are presented for simple and for wide-band matching and for a double antenna. Radiation patterns are shown.

621.396.677.012.12 29

Spatial Power Distribution Diagrams for Aerials with Vertical Radiation—P. Adorian. (*Jour. Brit. IRE*, vol. 14, pp. 434–435; September, 1954.) Diagrams are presented, in a form suitable for design calculations, for 4-element and 16-element arrays intended primarily for broadcasting in the tropics [2335 of 1952 (Adorian and Dickinson)]. These diagrams are to appear as Figs. 38 and 39 in the C.C.I.R. Antenna Diagrams Handbook.

621.396.677.3:[621.396.65+621.396.96 30

The Application of [u.h.f.] Radio Beams to Radar, Multiplex and Television Techniques—R. Aubert. (*Rev. gén. élect.*, vol. 63, pp. 348–363; July, 1954.) Basic principles of radar are reviewed in simple terms to emphasize the significance of the high gain resulting from use of very short wavelengths with directive antennas. Illustrations show various types of radar and radio-link antenna.

AUTOMATIC COMPUTERS

681.142 31

Lectures on Electronic Computing—L. Kosten and W. L. v.d. Poel. (*Tijdschr. ned. Radiogenoot.*, vol. 19, pp. 211–212; July, 1954.) English summaries are given of the following papers:

"The History of the Electronic Computing Machine 'PTERA', Purpose and Possibilities,"—L. Kosten.

"The Functioning of the Electronic Computing Machine 'PTERA',"—W. L. v.d. Poel.

"Programming for the Electronic Computing Machine 'PTERA',"—W. L. d.v. Poel.

"Discussion of Programme 'A7' for the Electronic Computing Machine 'PTERA',"—L. Kosten.

The complete papers are published in *P.T.T. Bedrijf*, vol. 5, pp. 116–148; 1953.

681.142 32

Elimination of Waiting Time in Automatic Computers with Delay-Type Stores—A. L. Freedman. (*Proc. Camb. Phil. Soc.*, vol. 50, part 3, pp. 426–438; July, 1954.) A critical survey is made of methods which have been tried for eliminating waiting time, and a description is given of a process developed for determining the amount of waiting time eliminated. The "optimum programming" method adopted with the ACE pilot model is found to be a combination of several methods. It appears that reduction of waiting time generally has to be paid for in extra complication of programming or design; some exceptions to this rule are indicated.

681.142 **33**
Applications of Electronic Computers to Clerical Work—T. R. Thompson. (*Jour. Brit. IRE*, vol. 14, pp. 400–411; September, 1954.) An examination is made of different types of clerical work and the circumstances in which an electronic computer can be used with advantage. Experience obtained with LEO, the Lyons equipment, is discussed. See also 3473 of 1954 (Pinkerton et al.).

681.142 **34**
Numerical Methods in Digital Real-Time Simulation—H. J. Gray, Jr. (*Quart. Appl. Math.*, vol. 12, pp. 133–140; July, 1954.)

681.142:519.272.1:621.376.22 **35**
A Simple Microwave Correlator—R. H. Wilcox. (Proc. I.R.E., vol. 42, pp. 1512–1515; October, 1954.) The correlator described uses the ring modulator circuit as a rapid-response multiplier; it accepts signals on coaxial cables and has a wide frequency range.

681.142:621.314.7 **36**
The Transistor Regenerative Amplifier as a Computer Element—G. B. B. Chaplin. (*Proc. IEE*, part III, vol. 101, pp. 298–307; September, 1954. Discussion, pp. 308–313. Digest, *ibid.*, part II, vol. 101, pp. 572–573; October, 1954.) The transistor is considered as a regenerative amplifier; practical circuits are of two types, those with positive and those with negative output pulse. Applications in the following computer circuits are described: (a) single-ended electrical delay-line store; (b) shift register; (c) circuits performing logical operations.

681.142:621.314.7:621.318.5 **37**
A Versatile Transistor Circuit—E. H. Cooke-Yarborough. (*Proc. IEE*, part III, vol. 101, pp. 281–287; September, 1954. Discussion, pp. 308–313. Digest, *ibid.*, part II, vol. 101, pp. 567–568; October, 1954.) The design is described of point-contact transistor switching circuits such that direct currents of the order of several tens of milliamperes can be handled with a voltage drop of only one or two volts. Applications of these circuits in (a) a symmetrical push-pull magnetic writing circuit, and (b) a shift register, are considered.

681.142:621.317.729 **38**
The "Mechanical Particle," an Analog Computing Machine—B. Rankin. (*Rev. Sci. Instr.*, vol. 25, pp. 675–678; July, 1954.) An arrangement is described in which a mechanism guided by remote control moves over a contour map to simulate the motion of a charged particle in a two-dimensional magnetic field.

CIRCUITS AND CIRCUIT ELEMENTS

621.3.018.75:621.387.4 **39**
A Method ensuring Channel-Width Stability and Equality in a Pulse Amplitude Analyser—H. Guillon. (*Onde élect.*, vol. 34, pp. 603–608; July, 1954.) Apparatus based on Wilkinson's work (1085 of 1951) has the following characteristics: (a) channel width variable between 0.2 and 8 v; (b) channel stability within ±0.2 per cent for a 10-hour period of operation; (c) possible number of channels, 150 or more according to the type of recorder available.

621.3.018.75:621.387.4 **40**
A Flexible Single-Channel Pulse-Amplitude Analyser—F. J. M. Farley. (*Jour. Sci. Instr.*, vol. 31, pp. 241–245; July, 1954.) The instrument described is designed for measuring the amplitude of voltage pulses of duration 0.2–1000 μs by pre-setting two voltage limits. It can also be used as a simple discriminator. The complete circuit diagram is given, including details of component values, tube types etc.

621.314.7:621.372.5 **41**
Computation Methods for Transistors and Transistor Circuits treated as Active Quadripoles—B. Heyman. [*IVA* (*Stockholm*), vol. 25, no. 6, pp. 281–299; 1954.] Matrix methods are used. Upper and lower limits for frequency of operation are found using experimentally determined values for the equivalent-network impedances. Stability is discussed.

621.314.7:621.375.4 **42**
Raising the Cut Off Frequency of Transistors—W. Herzog. (*Arch. elekt. Übertragung*, vol. 8, pp. 297–300; July, 1954.) The cut off frequency of transistor operation is raised by neutralizing the collector capacitance by means of inductance connected between collector and emitter. Calculations of the bandwidth between the 3-db points on both sides of the resonant frequency are made for grounded-base, grounded-emitter and grounded-collector arrangements.

621.316.8:621.396.822 **43**
L.F. Noise in Resistors—N. B. Montagnon. (*Wireless Eng.*, vol. 31, pp. 255–263 and 301–305; October and November, 1954.) Account of an extended investigation of the noise produced by resistors carrying ac. Exciting voltages were used having magnitudes between 10^7 and 10^8 times the noise voltage over a narrow frequency band; the filtering techniques for separating these two voltages are discussed. Measurements on various types of resistor were made at 5 kc with excitation frequencies ranging from 50 kc to 5 mc and various excitation levels. The noise varies as an inverse power of frequency up to a few megacycles per second, beyond which it is independent of frequency. The rms noise in volts per cycle bandwidth depends on a power of the applied voltage which ranges from 2.26 at 50 kc to 2.75 at 1 mc. Some composition-type resistors exhibit an increase in noise output after passing ac for long periods.

621.317.727:621.316.8 **44**
Component Design Trends—Precision Potentiometers use New Materials—F. Rockett. (*Electronics*, vol. 27, pp. 144–151; October, 1954.) Use of resistance elements made from deposited metal films, conductive plastics or lossy liquid dielectrics gives "infinite resolution." Other new design and construction techniques give increased life and reliability.

621.318.4:621.396.61 **45**
Dimensioning Solenoids for Transmitter Circuits—E. Achard. (*Ann. Radioélect.*, vol. 9, pp. 281–285; July, 1954.) Simple formulas and a graph, based on Medhurst's expression for Q (1694 of 1947), are assembled, and their use illustrated in four worked examples.

621.319.4 **46**
The Effect of Certain Contaminants on the Capacitance and Losses of Pyralene-Impregnated-Paper Capacitors—J. Coquillion. (*Rev. gén. élect.*, vol. 63, pp. 401–411; July, 1954.) Undesirable effects can be eliminated by avoiding the use of resin flux in the soldering process.

621.372 **47**
Conversion of a Brune Cycle with an Ideal Transformer into a Cycle without an Ideal Transformer—F. M. Reza. (*Jour. Math. Phys.*, vol. 33, pp. 194–198; July, 1954.) An alternative proof to that of Bott and Duffin (1108 of 1951) is given for the existence of a network configuration without an ideal transformer corresponding to any positive real function. See also *Jour. Appl. Phys.*, vol. 25, pp. 807–808; June, 1954.

621.372 **48**
On Electrical Network Determinants—N. F. Tsang. (*Jour. Math. Phys.*, vol. 33, pp. 185–193; July, 1954.) Four theorems dealing with the relation between the loop determinant and the node determinant of a network are presented, with examples of their application.

621.372 **49**
Analysis of Transmission-Line Directional Couplers—W. L. Firestone. (Proc. I.R.E., vol. 42, pp. 1529–1538; October, 1954.) "Five different types of transmission line systems are analyzed and are shown to possess directional properties at the lower radio frequencies. The conditions of mismatch on either transmission line or on both transmission lines have been taken into account, as well as lengths of coupling greater than a fractional wavelength. A new and more general scatter matrix for directional couplers which includes the condition of mismatch is developed. In addition, lumped circuit directional couplers have been developed as a consequence of the general transmission line theory." See also 987 of 1954.

621.372 **50**
The Relations between Circuit Bandwidth and Time Constant—P. Poincelot. (*Ann. Télécommun.*, vol. 9, pp. 191–192; June, 1954.) See 664 of 1954. A correct method for specifying bandwidth involves fixing *a priori* limits for a response curve and considering the relation between amplitude and phase distortion in order to determine the limits applicable under transient conditions.

621.372:681.142 **51**
Weighting Functions for Time-Varying Feedback Systems—J. A. Aseltine and R. R. Favreau. (Proc. I.R.E., vol. 42, pp. 1559–1564; October, 1954.) Technique is presented for analyzing the response of a linear time-varying system to a step-function input, using an analog computer. The method involves synthesis of the adjoint system.

621.372.015.3 **52**
Measurement and Calculation of Carrier-Frequency Transients—W. Händler and J. Peters. (*Arch. elekt. Übertragung*, vol. 8, pp. 301–304; July, 1954.) A carrier modulated by rectangular pulses is passed through a transmission system, and the output is observed oscillographically, the timebase being synchronized by the pulses. The oscillogram thus displays the envelope of outputs for different carrier phases at initiation of the pulses. It is shown mathematically that this envelope corresponds with the result obtained analytically by the reduction method [1249 of 1953 (Peters)]. See also 2246 of 1953.

621.372.029.6:538.221 **53**
Practical Applications of Ferromagnetic Resonance—K. H. Reich. (*Arch. elekt. Übertragung*, vol. 8, pp. 317–323; July, 1954.) Theory is outlined and a survey is made of known applications such as uhf attenuators, modulators, gyrators, etc. Advantages and disadvantages of devices based on this effect are compared with those of devices based on the Faraday effect. Deeper understanding of the physical processes involved is necessary for further practical development.

621.372.029.64:538.569.4 **54**
Molecular Microwave Oscillator and New Hyperfine Structure in the Microwave Spectrum of NH$_3$—Gordon, Zeiger and Townes. (*See* 100.)

621.372.412:538.565.4.029.6 **55**
Resonance Absorber for Electromagnetic Waves—E. Meyer, H. Severin and G. Umlauft. (*Z. Phys.*, vol. 138, pp. 465–477; July 22, 1954.) An absorber for centimeter wavelengths consists of resonators regularly distributed over

a metal plate. The resonators are cavities containing a few milligrams of Fe powder, and absorb energy by interaction with the magnetic component of the em field. The impedance of the absorber depends on the losses of the individual resonators and on their concentration; a system theoretically giving total absorption at $\lambda = 3.2$ cm is obtained by making the impedance 377 Ω, the characteristic impedance of free space.

621.372.5 **56**
New Null Transmission Networks—E. M. Reid. (*Electronic Eng.*, vol. 26, pp. 444–446; October, 1954.) Three frequency-selective networks are discussed: (a) a balanced *RC* lattice; (b) a *RC* variable T; (c) a mutual-inductance T. Type (a) gives the largest off-null outputs but is not easily adjustable over a range of frequencies. An application of type (c) for transformer testing is described.

621.372.5 **57**
The Parallel-T Resistance-Capacitance Network—L. G. Cowles. (PROC. I.R.E., vol. 42, p. 1547; October, 1954.) Correction to paper abstracted in 661 of 1953.

621.372.5 **58**
The Transfer Function of Networks without Mutual Reactance—A. Fialkow and I. Gerst. (*Quart. Appl. Math.*, vol. 12, pp. 117–131; July, 1954.) Extension of analysis presented previously (3369 of 1952). The theory is applicable generally to two-terminal-pair networks. Synthesis procedure is illustrated by examples.

621.372.5 **59**
An Electrodynamic Perturbation Theorem, with Application to Nonreciprocal Systems—A. G. Redfield. (*Jour. Appl. Phys.*, vol. 25, pp. 1021–1024; August, 1954.) A modification of the reciprocity theorem is used to evaluate the antisymmetric part of the admittance matrix of an electrodynamic system in terms of the em fields produced by the applied voltages. The effect of system perturbations on the admittance matrix is determined. The method is applicable to dc and microwave gyrators as well as to reciprocal systems, but gives solutions only to a first order of approximation.

621.372.5 **60**
The Voltage Ratio and Output Impedance of a Ladder Network composed of *n* Similar Elements—T. S. Fox and K. R. Sturley. (*Electronic Eng.*, vol. 26, pp. 447–448; October, 1954.) Simple expressions are derived, using Thévenin's theorem.

621.372.5 **61**
The Complete Specification of a Network by a Single Parameter—M. S. Corrington, T. Murakami and R. W. Sonnenfeldt. (*RCA Rev.*, vol. 15, pp. 389–444; September, 1954.) "If the transfer function of a linear passive network is defined as the output response divided by the input driving force, it can be written in either polar or Cartesian form, $T(\omega)e^{i\theta\omega} = P(\omega) + iQ(\omega)$, where $T(\omega)$ is the amplitude response, $\theta(\omega)$ is the phase characteristic, $P(\omega)$ is the in-phase component, and $Q(\omega)$ is the quadrature component. The transient response to a unit-step function $A(t)$, can be determined within a constant from either $P(\omega)$ or $Q(\omega)$ alone. $P(\omega)$, $Q(\omega)$, and $A(t)$ are all related, and any one can be used to compute the other two. The derivation of these relations is valid for networks with either distributed or lumped constants, including transducers, and the question of minimum phase does not arise. A graphic method is described for computing $A(t)$ from either $P(\omega)$ or $Q(\omega)$ and universal curves are included. Equipment is described which sweeps $P(\omega)$, $Q(\omega)$, or a polar plot of $T(\omega)$ and $\theta(\omega)$ directly. An intensity frequency marker circuit is included which produces multiple, harmonically related dots on the sweep response. It is also possible to sweep the departure from phase linearity. By a heterodyne process the sweep can be used on low-pass or bandpass systems."

621.372.5.012 **62**
A New Transducer Diagram—R. N. Bracewell. (PROC. I.R.E., vol. 42, pp. 1519–1521; October, 1954.) A diagram is presented in which a loss-free quadripole is completely represented by two straight lines and a point. The method is based on projective geometry and gives a visual as well as a numerical presentation of the impedance transformation effected by the network.

621.372.54 **63**
The Correspondence between Ladder Filters connected between a [finite] Resistance and Zero or Infinite Impedance, and Ladder Filters connected between Two Resistances—J. E. Colin. (*Câbles & Trans.*, vol. 8, pp. 205–218; July, 1954.) The response curve of a quadripole, defined in terms of image parameters, and inserted between two finite resistances, is determined by separating the actual insertion loss into components. The analysis is developed for the case of one of the resistances becoming infinite or zero. Alternative analysis is given for the quadripole defined in terms of its component impedances. Relations are derived for transforming a ladder filter connected between two resistances to a network giving the same attenuation/frequency characteristic when the source impedance is infinite or zero.

621.372.54 **64**
Antimetrical Lattice Filters—J. Oswald. (*Câbles & Trans.*, vol. 8, pp. 225–253; July, 1954.) Detailed treatment by image-parameter theory illustrates the complete correspondence between this class of filter and the conventional symmetrical type. Practical examples are given and design formulas for low-pass, high-pass and band-pass networks are tabulated. See also 2597 of 1953.

621.372.55 **65**
Delay-Line Equalizer—P. F. Gloess and H. Martin. (*Onde élect.*, vol. 34, pp. 584–587; July, 1954.) Experimental equipment designed for low-definition television can be used either in conjunction with test signals or on lines in service. Manual adjustments are made according to the position of the pulse on the oscillograph screen. A total delay of 2 μs is provided in steps of 0.1 μs, and the cut-off frequency is 4 mc.

621.372.6:621.375.232 **66**
Some Properties of Linear Networks with Three Pairs of Terminals and their Applications in realizing Negative Impedances and Negative-Feedback Amplifiers—F. Job. (*Câbles & Trans.*, vol. 8, pp. 219–224; July, 1954). Analysis of six-terminal networks based on a generalization of Thévenin's theorem gives a general method of circuit synthesis in which the prescribed impedances may have a positive or negative real part which is independent of the gain and internal impedance of the active element. A method of amplifier design on this principle is illustrated in which input and output impedances are independent of the terminations at the opposite ends.

621.373 **67**
Theory of 'Pulling-In' by a Small-Amplitude External Force—R. V. Khokhlov. [*Compt. Rend. Acad. Sci.* (*URSS*), vol. 97, pp. 411–414; July 21, 1954.] A method is developed for calculating the effect of small periodic external forces on an oscillating system. The method is illustrated by considering the effect of a small sinusoidal voltage of frequency p on a tube oscillator with a natural frequency ω_0, the difference between the frequencies being small.

621.373.42:621.376.3 **68**
Nonlinear Study of Frequency-Modulated Oscillator—J. Gross. (*Jour. Frank. Inst.*, vol. 257, pp. 481–490; June, 1954.) Analysis is presented to show how the nonlinear damping of the tube limits the growth of oscillations in the case of parametric excitation, thus permitting the establishment of a stationary oscillation.

621.373.421 **69**
Generalized Equations for *RC* Phase-Shift Oscillators—S. Sherr. (PROC. I.R.E., vol. 42, p. 1568; October, 1954.) Correction to paper abstracted in 2890 of 1954.

621.373.43 **70**
The Design of a Simple [pulse] Modulator of Moderate Cost—C. Azéma. (*Onde élect.*, vol. 34, pp. 609–613; July, 1954.) A low-power (7000 v, 6 amp peak) pulse generator for laboratory work designed to deliver 0.8–1-μs or 2.2-μs pulses at varying repetition frequencies when the load impedance may vary between 900 and 1700 Ω is described. Since the power required is low, a Type-*PL 21* thyratron, with a delay line in the anode circuit, is used to drive the Type-*QQE06/40* double-tetrode modulator stage.

621.373.43 **71**
A Low-Frequency Pulse Generator with Independent Control of Pulse Shape and Pulse Frequency—W. Seefeldner (*Z. angew. Phys.*, vol. 6, pp. 282–283; June, 1954.) A modified multivibrator circuit is described in which the pulse repetition frequency is controlled by a variable resistance in the control-grid circuit of a heptode and the pulse duration by the voltage on a second control grid, the screen voltage being stabilized. The circuit shown can be used with the "photoformer" described by Sunstein (*Electronics*, vol. 22, pp. 100–103; February, 1949) to generate pulses of any shape with repetition frequency variable between 0.5 and 2,800 pulses/second and pulse duration 140 ms–350 μs.

621.375.13:621.3.016.35 **72**
Multiloop Feedback Amplifiers—O. P. D. Cutteridge. (*Wireless Eng.*, vol. 31, pp. 293–294; November, 1954.) A stability criterion is derived which involves only one Nyquist plot.

621.375.132 **73**
Rational Negative-Feedback and Equalizer Circuits or Servomechanisms with Prescribed Characteristics—W. Bader. (*Arch. elekt. Übertragung*, vol. 8, pp. 285–296; July, 1954. Correction, *ibid.*, vol. 8, p. 425; September, 1954.) The basic feedback-amplifier circuit is examined with the object of determining the design of the transformation and feedback networks so as to obtain a given over-all frequency response for a given response of the amplifier alone. Servomechanisms and equalizers are treated as particular cases.

621.375.221 **74**
Wide-Band Amplifiers for Bandwidths up to 200 Mc/s—L. M. Hellerstedt. (*Chalmers Tek. Högsk. Handl.*, no. 137, 36 pp.; 1954.) An account is given of theoretical and experimental investigations of amplifiers of the type using low-pass filters as interstage couplings. These are superior to distributed amplifiers up to a certain frequency, the value of which is about 130 mc when Type-*6A K5* tubes are used and 200 mc with Type-*404A* tubes. A practical limit for the number of reactances in the coupling circuit is about five; further increase would call for too narrow tolerances on the components and would greatly increase alignment difficulties. Theoretical computations of the coupling circuits could not be made accurately because of frequency variations of the components. A high-accuracy frequency-sweep generator is essential for the experimental investigations.

621.375.223 **75**
The Transfer Function as a Tool in the Analysis of a Resistance-Capacitance Coupled Voltage Amplifier—D. L. Ming and R. W.

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irregularities."

523.16:621.396.822.029.62 **104**
Radio Emission from the Andromeda Nebula—J. E. Baldwin. [*Nature* (*London*), vol. 174, pp. 320–321; August 14, 1954.] Observations have been made at a wavelength of 3.7 m with interferometers of different resolving powers to determine the distribution of radio brightness across the nebula M31. The results suggest the existence of a hitherto unexpected population of radio sources; a similar population in our own galaxy might also account for a large part

don), vol. 174, pp. 334–337; August 21, 1954.] Brief report of a symposium held at Edinburgh in July, 1954, at which a survey of the existing state of knowledge about the ionosphere was given by Appleton. Meteor-trail-echo and radio-star-scintillation studies were also discussed.

551.510.534 **112**
Ozone Layer and Air Movements in the Stratosphere—H. K. Paetzold. (*Naturwiss.*, vol. 41, pp. 318–322; July, 1954.)

551.510.554:523.38 **113**
On New Investigations of the Ozone Layer

to compute ion densities for several missiles fired at the White Sands Proving Ground, New Mexico. Results gave density maximums of 0.747×10^{11} for the D layer at 38 miles, 1.69×10^{11} for the E layer at 56 miles, and 11.4×10^{11} for the F_2 layer at 201 miles (all densities in ions per cubic meter)."

551.510.535 **119**
Ionospheric Wind Systems and Electron Concentrations of the F Layer—D. G. Yerg. (*Jour. Met.*, vol. 8, pp. 244–250; August, 1951.) Theory based on viscous stresses in the ionosphere leads to a simple meridional circulation

Thorpe. (*Jour. Appl. Phys.*, vol. 25, pp. 934–937; August, 1954.)

621.375.23.029.4 76

Fifty-Watt Amplifier for High-Quality Audio—A. B. Bereskin. (*Electronics*, vol. 27, pp. 160–164; October, 1954.) See 2611 of 1954.

621.376.23 77

A Hyperbolic Detector—D. Ya. Svet. [*Compt. Rend. Acad. Sci.* (*URSS*), vol. 97, pp. 247–249; July 11, 1954. In Russian.] The detector considered comprises a double triode the

lic Films—F. J. Blatt. (*Phys. Rev.*, vol. 95, pp. 13–15; July 1, 1954.) Theory presented by Sondheimer (331 of 1951) is extended to cover cases involving temperature gradients.

537.311.33 85

Electrons in Lattice Fields—H. Fröhlich. (*Advances Phys.*, vol. 3, pp. 325–361; July, 1954.) A study of the motion of a free electron in the conduction band of an ionic crystal, taking account of the lattice vibrations.

537.525 86

rived within ±1 per cent of the mean transit time; the most probable transit time could be ascertained within ±0.25 per cent. The apparatus can be used as a velocity spectrograph and as a chronograph for measuring the time of rise of very steep surges.

537.533.8 91

Theory of Secondary Electron Cascade in Metals—P. A. Wolff. (*Phys. Rev.*, vol. 95, pp. 56–66; July 1, 1954.) A study is made of the diffusion, energy loss and multiplication of sec-

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which explains observed longitudinal differences in the F_2-layer electron concentration.

551.510.535:523.745 120

The Solar Control of the E and F_1 Layers at High Latitudes—B. Chatterjee. (*Jour. Geophys. Res.*, vol. 59, p. 435; September, 1954.) Comment on 406 of 1953 (Scott) and 3211 of 1954 (Saha).

551.510.535:621.396.11 121

Experiments on Interaction of Radio Waves in the Ionosphere—Boella. (*See* 245)

551.594.221 122

A Comparison of the Rates of Change of Current in the Step and Return Processes of Lightning Flashes—D. B. Hodges. (*Proc. Phys. Soc.*, vol. 67, pp. 582–584; July 1, 1954.)

551.594.5 123

A Statistical Analysis of Low-Latitude Aurorae—A. B. Meinel, B. J. Negaard and J. W. Chamberlain. (*Jour. Geophys. Res.*, vol. 59, pp. 407–413; September, 1954.)

551.594.5:550.384 124

Time Sequences and Spatial Relations in Auroral Activity during Magnetic Bays at College, Alaska—J. P. Heppner. (*Jour. Geophys. Res.*, vol. 59, pp. 329–338; September, 1954.)

551.594.5:621.396.96 125

Radio Reflections from Aurorae—K. Bullough and T. R. Kaiser. (*Jour. Atmos. Terr. Phys.*, vol. 5, pp. 189–200; September, 1954.) Analysis of auroral echoes observed at Jodrell Bank in May and October, 1953 indicates: (a) echoes are due to direct, nonspecular reflection from an auroral arc extending more than 1,000 km along a parallel of geomagnetic latitude; (b) reflection occurs in a region of limited vertical extent at a height of about 125 km; (c) observed movements of intense reflecting centers represent the motion of an ionizing agent rather than a mass movement of ionized gas.

551.594.51 126

Theory of the Aurora Based on Magnetic Self-Focusing of Solar Ion Streams—W. H. Bennett and E. O. Hulburt. (*Phys. Rev.*, vol. 95, pp. 315–319; July 15, 1954.)

551.594 127

Thunderstorm Electricity [Book Review]—H. R. Byers (Ed.). Publishers: University of Chicago Press, Chicago; Cambridge University Press, London; 1953, 344 pp. A collection of papers dealing with various aspects of the subject, most of them revised versions of papers presented at the conference held in Chicago in April, 1950.

LOCATION AND AIDS TO NAVIGATION

621.396.65+621.396.96]:621.396.677.3 128

The Application of [u.h.f.] Radio Beams to Radar, Multiplex and Television Techniques—Aubert (*See 30*).

621.396.93 129

Derivation of a Practical Approximation Formula for the "Inherent" Error in a 6-Mast Adcock Array—G. Ziehm. (*Telefunken Ztg.*, vol. 27, pp. 97–103; July, 1954.) The "inherent" error is the error due to the finite number of antennas in the array. For angles of incidence $0<\alpha_E<30$ degrees, the maximum error occurs at $\alpha_E=15$ degrees and is given approximately by 60 degrees. $J_6(K)/J_1(K)$ when $J_6(K)/J_1(K) \leqq 0.2$, where $K=b\pi/\lambda$ and b = distance between opposite masts. A graph shows the maximum error for $b=12$ m and $b=8$ m, at frequencies between 10 and 25 mc. With a 12-m base, but not with an 8-m base, calculation shows that sense determination becomes impossible at a frequency of about 19 mc; this was verified experimentally.

621.396.933.23 130

A New French Blind-Landing System—Guillaume. [*Électronique* (*Paris*), pp. 14–18; July/August, 1954.] A description of Type-*A.S.V.23* equipment. A single airfield transmitter is provided with six channels spaced 2.5 mc apart in the range 1.1735–1.186 kmc. Four of these are used to transmit pulses at frequencies of 20 and 24 kc for course indication, and 30 and 34 kc for height indication; 2-μs transponder pulses for distance measurement occupy a fifth channel. The transmitter is connected in turn to appropriate antennas by means of a commutator. The glide path is defined by the axes along which pulse amplitudes are equal. Aircraft equipment comprises a six-channel receiver with a crossed-needle course-height indicator, an interrogator with cro for distance measurement, and a single common antenna.

621.396.96 131

A Method of making a Radar Self-Calibrating—E. A. Wolff. (PROC. I.R.E., vol. 42, pp. 1521–1526; October, 1954.) A fraction of the transmitter pulse power is diverted into a microwave transmission line short-circuited at both ends. Each time the pulse is reflected back to the input end, a fraction of the power is tapped off and fed to the receiver; the attenuation/delay curve of the successive reflected pulses gives the calibration. Constructional details and experimental results are given.

MATERIALS AND SUBSIDIARY TECHNIQUES

533.5 132

A Differential Leak Detector for Evacuated Vessels—D. A. Lundberg. (*Electronic Eng.*, vol. 26, pp. 436–440; October, 1954.) The apparatus described uses two cold-cathode ionization gauges in a bridge circuit, the balance being disturbed when a jet of calor gas is passed over the leak. Operating instructions are given.

535.215:546.23 133

Rectifying Action and Photoelectromotive Force of Selenium Photocells and the Nonadditivity of their Photoconductivity—Z. A. Gol'dman. [*Compt. Rend. Acad. Sci.* (*URSS*), vol. 97, pp. 415–416. July 21, 1954. In Russian.] The nonadditive effect of illumination by light of wavelengths $\lambda<650\times10^{-9}$m and $\lambda>670\times10^{-9}$m was observed by determining experimentally the voltage/current characteristics of the rectifier in darkness and under illumination. The results are presented graphically.

535.37 134

Luminescence Today—J. Ewles. (*Sci. Progr.*, vol. 42, pp. 449–455; July, 1954.) A short general survey of progress since 1938. The emergence is discerned of general empirical principles for prescribing the composition and crystal structure of a phosphor to have good efficiency and a desired spectral emission. The effect of addition of a second activator is discussed. Infrared luminescence may be an important future development. Electroluminescence is briefly mentioned.

535.371 135

Effect of Internal Field of Phosphor Lattice on Electron Levels of Activators—K. V. Shalimova. [*Compt. Rend. Acad. Sci.* (*URSS*), vol. 97, pp. 437–440; In Russian.] Tables are presented and discussed of the wavelengths of absorption maxima of activators both in the free state and in the phosphor lattice, and of the corresponding electron states. Activators in the form of ions and atoms in ionic, atomic and layer-type lattices are included.

537.222.2 136

Behaviour of the Electron Constituent of an Insulator in an Electric Field—H. Volz. (*Z. Phys.*, vol. 138, pp. 330–335; July 22, 1954.)

537.226.33:546.431.824–31 137

Dielectric Hysteresis in $BaTiO_3$ Single Crystals—N. S. Novosil'tsev and A. L. Khodakov. (*Zh. Eksp. Teor. Fiz.*, vol. 27, pp. 94–96; July, 1954.) An experimental investigation is reported. Results, which are presented graphically, show the dependence of the dielectric constant of one of the specimens on the temperature between 20 degrees and 150 degrees C., (a) at 50 cps and in a field of strength 9.1 kv/cm, (b) at 50 cps, 22 kv/cm and (c) at 10^6 cps, 0.5 kv/cm. The dielectric-constant/field-strength characteristic of another specimen is shown for field strengths up to 6 kv/cm. Oscillograms of dielectric hysteresis at 50 cps and 9 kv/cm are shown for the one specimen and at 50 cps 22 kv/cm for the other.

537.311.3:535.215 138

A. C. Hall and Magnetostrictive Effects in Photoconducting Alkali Halides—J. R. Macdonald and J. E. Robinson. (*Phys. Rev.*, vol. 95, pp. 44–50; July 1, 1954.) Results are reported of measurements at room temperature on KBr single crystals with a low concentration of *F* centers, using a strong steady illumination in the *F* absorption band and an ac technique eliminating space-charge polarization effects.

537.311.33 139

Lifetime Measurements for Minority Carriers in Semiconductors—P. Aigrain. (*Ann. Radioélect.*, vol. 9, pp. 219–226; July, 1954.) A critical survey of known methods, from the manufacturers' point of view; a method based on the photomagnetoelectric effect is preferred.

537.311.33:535.215 140

Surface States of Cadmium Sulfide—S. H. Liebson. (*Jour. Electrochem. Soc.*, vol. 101, pp. 359–362; July, 1954.) "Photoconductive and phosphorescent properties of cadmium sulfide are modified by absorbed molecules. Change in spectral response of photoconductivity and the phosphorescence efficiency when crystals are exposed to vapors suggest that surface states due to absorbed molecules aid in recombination. Photovoltaic behavior of rectifying contacts lends credence to the hypothesis that infrared releases otherwise immobile holes."

537.311.33:535.215 141

Photoelectric Saturation Currents in Semiconductors—F. Stöckmann. (*Z. Phys.*, vol. 138, pp. 404–410; July 22, 1954.) Two mechanisms of conduction are described. In Ge the current is carried by both electrons and holes, hence saturation currents are possible without producing noticeable space charges. In CdS saturation results from current limitation by space charges.

537.311.33:537.323 142

The Effects of Heat Flow on Thermoelectric Power in Semiconductors—J. E. Parrott. (*Proc. Phys. Soc.*, vol. 67, pp. 587–588; July 1, 1954.) A discussion based on a more physical approach than that of Frederikse (1093 of 1954).

537.311.33:538.63 143

Change of Resistance of InSb due to Transverse Magnetic Field—H. Weiss and H. Welker. (*Z. Phys.*, vol. 138, pp. 322–329; July 22, 1954.) The dependence of the resistance change on the type of conduction, the mobility of charge carriers and the geometry of the specimen is calculated and compared with experimental results. The geometry is of importance for mobilities greater than 10,000 cm per v/cm. The resistance of a Corbino disk increased 24.6-fold on applying a transverse field of 10,000 gauss. Results are presented graphically and are also tabulated.

537.311.33:546.28 144

Conductivity of Silicon—W. Heywang, M. Zerbst and F. Bischoff. (*Naturwiss.*, vol. 41, pp. 301–302; July, 1954.) Measurements were made on high-purity n-type specimens with high resistivity and high carrier mobility. over a wide temperature range. Anomalies observed in the temperature characteristic of a polycrystalline specimen indicate the presence of barrier layers at grain boundaries. An electron-mobility value of 1200 ± 100 cm per v/cm was determined from measurements on n-type single crystals of lower resistivity. Measurements on p-type specimens yielded the same linear temperature characteristic for the intrinsic conductivity. The value of 1.12 ev was found for the energy gap.

537.311.33:546.28 145

Use of Silicon p-n Junctions for Converting Solar Energy to Electrical Energy—R. L. Cummerow. (*Phys. Rev.*, vol. 95, pp. 561–562; July 15, 1954.) On adapting formulas obtained previously for the efficiency of Si p-n junctions in converting monochromatic radiation (155 below), the efficiency of conversion over the whole solar spectrum is found to be less by a factor of two. The value of 17 per cent obtained may be reconcilable with Chapin's results (unpublished) when surface reflection losses and differences in the Si specimens are taken into account.

537.311.33:546.281.26 146

The Electrical Conductivity of Silicon Carbide—M. O. Williams. (*A.T.E.J.*, vol. 10, pp. 144–158; July, 1954.) The unique molecular structure of SiC is discussed. The apparent deviation of the resistance from Ohm's law is ascribed to effects due to Mott or Schottky potential barriers at the contact surface. Dynamic characteristics are shown for small atmite disks with applied ac and pulsed wave forms. An equivalent circuit based on these oscillograms seems consistent with the existence of both types of barrier in the material.

537.311.33:546.289 147

Theory of the Galvanomagnetic Effects in Germanium—B. Abeles and S. Meiboom. (*Phys. Rev.*, vol. 95, pp. 31–37; July 1, 1954.) An attempt is made to explain observed magnetoresistance effects on the basis of a simple anisotropic model in which the energy surfaces in momentum space exhibit a number of extrema. Equations are derived for the galvanomagnetic coefficients in any crystallographic direction, and an expression is given for the ratio between the mobilities found from Hall-effect and from conductivity considerations. The calculated values of magnetoresistance are in good agreement with those observed by Pearson and Suhl (166 of 1952) for n-type but not for p-type Ge. See also 2425 of 1954 (Meiboom and Abeles).

537.311.33:546.289 148

Vacancies and Interstitials in Heat Treated Germanium—S. Mayburg. (*Phys. Rev.*, vol. 95, pp. 38–43; July 1, 1954.) The thermal production of acceptors was studied by annealing experiments. A critical point is found at 516 degrees C.; annealing curves for temperatures above this point suggest a bimolecular recombination process, implying that the heat treatment produces comparable numbers of vacancies and interstitials; curves for temperatures below this point suggest that most interstitials are trapped near dislocations before they can recombine with vacancies.

537.311.33:546.289 149

Oxygen and the Surface Energy-Level Structure on Germanium—E. N. Clarke. (*Phys. Rev.*, vol. 95, pp. 284–285; July 1, 1954.) A brief account of experiments providing further evidence that oxygen produces surface acceptor levels (168 of 1954).

537.311.33:546.289 150

Spin-Orbit Interaction and the Effective Masses of Holes in Germanium—G. Dresselhaus, A. F. Kip and C. Kittel. (*Phys. Rev.*, vol. 95, pp. 568–569; July 15, 1954.)

537.311.33:546.289 151

Anisotropy of Cyclotron Resonance of Holes in Germanium—R. N. Dexter, H. J. Zeiger and B. Lax. (*Phys. Rev.*, vol. 95, pp. 557–558; July 15, 1954.) Measurements were made on p- and n-type Ge specimens at the temperature of liquid He and frequencies of 8.9 and 23 kmc, using infrared excitation of carriers. Resonances corresponding to two different hole masses were observed; the two resonances depend to different degrees on the direction of the applied magnetic field. An interpretation in terms of the valence band structure is outlined.

537.311.33:546.289 152

Infrared Absorption Spectrum of Germanium—L. H. Hall, J. Bardeen and F. J. Blatt. (*Phys. Rev.*, vol. 95, pp. 559–560; July 15, 1954.) Calculations of the absorption by valence electrons in Ge for direct and indirect transitions to the conduction band are based on a band structure partly deduced from cyclotron-resonance experiments (*see* e.g. 151 above). The results are in qualitative agreement with observations by Brattain and Briggs on thin films of Ge (*Phys. Rev.*, vol. 75, pp. 1705–1710; 1949).

537.311.33:546.289 153

The Influence of Cathodic Sputtering in High Vacuum on the Rectifier Effect in Germanium—H. Baldus. (*Z. angew. Phys.*, vol. 6, pp. 241–246; June, 1954.) Single-crystal and polycrystalline specimens of n-type Ge with specific resistance between 1.3 and 9.9Ω cm were subjected to a cathodic sputtering process carried out at a pressure of $<5\times 10^{-6}$ Torr with applied field above 2×10^{6} v/cm, the crystal acting as cathode. The process removed a surface layer of thickness 10^{-5} cm and completely destroyed the rectifying properties of the crystal. These were restored by chemical or electrolytic etching, by annealing at 150 degrees C. in an oxygen atmosphere, or by prolonged exposure to air. Voltage/current characteristics of the crystals before and after the different treatments are shown and results are discussed.

537.311.33:546.289 154

Power Efficiency for the Photovoltaic Effect in a Germanium Grown Junction—R. P. Ruth and J. W. Moyer. (*Phys. Rev.*, vol. 95, pp. 562–564; July 15, 1954.) An experimental investigation is reported of the variation with incident intensity of the efficiency with which the junction converts incident radiation into electrical power. A disk-shaped specimen of thickness <1 mm was used, with the junction parallel to the faces and about 0.1 mm from the n face; the resistivity of the n material was $>20\Omega$ cm, that of the p material $<1\Omega$ cm. Observations were made with continuous-spectrum and with monochromatic illumination. Results are shown graphically.

537.311.33:546.289:535.215.3 155

Photovoltaic Effect in p-n Junctions—R. L. Cummerow. (*Phys. Rev.*, vol. 95, pp. 16–21; July 1, 1954.) "The relations between the incoming radiant energy and the outgoing electrical energy are developed in terms of the experimentally measurable constants of the semiconducting material. These results are applied to germanium by making use of constants found in the literature. The high efficiencies calculated for power conversion are strong indication that the p-n junction may be a practical device for the direct utilization of solar energy."

537.311.33:546.289:544.65 156

Fluorometric Detection and Estimation of Germanium—N. A. Raju and G. G. Rao. [*Nature* (*London*), vol. 174, p. 400; August 28, 1954.] Traces of Ge have been found to give an intense greenish-yellow fluorescence with a solution of resacetophenone in concentrated sulphuric acid or syrupy phosphoric acid under filtered ultraviolet light. Test procedure is outlined.

537.311.33:546.3-1-289-28 157

Some Properties of Germanium-Silicon Alloys—E. R. Johnson and S. M. Christian. (*Phys. Rev.*, vol. 95, pp. 560–561; July 15, 1954.) Data on composition, density, lattice constant and width of energy gap are tabulated for a series of Ge-Si alloys prepared by a process of homogenization at high temperature.

537.311.33+535.37]:546.47-31 158

Effect of Hydrogen on the Conductivity and Luminescence of Zinc Oxide Crystals—E. Mollwo. (*Z. Phys.*, vol. 138, pp. 478–488; July 22, 1954.) Results of an experimental investigation, which is described, show that the electrical conductivity of ZnO crystals increases on heating the specimen in hydrogen and that the green luminescence decreases when the hydrogen pressure is increased at room temperature. Both effects are reversible. The results are presented graphically.

546.47-31:537.311.33 159

Effect of Adsorbed Oxygen on the Electrical Conductivity of Zinc Oxide Crystals—G. Heiland. (*Z. Phys.*, vol. 138, pp. 459–464; July 22, 1954.) Report of measurements on synthetic single crystals of ZnO in the temperature range from -183 degrees to 300 degrees C. The decrease in conductivity with increased adsorption may be due to the higher donor concentration in the thin surface layer compared with the concentration inside the crystal.

537.311.33:546.47-31:535.3 160

Dispersion, Absorption and Thermoluminescence of Zinc Oxide Crystals—E. Mollwo. (*Z. angew. Phys.*, vol. 6, pp. 257–260; June, 1954.) A report of measurements made of the optical properties of synthetic single crystals of ZnO.

537.311.33:546.623.86 161

Electrical Properties of Semiconducting AlSb—R. K. Willardson, A. C. Beer and A. E. Middleton. (*Jour. Electrochem. Soc.*, vol. 101, pp. 354–358; July, 1954.) Results are reported of experimental investigations of the resistivity, thermoelectric power and Hall voltage over the temperature range 80 degrees to 1200 degrees K. The energy band separation is 1.5–1.6 ev; electron and hole mobilities are approximately equal and are over 100 cm per volt/cm. Rectification characteristics are presented for both p-type and n-type specimens. The semiconducting characteristics are similar to those of Si, the melting point is 370 degrees C. lower and the material is considerably cheaper.

537.311.33:546.681.86 162

Some Properties of p-Type Gallium Antimonide between 15 degrees K and 925 degrees K—H. N. Leifer and W. C. Dunlap, Jr. (*Phys. Rev.*, vol. 95, pp. 51–56; July 1, 1954.) The energy-level scheme, mobilities and charge-carrier masses are determined from measurements of Hall effect and resistivity. The ratio of electron to hole mobility is about 5, and the intrinsic energy gap is 0.8 ev. Two acceptor levels must be assumed in order to fit the Hall-effect data.

537.311.33:[546.817.221+546.817.231
+546.817.241 163

The Molar Heats of Lead Sulphide, Selenide and Telluride in the Temperature Range 20 degrees K to 260 degrees K—D. H. Parkinson and J. E. Quarrington. (*Proc. Phys. Soc.*, vol. 67, pp. 569–579; July 1, 1954.)

537.311.33:549.212 164

Electrical Conductivities of Natural Graphite Crystals—W. Primak and L. H. Fuchs.

(*Phys. Rev.*, vol. 95, pp. 22–30; July 1, 1954.) Measurements of potential distributions on the surfaces of crystals carrying current indicate that the ratio between σ_a, the conductivity in the basal plane, and σ_c, perpendicular to the basal plane, is of the order of hundreds at room temperature. Direct measurements gave values of $\sigma_a = (2.6 \pm 0.2)10^4 \Omega^{-1}$ cm^{-1} and σ_c between 150 and 230Ω^{-1} cm^{-1} ± 20 per cent.

537.311.33:549.324.41 **165**

Properties of Point Contacts on Cobaltite—G. G. E. Low. (*Proc. Phys. Soc.*, vol. 67, pp. 589–590; July 1, 1954.) Measurements are briefly reported which support the previously obtained result that point contacts on single crystals of CoAsS give symmetrical *I/v* characteristics, with peak voltages of 5–15 v in both directions of current flow. Pulse measurements confirm the view that the shape of the dc characteristic results from heat dissipation and consequent reduction of spreading resistance.

537.311.33:[621.314.63+621.314.7](083.7) **166**

I.R.E. Standards on Electron Devices: Definitions of Semiconductor Terms, 1954—(PROC. I.R.E., vol. 42, pp. 1505–1508; October, 1954.) Standard 54 I.R.E. 7.S2.

537.311.33:621.314.632 **167**

The Theory of Rectification and Injection at a Metal-Semiconductor Contact—J. B. Gunn. (*Proc. Phys. Soc.*, vol. 67, pp. 575–581; July 1, 1954.) "The diffusion equations for holes and electrons are solved for the region of a semiconductor near a planar contact with a metal, using assumptions appropriate to transistor-quality silicon and germanium. The hole and electron currents are calculated separately, and from them are obtained the rectification equation and injection ratio of the contact."

537.311.33:669.783 **168**

Germanium Technology—J. M. Mercier. (*Onde élect.*, vol. 34, pp. 559–572; July, 1954.) A survey of the processes involved in modern methods of extraction, purification, reduction by crystallization or zone melting and the production of single crystals. 31 references.

537.525.8:539.231 **169**

Cathode Sputtering in Glow Discharges—G. Ecker and K. G. Emeléus. (*Proc. Phys. Soc.*, vol. 67, pp. 546–552; July 1, 1954.) Discrepancies between experimental results and previously published theories are discussed, and a new formulation is presented which takes account of initial scattering, lateral boundaries, distribution of current over the cathode, high emission velocities, and the difference in mass between metal atoms and gas molecules.

538.221 **170**

Anhysteretic Magnetization of Alcomax III—J. E. Gould and M. McCaig. (*Proc. Phys. Soc.*, vol. 67, pp. 584–586; July 1, 1954.) Curves obtained by measurements in the preferred and in the transverse direction are shown. The results indicate the practicability of magnetizing alcomax by a combination of direct and alternating fields.

538.221 **171**

Magnetically Oriented Structure in Permanent Magnets—K. J. Kronenberg. (*Z. Metallkde*, vol. 45, pp. 440–447; July, 1954.) Electron-microscope investigations of alnico (51 per cent Fe, 24 per cent Co, 14 per cent Ni, 8 per cent Al, 3 percent Cu) cooled from 950 degrees to 750 degrees in a magnetic field are reported. The resulting structure for material annealed at 800 degrees is similar to that observed by Heidenreich and Nesbitt (2530 and 2531 of 1952). Examination of unannealed material revealed an oriented fine structure whose form and high dispersion confirm previous hypotheses of a magnetically significant structural anisotropy.

538.221 **172**

Factors determining the Permanent Magnet Properties of Single Crystals of Fe_2NiAl—E. A. Nesbitt, H. J. Williams and R. M. Bozorth. (*Jour. Appl. Phys.*, vol. 25, pp. 1014–1020; August, 1954.) The effect of the plate-like structure revealed by electron micrographs was investigated analytically and experimentally, using three models consisting respectively of (a) a single wire, (b) two mutually perpendicular wires, and (c) three mutually perpendicular wires embedded in lucite. Measurements were made of the torque on these models as a function of their orientation relative to an applied magnetic field. The results indicate that shape anisotropy of the precipitated particles is a major factor in determining the coercive force.

538.221 **173**

The Magnetic Properties of Alloys of Cobalt and Nickel with Palladium and Platinum—E. P. Wohlfarth. (*Phil. Mag.*, vol. 45, pp. 647–649; June, 1954.)

538.221:[621.318.124+621.318.134 **174**

Ferromagnetism of Ferrite-Type Materials and Antiferromagnetism—K. B. Vlasov and B. Kh. Ishmukhametov. (*Zh. Eskp. Teor. Fiz.*, vol. 27, pp. 75–86; July, 1954.) A quantum-mechanics calculation is presented of the free energy and the magnetic equation of state for ferrites and antiferromagnetics.

538.221:621.318.134 **175**

Motion of Individual Domain Walls in a Nickel-Iron Ferrite—J. K. Galt. (*Bell. Sys. Tech. Jour.*, vol. 33, pp. 1023–1054; September, 1954.) Samples were cut from a Ni-Fe ferrite so as to contain only one movable ferromagnetic domain wall. The viscous damping coefficient for this wall was measured as a function of temperature; the damping increases markedly as the temperature falls down to about 77 degrees K. Existing theory is used to correlate the damping with the Landau-Lifshitz equation for the rotational motion of magnetization. The increase in the damping at low temperatures is attributed to a relaxation associated with a rearrangement of the valence electrons on the divalent and trivalent Fe ions. A tentative explanation of the losses is based on this mechanism.

538.221:621.372.413.029.64/.65 **176**

Ferromagnetic Resonance in Ferrites—P. A. Miles. [*Nature* (*London*), vol. 174, pp. 177–178; July 24, 1954.] Report of studies made on polycrystalline specimens of the ferromagnetic systems $(1\text{-}x)$ $(LiFe_5O_8)$ $x(CdFe_2O_4)$, $Li(Fe_{1-x}Al_x)_5O_8$, $Ni_{(1-x)}Zn_xFe_2O_4$ placed in resonant cavities operating at frequencies of 9.47, 23.94 and 34.4 kmc. The strength of an externally applied magnetic field necessary to induce peak resonance loss, and the resonance line width were studied as functions of frequency, specimen size and position of specimen along cavity axis.

538.614:[621.318.124+621.318.134 **177**

Susceptibility Tensor and the Faraday Effect in Ferrimagnetics—R. K. Wangsness. (*Phys. Rev.*, vol. 95, pp. 339–345; July 15, 1954.) Calculations for a ferrimagnetic with two sublattices are based on replacement of the gyromagnetic ratio for the single electron by the effective ratio for the material. The Faraday rotation changes sign as the temperature or composition of the material is varied through a point at which the magnetizations of the two sublattices are equal and opposite. The rotation for an unmagnetized antiferromagnetic is also determined, and results are generalized to cover an arbitrary number of sublattices.

539.23:535.215.1 **178**

Photoeffect in Thin Metal Films—D. J. Fourie. (*Naturwiss.*, vol. 41, pp. 328–329; July, 1954.) Continuation of work described previously (773 of 1954). Photoelectric emission from Cd, Te, Bi and Sn films on glass was investigated as a function of dc or ac flowing in the film. Results are shown graphically for a Te film with dc. The different behavior of the elements investigated is discussed in relation to their position in the periodic table.

621.315.612.6:537.52 **179**

The Impulse Breakdown Strength of Pyrex Glass—J. Vermeer. (*Physica*, vol. 20, pp. 313–326; June, 1954.)

621.315.613.1 **180**

Synthetic Mica Investigations: Part 4—Dielectric Properties of Hot-Pressed Synthetic Mica and Other Ceramics at Temperatures up to 400 degrees C—J. E. Comeforo and R. A. Hatch. (*Jour. Amer. Ceram. Soc.*, vol. 37, pp. 317–322; July 1, 1954.) Continuation of work noted in 784 of 1954. (Comeforo et al.). Measurements were made of power factor and dielectric constant of a number of ceramic insulating materials at 1 mc, and of the dc volume resistivity with a voltage of 22.5 v. The hot-pressed mica had the lowest loss factor at temperatures up to 200 degrees C. The importance of determining the dielectric properties at the temperature of expected operation is emphasized.

621.315.616 **181**

Direct-Current Transients in Polymethyl Methacrylate and in Polystyrene—P. Ehrlich. (*Jour. Appl. Phys.*, vol. 25, pp. 1056–1058; August, 1954.) Measurements are reported and the relevance of the results to ac loss factor is discussed.

621.359.3 **182**

Centripetal and Centrifugal Electromagnetophoresis—A. Kolin. (*Jour. Appl. Phys.*, vol. 25, pp. 1065–1066; August, 1954.) Report of an experimental investigation in which observations were made of the rate of migration of polystyrene spheres with diameters of the order of 100 μ suspended in NaCl solutions. Techniques eliminating convection were evolved.

621.68.01 **183**

Valveless Pump Action—G. Liebau. (*Naturwiss.*, vol. 41, p. 327; July, 1954.) A pump action is produced in a system of pipes of different diameters by applying periodic pressure pulses at a point along the wider pipe. The action results from turbulent flow.

621.885:621.3 **184**

Stress Systems in the Solderless Wrapped Connection and their Permanence—W. P. Mason and O. L. Anderson. (*Bell. Sys. Tech. Jour.*, vol. 33, pp. 1093–1110; September, 1954.)

666.22:546.244-31 **185**

Dielectric Properties of Tellurite Glasses—J. P. Poley. [*Nature* (*London*), vol. 174, p. 268; August 7, 1954.] Continuation of investigation reported by Stanworth (2834 of 1952). Measurements at frequencies up to 24 kmc indicate that the dielectric properties are frequency independent.

MATHEMATICS

512.3 **186**

A Neglected Method for Resolution of Polynomial Equations—W. C. Taylor, Jr. (*Jour. Frank. Inst.*, vol. 257, pp. 459–464; June, 1954.) Bernoulli's method is explained, with examples; for a wide variety of problems it is quicker than other methods, assuming a desk calculator is available.

512.393 **187**

Solution of Cubics and Quartics—A. C. Sim. (*Wireless Eng.*, vol. 31, pp. 294–300; November, 1954.) "A routine for the determination of the roots of cubic equations is developed specifically to meet the requirements of circuit designers. The method is based upon that used by Emde and is organized so that the solutions are developed with minimum effort. Three significant figures can be obtained using a slide-rule for the subsidiary computations. Ferrari's method for reducing a quartic equation is utilized to develop a similar routine to determine the quadratic factors. Simple checks are provided at appropriate stages in the routines, and a few numerical examples are included. A collection of cubic and quartic Laplace Transforms is appended."

512.83 188

The Distribution of Random Determinants—H. Nyquist, S. O. Rice and J. Riordan. (*Quart. Appl. Math.*, vol. 12, pp. 97–104; July, 1954.) Random determinants are considered whose elements are independent random variables having a common distribution which is symmetrical about zero and has unit variance. These determinants arise in considering the problem of solving large systems of linear equations on an automatic computer, and have a bearing on the relation between the computer precision and the order of the largest system which should be tried.

517 189

The Operational Calculus of Legendre Transforms—R. V. Churchill. (*Jour. Math. Phys.*, vol. 33, pp. 165–178; July, 1954.)

517 190

The Monte Carlo Solution of some Integral Equations—E. S. Page. (*Proc. Camb. Phil. Soc.*, vol. 50, pp. 414–425; July, 1954.) "Estimators are given for the solution by Monte Carlo methods of the Fredholm integral equation of the second kind and the variances of the estimators are compared. Two integral equations arising in sequential analysis are considered in detail; some numerical examples are given."

517.43 191

Elementary Observations on Symbolic Calculus—F. H. Raymond. (*Ann. Télécommun.*, vol. 9, pp. 194–196; July/August, 1954.) Abel's theorem is presented in a form of practical importance. A fundamental form of the superposition theorem is derived from the postulate of linearity.

512.14(083.4) 192

50–100 Binomial Tables [Book Review]—H. G. Romig. Publishers: J. Wiley, New York, N.Y. and Chapman and Hall, London, Eng. 1953, 172 pp., $4. (*Quart. Appl. Math.*, vol. 12, p. 206; July, 1954.) The value of the individual terms and the sum of the first x terms of $[P+(1-P)]^n$ are given for n in the range 50–100 in steps of 5 and P in the range 0.01–0.50 in steps of 0.01 to six decimal places, the last place being doubtful.

517 193

Complex Variable Theory and Transform Calculus [Book Review]—N. W. McLachlan. Publishers: University Press, Cambridge, Eng. 2nd ed., 1953, 388 pp., 55s. (*Proc. Phys. Soc.*, vol. 67, p. 591; July 1, 1954.) Deals with the use of Laplace transforms and the Mellin inversion theorem in solving certain types of differential equations which arise in technical problems. A wide range of applications, including electrical circuits, is discussed.

517.9 194

Numerical Solution of Differential Equations [Book Review]—W. E. Milne. Publishers: Chapman and Hall, London, Eng., 1953, 275 pp., 52s. (*Sci. Progr.*, vol. 42, p. 510; July, 1954.)

MEASUREMENTS AND TEST GEAR

621.317.3:621.314.7 195

The Measurement of the Small-Signal Characteristics of Transistors—E. H. Cooke-Yarborough, C. D. Florida and J. H. Stephen. (*Proc. IEE*, part III, vol. 101, pp. 288–293; September, 1954. Discussion, pp. 308–313. Digest, *ibid.*, part II, vol. 101, p. 569; October, 1954.) Ac bridge circuits are used, the transistor characteristics being derived from the setting of decade resistance boxes adjusted to give zero reading on a cro indicator. Emitter current values ranged from 1 μa to several milliamperes. Results can be used to determine the sensitivity and stability of transistor trigger circuits.

621.317.3:621.372.5.012 196

Experimental Procedures for Determining the Efficiency of Four-Terminal Networks—H. F. Mathis. (*Jour. Appl. Phys.*, vol. 25, pp. 982–986; August, 1954.) Various procedures are presented based on plotting circle loci in the impedance or reflection-coefficient plane.

621.317.3:621.376.2 197

The Calibration of Amplitude-Modulation Meters with a Heterodyne Signal—J. R. Macdonald. (Proc. I.R.E., vol. 42, pp. 1515–1518; October, 1954.) "Errors which may occur in the calibration of peak or average reading amplitude modulation meters with a heterodyne signal are investigated in detail. Relations between the heterodyne-amplitude ratio M and the true modulation factor m of a sinusoidally modulated wave are derived. Using these results, heterodyne calibration of modulation analyzers to read m exactly can readily be carried out."

621.317.328:621.372.413 198

The Measurement of Electromagnetic Field in Resonant Cavities by Introduction of Small Metallic Rings—A. Gilardini. (*Jour. Appl. Phys.*, vol. 25, pp. 1064–1065; August, 1954.) A variant of the method described by Maier and Slater (2265 of 1952) is discussed.

621.317.33:621.372.413 199

Measurement of Resonant-Cavity Characteristics—G. L. Hall and P. Parzen. (Proc. I.R.E., vol. 42, p. 1495; October, 1954.) Correction to paper abstracted in 799 of 1954.

621.317.332.029.64 200

A Method for the Measurement of Conductivity of Metals at Microwave Frequencies—S. K. Chatterjee, P. R. Shenoy and C. R. Bai. (*Jour. Indian Inst. Sci.*, section B, vol. 36, pp. 107–122; July, 1954.) Theory and experimental details of a method of determining the conductivity from measurements of the reflection coefficient are given. The reflection coefficient is expressed in terms of the vswr, attenuation constant, scattering coefficient of discontinuities which may be present in the waveguide system, and phase factors. Results for silver, copper and brass, at a frequency of 9.6979 kmc are in fair agreement with values obtained by Beck and Dawson (394 of 1951). The conductivity of duralumin was also determined.

621.317.335.3.029.64:535.325 201

Some Measurements on Refractive Indices of Gases in the Microwave Region—F. W. Heineken and F. Bruin. (*Physica*, vol. 20, pp. 350–360; June, 1954.) A method is described in which a measurement is made of the change in the length of a resonant cavity required to keep the cavity tuned to the ammonia absorption line at about 25 kmc on replacing a filling of nitrogen with a filling of the gas under test. Results are given for ten gases.

621.317.335.3.029.64:535.325:546.217 202

Measurement of Refractive Indices of Air, Nitrogen, Oxygen, Carbon Dioxide and Water Vapour at 3 360 Mc/s—W. Jasinski and J. A. Berry. (*Proc. IEE*, part III, vol. 101, pp. 337–343; September, 1954.) A frequency-modulation technique comparable with that of Birnbaum et al. (1426 of 1951) was used to measure the change in resonance frequency of an evacuated cavity on filling it with a gas. A cro displays (a) the cavity resonance curve and (b) pairs of pulses indicating the carrier frequency and two sideband frequencies derived from modulation of a 3.36-kmc signal by a standard signal generator. The signal-generator frequency is adjusted until the peak of the resonance curve falls in the middle of one pair of the sideband pulses; to increase the accuracy of this adjustment, horizontal markers derived from these pulses are superposed on the resonance curve. The signal-generator frequency is then accurately measured by a wavemeter, and addition to or subtraction from the carrier frequency gives the cavity resonance frequency. Estimated accuracies are within ±2 parts in 10^7 for dry CO_2-free air, nitrogen and oxygen, ±3.5 parts in 10^7 for CO_2, and ±1 part in 10^7 for water vapor. The precautions observed and the errors involved are considered in detail.

621.317.336.029.6 203

Impedance Measurement by means of a Broadband Circular-Polarization Coupler—S. B. Cohn. (Proc. I.R.E., vol. 42, pp. 1554–1558; October, 1954.) A section of circular waveguide is arranged perpendicular to a rectangular waveguide and is coupled to it by three slots in π formation in its wide side. TE_{10} waves traveling in the rectangular guide excite TE_{11} waves in the circular guide with circular polarization whose sense depends on the direction of the exciting wave. A probe rotated through one turn in the circular guide samples a field variation exactly equivalent to that in one guide wavelength of the rectangular guide. Operation over a bandwidth of about 20 per cent is possible.

621.317.34 204

Pulse Analysis of Cables and its Developments—J. Oudin. (*Onde élect.*, vol. 34, pp. 573–583; July, 1954.) A survey of the technique covering basic measurement equipment, and the special requirements for pulse tests over long distances. The improvement in signal/noise ratio required for long-distance work may be obtained by passing the received signal through an optimum filter of the Wiener type, involving pulse switching and integration. Current applications of the technique are also reviewed.

621.317.342.018.782.3:621.397.62 205

An Instrument for measuring Group Delay—H. J. de Boer, and A. van Weel. (*Philips Tech. Rev.*, vol. 15, pp. 307–316; May, 1954.) The group delay of a video signal in a television receiver is measured accurately to within 10^{-9} seconds by an arrangement constituting a sensitive phase-difference meter. The phase shift to be measured controls the frequency of an oscillatory circuit; change in the oscillation frequency is converted into a voltage variation by means of a discriminator. Results of some measurements are reported.

621.317.361:621.396.822 206

Short-Time Frequency Measurement of Narrow-Band Random Signals in the Presence of Wide-Band Noise—P. M. Schultheiss, C. A. Wogrin and F. Zweig. (*Jour. Appl. Phys.*, vol. 25, pp. 1025–1036; August, 1954.) Comparison of the performance of the autocorrelator and the frequency discriminator in regard to the accuracy attainable in measuring the center frequency of a symmetrical power spectrum within a given short time interval. When both systems are adjusted for optimum operation at a given signal/noise ratio, their performances are closely equivalent. For operation in conditions other than optimum the discriminator is preferred on account of its flat characteristic. The effect of filter adjustment is examined.

621.317.4 207

The Flux Linkage with a Search Coil produced by a Coaxial Uniformly Magnetized Prolate Spheroid—G. H. Hunt. (*Brit. Jour. Appl. Phys.*, vol. 5, pp. 260–263; July, 1954.) The expression for the flux enclosed by the search coil takes the form of a power series with coefficients which can readily be calculated from mathematical tables.

621.317.7:621.372.8 208

Bibliography of Directional Couplers—R. F. Schwartz. (*Trans. I.R.E.*, vol. MTT-2, pp. 58–63; July, 1954.) About 100 references are listed.

621.317.7:621.396.82.551.594.6 209

Measurement of Atmospheric Noise Interference to Broadcasting—Chandrashekhar Aiya. (*See* 257.)

621.317.715 210

A Note on the Use of the Ballistic Galvanometer—G. F. Tagg. (*Instrum. Practice*, vol. 8, pp. 609–610; July, 1954.) A correction factor applicable for any value of damping is given.

681.142:621.317.729 211

The "Mechanical Particle," an Analog Computing Machine—Rankin. (*See* 38.)

621.317.73 .74:621.315.212 212

The Development of a Precision Termination for 0.375-in. Polythene-Disc-Insulated Coaxial Cable—R. J. Cheetham, E. L. Mather and W. W. H. Clarke. (*Proc. IEE*, part III, vol. 101, pp. 347–349; September, 1954.) Digest of 2178 of 1954.

621.317.733:621.314.7 213

A Bridge for measuring the A.C. Parameters of Point-Contact Transistors—A. R. Boothroyd and S. K. Datta. (*Proc. IEE*, part III, vol. 101, pp. 294–297; September, 1954. Discussion, pp. 308–313. Digest, *ibid.*, part II, vol. 101, p. 570; October, 1954.) A bridge for measuring the ac parameters at 1 kc for chosen dc conditions is described, which is based on the comparison of the transistor with a practical representation of its ac equivalent-T circuit. Accuracy obtainable is within ±3 per cent.

621.317.733:621.314.7 214

A Bridge for measuring the A.C. Parameters of Junction Transistors—A. R. Boothroyd and J. Almond. (*Proc. IEE*, part III, vol. 101, pp. 314–316; September, 1954. Digest, *ibid.*, part II, vol. 101, pp. 570–571; October, 1954.) A simple arrangement for measuring the low-frequency parameters under emitter-open-circuit and collector-short-circuit conditions is described. The parameters measured are those suggested by Knight et al. (3358 of 1953). Accuracy obtainable is within ±4 per cent.

621.317.733:621.316.86:537.312.6 215

A Simple Direct-Reading Thermistor Bridge—D. C. Cooper. (*Electronic Eng.*, vol. 26, pp. 448–451; October, 1954.) The instrument described is suitable for measuring microwave power up to 1 mw; the current in the indicating instrument is 400 μa at this power level.

621.317.755/.756 216

The Dampometer—C. O. Olsson and K. Orlik-Rückemann. (*Electronic Eng.*, vol. 26, pp. 420–428; October, 1954.) An arrangement for automatically recording logarithmic decrement and oscillation frequency at audio and lower frequencies is based on the representation of the damped oscillation by a rotating vector on the screen of a cro, the rate of decrease of the length of the vector constituting a measure of the damping. The screen is covered by a radially slotted disk, and a photocell is arranged to receive light pulses as the screen spot passes the slots. Results are obtained in the form of decimal digits inversely proportional to the logarithmic decrement and the frequency respectively. The apparatus has been used in Sweden for measurements on aeroplane models in wind tunnels.

621.317.755 217

A Large Magnetically-Deflected Oscilloscope—P. E. K. Donaldson. (*Electronic Eng.*, vol. 26, pp. 442–444; October, 1954.) Details are given of a cro designed for demonstrating biological phenomena in a large lecture theatre; a large-screen cathode-ray tube is operated as slave to an oscilloscope tube of usual size.

621.317.755:537.533 218

Ultra-high-Frequency Beam Analyzer—L. R. Bloom and H. M. VonFoerster. (*Rev. Sci. Instr.*, vol. 25, pp. 649–653; July, 1954.) Electron beams modulated at uhf, e.g. as in klystrons, are studied by means of a cro in which the deflection system comprises two mutually perpendicular pairs of Lecher wires resonating at the beam-modulation frequency. With proper adjustment a circular trace is obtained. In a particular system described, the electron-velocity resolution was about 30v, but by increasing the length of the drift-space between the pairs of wires the sensitivity could be made high enough to measure the velocity spread in an unmodulated beam.

621.317.755:621-526 219

The Transferometer—R. Landrin. (*Onde élect.*, vol. 34, pp. 594–602; July, 1954.) A cro instrument for determining points on the gain/frequency and phase/frequency curves of servomechanisms or servo elements.

621.317.78.029.64.089.6 220

The Comparison and Calibration of Power-Measuring Equipment at Wavelengths of 3 cm and 10 cm—R. A. Bailey, H. A. French and J. A. Lane. (*Proc. IEE*, part III, vol. 101, pp. 325–329; September, 1954.) Two sets of substandard equipment designed to measure power of about 1 mw are described, one for each waveband; each consists basically of a thermistor mount, a power unit and an output meter. The accuracy of the final calibration carried out at wavelengths of 3.18 and 10.77 cm is estimated at ±2 per cent and ±1 per cent respectively. The 3-cm equipment was calibrated in terms of two different standards, the water calorimeter and the torque-operated vane wattmeter [1082 of 1953 (Cullen and Stephenson)]; good agreement was obtained.

621.317.791 221

Automatic Circuit Tester speeds Production—R. J. Stahl and G. R. West. (*Electronics*, vol. 27, pp. 136–139; October, 1954.) Description of equipment comprising a universal unit, containing basic measurement circuits and controls, together with a plug-in adapter unit, containing programming and selector devices. The selector switch is advanced one step on receiving information from the measurement element that the previous test is satisfactorily completed.

621.317.794 222

Absolute Water Flow Calorimeter for the Measurement of Intense Beams of Radiant Energy—A.B. Willoughby. (*Rev. Sci. Instr.*, vol. 25, pp. 667–670; July, 1954.) The instrument was designed primarily for measurements on a searchlight radiating energy of the order of 100 cal cm^{-2} sec^{-1}. The heating effects produced on two identical blackbody receivers by the unknown energy and by an electrical coil are balanced.

OTHER APPLICATIONS OF RADIO AND ELECTRONICS

534.1-8:531.717.1 223

An Ultrasonic Method of Gauging—F. M. Savage. (*Jour. Brit. IRE*, vol. 14, pp. 436–444; September, 1954. Discussion, p. 444.) A method is described for measuring wall thickness when only one surface is accessible. Standing waves are set up between the two surfaces of the wall and current peaks are observed as the frequency of the generator is varied through values corresponding to an integral multiple of λ/2; the thickness is calculated from the frequency interval between successive peaks. Details of two instruments are discussed.

534.1-8:616-006 224

On the Use of Ultrasound for Tumor Detection—H. T. Ballantine, Jr., T. F. Hueter and R. H. Bolt. (*Jour. Acoust. Soc. Amer.*, vol. 26, p. 581; July, 1954.) The possibility of using ultrasonic shadow technique for examining brain structure has been investigated. Results indicate that the information obtainable about abnormalities is limited by scattering and refraction associated with normal inhomogeneities in skull and brain.

621.3.018.75:621.383 225

Automatic Particle-Sizing by Successive Counting—G. Jordanides and N. H. Chamberlain. [*Nature* (*London*), vol. 174, pp. 83–84; July 10, 1954.] A specimen under examination, sandwiched between glass disks, is rotated and scanned spirally by a photoelectric head of usual type, the size of the scanning spot being such that particles may give rise to more than one pulse each. The photocell output, consisting of pulses of various heights, is passed after linear amplification through a clipping circuit. By repeating the process with different clipping levels and plotting counts against clipping level, both the number of particles and their average diameter can be determined.

621.316.7.002:621.374:621.396.82 226

Coincidence of Pulse Trains—Friedman. (*See* 252.)

621.317.39:539.32 227

Electroacoustic Measurements of Elastic Modulus—A. Bressi. (*Alta Frequenza*, vol. 23, pp. 51–61; April, 1954.) The elastic modulus of a concrete prism is evaluated from the velocity of propagation of elastic waves in the material, as determined by a resonance method. Vibrations are excited by means of a 15-w loudspeaker unit and are detected by means of a telephone-type electromagnet arranged to face an iron plate fixed to the end of the test specimen. Resonance is indicated by a tube voltmeter, and a cro indication is also provided.

621.317.39:539.32 228

An Improved Method of Measuring Dynamic Elastic Constants, using Electrostatic Drive and Frequency-Modulated Detection—H. Pursey and E. C. Pyatt. (*Jour. Sci. Instr.*, vol. 31, pp. 248–250; July, 1954.) Details are given of an arrangement which permits rapid and precise measurement of the natural resonance frequencies of metal bar specimens, from which the elastic moduli can be determined with an accuracy to within 1–2 per cent.

621.384.6 229

Electronic-Ram Experiments—I. J. Billington and W. R. Raudorf. (*Wireless Eng.*, vol. 31, pp. 287–292; November, 1954.) A description is given of apparatus designed on principles discussed previously [2788 of 1951 (Raudorf)]. A 100-ma rotating cylindrical electron beam is produced; the axial velocity, space-charge density and cross-sectional area are controlled by a steady axial magnetic field. The results confirm that a ram effect is produced by the braking of the beam on entering a region of rapidly increasing magnetic-field intensity.

621.384.612:517.572.4 230

Asymptotic Properties of Bessel Functions and the Radiation from a Synchrotron—D. Park. (*Jour. Math. Phys.*, vol. 33, pp. 179–184; July, 1954.) An investigation is made of the behavior of the Bessel function occurring in the formula for the power radiated from the synchrotron, over a critical range at high orbital frequencies.

621.384.613 231

A Pulsed Magnetic Extractor for removing the Electron Beam from a Betatron—R. S. Foote and B. Petree. (*Rev. Sci. Instr.*, vol. 25, pp. 694–698; July, 1954.) Description of the device used with NBS betatron.

621.384.622.2 232

An 8-MeV Linear Accelerator for X-Ray Therapy—C. W. Miller. (*Proc. IEE*, part 1, vol. 101, pp. 207–219; July, 1954. Discussion, pp. 219–222.) An account is given of the four-year program of research and development leading to the installation of the X-ray machine at Hammersmith Hospital. 8-mv X-rays are obtained by accelerating electrons in a corrugated waveguide, of length 3 m, energized by a magnetron giving a pulsed output of peak power about 2 mw at a free-space wavelength of 10 cm.

621.385.833 233

The Adjustment of Electron-Optical Filter Lenses—O. Rang. [*Optik* (*Stuttgart*), vol. 11, no. 7, pp. 327–334; 1954.] The method used for adjusting velocity-filter lenses [401 of 1952 (Mollenstedt and Rang)] is described.

621.385.833 234

Third-Order Aberrations of "Doubly Symmetric" Systems—J. C. Burfoot. (*Proc. Phys. Soc.*, vol. 67, pp. 523–528; July 1, 1954.) Imaging systems are considered which retain symmetry about each of two mutually perpendicular planes while lacking rotational symmetry. The third-order aberrations are classified and presented diagrammatically for the case of a circular exit aperture.

621.385.833 235

Theory of the Independent Electrostatic Lens with Thick Middle Electrode—P. Ehinger and M. Y. Bernard. (*Cahiers de Phys.*, no. 50, pp. 8–16; July, 1954.) Analysis is given for a three-diaphragm electron lens, the thickness of the middle diaphragm being large compared with the diameter of the aperture. The potential distribution along the axis is calculated, and the position of the cardinal points hence derived. The accuracy of the method is confirmed by comparing the results with observations.

621.385.833 236

The Lower Limit of the Aperture Error in Magnetic Electron Lenses—W. Tretner. [*Optik* (*Stuttgart*), vol. 11, pp. 312–326; 1954.] A variational method is used to find the lower limit set to the values of the lens excitation parameters by the saturation of the iron and the degree of mechanical imperfection.

621.385.833 237

On the Chromatic Field Aberration of the Magnetic Electron Lens in the Electron Microscope—N. Morito. (*Jour. Appl. Phys.*, vol. 25, pp. 986–993; August, 1954.) Analysis is presented; observed results support the theory.

621.385.833:061.3(47) 238

Session of the Physical-Mathematical Section of the U.S.S.R. Academy of Sciences and the β-γ Spectroscopy Conferences 1950, 1953 and 1954—[*Bull. Acad. Sci.* (*USSR*), *sér. phys.*, vol. 18, pp. 173–246; March/April, 1954.] The text is given of papers dealing with various aspects of focusing by magnetic electron lenses.

621.387.4:531.7 239

The Alpha Gauge—E. N. Shaw. (*Jour. Brit. IRE*, vol. 14, pp. 414–418; September, 1954. Discussion, p. 433.) "The apparatus described is for the measurement of weight per unit area of very thin materials, such as capacitor paper. An alpha source is used in conjunction with an ionization chamber backed off by a similar system. The algebraic sum of the currents is fed into a stable dc amplifier, and the out-of-balance reading calibrated in terms of weight. The sources of error are investigated, together with methods of compensation. Results obtained under factory conditions are also discussed."

621.387.4:531.7 240

A Combined Beta and Dielectric Gauge—R. Y. Parry. (*Jour. Brit. IRE*, vol. 14, pp. 427–432; September, 1954. Discussion, p. 433.) By combining the two gauges in a single installation, an equipment is obtained having long-term stability and rapid response.

621.387.4:531.717.1 241

A Gamma-Ray Thickness Gauge for Hot Steel Strips and Tubes—G. Syke. (*Jour. Brit. IRE*, vol. 14, pp. 419–426; September, 1954. Discussion, p. 433.) A gauge for steel strip of thickness 0.05 to 0.30 inch is described, using a scintillation detector and providing readings at short time intervals. An adaptation for gauging the wall thickness of tubes is also discussed.

PROPAGATION OF WAVES

538.566 242

Validity of the Sommerfeld-Pfrang Reciprocity Theorem [for e.m. wave propagation] in Absorbing Media—C. V. Fragstein. [*Optik* (*Stuttgart*), vol. 11, pp. 301–311; 1954.]

538.566:551.594.6 243

The Propagation of Long Waves from a Horizontal Dipole in the Air Space between Earth and Ionosphere—W. O. Schumann. (*Z. angew. Phys.*, vol. 6, pp. 225–229 and 267–271; May and June, 1954.) Detailed analysis of propagation between the earth and an ionosphere of finite conductivity to determine the radiation field at frequencies above and below certain critical values. Principal radiation is in the *H*-mode transverse to the dipole direction, and the assumption of a vertical-magnetic-dipole equivalent is justified. *E*-mode components propagated in the direction of the dipole are only significant at very low frequencies. See also 1544 of 1954 and 2195 of 1954.

621.396.11:551.510.535 244

Maximum Usable Frequencies and Lowest Usable Frequencies for the Path Washington to Resolute Bay—S. N. Ostrow. (*Jour. Geophys. Res.*, vol. 59, p. 434; September, 1954.) Comment on 1889 of 1954 (Hanson et al.).

621.396.11:551.510.535 245

Experiments on Interaction of Radio Waves in the Ionosphere—M. Boella. (*Nuovo Cim.*, vol. 12, pp. 140–142; July 1, 1954.) Discussion of investigations reported by Cutolo (1167 and 2084 of 1954, etc.). Reasons are given for considering it unlikely that the value of the earth's magnetic field in the upper atmosphere can be determined from electron gyromagnetic effects with an accuracy as good as has been suggested. A possible method of investigating self-demodulation is indicated by periodically varying the power of the radio transmission while maintaining the carrier and modulation frequencies constant.

621.396.11.029.51 246

A Technique for Sweep-Frequency Polarization Measurements at Low Frequencies—E. L. Kilpatrick. (*Jour. Geophys. Res.*, vol. 59, pp. 345–349; September, 1954.) A technique for simultaneously recording the polarization of echoes and ionosphere virtual height is described. The polar and phase diagrams of each echo are recorded on photographic film with displacement in one direction proportional to virtual height and in the other direction proportional to frequency. A block diagram of the equipment and specimen records are shown.

621.396.11.029.55 247

A Rotating Interferometer for the Measurement of the Directions of Arrival of Short Radio Waves—H. A. Whale. (*Proc. Phys. Soc.*, vol. 67, pp. 553–562; July 1, 1954.) Two horizontal loop antennas are used, one of which is fixed while the other moves in a circular path several wavelengths in diameter. The phases of the signals from the two antennas are compared in a system which gives an output voltage approximately proportional to $A_1A_2 \cos \Phi$, where A_1 and A_2 are the amplitudes of the two signals and Φ is the phase angle between them. The output thus has zero value when $\Phi = \pm 90$ degrees, irrespective of the amplitudes, so that the method is useful even when there is considerable differential fading. Some experimental records are shown (in a plate separated from the text).

621.396.11.029.6:551.5 248

Influence of Weather Conditions on the Characteristics of U.S.W. Long-Distance Reception—E. A. Lauter and L. Klinker. (*Z. Met.*, vol. 8, pp. 222–230; July/August, 1954.) Field-strength records for propagation over land and sea paths over several years are analyzed. Three characteristic types of reception are distinguished, (a) stable, (b) slow fading, (c) scintillation fading; transitional types are also recognized. Stable reception with a relatively high mean field strength is predominant during anticyclonic conditions; scattering phenomena coupled with low field strength are observed during cyclonic conditions. Seasonal differences in the frequency of occurrence of the different types of reception are caused by variations in the structure of the lower atmosphere.

621.396.11.029.62/.64 249

The Propagation of Metre and Centimetre Waves (Wavelengths between 6 m and 3 cm). Determination of the Transmission Equivalent—J. Ortusi. (*Ann. Radioélect.*, vol. 9, pp. 227–273; July, 1954.) Propagation over both direct-visibility and long-distance paths is considered. Characteristics studied include received power, attenuation and the effect of mountains. Relevant diffraction theory and the measurement of turbulence fields are considered in appendixes. The results are summarized for convenient use in a series of ten nomograms, covering received power, transmission equivalent, attenuation, maximum range and effective antenna height.

621.396.11.029.62:523.5 250

Dependence of Integrated Duration of Meteor Echoes on Wavelength and Sensitivity—D. W. R. McKinley. (*Canad. Jour. Phys.*, vol. 32, pp. 450–467; July, 1954.) "The reflecting properties of short-duration and long-duration echoes from meteor trails are examined. For short-duration echoes only, the observed relation between relative numbers and durations of meteor echoes is independent of wavelength, the time of day, or the presence of a strong shower. Integrated duration times are determined from back-scatter experiments on 9.22 m, 5.35 m, and 2.83 m, and are found to vary with the 3.5th power of the wavelength, for either short- or long-duration echoes. The integrated echo power depends on the 6th power of the wavelength. The effect of changing the equipment sensitivity is considered. The data from the back-scatter observations are used to predict the integrated duration times in the forward-scatter case, and in particular, it is shown that the results of the Cedar Rapids-Sterling very-high-frequency experiment may be explained by meteoric reflections."

621.396.11.029.63/.64 251

Investigation of Centimetre-Wave Propaga-

tion in the Mediterranean Region—P. Chavance, L. Boithias and P. Blassel. (*Ann. Télécommun.*, vol. 9, pp. 158–185; June, 1954.) Report of tests carried out since April, 1952. These included field-strength recordings of vertically and horizontally polarized transmissions at 1.4 and 3.15 kmc over a 227-km sea path; psychrometer measurements in aircraft; simultaneous beamed transmissions on 3.15 kmc between four stations roughly in the same vertical plane; diversity reception; transmissions at 4 and 9.2 kmc over a 29-km path. A full description is given of the equipment used, and results are analyzed and discussed. Main conclusions are: (a) multipath propagation is often the predominant cause of fading over long sea paths, height-diversity reception being a particularly effective remedy; (b) over short sea paths reflection effects are preponderant, high-gain narrow-beam antennas improving reception considerably.

RECEPTION

621.374:621.396.82:621.316.7.002 252

Coincidence of Pulse Trains—H. D. Friedman. (*Jour. Appl. Phys.*, vol. 25, pp. 1001–1005; August, 1954.) Extension of investigation described by Miller and Schwarz (238 of 1954). Alternative methods are presented for determining the coincidence time fraction for simple or complex pulse trains with commensurable periods. A determination is made of the largest possible error resulting from direct use of elementary probability theory when considering three or more pulse trains. The theory is relevant to a variety of problems including communications and control of manufacturing operations.

621.376.23:621.396.822 253

The Joint Distribution of *n* Successive Outputs of a Linear Detector—W. C. Hoffman. (*Jour. Appl. Phys.*, vol. 25, pp. 1006–1007; August, 1954.) "The joint probability density function of *n* successive outputs of a linear detector is derived for the case of dependent Gaussian inputs."

621.396.62:621.396.822 254

On the Distributions of Signals and Noise after Rectification and Filtering—M. A. Meyer and D. Middleton. (*Jour. Appl. Phys.*, vol. 25, pp. 1037–1052; August, 1954.) A generalization of the method presented by Kac and Siegert (3645 of 1947) is used to find the probability density for wide-band and for narrow-band signals with random noise, after passage through a square-law rectifier and an audio or video filter. Explicit solutions are obtained for an integral equation involving the autocorrelation function of the noise, the weighting function of the filter, and an orthonormal set of eigenfunctions.

621.396.62+621.397.62].002.2 255

Dip-Soldered Chassis Production—W. R. Cass and R. M. Hadfield. (*Wireless World*, vol. 60, pp. 536–539; November, 1954.) An account of the use of the dip-soldering technique in conjunction with printed circuits to simplify the manufacture of sound and television receivers.

621.396.621 256

Notes on the History of the Broadcast Receiver—C. Dorsman. (*Tijdschr. ned. Radiogenoot.*, vol. 19, pp. 179–210; July, 1954.) Development of the radio receiver is traced from the invention of the Leyden jar; special emphasis is laid on the work of Maxwell, Hertz and Marconi. 40 references.

621.396.82:551.594.6:621.317.7 257

Measurement of Atmospheric Noise Interference to Broadcasting—S. V. Chandrashekhar Aiya. (*Jour. Atmos. Terr. Phys.*, vol. 5, pp. 230–242; September, 1954.) A criterion for assessing the annoyance value of noise in broadcast reception is established, based on investigations carried out in India over a period of several years. Taking into account the statistical variation of the duration of noise pulses, the lowest number of pulses per minute causing annoyance is ten. Objective measurements were made using a noise meter of the rapid-charge slow-recovery type; charging and discharging time constants of 10 ms and 500 ms respectively gave the closest agreement between the measured noise and the subjective results. Correlation was satisfactory for the greater part of the time, but for pulses lasting about 0.1 sec or less the meter reading was too high. No data are available for pulses longer than 0.4 sec. The design and calibration of noise-measurement equipment are considered and methods of recording and analyzing observations are discussed.

STATIONS AND COMMUNICATION SYSTEMS

621.376.2 258

A General Solution of the Two-Frequency Modulation Product Problem: Part 3—Rectifiers and Limiters—R. L. Sternberg. (*Jour. Math. Phys.*, vol. 33, pp. 199–205; July, 1954.) Theory developed in part 1 [2212 of 1954 (Sternberg and Kaufman)] and functions tabulated in part 2 (3028 of 1954) are used to obtain exact expressions for the amplitudes of the modulation products for ideal rectifiers and limiters having continuous polygonal output /input characteristics.

621.376.3:621.396.822 259

The Power Spectrum of a Carrier Frequency-Modulated by Gaussian Noise—J. L. Stewart. (Proc. I.R.E., vol. 42, pp. 1539–1542; October, 1954.) A modification of Middleton's method (see e.g. 802 of 1952) is used to obtain expressions for the power spectra for particular types of modulating signal.

621.39.001.11 260

Optimum Coding for Maximum Repeater Spacing—D. G. Holloway. (*A.T.E.J.*, vol. 10, pp. 188–198; July, 1954.) "The signals carried by a communications circuit may be recoded to occupy either more or less bandwidth without alteration to the amount of information. The selection of a preferred type of coding depends largely on the frequency characteristics of the transmission medium, and the practical limitations of transmitters and receivers impose other bounds. The increase of cable attenuation with frequency has a marked effect on the choice of coding for cable circuits, and it is found that binary coding is seldom desirable, for a multilevel system generally permits greater repeater spacing. To obtain the optimum conditions it may be necessary to recode signals to occupy a smaller bandwidth, with a consequent need to improve the accuracy of circuit equalization."

621.391.64:621.376.22:546.289 261

Germanium Modulator for Infrared Communication—A. F. Gibson. (*Electronics*, vol. 27, pp. 155–157; October, 1954.) A beam of infrared radiation is modulated by an electronic shutter comprising a small block of Ge whose infrared transparency is varied by injection of charge carriers under control of an af signal. Practical details are given for a modulator with a frequency response 3 db down at about 9.5 kc. A tungsten-filament lamp is used as power source and a PbS cell as receiver.

621.395.44 262

Twelve-Channel Systems on Non-Pupinized Pairs of the Verona-Brennero Cable—G. Saraco. (*Alta Frequenza*, vol. 23, pp. 62–78; April, 1954.) The carrier-current telephony system described operates over some 200 km of symmetrical-pair cables. Channel bandwidth is 4 kc and frequency bands 6–54 kc and 60–108 kc are used for transmission in the two directions respectively. The choice of these frequency bands is discussed. Details of modulation and repeater-station equipment and performance figures are given.

621.396.65 263

Automatic Testing of V.H.F. Radio Links—E. Petrozzi. (*Alta Frequenza*, vol. 23, pp. 102–106; April, 1954.) The central station of a mobile vhf network sends out a short modulated pulse at regular intervals; an automatic response is obtained from the peripheral stations if they are connected. Descriptions, with circuit diagrams, are given of arrangements suitable for testing duplex and simplex systems.

621.396.65 264

Miniature U.S.W. Radio Link—H. J. Fründt. (*Telefunken Ztg.*, vol. 27, pp. 88–96; July, 1954.) Transmitter, receiver and frequency-transposition units are described for a low-cost transportable radio link. Three telephone channels are provided and operation is in the 80- and 160-mc bands. The S/N ratio of 40 db is achieved even with two intermediate relay stations. The equipment differs only slightly from standard mobile telephone equipment for the same frequency bands, and is designed to be used in various ways in conjunction with such equipment.

621.396.65+621.396.96]:621.396.677.3 265

The Application of [u.h.f.] Radio Beams to Radar, Multiplex and Television Techniques—Aubert. (*See* 30.)

621.396.932 266

The Technical Equipment of Ship Radio Stations—W. Böttcher. (*Elektrotech. Z.*, *Edn B*, vol. 6, pp. 285–290; July 21, 1954.) Ship radio installations provide aids for communication and navigation purposes, and operate under conditions prescribed by international agreements. These general conditions are outlined, and the minimum equipment to be carried on ships of certain classes of size is specified. Typical transmitters, receivers, and navigation equipment are briefly described.

SUBSIDIARY APPARATUS

621–526 267

The "Least Squares" Criterion applied to Linear Servos—R. Voles. (*Electronic Eng.*, vol. 26, pp. 452–453; October, 1954.)

621–526 268

Transient Performance of Servomechanisms—R. C. Lathrop and D. Graham. [*Elec. Eng.* (*N.Y.*), vol. 73, p. 620; July, 1954.] Digest of paper published in *Trans. AIEE*, vol. 73, part II, *Applications and Industry*, pp. 10–17; 1954. A criterion of transient performance developed previously and based on the time integral of absolute value of error is applied to second- and third-order linear servomechanisms with derivative- or integral-type error correction and different types of input.

621–526(083.71) 269

The Terminology of Servo Systems—P. Naslin. (*Onde élect.*, vol. 34, pp. 588–593; July, 1954.) Definitions of fundamental concepts are given, which are to be submitted by the French Committee in the revision of the International Electrotechnical Vocabulary.

621.311.6:621.316.722 270

Regulated D.C. Supply has High Efficiency—D. C. Bakeman and J. E. Richardson. (*Electronics*, vol. 27, pp. 165–167; October, 1954.) Description of 200-w unit using magnetic amplifiers for regulation in response to slow variations of line voltage or load and electronic clamping circuits for regulation in response to rapid variations.

621.316.721 271

Direct-Current Stabilizers for Electromagnets—M. W. Jervis. (*Electronic Eng.*, vol. 26, pp. 429–431; October, 1954.) General principles of operation and factors affecting stability are reviewed.

TELEVISION AND PHOTOTELEGRAPHY

621.397 272

A New Continuous-Feed Facsimile Scanner—J. V. L. Hogan and G. M. Stamps. [*Elec. Eng.* (*N.Y.*), vol. 73, pp. 615–619; July, 1954.] The scanner comprises two rotating disks with spiral apertures in combination with a fixed linear slit. A photographic method of generating the spirals is outlined. The operation of the system in scanning wide copy is described; it has also been applied successfully in photo-recording on 35-mm film and in film scanning. For scanning bound copy the typewriter-style roller is replaced by a moving-frame mount.

621.397 273

Facsimile Scanning by Cathode-Ray Tube—W. H. Bliss and C. J. Young. (*RCA Rev.*, vol. 15, pp. 275–290; September, 1954.) Outlines are given of several experimental systems developed since the ultrafax system (1203 of 1949). It is more difficult to achieve scanning linearity with cathode-ray tube scanning than with a rotating drum, especially at low speeds. The mechanical scanner also gives better definition than available cathode-ray tubes. For scanning flat-bed material, for high transmission speeds, or for systems using photographic reproduction, cathode-ray-tube methods may have advantages.

621.397.3:778.5 274

Film Scanning in Television—R. Theile. (*Arch. elekt. Übertragung*, vol. 8, pp. 305–317; July, 1954.) Various known methods are critically reviewed and compared. The discussion indicates that equipment using simple optical and mechanical arrangements only works with the more complicated television scanning methods, and vice versa. The two most important combinations in use are (a) flying-spot scanning with continuous film motion, one-half of the vertical scanning being provided by the film motion, and (b) storage-tube scanning with intermittent film motion.

621.397.5:535.623 275

Colour Camera Convertor—(*Wireless World*, vol. 60, p. 540; November, 1954.) A frame-sequential camera system is adapted for simultaneous transmission by passing the sequential color signals from the camera to an electronic switching system which distributes the red signals to one cathode-ray tube, the blue signals to a second, and fractions of all three signals to a third. These three cathode-ray tubes are viewed by three pickup tubes, from whose outputs the simultaneous signals are derived. A brief account is given of a demonstration in which the frame-sequential camera was operated on 405 lines interlaced 2:1 with 150 frames/second, the bandwidth being 9 mc. The three pickup tubes were operated on 615 lines interlaced 2:1 with 50 frames/second. Various display systems were used, including a tricolor tube and a three-tube projection unit.

621.397.5:535.623 276

Experimental Colour Television System using an Electrically Controlled Crystal [colour] Filter—V. A. Babits. (*Ann. Télécommun.*, vol. 9, pp. 187–190; June, 1954.) Report of preliminary tests carried out using an ADP-crystal color filter in a projection system. Pulses of amplitude 8–10 kv and duration 1/144 second were applied to the crystal in synchronism with the color-sampling process in the transmitter. A block diagram of the complete system is given with details of the filter control circuit. With a single filter the color saturation was about 55 per cent. See also paper by Babits and Hicks in *Electronics*, vol. 23, pp. 112–115; November, 1950.

621.397.5(494) 277

Experimental Television Service in Switzerland—W. Gerber. (*Bull. schweiz. elektrotech. Ver.*, vol. 45, pp. 609–617; July 24, 1954.) A progress report on the stage of development reached at the end of 1953.

621.397.6 278

An Industrial Television Channel—R. J. Boddy and C. D. Gardner. (*Jour. Telev. Soc.*, vol. 7, pp. 248–261; April/June, 1954.) A detailed description is given of equipment providing broadcasting picture quality and comprising camera with Type-5907 cps emitron, control rack, and one or more monitoring receivers which are of standard type and fed with modulated rf from the rack output.

621.397.6 279

A Line Converter for the International Exchange of Television Programmes—J. Haantjes and T. G. Schut. (*Philips Tech. Rev.*, vol. 15, pp. 297–306; May, 1954.) See 2469 of 1953.

621.397.61/.62 280

Factors in the Design of Keyed Clamping Circuits—R. N. Rhodes. (*RCA Rev.*, vol. 15, pp. 362–371; September, 1954.) Analysis is given for double-diode circuits for clamping the dc level in television.

621. 397.61 281

Monochrome Vidicon Film Camera—W. L. Hurford and R. J. Marian. (*RCA Rev.*, vol. 15, pp. 372–388; September, 1954.)

621.397.61:535.623 282

Television Transmitter Considerations in Color Broadcasting—T. M. Gluyas, Jr. (*RCA Rev.*, vol. 15, pp. 312–334; September, 1954.) Large-area color fidelity depends on the amplitude/frequency characteristic, linearity and differential phase response. Color fidelity at area edges depends on amplitude/frequency characteristic and envelope delay. The signal is pre-distorted in auxiliary equipment to obtain good final linearity and prescribed envelope delay. Monitoring arrangements include a vestigial-sideband demodulator.

621.397.611:778.5 283

Continuous Scanner for Televising Film—R. E. Graham. (*Bell Lab. Rec.*, vol. 32, pp. 250–256; July, 1954.) A flying-spot scanner for standard 35-mm film, developed for research on television transmission, uses a mirror-drum arrangement in which the mirrors are individually as well as collectively rotated for optical compensation of the continuous film motion. The brightness of the scanning spot is controlled by means of a flicker-suppressing servo system operated by pulses derived from an "over-scan" area of the cathode-ray-tube face.

621.397.611.2 284

An Experimental Photoconductive Camera Tube for Television—L. Heijne, P. Schagen and H. Bruining. (*Philips Tech. Rev.*, vol. 16, pp. 23–25; July, 1954.) Further details are given of a tube described previously (1935 of 1954). The sensitivity for illumination of color temperature 2600 degrees K is 100–200 μa per lumen, and the spectral distribution of sensitivity is about the same as that of the transparent CsSb photoemission-type target. The response time of the experimental model is sufficiently short for most industrial purposes; it is hoped to reduce this time further to permit use of the tube for television broadcasting.

621.397.62 285

TV Receiver operates on Four System Standards—W. Werner. (*Electronics*, vol. 27, pp. 140–143; October, 1954.) A receiver designed to operate on the CCIR 625-line and the French 819-line as well as the two Belgian standards is described. After providing adequate rejection of the sound, which is amplitude modulated in three of the systems, the available video bandwidth is 4.25 mc. The same IF picture amplifier is used for all four systems, with a carrier frequency of 38.9 mc. A separate IF sound amplifier is taken off directly after the tuner; the sound IF is converted to 7 mc by means of a second oscillator. Switching arrangements between AM and FM sound and between negative and positive picture modulation are described. Amplified picture agc is provided.

621.397.62:535.623 286

The CT-100 Commercial Color-Television Receiver—L. R. Kirkwood and A. J. Torre. (*RCA Rev.*, vol. 15, pp. 445–460; September, 1954.) A receiver designed to operate on the FCC compatible color standards approved in December, 1953 uses 37 receiving tubes, two Se rectifiers, one Si diode and two Ge diodes as well as a Type 15*GP22* three-gun color kinescope. A detailed description including complete circuit diagrams is given.

621.397.62+621.396.62].002.2 287

Dip-Soldered Chassis Production—Cass and Hadfield. (*See* 255.)

621.397.621.2:535.623:621.385.832 288

Beam-Deflection Color-Television Picture Tubes—J. M. Lafferty. (PROC. I.R.E., vol. 42, pp. 1478–1495; October, 1954.) Detailed analysis is presented for tubes of the type in which an electrostatic field is produced between the phosphor screen and a parallel perforated screen, and the beam is directed obliquely into this field. The beam direction within the field is controlled by means of color-signal voltages applied to one of the electrodes, so that the beam strikes either the front of the phosphor screen ("transmission" case, accelerating field) or the back of the perforated screen ("reflection" case, retarding field) at a spot coated with phosphor of corresponding color. A reflection-type tube was described by Weimer and Rynn (846 of 1952). Advantages of both types are automatic color registry, simple monochrome presentation, short tube length, low color-switching-electrode capacitance and equal numbers of the three color elements. Techniques used in the construction of 16-inch and 24-inch reflection-type tubes, and methods of preparing the color screens are described.

621.397.621.2:537.533.8 289

Secondary Emission from the Screen of a Picture-Tube—J. de Gier, A. C. Kleisma and J. Peper. (*Philips Tech. Rev.*, vol. 16, pp. 26–32; July, 1954.) Methods of measuring the secondary-emission factor δ and the potential of the fluorescent screen under operating conditions are discussed. Negative charging of the screen when δ is less than or not much greater than unity may give rise to ion burn. A suitable value of δ is obtained by applying a very thin film of MgO to the screen.

621.397.82 290

Interference to Color and Monochrome Television Receivers by Oscillator Radiation and other C.W. Signals—E. W. Chapin, W. K. Roberts and L. C. Middlekamp. (*Trans. I.R.E.*, no. PGBTR-7, pp. 47–58; July, 1954.) The concept and measurement of the "beat size" effect are discussed, the term "beat" being used to indicate a sequence of areas having brightness values alternately greater and less than that properly associated with the picture. The size of these areas depends on the frequency separation between the interfering signal and the picture carrier; for a monochrome picture the interference level that can be tolerated is 25–30 db greater if it falls in the upper part of the channel than if it falls near the picture carrier. With color television additional suppression of oscillator radiation may be necessary since, because of the greater degree of occupancy of the channel by the desized signal, it is not possible to derive much advantage from this beat size effect.

TRANSMISSION

621.396.61 291

S.W. Transmitter Pre-amplifier and Driver Stages—E. Kettel. (*Telefunken Ztg*, vol. 27, pp. 114–123; July, 1954.) Two transmitters are considered. The first is a ssb telephony transmitter with built-in monitor, accommodating four telephony channels. The second is a telegraphy transmitter for *A*1, *A*2 and *F*1 working, with provision for *A*3 and *F*4 working as required. Special filter arrangements limit the bandwidth transmitted.

TUBES AND THERMIONICS

621.314.63:546.289 292

Barrier-Layer Capacitance of the Ge-In Alloyed Rectifier—H. U. Harten, W. Koch, H. L. Rath and W. Schultz. (*Z. Phys.*, vol. 138, pp. 336–344; July 22, 1954.) Report of an experimental investigation of the equation $1/C^2=\alpha(U+U_0)$, where C is the capacitance, defined as the change of charge with change of blocking voltage U, and α is a function of the donor density. An approximate formula for U_0 is given; calculated values agree well with experimental results obtained both at temperatures in the range 100 degrees–300 degrees K with donor density 3.2×10^{14} cm^{-3} and at a temperature of 295 degrees K with donor densities between 10^{14} and 10^{15} cm^{-3}. Applied blocking voltage was 0.3 v in both cases. The effect of the inversion layer on capacitance is explained by consideration of a simple barrier-layer model. See also 3069 of 1954 (Rath).

621.314.63+621.314.7](083.7)]:537.311.33 293

I.R.E. Standards on Electron Devices: Definitions of Semiconductor Terms, 1954—(Proc. I.R.E., vol. 42, pp. 1505–1508; October, 1954.) Standard 54 I.R.E. 7.S2.

621.314.632:621.396.822 294

Noise in Silicon Microwave Diodes—G. R. Nicoll. (*Proc. IEE*, part III, vol. 101, pp. 317–324; September, 1954.) Measurements made on point-contact diodes with dc bias current are discussed. Flicker noise may be greater than shot noise at measurement frequencies up to and probably appreciably above 45 mc. Diodes with a low value of flicker noise show for small bias currents good agreement at 45 mc with calculated values of shot noise. As the bias current is reduced the shot noise tends to the value expected for the thermal noise; thus the thermal noise, corresponding to zero bias, may be calculated using the shot-noise concept. Noise in the range 30–40 kmc produced by reverse bias may be ascribed entirely to shot noise. Mixer noise correlates fairly closely with dc bias noise; noisy mixer action is therefore due to a large component of flicker noise.

621.314.7 295

The Transistor: Part 1—General Introduction—J. R. Tillman. (*P.O. Elec. Eng. Jour.*, vol. 47, part 2, pp. 92–93; July, 1954.) A brief historical account of the development of the transistor, with an indication of possible applications in telecommunications.

621.314.7 296

The Transistor: Part 2—Outline of the Theory of Point-Contact and Junction Transistors—F. F. Roberts. (*P.O. Elec. Eng. Jour.*, vol. 47, part 2, pp. 94–96; July, 1954.) Transistor action is briefly explained in terms of the injection and collection of holes or electrons in excess of the equilibrium concentration.

621.314.7:621.317.3 297

The Measurement of the Small-Signal Characteristics of Transistors—Cooke-Yarborough, Florida and Stephen. (*See* 195.)

621.314.7:621.317.733 298

A Bridge for measuring the A.C. Parameters of Point-Contact Transistors—Boothroyd and Datta. (*See* 213.)

621.314.7:621.317.733 299

A Bridge for Measuring the A.C. Parameters of Junction Transistors—Boothroyd and Almond. (*See* 214.)

621.314.7.012.8 300

Physical Theory of New Circuit Representation for Junction Transistors—J. Zawels. (*Jour. Appl. Phys.*, vol. 25, pp. 976–981; August, 1954.) An equivalent circuit is derived which directly interprets the diffusion equation and the boundary conditions including the effects of base-width modulation. The active part of the circuit is found to be independent of frequency. A modified form particularly convenient for representing the transistor with common grounded emitter is discussed, and the parameters are evaluated from experimental results.

621.385:537.533.1 301

On Some Effects of Velocity Distribution in Electron Streams—S. V. Yadavalli. (*Quart. Appl. Math.*, vol. 12, pp. 105–116; July, 1954.) The problem of the electron beam with rectangular distribution of electron velocities and small-signal modulation is solved by a Laplace-transform method using an integral equation based on the Liouville theorem. The results are consistent with those derived by Llewellyn and Peterson (2578 of 1944) for a uniform-velocity beam. The case of a beam with a narrow velocity spread in an accelerating field is considered briefly. See also 3412 of 1954.

621.385:621.318.57 302

Development of Trochotrons—J. Björkman and L. Lindberg. (*Ericsson Tech.*, vol. 10, no. 1, pp. 3–105; 1954.) See 3079 of 1954.

621.385:621.396.822 303

The Noise of Valves—C. S. Bull. (*Brit. Jour. Appl. Phys.*, vol. 5, p. 270; July, 1954.) Correction to paper abstracted in 3080 of 1954.

621.385:621.396.822 304

A Theorem concerning Noise in Electron Streams—J. R. Pierce. (*Jour. Appl. Phys.*, vol. 25, pp. 931–933; August, 1954.) A formula is derived for the lower limit value of the product of the maximum and minimum values of noise current in a noise standing wave on an electron stream.

621.385.029.6 305

Positive-Ion Trapping in Electron Beams—E. L. Ginzton and B. H. Wadia. (Proc. I.R.E., vol. 42, pp. 1548–1554; October, 1954.) A detailed study is made of the use of positively biased gridless electrodes near the cathode, in tubes with drift spaces, to prevent positive ions from being collected by the cathode and thus to keep them available for neutralizing electron space-charge. Experiments indicate that if the electron beam nearly fills the cross section of the cylindrical electrode surrounding it, traps of this type are not so successful as when the beam diameter is small compared with the electrode diameter. In one case the electron beam current transmitted through the drift space was increased from 12 per cent to 80 per cent of the cathode current.

621.385.029.6:621.372.8 306

Measurement of Circuit Impedance of Periodically Loaded Structures by Frequency Perturbation—E. J. Nalos. (Proc. I.R.E., vol. 42, pp. 1508–1511; October, 1954.) The impedance of the wave-retarding structure in a traveling-wave tube is determined by a method which has been used previously in the design of linear accelerators [2595 of 1949 (Slater)] and which does not involve the electron beam. The structure is short-circuited at suitable planes of symmetry to make it resonant, and observations are made of the change of resonance wavelength as a function of the position of a perturbing body introduced into the field. Values predicted by this method for the gain of a tube with a disk-loaded structure are in agreement with measured values.

621.385.029.6.012.3 307

A Nomogram for Hartree's Threshold-Criterion for Magnetrons—J. D. Harmer. (*Electronic Eng.*, vol. 26, p. 441; October, 1954.) "Hartree's threshold voltage criterion is used to predict the operating conditions or identify from test results the mode of operation of a cylindrical multi-resonator magnetron. A nomogram for this criterion is presented. It includes a scale giving the upper limit to the electronic efficiency of the magnetron."

621.385.832 308

Characteristics of a Transmission Control Viewing Storage Tube with Halftone Display—M. Knoll, H. O. Hook and R. P. Stone. (Proc. I.R.E., vol. 42, pp. 1496–1504; October, 1954.) Description of a tube of the general type described previously [1975 of 1954 (Knoll et al.)] but modified in regard to various constructional features and including a separate erasing gun. Applications to radar, projection television, television systems conversion and oscillography are mentioned.

621.385.832 309

Method of Determining the Aberrations of a Magnetic-Deflection Unit—G. Wendt. (*Ann. Radioélect.*, vol. 9, pp. 286–307; July, 1954.) A specially designed cathode-ray tube has an extra long neck which accommodates (a) an electron gun producing a fine pencil beam, (b) a focusing coil, (c) a deflection coil rotating at about 1 rps, (d) a second focusing coil, (e) the deflection coil under examination. Careful centering of all electrodes and coils is essential. For measurements of aberrations causing beam defocusing, the figures described on the screen as the current in the deflection coil under test is varied, are photographed. Aberrations of various types can be distinguished, and their numerical values ascertained from tables provided. Distortions are measured from photographs of a grid of lines produced on the screen by the deflection coil under test.

MISCELLANEOUS

68:621.3 310

Mechanical Design of Electronic Equipment—(*Electronics*, vol. 27, pp. M1–M64; October, 1954.) A special supplement surveying latest production methods and materials.

Gulton abstracts

2

MATERIALS RESEARCH • ELECTRONIC COMPONENTS • PRECISION INSTRUMENTS • SYSTEMS ENGINEERING

Low noise, self-contained decade amplifier features cathode follower input

Specifications: Frequency response, flat from 2.5 cps—100 KC with load of ½ megohm; Input impedance, 500 ohms; Input impedance of cathode follower, 100 megohms; Output impedance, at X10 about 2400 ohms, at X100 about 1700 ohms; Gain, X10 (20 db), X100 (40 db); Maximum input level, 0.3 volts; Phase shift and distortion, negligible: Noise, 5 microvolts rms, input shorted.

The Glennite Model F-408, a new completely self-contained A.C. operated amplifier, enables measurement of low level voltages with conventional instruments while minimizing circuit loading.

Comprising an amplifier unit and a ruggedized cathode follower probe mounted on a nine-foot connecting cable, this instrument features extremely low noise level and high input impedance.

The front panel is designed for the convenient insertion of filters between the cathode follower and the decade amplifier connected by a selector switch.

Of anti-microphonic construction, the unit is only 5" high, 5⅞" wide and 8½" deep. Power requirements are: 10.5 watts; 117 volts; 60 cycles.

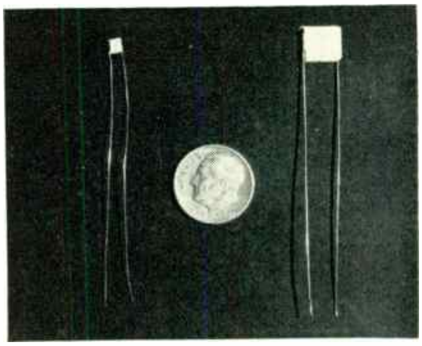
Convenient fixtures are provided for hand carrying the unit and for mounting the power and cathode follower cables when not in use.

Gulton Mfg. Corp.

New wafer-type thermistor has high surface-to-mass ratio

A new wafer-type thermistor has been developed by the Thermistor Corporation of America. Outstanding features of this thermistor are: high surface-to-mass ratio; good heat dissipation ability; short thermal time constant; high negative coefficient of resistance for given resistance value; ease of manufacture of special resistance values for special applications; and low unit cost in quantity production.

Typical uses include temperature measurement and control; compensation of other electronic devices exposed to varying temperatures; suppression of current pulses; and provision of time delay without moving parts.



New TCA wafer-type thermistors.

The normal maximum operating temperature is 150°C. Typical units have a temperature coefficient of −4%/°C, although both higher and lower coefficients are available. Special mountings can be provided for very large current ratings.

Thermistor Corporation of America

Wide range miniature accelerometer eliminates housing distortion signals

The Glennite Model A-314 accelerometer has introduced a new concept of subminiaturization to the shock and vibration field. A newly developed seismic suspension provides excellent frequency response and complete mechanical isolation between housing and seismic element, eliminating spurious housing distortion signals.

Its high natural resonant frequency makes this rugged unit a natural for measuring high frequency vibration and shock over an acceleration range of .5 to 4000 g. Utilizing a highly stable Glennite piezoelectric ceramic transducer, this accelerometer affords very high stability of sensitivity at normal operation temperatures and even over the extended range between −40°C and +90°C.

Glennite Accelerometer A-314 specifications: Sensitivity (with cable), 1 mv/g; Resonant frequency, 35 KC; Useful frequency range, 3 to 12,000 cps; Lateral sensitivity, less than 5% of maximum; Capacitance (with cable), 2000 mmf.

Available in aluminum or titanium housings, the size of the unit is .450" x .400" and its weight is 2½ grams. Units are furnished with a special low noise cable and new type screw connector.

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Professional Group Meetings

(Continued from page 78A)

AUDIO

The San Diego Chapter of the Professional Group on Audio met in August with W. B. Bernard, Chairman. Dr. Leo Beranek, Director of the Acoustics Laboratory at MIT, delivered a paper on "Music Reproduction." He discussed the various types of high fidelity systems and demonstrated the more common faults encountered in these systems.

The Cleveland Chapter met in October with H. H. Heller presiding. P. B. Williams, Chief Engineer at Jensen Manufacturing Company, discussed "Loudspeaker Enclosures."

CIRCUIT THEORY

On November 11 the Los Angeles Chapter of the Professional Group on Circuit Theory met at the Institute for Numerical Analysis on the UCLA campus. W. R. Abbott was Chairman. D. W. Slaughter delivered a paper on "Theory and Application of the Transistor Differential Amplifier," and H. V. Nuttall spoke on "Magnetic Systems."

COMPONENT PARTS

Gustave Shapiro, Chairman, presided at the November 10 meeting of the Professional Group on Component Parts. E. H. Bradley, Project Engineer at Melpar Electronics, spoke on "Band-Pass Filters Using Strip Line Techniques."

At an October meeting of the Washington Chapter, R. W. Tucker, of the Diamond Ordnance Fuze Laboratories, discussed "The Effective Leakage Resistance of Capacitors." He compared various dielectrics and described means for testing them.

COMMUNICATION SYSTEMS

On November 18, the Washington Chapter of the Professional Group on Communication Systems met in the auditorium of the Potomac Electric Power Company. M. L. Doelz, of Collins Radio Company, delivered a paper called "Predicted Wave Radio Telegraph and Data Transmission Systems." The speaker discussed predicted wave methods for frequency division multiplexing up to forty teletype channels in a three kc voice channel and the use of this system for high speed transmission of binary information. Mr. Doelz also described an integrated HF communication system for transmission of both voice and binary information utilizing Collins-developed components.

ELECTRONIC COMPUTERS

The Akron Chapter of the Professional Group on Electronic Computers met on October 26 with C. D. Morrill presiding. C. H. Reynolds, of the Dynamic Systems and Computations Laboratory, delivered the evening's speech. His topic was "The Application of Analog Computers in Two Operations Research Problems."

(Continued on page 84A)

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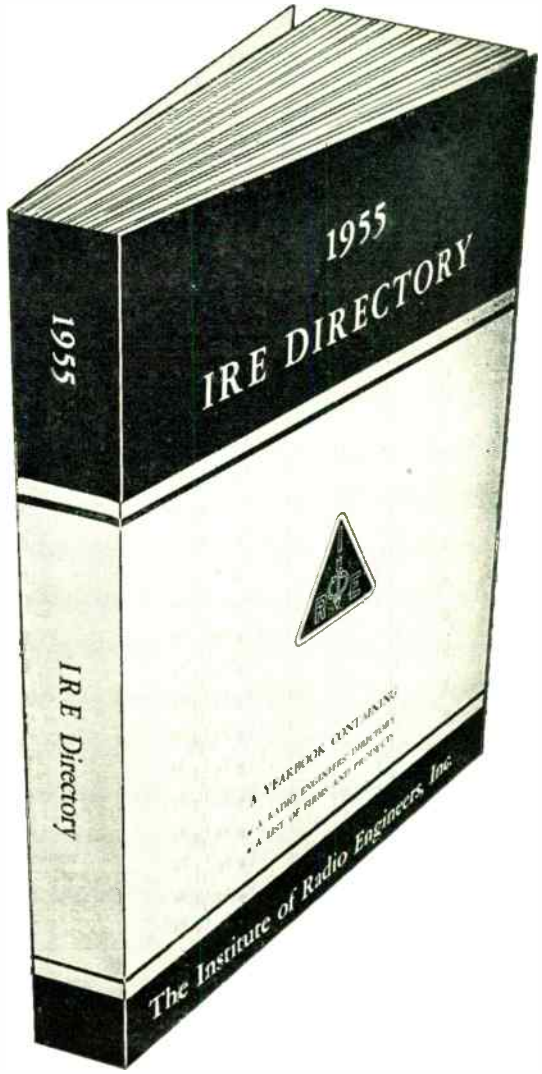

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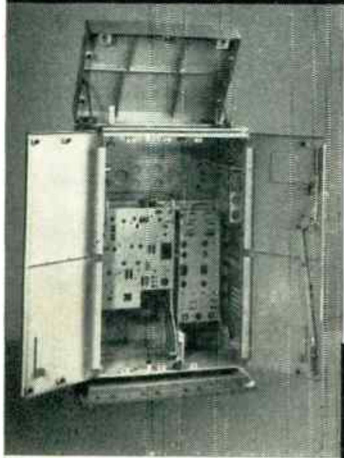

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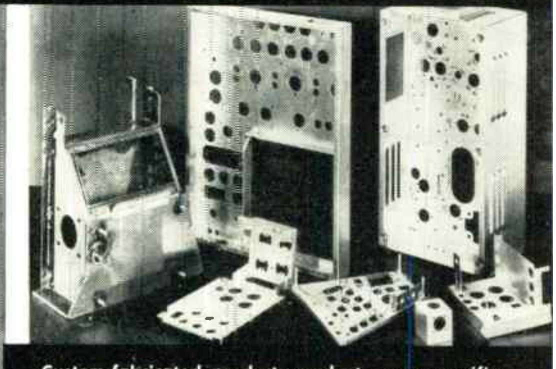


Professional Group Meetings

(Continued from page 82A)

The Dallas-Fort Worth Chapter met on October 19 at Chance Vought Aircraft, Incorporated, and Chairman L. B. Wadel presided. A demonstration of the electronic analog computer installation at Chance Vought was held.

The Los Angeles Chapter met on October 21 with Dr. Willis Ware presiding. The speakers were Dr. Gilbert King, of International Telemeter Corporation, and Dr. John Bower, of North American Aviation, Incorporated. Dr. King spoke on "A Photoscopic Memory Device," and Dr. Bower delivered a paper on "Automatic Machine Control."

At the September meeting of the Los Angeles Chapter officers were installed and a social gathering with wives present was held.

The Boston Chapter of the Professional Group on Electronic Computers met at MIT with D. R. Brown presiding. Dr. S. N. Alexander, of the National Bureau of Standards, delivered a paper, co-author of which was A. L. Leiner, called "DYSEAC —A Computer for Control Purposes." Dr. Alexander described the design considerations which governed the development of the DYSEAC; he also described several novel experimental applications of this computer, including real-time tie-ins with human operators and joint operation with the SEAC computer.

ELECTRON DEVICES

On October 13, the San Francisco Chapter of the Professional Group on Electron Devices met in the Stanford University Physics Building. Chairman S. F. Kaisel presided, and Dr. A. V. Haeff, Director of the Research and Development Laboratories at Hughes Aircraft Company, spoke on "Storage Tubes."

ENGINEERING MANAGEMENT

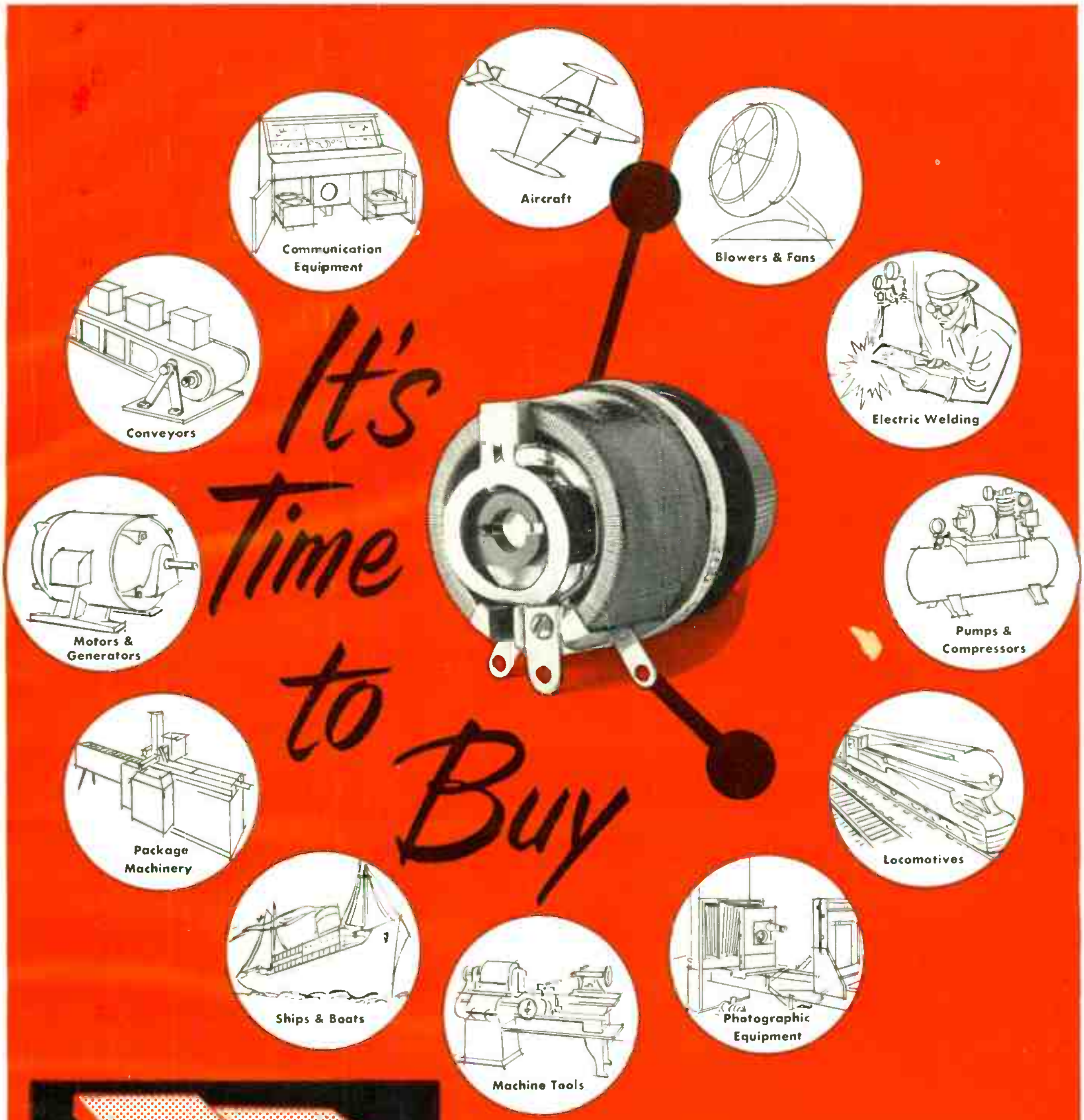
The Boston Chapter of the Professional Group on Engineering Management met on November 23 with S. Fishbein presiding. Professors A. Rubenstein and H. Shephard jointly delivered a paper called "Problems in the Transition of an Engineering Sample from One Stage to Another." The meeting divided into four groups, each group representing sales, production, engineering, and research. In this way the members looked at the problem of the transition of an engineering project from one stage to another.

The Los Angeles Chapter met in October at the Institute of Aeronautical Sciences. P. M. Kelly, of Hughes Aircraft Company, spoke on "Successful Business Planning Through Operations Research."

INFORMATION THEORY

The Washington Chapter of the Professional Group on Information Theory met at the National Academy of Sciences

(Continued on page 86A)



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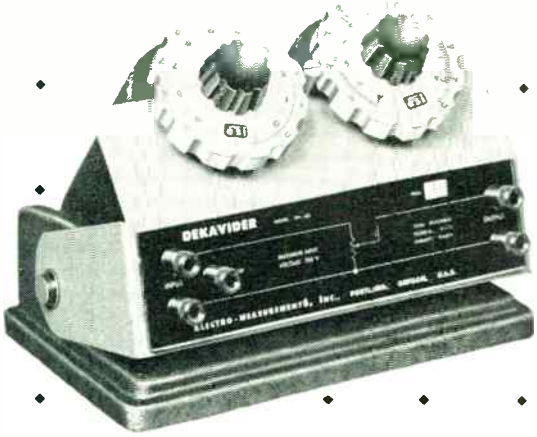
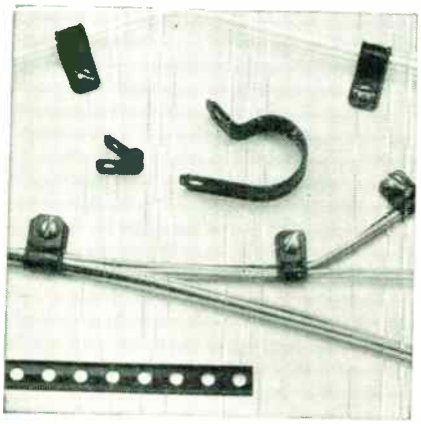




News-New Products

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

(Continued from page 100A)

Miniature Speaker

Production of the P275-Y, the first miniature speaker designed for transistorized pocket radios, has been introduced by the **Jensen Manufacturing Co.,** 6601 S. Laramie, Chicago, Ill.

The initial product appearance of the speaker was made in the TR-1, transistorized pocket radio recently introduced by Regency, a division of I.D.E.A., Inc.

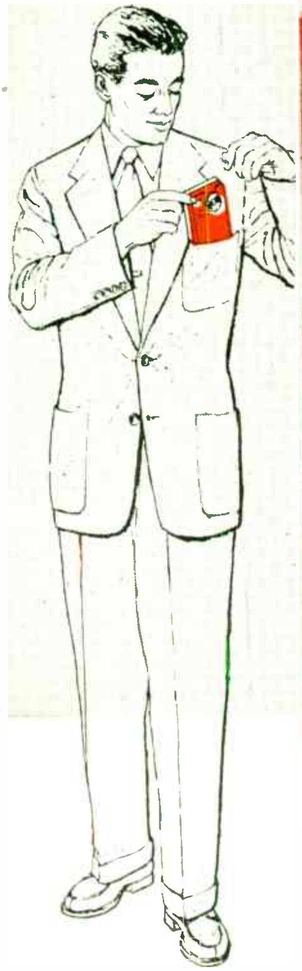
The speaker is $2\frac{3}{4}$ inches in diameter, $1\frac{3}{32}$ inches in depth, and weighs less than $2\frac{3}{4}$ ounces. An unusually high output performance with relatively low signal input is attained through design and engineering features which make fullest use of energy from the magnet. Nominal voice coil impedance at 1,000 cps is 16 ohms.

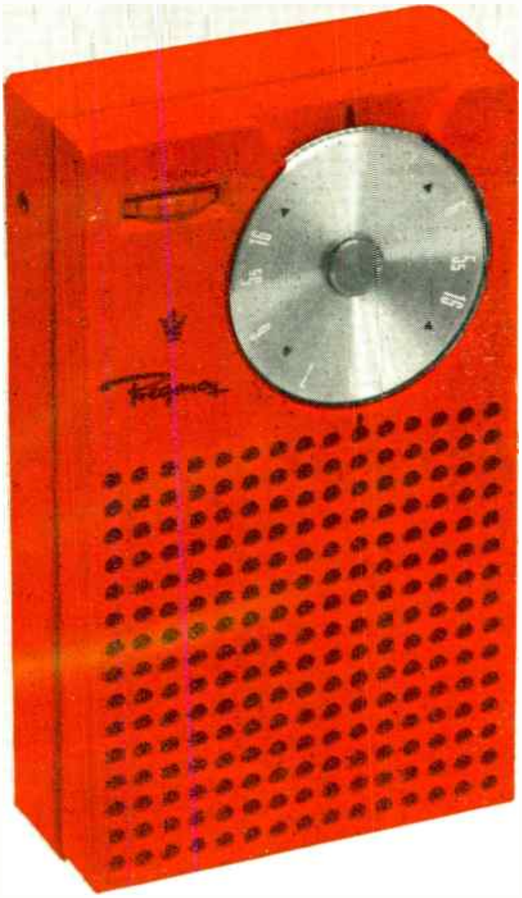
The P275-Y has future applications in miniature and portable radios, transceivers, paging units, and equipment of similar size and weight.

Self-Cooled Servo

A new compact self-cooled servo, series 5100-2237, is now available from **John Oster Manufacturing Co., Avionic Div.,** Racine, Wis. The entire device weighs 3.188 pounds, the servo motor is able to pull 1/15th hp at 6,000 rpm and has 22 ounce inches of stall torque. Overheating of the servo motor is prevented by a blower which functions independently yet is an integral part of the servo. The device is designed to drive an antenna on airborne military radar or for any other similar application.

(Continued on page 107A)





the First transistorized consumer product

. . . uses TI transistors!

Using four high gain Texas Instruments transistors, the world's first transistorized consumer product — a high performance pocket size radio — is now available on the retail market! Priced under $50, the world's smallest commercial radio receiver (manufactured by Regency of Indianapolis) achieves better performance than many much larger conventional sets. To produce the specially designed transistors used in this superb little instrument, TI has developed advanced manufacturing techniques that assure uniformly high product quality as well as mass production quantities.

With the transistor radio already a reality, the multi-million dollar consumer market is ready and waiting for still more transistorized products. Don't delay your own product development for lack of suitable low cost, high performance transistors. In designing transistorized products, depend on transistors from Texas Instruments, a leading supplier of transistors for a variety of commercial and military applications. Producing the industry's widest range of semiconductor devices — silicon or germanium; diodes or transistors — Texas Instruments is your most *experienced* source of supply for dependable semiconductor products.

* *With four Texas Instruments grown junction n-p-n germanium low cost, high gain transistors,* the Regency radio achieves power gains of 32 decibels in each intermediate-frequency stage and 37 decibels in the audio stage. One transistor is used as a combination mixer-oscillator, two as intermediate-frequency amplifiers, and one as an audio amplifier. Output transformer also TI manufactured.

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At least one of your interests is now served by one of IRE's 21 Professional Groups

Each group publishes its own specialized papers in its *Transactions*, some annually, and some bi-monthly. The larger groups have organized local Chapters, and they also sponsor technical sessions at IRE Conventions.

Aeronautical and Navigational Electronics (G 11)	Fee $2
Antennas and Propagation (G 3)	Fee $4
Audio (G 1)	Fee $2
Automatic Control (G 23)	No Fee
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Ultrasonics Engineering (G 20)	Fee $2
Vehicular Communications (G 6)	Fee $2

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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Please enclose remittance with this order.

A Technical Inventory of the Professional Groups

On June 2, 1948, one of the most startling developments in engineering society history came to fruition: the formation of the first Professional Group of the IRE. Just how important this development was, and is, can be convincingly demonstrated by a brief inventory of the Professional Group activities in 1954.

By the end of the year 28,000 IRE members had joined 23 Professional Groups. They joined because these Groups were able to provide them with specialized technical services and information they could not afford to miss.

One of the services they could not afford to miss was the Professional Group *Transactions.* In 1954 alone, Group members were flooded with 51 issues of *Transactions* totaling 3646 pages of valuable technical material. This was twice as many editorial pages as were published in the *Proceedings.* And this wealth of technical information could be had by paying only the small assessment fees levied by the various Groups.

Another service which 28,000 Group members found extremely important was the many meetings, sessions, and symposia held all over the country by the Groups. In fact, during 1954 the Groups participated in 70 major conferences and conventions, thus making available to their members, in still another way, the latest information on important new developments in their field.

The extensive national activities of the Groups were greatly supplemented by the activities of local Group Chapters in all parts of the country. A total of 117 Chapters have been organized in 27 local IRE Sections and have been holding meetings regularly.

The members of each Group have been introduced to one other important commodity—each other. Through local and national meetings and committees, thousands of engineers have had an invaluable opportunity to meet and exchange ideas with other engineers who are interested in exactly the same technical problems.

The inventory shows that if you have not yet joined a Professional Group, you are not getting the most out of your IRE membership.

W. R. Baker

Chairman, Professional Groups Committee

News-New Products

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

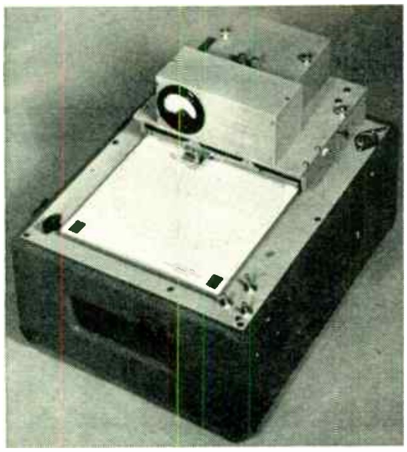
(Continued from page 104A)

The servo motor is a 2-phase 115 volt 400 cps motor with a no load speed of 10,000 rpm and a full load speed of 6,000 rpm. Stalled power input is 150 watts per phase. Acceleration is 31,000 Radians per second squared minimum. Rotor inertia is 50-gram centimeters square maximum.

The blower is a 1-phase 115 volt 400 cps motor. Power input total is 35 watts.

Servo-Polar Recorder

A new instrument designed especially for recording of antenna patterns and patterns of other directional devices is announced by **Sound Apparatus Co.**, Stirling, N. J.



This new recorder includes a self-contained servo system with amplifier, powerpack, and so forth. Accuracy of the recorder is determined by the specific component servo-system supplied and is priced accordingly.

The recorder can also be furnished with a Selsyn motor alone (as Model PR) having a standard gear reduction of 36:1 or other gear reductions to customer's specification.

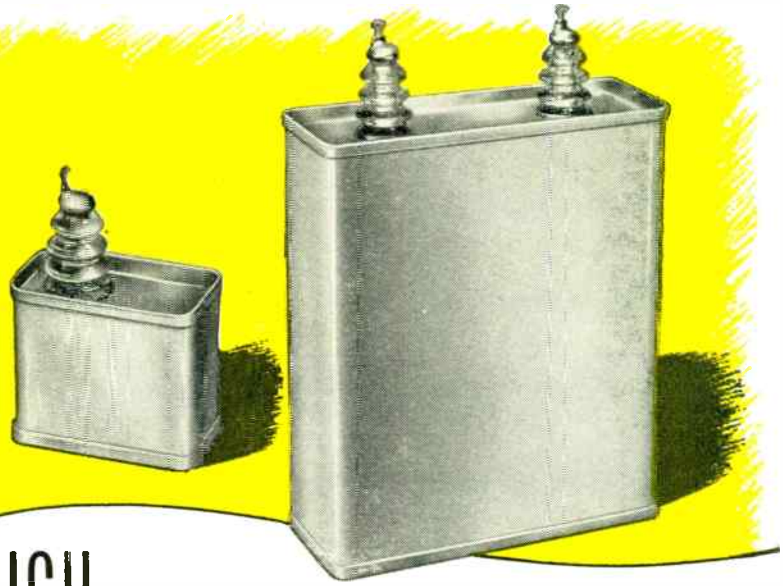
Recording width is 4⅛ inches; Potentiometer ranges from 0–20 db to 0–80 db; also linear, square root and squaring scales are available.

Frequency response from 20 to 200 kc. The electronic circuit can be furnished for either ac or ac/dc signal recording. Bulletins will be mailed upon request.

Frequency Divider

Gertsch Products, Inc., 11846 Mississippi Ave., Los Angeles, Calif., has introduced a new instrument, the FM-5 Frequency Divider, designed specifically to extend the frequency measuring range of either the Gertsch FM-3 or AM-1 down to 50 kc and the frequency generating range down to 200 kc with no loss of acracy. It both measures and generates up to 20 mc with continuous coverage.

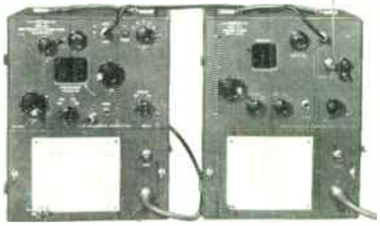
(Continued on page 108A)



News-New Products

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

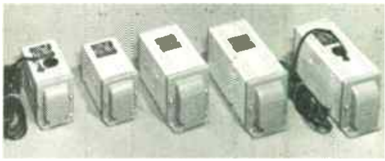
(Continued from page 107A)



The FM-5 consists basically of two tuned frequency dividers in cascade, each dividing by ten. These dividers are used to divide the fundamental output frequency (20–40 mc) of either the FM-3 or the AM-1 by exactly ten or one hundred depending on whether one or both dividers are being used. This gives a source of 2–4 mc and harmonics, or 200–400 kc and harmonics, as accurate and stable as the 20–40 mc input. Included is a detector-audio system for heterodyne type measurements. The new FM-5 is available in both rack panel and portable models. The portable model is available for either battery or ac operation.

Magnetic Voltage Regulators

Sorensen & Co., Inc., 375 Fairfield Ave., Stamford, Conn., now have available the first four models of what will be an extensive line of magnetic voltage regulators, or regulating transformers.



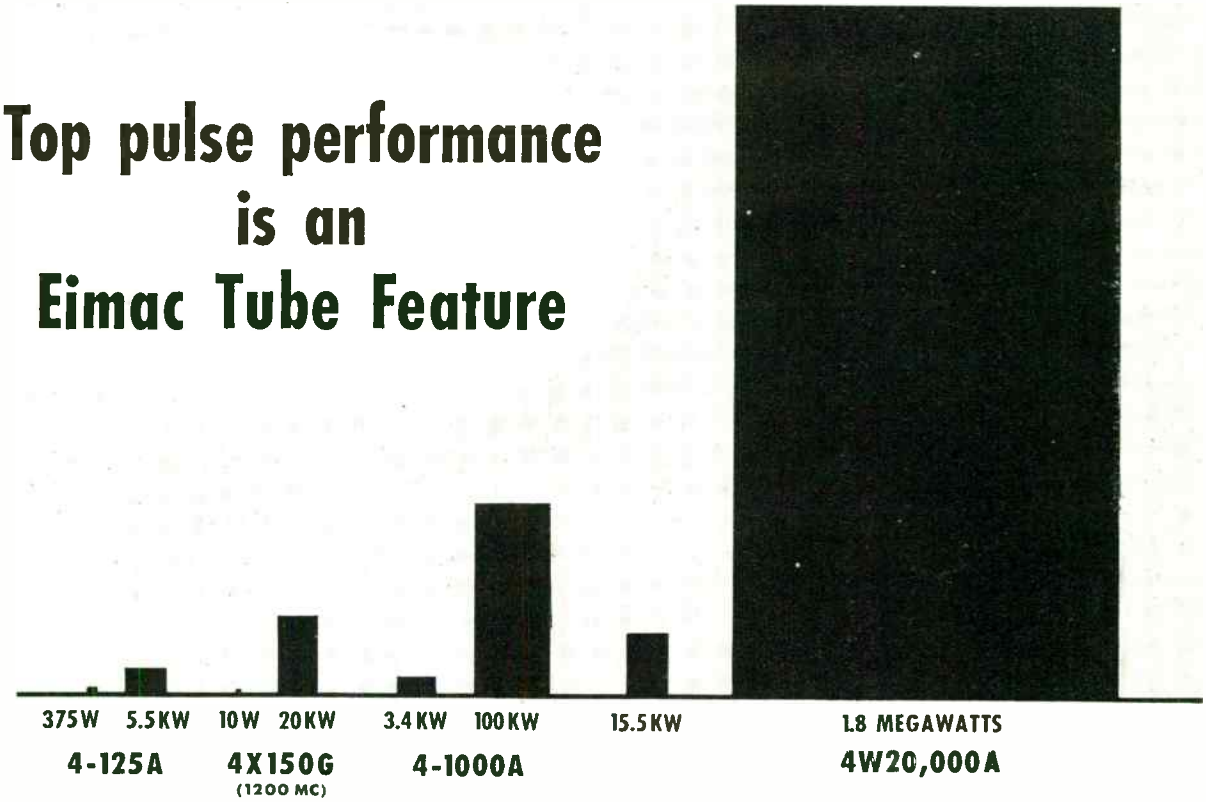
The units now available have capacities of 15, 30, 60 and 120 va. Soon to be added will be units of 250, 500, and 1,000 va capacities. They are primarily intended for incorporation into other equipment, where performance becomes more effective when the incoming line voltage is stabilized. However, they can be used as auxiliary line stabilizers.

Electrical specifications are as follows: Input voltage range, 95–130 vac, single phase, 60 cps; Output range, 115 vac, rms single phase; Regulation accuracy, ±0.5 per cent against line changes; Load conditions, ±0.5 per cent against line at any given load from 0 to full. Time constant, from 2 to 6 cps for line changes.

Full information, including mechanical configurations, is presented in catalog MVRI, available from Sorensen.

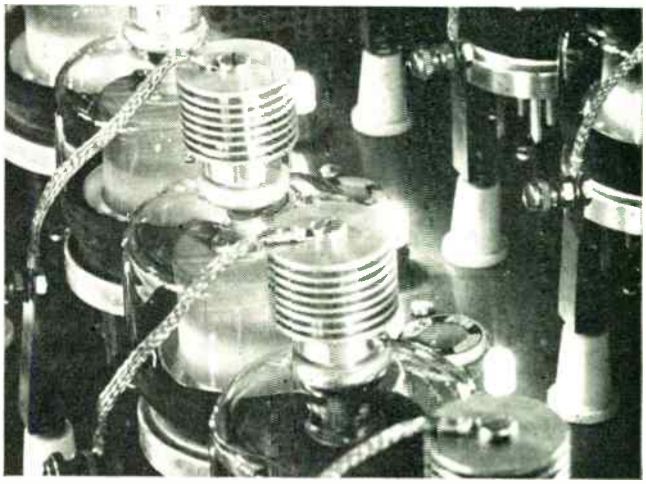
(Continued on page 110A)

Top pulse performance is an Eimac Tube Feature



EXAMPLE OF HIGH POWER OUTPUT CAPABILITIES OF EIMAC TUBES IN TYPICAL PLATE PULSED RF AMPLIFIER OPERATION

The chart on this page illustrates the amazing power capabilities of versatile Eimac broadcast and communications tubes in typical pulse amplifier application. Incomparable pulse performance is a feature of Eimac tubes stemming from reserve filament emission and ability to handle high electrode voltages and resulting currents. This, plus clean, simple design, free of troublesome internal insulators, and advanced production techniques, produces an unmatched quality enabling Eimac tubes to give long, reliable performance in pulse RF operation and pulse modulator service.



In addition to pulse rated CW tubes, Eimac has designed and produced many tube types specifically for pulse application. The 4PR60A radial-beam pulse tetrode, pictured here, is one of this famous family. An oxide coated cathode tube, it delivers 300kw of power output in pulse modulator service with only one kilowatt of pulse driving power. From the 100T power triode, used in the first Navy sea radar tests, to the 4W20,000A, Eimac pulse-rated tubes have filled key sockets in sea, land and air pulse operation.

Contact our Technical Services Department for your free copy of Eimac application bulletin No. 3, "Pulse Service Notes."

Eimac

EITEL-McCULLOUGH, INC.
SAN BRUNO, CALIFORNIA
THE WORLD'S LARGEST MANUFACTURER OF TRANSMITTING TUBES

NEW! 1955
MICROTRAN
TRANSFORMER CATALOG!
LISTS HUNDREDS OF MINIATURE TRANSFORMERS AVAILABLE AS STOCK ITEMS!

Miniaturizing? Don't gamble! Use these field-tested and proven MIL-T-27 type designs.
- No sampling expense — no wasted time!
- Eliminate redesign of production equipment!
- Used in guided missiles, airborne equipment, servos, transistor amplifiers, high temperature applications, and many, many other applications

Immediate Delivery at key industrial distributors!

Write — right away — for the brand new 1955 Microtran Catalog! Gives detailed information about available stock items: Hermetically Sealed, Molded, Encapsulated, Cased.

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hermetically sealed and type transistor type
miniature sub-miniature micro-miniature also standard types
microtran company

microtran co. 84-11 Blvd., Rockaway Beach, N.Y.

UHF ATTENUATORS

UHF ATTENUATORS, MODELS AT-50, AT-60

50 ohm resistive T-networks of concentric line construction.
FREQUENCY RANGE: AT-50: DC to 4000 MC.
AT-60: DC to 3000 MC.
VSWR: Better than 1.1 at all frequencies.
ACCURACY: ±½ DB.
RATED POWER: AT-50: 1W continuous • 1KW peak
AT-60: 2W continuous • 2KW peak
ATTENUATION: Standard: 3, 6, 10, 20, 40 or 60 DB.

AT-50
AT-60

SPECIAL VALUES UPON REQUEST

STEP ATTENUATOR MODEL AT-101

Uses AT-50 pads in multiple step coaxial turret arrangement.

AT-101A, ATTENUATION:
0, 10, 20, 30, 40, 50 DB.

AT-101B, ATTENUATION:
0, 20, 40, 60 DB.

EMPIRE DEVICES' expert engineering staff is available to give careful attention to your inquiries.

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News-New Products

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(Continued from page 108A)

Decade Delay Line

Gudeman Co., of California, Inc., 9200 Exposition Blvd., Los Angeles 34, Calif., now has in production a decade delay line, model GDDL-1000-1, with an overall delay of 1 μs. Dial-selected taps are at 0.1 μs intervals. Impedance is 1,000 ohms, and overall rise time is 0.1 μs. Delay element is hermetically sealed in epoxy resin, and the selectors for delay and termination are equipped with ceramic wafer switches which have solid silver contacts. Size: 7⅝ long×4⅜×4⅜ inches exclusive of terminals.

Complete data is available from Donald H. Allen, at the firm.

Video Sweep Generator

A new Video Sweep Generator, Type 1106, designed for the observation of frequency-versus-amplitude characteristics of wide band circuitry, and suited for color television video test purposes, has been announced by the **Tel-Instrument Co., Inc.**, Carlstadt, N. J.

The Type 1106 has a video frequency sweep of 50 kc to 6 mc with output adjustable from 1 millivolt to 2.0 volts peak-to-peak into a 75 ohm load from a source impedance of 75 ohms. Front panel switches control a maximum of 10 optional crystal markers each of which are furnished to customer specifications.

The type 1106 is designed for bench or relay rack mounting. The entire unit, including cabinet, weighs 29 pounds.

(Continued on page 112A)

How to pass a physical exam

Laboratory Coil Kit. Type X2060 aids in developing prototypes and pilot models. Contains 10 slug tuned coils of L86 size Type C, ranging from 2 Microhenries to 800 Microhenries, each slightly overlapping next coil in scale. Kit contains mounting hardware and lists such information as inductance range, wire size, number of turns, Q value. Coils are color-coded to chart for easy quantity-order.

CTC's coil forms pass their physical exams in great shape — thanks to precision manufacture.

The basic materials of these forms are certified, then checked again by us, before the forms are made. Each manufacturing detail is quality controlled to the high quality standards that enable us to offer *guaranteed* electronic components, custom or standard.

Forms then get these physical checkups: *mounting studs* checked for internal and external threads, for general size and electroplating; *form* checked for I.D., O.D. and concentricity; *slug* checked for threads, dimensions, electroplating and checked electrically for Q and permeability; *final assembly* checked for tightness, chips and cracks.

Other CTC components benefiting from CTC precision manufacture include terminal boards, terminals, capacitors, swagers, hardware, insulated terminals and coils. For all specifications and prices, write to Cambridge Thermionic Corporation, 456 Concord Avenue, Cambridge 38, Massachusetts. West Coast Manufacturers contact: E. V. Roberts, 5068 West Washington Blvd., Los Angeles 16 and 988 Market St., San Francisco, California.

Coil Form Data: Made of grade L-5 silicone impregnated ceramic. Winding diameters from .205" to $\frac{1}{2}$". Mounted heights from $\frac{19}{32}$" to $1\frac{11}{16}$". Certain forms, known as Type C, are also available with silicone fibreglas terminal retaining collars permitting 2 to 4 terminals. These are excellent for bifilar windings and advantageous for single pie windings because they permit terminals to be located above or below winding, thus shortening wiring to circuit elements.

CAMBRIDGE THERMIONIC CORPORATION

makers of guaranteed electronic components,
custom or standard

News-New Products

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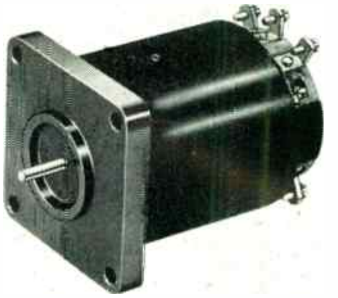
(Continued from page 110A)

Magnetic Resolver



A new magnetic resolver, Series 1800, is now offered by **John Oster Manufacturing Co., Avionic Div.**, Racine, Wis. Rapid response to step function waves is given by the specially processed high permeability steel core. A typical production test requirement is as follows: when checking null voltage output, the voltage decays to 2 mv within 175 μs after switchover with a 13 volt 1,000 cps square wave applied to the primary. The unit can be supplied with rotor and stator inductance values held within ±3 per cent when desired. Minimum brush noise level makes Series 1800 specially suited for driving circular sweep radar presentations. The resolver is also designed for other applications requiring exceptionally fast recovery time to a step function voltage wave. The vector sum of the output voltages of the quadrature rotor windings is constant in amplitude within ±0.5 per cent and at an electrical angle within 30 minutes of the resolver shaft. Bifilar or quadrature windings are available in the stator. Nominal input voltage is 26 volts 400 cycles with a transformation ratio of 0.29±5 per cent. Special design features may be incorporated as required.

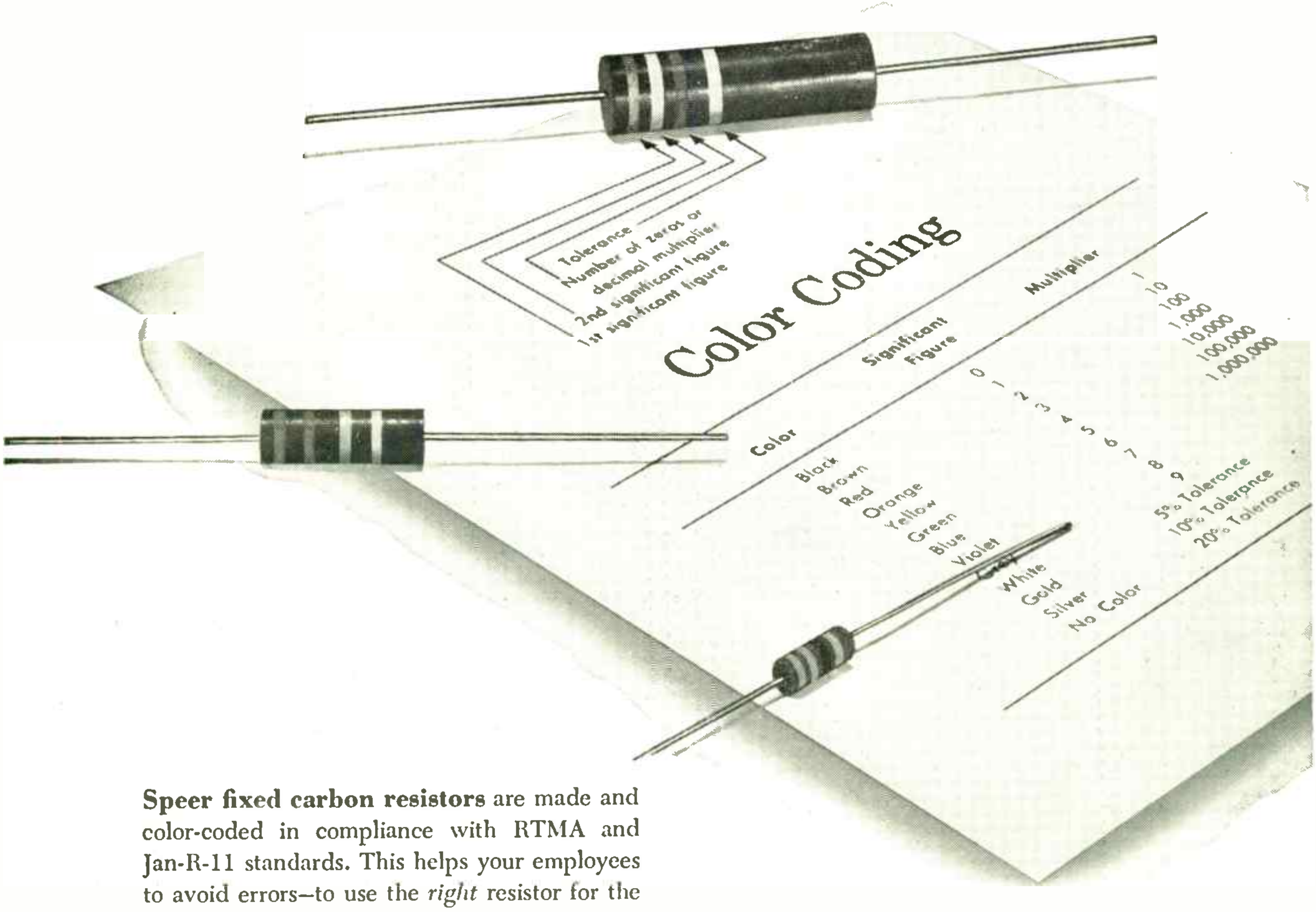
Tubeless Power Supplies

A catalog sheet covering new additions to the line of tubeless regulated power supplies manufactured by **Electronic Research Associates, Inc.**, 67–69 Centre St., Nutley, N. J., is now available. Units illustrated and described include a combined dc/ac medium voltage supply ideally suited for life-testing racks, computers, experimental equipment, and applications where low heat dissipation, long life and good transient response is a basic requirement. Also described is a portable, variable low-voltage, high current dc/ac supply designed especially for high amperage applications such as power transistor amplifiers, solenoid and magnetic clutch operation and ac motor control. Descriptive data is also included on a dual transistor supply which is designed especially for transistor and other multi-polarity applications.

A copy of this bulletin and related data can be obtained from the manufacturer.

(Continued on page 114A)

Speer makes it easy for you to choose the right Carbon resistor!



Speer fixed carbon resistors are made and color-coded in compliance with RTMA and Jan-R-11 standards. This helps your employees to avoid errors—to use the *right* resistor for the circuit every time.

Speer resistors are made better – are the right resistors for *every* circuit. By using very high pressure to create an inseparable bond between the protective phenolic shell and the carbon core, Speer gives its resistors these important advantages:

1. More efficient heat transfer.
2. Greater ability to sustain overloads for long periods of time.
3. Uniform diameter resistive element for the entire length of the resistor, which eliminates weak points and potential burn-outs.
4. Uniformly thick protective covering over the entire length, which eliminates low-voltage breakdown between resistive element and adjacent conductor – makes for minimum change in resistance when subjected to adverse humidity conditions.

All shipments of Speer resistors are given numerous tests for resistance rating, and are backed by a minimum resistance change when exposed to an accelerated ten-day humidity test. Speer manufactures a complete line of ½, 1 and 2 watt resistors in all standard values from 10 ohms to 20 megohms. Nonstandard values are available for special applications.

Write today for your free copy of Speer Resistor's new complete catalog

SPEER
RESISTOR

SPEER RESISTOR DIVISION

SPEER CARBON COMPANY
Bradford, Pennsylvania
Other Divisions: Jeffers Electronics
International Graphite & Electrode

America's most complete line

Carter

ROTARY POWER SUPPLIES

ROTARY POWER IS BEST

The "clop-clop" of "Old Bess" gave Grandma's buggy ride more vibration than the smooth Rotary Power of today's modern automobiles. ROTARY POWER is best for mobile radio, too . . . and for all DC to AC conversion . . . smoother . . . more dependable.

DC TO AC CONVERTERS

For operating tape recorders, dictating machines, amplifiers and other 110-volt radio-audio devices from DC or storage batteries. Used by broadcast studios, program producers, executives, salesmen and other "field workers".

DUO-VOLT GENEMOTORS

The preferred power supply for 2-way mobile radio installations. Operates from either 6 or 12-volt batteries. Carter Genemotors are standard equipment in leading makes of auto, aircraft, railroad, utility and marine communications.

CHANGE-A-VOLT DYNAMOTORS

Operates 6-volt mobile radio sets from 12-volt automobile batteries . . . also from 24, 32 and 64-volt battery power. One of many Carter Dynamotor models. Made by the world's largest, exclusive manufacturer of rotary power supplies.

BE SAFE . . . BE SURE . . . BE SATISFIED

AC can be produced by reversing the flow of DC, like throwing a switch 120 times a second. But ROTARY converters actually generate AC voltage from an alternator, same as utility stations. That is why ROTARY power is such clean AC, so dependable . . . essential for hash-free operation of recorders from DC power.

MAIL COUPON for illustrated bulletin with complete mechanical and electrical specifications and performance charts. Carter Motor Co., Chicago 47.

CARTER MOTOR CO.
2645 N. Maplewood Ave.
Chicago 47, Illinois

Carter

Please send illustrated literature containing complete information on ☐ Carter "Custom" Converters and ☐ Dynamotor Power Supplies

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Address ....

City ....State ....

News-New Products

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

(Continued from page 112A)

30-Channel Recorder

A new laboratory recording tool, used to monitor up to 30 phases of an experiment and have continuous simultaneous recordings of the activities on one paper, so that the entire 30 can be seen at once and visual comparisons can be made at the actual time of occurrence, is announced by **Alden Electronic and Impulse Recording Equipment Co.**, Westboro, Mass. The paper called Alfax which uses "electricity as the ink," makes it possible to pass a current from a stylus to the paper and make a mark. All elements are plug-in unit construction easy to set up and maintain.

It can be set up to monitor any operation mechanical, physical, chemical or electrical, or anything where information can be picked up from a switch controlled by a motion or a sensing device which can provide current for the marking power. The switches are attached by bolt, thumb tack or tape or just slipped onto the test device or equipment being monitored. From the switch a line is run to the recorder. To commence recording a push on, push off button is pressed; from this point on the recorder may be operated unattended.

Two models are available, one with tape speeds of 1 and 6 inches per minute and the other with 1 and 12.

(Continued on page 116A)

From servo-mechanisms to electronic computers, "RADIO" is a way of THINKING!

Far-reaching progress in the radio-electronic field is no "happy accident." Television, electronic computers and the "radiation" power of the atom, which soon will be harnessed to industry were not discovered . . . they were engineered. From "fission" to "computation," these engineering achievements are accomplished through an enormous process of information exchange—the methodical and brilliant teaming together of engineering *thinking* to solve a problem. In radio this work has been done deliberately by a growing engineering society, through its meetings and published proceedings, which unleash the creative minds of men.

In 1954, "Proceedings of the I-R-E" published 1837 text pages, exclusive of product news and departmental features. This is the word-count equivalent of seven 500-page textbooks on radio-electronics for engineers. It exceeds the contents of the next two contemporary publications put together. This "high" in genuine reader service was logically matched by advertising worth over a half-million dollars, by firms investing in the engineers' reading interest and benefiting by it.

AN/APR-4 LABORATORY RECEIVERS

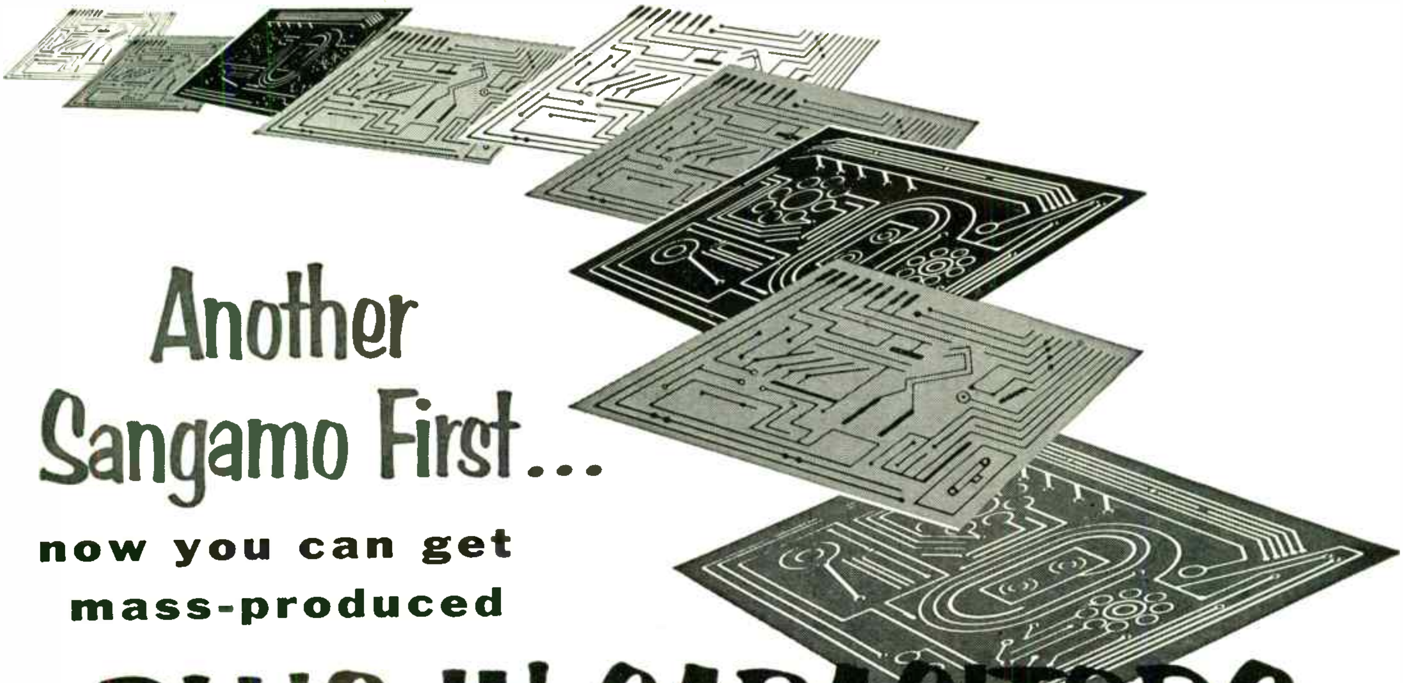
Complete with all five Tuning Units, covering the range 38 to 4,000 Mc.; wideband discone and other antennas, wavetraps, mobile accessories, 100 page technical manual, etc. Versatile, accurate, compact—the aristocrat of lab receivers in this range. Write for data sheet and quotations.

We have a large variety of other hard-to-get equipment, including microwave, aircraft, communications, radar; and laboratory electronics of all kinds. Quality standards maintained. Get our quotations!

NEW TS-13/AP X-BAND SIGNAL GENERATORS, with manual, $575.00 . . . T-47A/ART-13 Transmitters, $450.00 . . . H-P, Boonton, G-R, Measurements, and other standard items in stock; also nucleonic equipment.

ENGINEERING ASSOCIATES

434 PATTERSON ROAD — DAYTON 9, OHIO



Another Sangamo First...

now you can get mass-produced

PLUG-IN CAPACITORS

for printed circuitry applications

Sangamo now offers you production quantities of plug-in paper tubular and dry electrolytic capacitors for use in your automated production of under-chassis assemblies. These Sangamo plug-in capacitors are designed specifically for use in printed circuit applications.

PLUG-IN TUBULAR PAPER CAPACITORS

These plug-in paper tubulars incorporate all the internal design features of the famous Sangamo Telechief. They come in a molded bakelite case with a moisture resistant end fill, and leads cut and properly spaced to fit. They are available in a range of popular sizes for almost any application.

PLUG-IN ELECTROLYTICS

Leads will not contaminate solder pots during the printed circuitry dipping process . . . heat created when leads are soldered will not injure Sangamo plug-ins because terminals are designed so that the unit stands off from the circuit board . . . this "stand-off" feature also permits the designer to run additional circuits under the capacitor.

Write for complete information.

SANGAMO ELECTRIC COMPANY

MARION, ILLINOIS

SC55-1

NEW UHF MEGACYCLE METER

With the Widest Frequency Coverage in a Single Band

FEATURES

- Excellent coupling sensitivity.
- Fixed coupling point.
- Small grid current variation over band.
- Calibration point every 10 Mc.
- Uses split-stator tuning condenser with no sliding metal contacts.
- Standard camera socket for tripod fixtures.
- Octogonal case for convenient positioning.
- Useful in television transmitting and receiving equipment.

MODEL 59 UHF

SPECIFICATIONS

FREQUENCY RANGE: 430-940 Mc in a single band
FREQUENCY ACCURACY: ±2% (Individually calibrated)
OUTPUT: CW or 120-cycle modulation
POWER SUPPLY: 117 volts, 60 cycles, 30 watts
DIMENSIONS: Oscillator Unit 4⅜" x 2½"
Power Unit 5⅛" wide x 6⅛" high x 7½" deep

Laboratory Standards

MEASUREMENTS CORPORATION
BOONTON · NEW JERSEY

Ride that comet!

"Hitch your wagon to a star!" Everyone who knows the pace of the radio-electronic industry is riding the IRE comet in some way. 704 exhibitors will be in the Radio Engineering Show. And almost all of them will use the March issue as a convention-in-print, in which the advertising itself is a Radio Engineering Show. Best of all, the show space is sold out . . . but the March issue of "Proceedings of the IRE" is open to you and will do a good job. Deadline—February 1.

Engineers are educated to specify and buy!

INSTITUTE OF RADIO ENGINEERS
Proceedings of the IRE
Advertising Department
1475 Broadway, New York 36, N. Y.

News-New Products

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(Continued from page 114A)

Precision Resistors Catalog

Monson Manufacturing Corp., 6059 W. Belmont Ave., Chicago 34, Ill., is now offering a catalog page picturing and describing its new line of flat rectangular modular construction bobbinless precision non-inductive-wire resistors. Full technical information includes data on fibre glass epoxy, or polyester resin housing, vibration and shock resistance, temperature characteristics, resistance range from $\frac{1}{10}$ ohm to 2½ megohms, tolerances, resistance wire, terminals wide variety of sizes, thicknesses from 1/16 inch up, applications and a table showing typical sizes and resistances available. Free upon request to manufacturer.

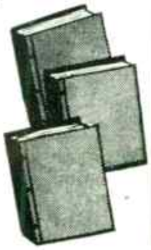
Metal Film Resistor

The Daven Co., 195 Central Ave., Newark, N. J., announces a new hermetically sealed, metal film type resistor. Designated the Davohm Series 850, it will reliably performed to requirements which previously dictated use of precision wire-wound resistors.

(Continued on page 118A)

ENGINEERS

Save your firm thousands of dollars in searching for data on ELECTRONIC TEST EQUIPMENT of interest to USAF.



By special permission data sheets on Research supported and monitored under our WADC, ARDC contract now available to manufacturers at low cost.

- Order your copy of a three volume set containing illustrated descriptive data sheets on 870 items procured for use by the U. S. Air Force.
- Contains 2400 (8½ x 11") pages, recently brought up-to-date, mounted in 3 post expandable hard back binders.
- Price $100 per set plus postage while supply lasts. Orders accompanied by check filled as received with postage paid.

CARL L. FREDERICK
AND ASSOCIATES
Bethesda 14, Maryland

LAMBDA POWER SUPPLIES FOR

Fixed Voltages through 405V

Heavy-duty "600 MA" series now includes twelve models, six voltage ranges

New regulated power supplies in Lambda's precision "600 MA" series are designed for installations which require fixed voltages through 405 V, but may be adjusted over the voltage ranges indicated for each model. They are engineered primarily for industrial applications and based on continuous-duty operation at maximum ratings.

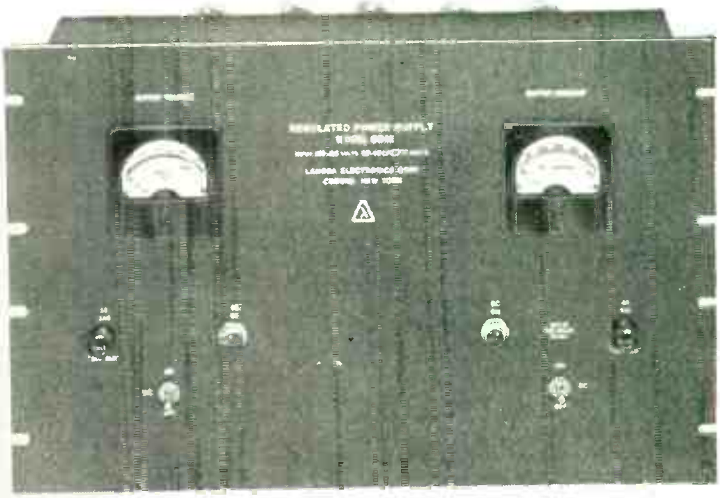
Produced by power supply specialists, Lambda "600 MA" power supplies are economical in cost. They free your own staff from the costly and time-consuming design and construction supervision which would be necessary if you constructed your own equipment.

BROAD USES

"600 MA" models are exceptionally suited for television studio and transmitter equipment, tube ageing apparatus, computer installations and multi-channel equipment, among other applications.

IMMEDIATE DELIVERY

All models are now available from stock. Shipment will be made promptly on receipt of your order.



Rack Model 60M (with meters) $289.50
(Also illustrates Models 61M, 62M, 63M, 64M and 65M. Models 60, 61, 62, 63, 64 and 65 identical equipment without meters.)

SPECIAL FEATURES

- Excellent regulation—low output impedance—low ripple
- Oil-filled, hermetically sealed capacitors
- Vacuum varnish-impregnated transformers and chokes
- Stable 5651 voltage reference tube
- 30-second time-delay relay circuit
- Rated for 24-hour duty
- Vernier high voltage adjustment
- Easy-to-read 3½" meters on M models
- Extra-length cord
- Can replace several smaller units
- Every specification lab-checked before shipment

SCHEDULE OF PRICES

Model 60	$259.50	Model 63	$239.50
Model 60M	289.50	Model 63M	269.50
Model 61	249.50	Model 64	244.50
Model 61M	279.50	Model 64M	274.50
Model 62	239.50	Model 65	249.50
Model 62M	269.50	Model 65M	279.50

Available for immediate delivery. Prices F.O.B. factory, Corona, N.Y.

SPECIFICATIONS FOR "600 MA SERIES"

Input:
105-125VAC, 50-60C, 875W (Model 60); 825W (Model 61); 775W (Model 62); 715W (Model 63); 675W (Model 64); 585W (Model 65)

DC Output (regulated)
Voltage and currents:

Models	Voltage range*	Current range**
60 & 60M	345-405VDC	0-600MA
61 & 61M	295-355VDC	0-600MA
62 & 62M	245-305VDC	0-600MA
63 & 63M	195-255VDC	0-600MA
64 & 64M	100-200VDC	0-600MA
65 & 65M	0-100VDC	50-600MA

**Voltage range for any given model is completely covered in four continuously variable bands.*
***Current rating applies over entire voltage range.*

Regulation (line)	Better than 0.15% or 0.3V
Regulation (load)	Better than 0.25% or 0.3V
Impedence	Less than 2 ohms
Ripple and Noise	Less than 5 millivolts rms
Polarity	Either positive or negative may be grounded

AC Output (unregulated):
6.5VAC at 20A (at 115VAC input). Allows for voltage drop in connecting leads. Isolated and ungrounded.

Ambient Temperature and Duty Cycle:
Continuous duty at full load up to 50°C (122°F) ambient.

Controls, Terminals and Overload Protection:

DC output controls:	Band-switches and screw-driver adjusting vernier-control, rear of chassis
AC and DC switches:	Front panel
External overload protection:	AC and DC fuses, front panel
Internal failure protection:	Fuses, rear of chassis
Input and output terminals:	Barrier terminal block, rear of chassis

Meters:
3½" rectangular voltmeter and milliameter (Models 60M, 61M, 62M, 63M, 64M and 65M only).

Voltage Reference Tube:
A stable 5651 voltage reference tube is used to obtain superior long-time voltage stability.

Time-Delay Relay Circuit:
A 30-second time-delay relay circuit is provided to allow tube heaters to come to proper operating temperatures before high-voltage can be applied.

Size, Weight, Panel Finish:

Size:	Standard 19" relay-rack mounting 12¼" H x 19" W x 9" D
Weight:	70 lb. net; 105 lb., shipping
Panel Finish:	Black ripple enamel (standard)

LAMBDA Electronics Corp.

THE FIRST NAME IN POWER SUPPLIES

103-02 NORTHERN BLVD. • CORONA 68, NEW YORK • TWINING 8-9400

AUTOMATIC! Transistor Noise Figure Measurement

Now available, a new instrument for transistor Noise Figure measurement.* Automatically indicates Noise Figure of all types of transistors and transistor amplifiers on a continuous reading basis. Just plug in the transistor or amplifier and read Noise Figure directly on the meter!

Model NFT Transistor NF Meter

- V For Laboratory and Factory Applications
- V Quality Control, Production Testing
- V Low Noise Figure Selection and Evaluation
- V Optimization of Circuit and Operating Parameters
- V Rating and Specification Checks
- V Trouble Shooting of Transistor Devices
- V Reliability Evaluation

Specifications

Noise Figure Range	5 to 65 db
Measurement Freq.	1000 cps center F.†
Type of Reading	Direct Reading
Input Circuit	500 ohm emitter R.
Emitter Supply	Ie, 0-1.0/10 MA
Collector Supply	Ec, 0-10/100 volts
Indicating Meters	4½" meters
Hardwood Case, 8¾ x 19" Panel, 14" Depth	

Price $625 FOB Caldwell, N.J.

Used By Leading Laboratories and Factories

For Additional Information Write for Bulletin PC

*Patents Applied For
†Other Frequencies on Special Order

Sales Engineers in all Areas

ELECTRONIC RESEARCH ASSOCIATES, INC.
MAILING ADDRESS: BOX 29, CALDWELL, NEW JERSEY
67 EAST CENTRE STREET, NUTLEY, N.J. NUtley 2-5410

PORTABLE PHONOGRAPHS · TV BOOSTERS · INDUSTRIAL and MEDICAL EQUIPMENT

When You Need Coated fabrics...

Fabric-covering problems vary with the size and shape and function of the carrying case. Here's the cue for APEX specialists! For fast-colored, durable fabrics to make your units SELL faster and LAST longer... ask men who KNOW.

It will cost you nothing to let APEX specialists consider your problems.

APEX COATED FABRICS

For 29 years "THE HOUSE of SERVICE"

APEX COATED FABRICS, Inc.
12-16 East 22nd St., N. Y. City 10
SPring 7-3140

SERVICING KITS · TAPE RECORDERS · ANTENNA ROTATOR · CONTROL CABLES

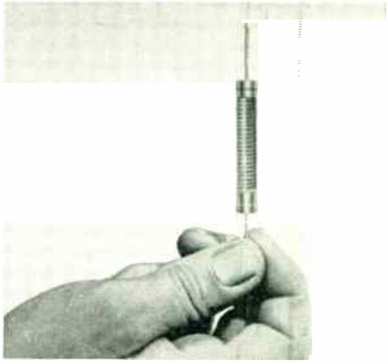
PORTABLE RADIOS · SERVICEMEN'S CARRYING CASES · PORTABLE PA SYSTEMS

SOUND and PROJECTION EQUIPMENT · PORTABLE TV SETS · TEST INSTRUMENTS

News-New Products

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

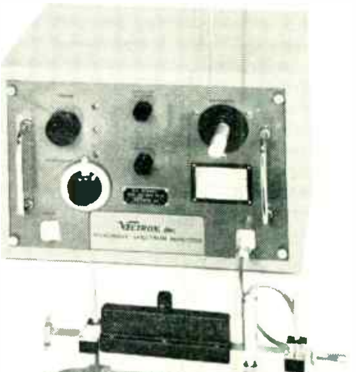
(Continued from page 116A)



The resistive element of the Series 850 is deposited on the inner surface of a glass tube. Electrical connections are silver bands fused to the element and the glass. End caps are bonded to the glass in a true glass-to-metal seal, providing complete hermetic sealing for over 60 psi. Various resistances are obtained by varying the metal deposit in solid form, spirals, or parallel bands between the end caps, depending on the application. Performance characteristics are said to exceed the requirements of MIL-R-10509A. Accuracies to ±1, ±½ and ±¼ per cent are possible in production quantities because of the great stability.

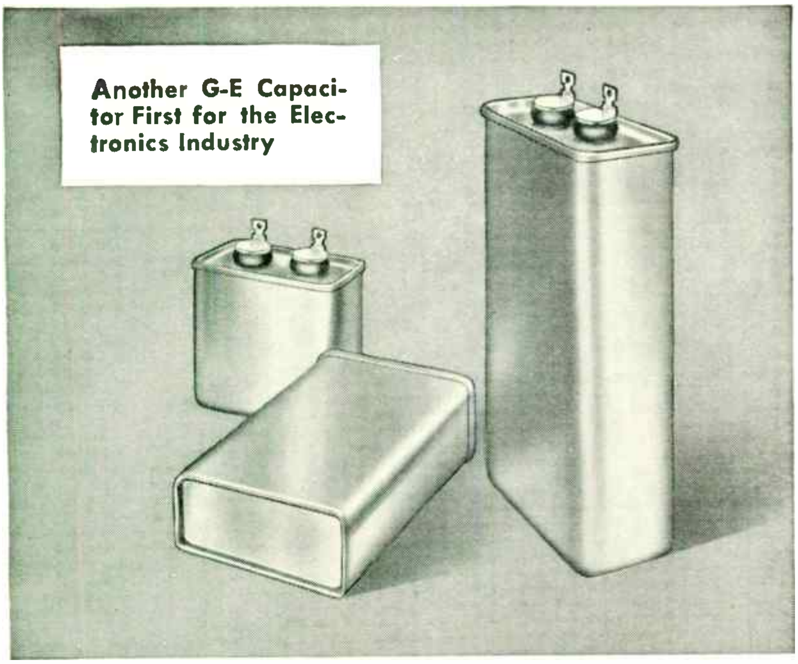
The Series 850 resistors are now available in ½, 1 and 2 watt sizes. The ½ watt, Type 850, is available in values from 4 ohms to 100,000 ohms; the 1 watt size, Type 851, from 10 ohms to 100,000 ohms; and the 2 watt size, Type 852, from 10 ohms to 200,000 ohms. Higher values will be available shortly. Further information and data is available from Daven Electronic Sales Corp.

K-Band RF Heads



New K-Band rf heads, manufactured by **Vectron, Inc.**, 402 Main St., Waltham 54, Mass., covering the microwave spec-

(Continued on page 120A)


Another G-E Capacitor First for the Electronics Industry

DRAWN-RECTANGULAR CASE has no soldered seams, does not depend on solder for mechanical strength and effective sealing.

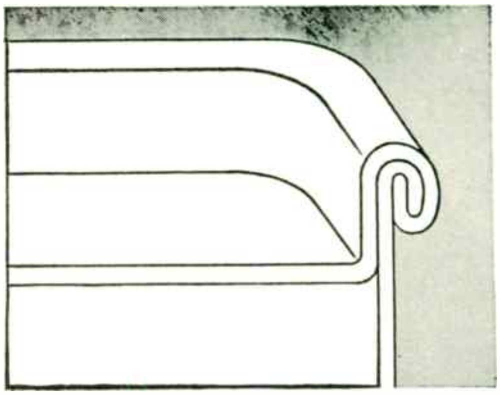
new . . . G-E CAPACITORS IN DRAWN-RECTANGULAR CASES

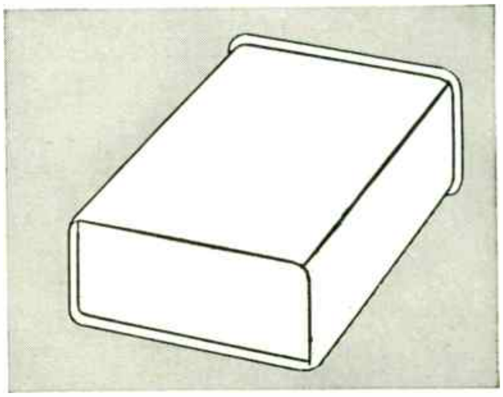
- **Solderless, double-rolled cover seam**
- **Seamless case with standard dimensions**

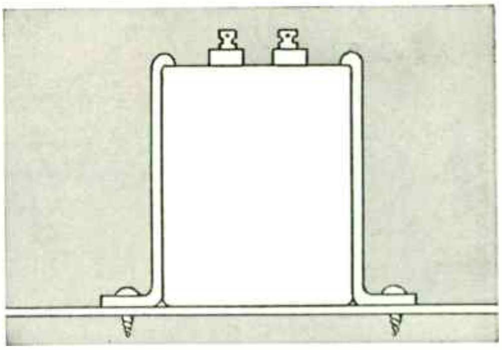
General Electric is now producing fixed paper-dielectric capacitors in seamless, solderless cases with standard dimensions that comply with or exceed MIL specifications. For complete information contact your G-E Apparatus Sales Office or write for Bulletin GEC-809A to Section 442-24, General Electric Co., Schenectady 5, N. Y.

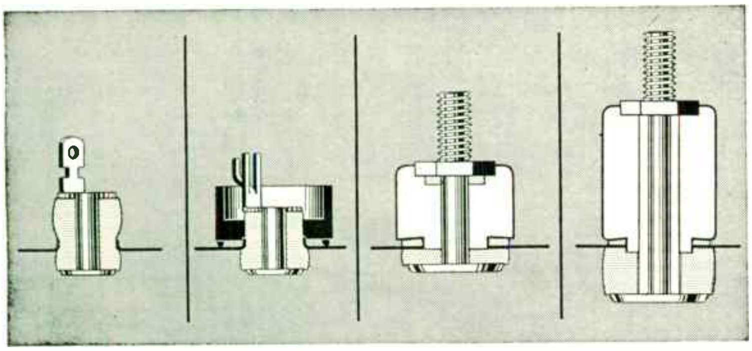
Progress Is Our Most Important Product

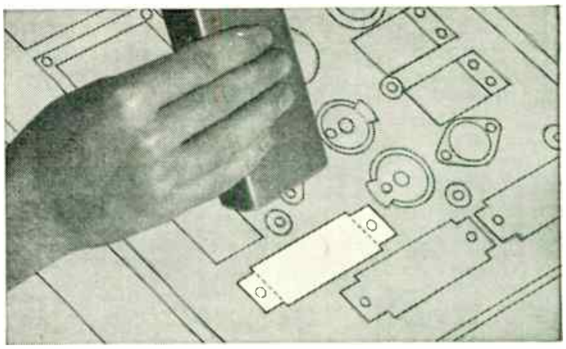
GENERAL ELECTRIC


SOLDERLESS DOUBLE-ROLLED COVER SEAM makes a mechanically strong, hermetic seal.


BOTTOM OF CASE IS INDENTED to permit mounting in inverted position.


UPRIGHT OR INVERTED MOUNTING is possible using either spade lug, or footed brackets (above)


FOUR BUSHINGS STYLES are available for applications below 2000 volts d-c, special skirted bushings for higher voltages.


STANDARD CASE SIZES are interchangeable, making it unnecessary to change drawings or circuit layouts.

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

(Continued from page 118A)

trum from 12,400 to 40,000 mc are complete microwave tuning units which include an rf assembly and a K-Band mixer. These heads were specifically designed for use with the Vectron SA25 microwave spectrum analyzer, but earlier models of the analyzer, as well as other analyzers, can be modified or adapted to use these assemblies. The broad range of K-Band requires three mixers with different size waveguides, to cover the full range in conjunction with special rf assemblies. Standard heads permit economical coverage of the most actively used portions of the spectrum; the 25K1 tunes from 15,300 to 17,700 mc, the 25K2 covers 22,800 to 26,400 mc, and the 25KQ1 includes 34,000 to 38,600 mc. Other portions of the band are covered by special combinations as required. Detailed specifications and operating data are contained in Bulletin K-Band, available from the manufacturer.

Graham Appointed by Ford Instrument

Robert L. Graham has been appointed Sales Promotion Coordinator of **Ford Instrument Co., Div. Sperry Corp.,** 21-10 Thomson Ave., Long Island City 1, N. Y., and will handle product promotion for the company, including product advertising, exhibitions, and literature.

Mr. Graham was previously Assistant to the Director of Public Relations at Ford Instrument. A graduate of Columbia University, he has served on the editorial staffs of "American Machinist," "Design News," "Product Design and Development News," and was an Editor of sales publications for the Industrial Division of Minneapolis-Honeywell Regulator Co.

Flat-Frame Switches

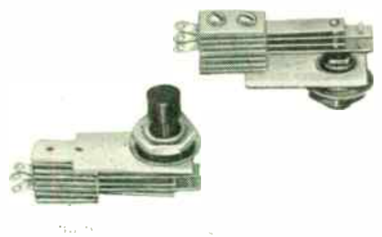
Through the utilization of a smaller spring design, which has resulted in the reduction of the entire physical size of the switch, **Switchcraft, Inc.,** 1328 N. Halsted St., Chicago 22, Ill., has developed a new line of flat-frame switches, called "NF Switches."

A rugged flat frame readily adaptable to any stack or "pile-up" of contact springs provides a simple, direct acting, small, push button switch. Through modification and combinations of contact springs, these switches can be made to meet most requirements.

(Continued on page 121A)

News-New Products

(Continued from page 120A)



Contacts are silver for minimum contact resistance, rated at 3 amperes, 120 volts ac non-inductive load. Also can be made with welded cross-bar Palladium contacts for low level circuits.

Seven standard circuits: Single "Make"; Single "Break"; Single "Break-Make" SPDT; Two "Makes"; Two "Breaks"; Two "Break-Makes" DPDT; Three "Break-Makes" 3PDT (3 form C).

Full details may be had by contacting the manufacturer.

Positions Wanted

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 Institute publishes free of charge notices of positions wanted by I.R.E. 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 Institute necessarily reserves the right to decline any announcement without assignment of reason.

AUTOMATION ENGINEER

Capable engineer desires connection at management level with company doing automation work for itself or customers. Will consider consulting. Please describe situation in detail. Box 785 W.

ELECTRONIC ENGINEER

BEE June 1954. 3 years U.S. Navy ETM 1/c. 1 year design and development; 5 years technical experience. Desires future. Will relocate. Box 786 W.

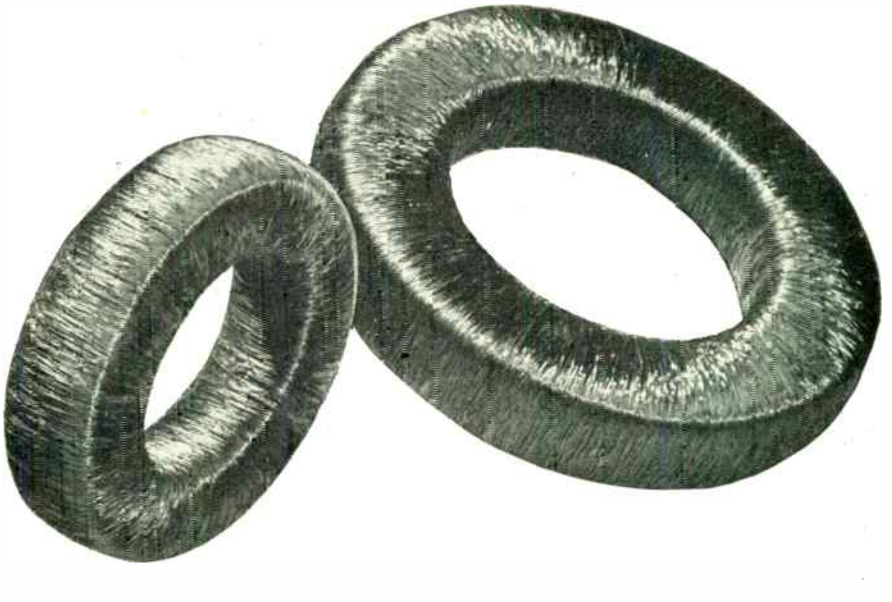
ENGINEER

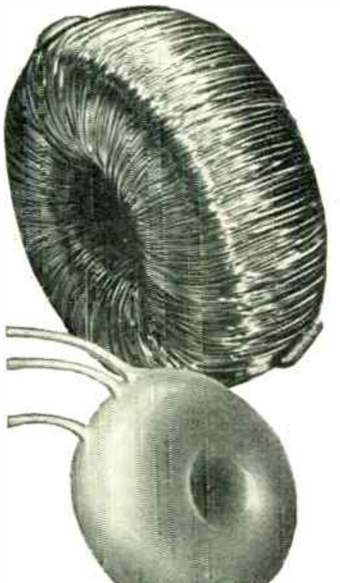
BSEE, MSEE, age 28, married, one child. Graduate work in mathematics, servomechanisms, feedback amplifiers. 2 years electronic work in Army; 2 years university instructor; 2 years circuit development and design; 2 years system Project Engineer on classified Government contract. Desires responsible position in Philadelphia metropolitan area. Box 787 W.

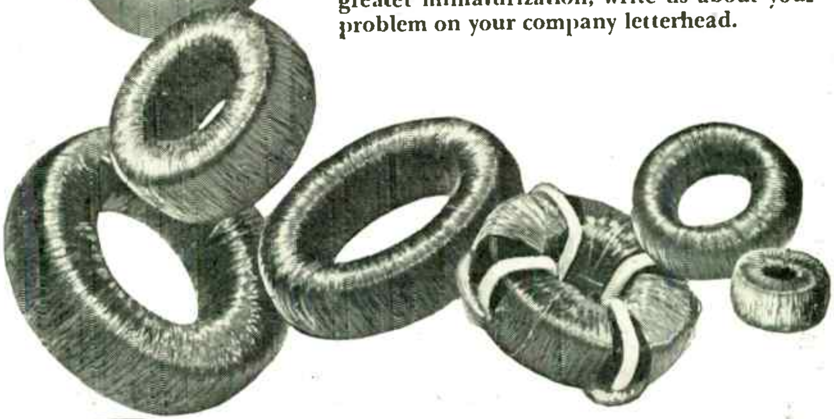
ENGINEER

BS in engineering physics. 3 years as engineer in electronics development and design, product engineering and technical writing. Will be released from service this winter. Desires work abroad. Age 25, married. Box 789 W.

(Continued on page 121A)







Positions Wanted

(Continued from page 121A)

SYSTEMS ENGINEER

BEE degree, age 32. 8 years engineering experience; electromechanical development, instrumentation, environmental control on guided missiles and photo-reconnaissance systems; all phases of industrial engineering including incentive programs and cost analysis. Desires supervisory position in New York area utilizing above knowledge. Box 790 W.

ENGINEER

BEE 1951, age 29. 3½ years Project Engineer on classified R & D electronic fire control systems and equipment, radar and infrared; 3 years Radar Officer, U.S. Navy; Varied experience in design and production. 1 year LLB. Post-graduate courses in EE. Desires position in R & D, or application. Willing to learn and relocate. Box 791 W.

ENGINEER (No License)

Graduate of Brooklyn High School of Auto Trades and R.C.A. Institutes. Want position with future; can work in conjunction with engineering staff in electronics and mechanical fields. Married, age 30, veteran. Box 792 W.

ENGINEER

BS in Mil. Engineering, MS in com. engineering. Ph.D. in electrical engineering. Specialized in network theory, circuit design, filter design, transit analysis. Desires association with consulting engineering firm in anticipation of eventual retirement from Government service. Prefer northern New Jersey location. Box 793 W.

ELECTRONIC—PRODUCT ENGINEER

BEE 1951. Age 33. 13 years in electronics. Design, development, production on fire and missile-control radar systems. Video, servo, CRT, data transmission, systems integration, human engineering. Liaison between engineering and production. Supervisory and some administrative experience. Self-starter and neck sticker-outer when expediency requires. Seeks position slightly over his head. Will relocate. Present income $9,000. Box 802 W.

ELECTRONIC ENGINEER

BEE, MS. 5 years electronic engineering experience. Pulse circuits, microwave, radar development. 1 year technical writing. Desires position in electronic research and development. New York City area preferred. Box 803 W.

SALES ENGINEER

BEE. Age 27, married. 4 years experience in Military electronics, including 2 years Application Engineer in aviation electronics. Desires a challenging opportunity in a sales capacity. Metropolitan New York area. Box 804 W.

ENGINEER

Twenty-seven years a technical writer and editor on a New York newspaper. Wants public relations, publicity or technical writing-editing job in electronics. Preferably in New York area. Box 805 W.

(Continued on page 126A)

1922—Roll-out of a Boeing-built fighter

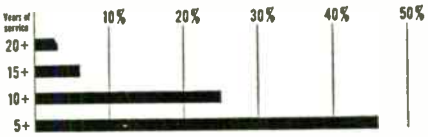
1954—Roll-out of America's first jet transport, the Boeing 707

Engineers—you can grow with Boeing

New career opportunities continue to open up at Boeing—as they have for the last 38 years. You can find direct application for your education and experience—in Research, Design or Production.

At Boeing you'd work with engineers who developed: The world's first all-metal, 3-mile-a-minute commercial transport. The first pressurized airliner. The first effective four-engine bomber (the B-17). Today's fastest operational bomber (the six-jet B-47). The even more advanced B-52 eight-jet global bomber, and the 707, America's first jet transport. Boeing engineers continue to design "years ahead," doing research on nuclear-powered aircraft and supersonic flight. They are also developing a new Air Force defense weapons system, based on the Boeing F-99 Bomarc pilotless interceptor. These long-range programs project Boeing progress far into the future.

One measure of the satisfaction of Boeing careers is given in the chart below. It shows that 46% of Boeing engineers have been with the company for five or more years; 25% for 10 or more years; and 6% for 15 or more years.



Here are other advantages: Boeing promotes from within and holds regular merit reviews to assure individual recognition. Engineers are encouraged to take graduate studies while working and are reimbursed for all tuition expenses. Of technical graduates at Boeing, 28% hold Mechanical Engineering degrees, 24% Electrical, 19% Aeronautical, and 9% Civil. The remainder is comprised of other engineering graduates, physicists and mathematicians.

For full Boeing career information, send résumé of your educational and experience background to:

JOHN C. SANDERS, Staff Engineer — Personnel
Boeing Airplane Company, Dept. G-9, Seattle 14, Wash.

BOEING

SEATTLE, WASHINGTON WICHITA, KANSAS

To the Engineer who is Very Particular

RCA expansion opens the kind of permanent opportunities you'll find most desirable

A whole new program of expansion at RCA—in Research, Systems, Design, Development and Manufacturing—opens a broad variety of permanent positions with all the features that appeal to the alert, creative engineer. These are opportunities with a future . . . available *today* for the man who wants to move ahead professionally with the world leader in electronics. They include work in fields of phenomenal growth. At the RCA engineering laboratories *listed in the chart on the right*, you'll find the kind of living and working conditions attractive to the professional man and his family.

Engineers and scientists find every important factor that stimulates creative effort . . . including a quality and quantity of laboratory facilities unsurpassed in the electronics industry . . . and everyday association with men recognized at the top of their profession.

RCA's benefits add up to an impressive list of "extras." Among them: tuition for advanced study at recognized universities . . . a complete program of company-paid insurance for you and your family . . . a modern retirement program . . . relocation assistance available.

Your individual accomplishments and progress are recognized and rewarded through carefully planned advancement programs. Financially as well as professionally, you move ahead at RCA!

about His Future . . .

What can RCA offer you?

Check the chart below for your career opportunity in

COLOR TELEVISION
AVIATION ELECTRONICS
ELECTRON TUBES
MISSILE GUIDANCE
RADIO SYSTEMS

FIELDS OF ENGINEERING ACTIVITY	TYPE OF DEGREE AND YEARS OF EXPERIENCE PREFERRED											
	Electrical Engineers			Mechanical Engineers			Physical Science			Chemistry Ceramics Glass Technology Metallurgy		
	1-2	2-3	4+	1-2	2-3	4+	1-2	2-3	4+	1-2	2-3	4+
RESEARCH • SYSTEMS • DESIGN • DEVELOPMENT												
COLOR TV TUBES—Electron Optics—Instrumental Analysis—Solid States (Phosphors, High Temperature Phenomena, Photo Sensitive Materials and Glass to Metal Sealing)	L	L	L	L	L	L	L	L		L	L	L
RECEIVING TUBES—Circuitry—Life Test and Rating—Tube Testing—Thermionic Emission	H	H	H		H	H		H			H	H
MICROWAVE TUBES—Tube Development and Manufacture (Traveling Wave—Backward Wave)		H	H	H			H	H			H	H
GAS, POWER AND PHOTO TUBES—Photo Sensitive Devices—Glass to Metal Sealing	L	L	L	L	L		L	L		L	L	
AVIATION ELECTRONICS—Radar—Computers—Servo Mechanisms—Shock and Vibration—Circuitry—Remote Control—Heat Transfer—Sub-Miniaturization—Automatic Flight—Design for Automation—Transistorization			M C			M C			M C			
RADAR—Circuitry—Antenna Design—Servo Systems—Gear Trains—Intricate Mechanisms—Fire Control			M C			M C			M C			
COMPUTERS (ANALOG AND DIGITAL)—Systems—Advanced Development—Circuitry—Assembly Design—Mechanisms			M C			M C			M C			
COMMUNICATIONS—Microwave—Aviation—Specialized Military Systems			M C			M C			M C			
RADIO SYSTEMS—HF-VHF—Microwave—Propagation Analysis—Telephone, Telegraph Terminal Equipment		O	O		O	O		O	O			
MISSILE GUIDANCE—Systems Planning and Design—Radar—Fire Control—Shock Problems—Servo Mechanisms			M			M			M			
COMPONENTS—Transformers—Coils—TV Deflection Yokes (Color or Monochrome)—Resistors		C	C		C	C		C	C			
MANUFACTURING TV Color Tubes—Microwave Tubes	L H		L	L H	L	L	L	L		L	L	
MACHINE DESIGN Mechanical and Electrical—Automatic or Semi-Automatic Machines		L H	L H		L H	L H		H	H			

Location Code

C—Camden, N.J.—in greater Philadelphia near many suburban communities.
H—Harrison, N.J.—just 18 minutes from downtown New York.
L—Lancaster, Pa.—in beautiful Lancaster County, about an hour's drive west of Philadelphia.
M—Moorestown, N.J.—quiet, attractive suburban community close to Philadelphia.
O—Overseas—RCA International Division, several locations.

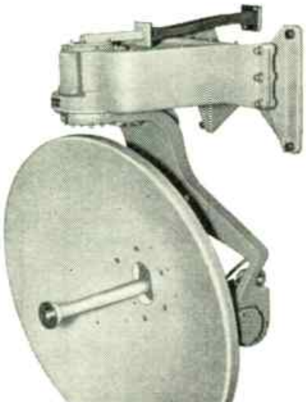
Please send resume of education and experience, with location preferred, to:

Mr. John R. Weld,
Employment Manager, Dept. C-1B
Radio Corporation of America
30 Rockefeller Plaza
New York 20, N. Y.

RADIO CORPORATION OF AMERICA

BANK ON Airtron inc.

A Rewarding Career at Airtron inc.



Here is an excellent opportunity to work in the intriguing and continually expanding field of microwaves. Your work will be stimulating and your advancement gratifying when you participate in the tasks of a professional, competent staff of fellow engineers.

Your place in a field with a future can be secured by joining one of America's leading designers and producers of microwave equipment and radar components. Assure yourself of a career position in a company with a future. Investigate these advantages now!

1. Profit sharing incentive bonus plan.
2. Thrift savings pension plan.
3. Subsidized tuition for advanced study.
4. Ideal suburban location in Metropolitan New York area.
5. Excellent schools and recreational facilities.
6. All the other usual benefits . . . paid holidays, vacations, credit union, etc.

If you have an EE or ME degree and/or related experience in electronics or microwaves you will be interested in the opportunities for junior and senior engineers now open at Airtron, Inc.

Write or call Mr. Arthur Eckerson, Industrial Relations Department, Linden 3-3762.

Airtron INC.
1107 West Elizabeth Avenue
Linden, New Jersey

Positions Wanted

(Continued from page 122A)

ADVERTISING & PUBLIC RELATIONS MANAGER

BS Engr./Bus. Admn., MBA Marketing. 10 years progressive experience all phases of industrial marketing. Program planning, budgeting and administration, market survey, agency liaison, media evaluation, copywriting and production. Pamphlets & brochures, catalogues & direct mail, trade shows & technical publicity. Media, industry, community & Government relations. Licensed radio operator. Age 35. Desires position offering greater responsibilities & advancement. Box 811 W.

COMPONENTS ENGINEER

BEE communications option, some graduate courses. Age 31, married, 2 children. 5 years experience in the field of radio-frequency coaxial, and multi-contact audio, power and control connectors and fittings. Desires development and/or production engineering position in this or related fields. Box 812 W.

PHYSICIST

MS Physics, 1952. Age 30, married. Research and development experience in electronics, ion devices, vacuum systems, and instrumentation. Prefer location in southwest or Florida. Box 813 W.

SYSTEMS ENGINEER

BSTE, January 1949. Age 30, married, 1 child. Six years diversified experience: radar, automatic data reduction systems, digital computers, telemetering and instrumentation systems. Desires similar project or systems engineering position. Box 814 W.

(Continued on page 128A)

Electronic and Mechanical Engineers!

Motorola Research Laboratories, located in the healthful climate of Arizona's Valley of the Sun, has several openings for experienced engineers in the following fields:

Electronic research and development for missile guidance, radar and VHF communications.

Mechanical design of missile-borne and vehicular electronics equipment.

Analysis and laboratory work involving development of new types of airborne and ground radiators and waveguide components.

VHF and microwave antenna and waveguide circuitry.

Transistor development

Desire men with B.S. degree or above. Salary commensurate with education and experience. Free health, accident and life insurance. Free hospitalization. Profit sharing. Paid holidays. Sick leave. Vacations. Ideal working conditions. Plenty of housing, reasonably priced. Excellent schools. Exceptionally mild and dry winter climate.

WRITE: J. A. Chambers, Manager
Motorola Research Laboratory
3102 North 56th Street
Phoenix, Arizona

NEW HORIZONS

Today's horizons in electronic engineering are limited only by the vision of the individual himself. To those qualified men who desire to stand on the constantly changing frontiers of electronic development, we offer a chance to pioneer and grow with a soundly-established, yet young and progressive company.

- Electronic Field Engineers

Local and Field Assignments Available

At least 5 years' experience in any *one* of these fields: Servo Mechanisms; Special Weapons; Microwaves; Antennas; Circuit Design; Flight Simulators; Radio Propagation; Electronic Computers and Communications.

Qualified to instruct in the operation and supervise installation, maintenance and repair of Radar, Sonar, Flight Simulators and allied electronic equipment in the field.

Salary and advancement commensurate with ability; liberal vacation, sick leave, 9 paid holidays, group life, sickness and accident insurance plans, and a worthwhile pension system.

STAVID Engineering, Inc.
Personnel Office, 312 Park Avenue
Plainfield, N.J.—PLainfield 6-4806

IBM *News* **FOR ENGINEERS**

THIS MONTH'S BIG CAREER OPPORTUNITIES

DEVELOPMENT ENGINEERING*

Digital computer circuit design—electronic pulse circuits for accounting and data processing machines—arithmetic, switching and logical circuitry—magnetic storage—transistor circuitry—input-output device controls—pulse amplifiers, shapers, gates, etc. **ALSO** excellent openings in systems planning, functional and reliability analysis, electronic component development, packaging, diagnostic and application program development.

MANUFACTURING ENGINEERING*

Design and development of electronic test equipment for digital computer production testing—circuit design—systems planning and analysis—test planning. **ALSO** excellent openings in functional and acceptance testing—test equipment installation and maintenance—automation engineering—manufacturing research.

*Required—a degree in E.E., M.E., or a Physics B.S. or B.A., or equivalent experience.

Desirable—experience in any of the following fields: digital and analog computers, including airborne types, radar, TV, communications equipment, relay circuitry, automation, servo-mechanisms, instrumentation, or data handling systems.

For information
on these career opportunities
WRITE,
giving details of education and experience, to:
William M. Hoyt
IBM, Dept. 686 (4)
590 Madison Ave., New York 22, N.Y.

Your replies, of course, will be held in strictest confidence.
INTERNATIONAL BUSINESS MACHINES CORPORATION

IBM joins America in saluting all ENGINEERS during NATIONAL ENGINEERS' WEEK, Feb. 20-26, 1955.

World's Leading
Producer of
Electronic
Accounting
Machines
and Computers

Join
IBM
FOR THE HAPPIEST
YEARS OF YOUR LIFE

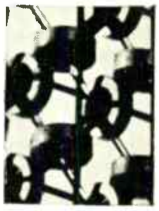
"IBM GREAT PLACE TO WORK"

says development engineer now in his 8th year with the company

"Every year with IBM is more challenging than the last," says Max E. Femmer, Development Engineer at Poughkeepsie. "It was a tremendous satisfaction in 1952 to help develop IBM's outstanding 701 Electronic Computer. Today our projects and our work are even more interesting. Both my wife and I think IBM is a wonderful company."

Mr. Femmer is Technical Administrator of the entire Electronic Data Processing Machine Development Program.

MAGNETIC CORE MEMORY DEVELOPED BY IBM STAFF



This is a Microsecond Memory—developed and perfected by IBM engineers—with data transmission in and out of storage at the rate of more than 43,500 characters a second. A random access unit, the IBM magnetic core can locate and move 5 characters to a programmed location in 35 millionths of a second.

Positions Wanted

(Continued from page 126A)

ENGINEER

BSEE 1950, MSEE 1953. Tau Beta Pi, Eta Kappa Nu. Age 26, married. 2 years industrial R & D experience in microwaves, antennas, and missile systems. 2 years Army experience in engineering evaluation of radar systems at White Sands. Good mathematical background. Resume upon request. Available May 1955. Box 815 W.

ELECTRONIC ENGINEER

Age 29, BEE, City College of N.Y. 1950. MEE Brooklyn Polytechnic Institute 1956. 2 years experience associated with design and development of pulse circuitry, RC oscillators, and regulated power supplies, including video amplifiers, audio detectors and filters. Desires position concentrated in design and development of pulse circuitry in metropolitan N.Y. area. Box 816 W.

ELECTRONIC ENGINEER

BEE 1950, MEE expected 1955 from New York University. Age 30, married. 5 years experience as electronic circuit and development engineer on automation. Considerable production and mechanical experience. Desires position in New York City area until June 1955 and then will relocate. Box 817 W.

ELECTRONIC ENGINEER

BEE 1955 (Jan.). Age 34, married. 3 years radio coils, 2 years radar, 2 years VHF communications, 2 years radio and TV service. 2 years dial switching ckts., 3 years TV broadcast lab. (color), 2 years sales. Desires responsible position where broad experience can be utilized. Box 718 W.

Positions Open

The following positions of interest to I.R.E. 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 I.R.E.
1 East 79th St., New York 21, N.Y.

BROADCAST AUDIO AND PHASOR DESIGN ENGINEERS

Immediate openings in expanding Engineering Department for men experienced in audio or phasor designing. Complete employee benefits. Salary open. Send complete details and photo to Gates Radio Company, Quincy, Illinois. Att: Mr. Roger M. Veach, Personnel Division.

ELECTRONIC ENGINEERS—MECHANICAL ENGINEERS

Openings are available for Electronic Engineers with a minimum of 5 years experience in circuit design with primary emphasis on pulse circuitry and high frequency RF technique. Openings also exist for Mechanical Engineers with a minimum of 5 years experience in packaging electronic equipment as well as in mechanical design of small electro-mechanical devices. Send complete resumes to Mr. J. K. Delano, Exec. Vice Pres., Applied Science Corp. of Princeton, N.J., P.O. Box 44, or call PLainsboro 3-4141.

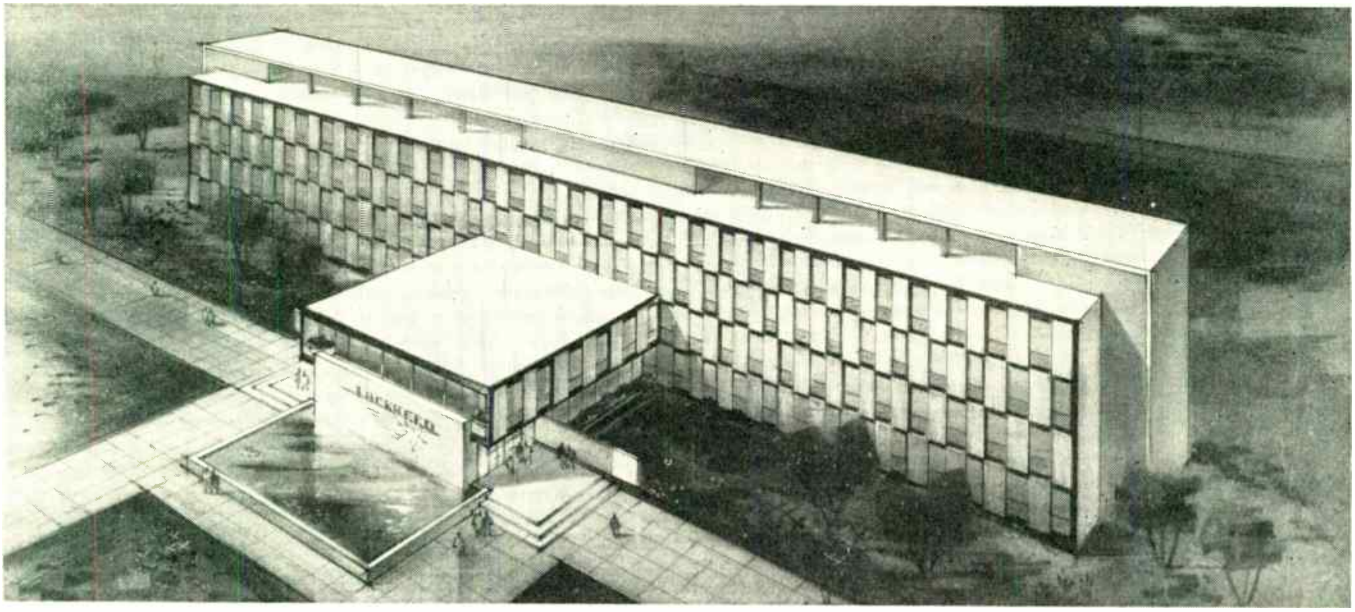
(Continued on page 132A)

NEW MISSILE SYSTEMS RESEARCH LABORATORY

The technology of guided missiles poses increasingly complex problems in virtually every field of science.

To provide physicists and engineers with the most modern facilities for meeting those problems, Lockheed Missile Systems Division has begun construction on a laboratory for advanced research—first step in a $10,000,000 research laboratory program.

Scheduled for occupation in early fall of 1955, it will augment existing Missile Systems Division facilities.

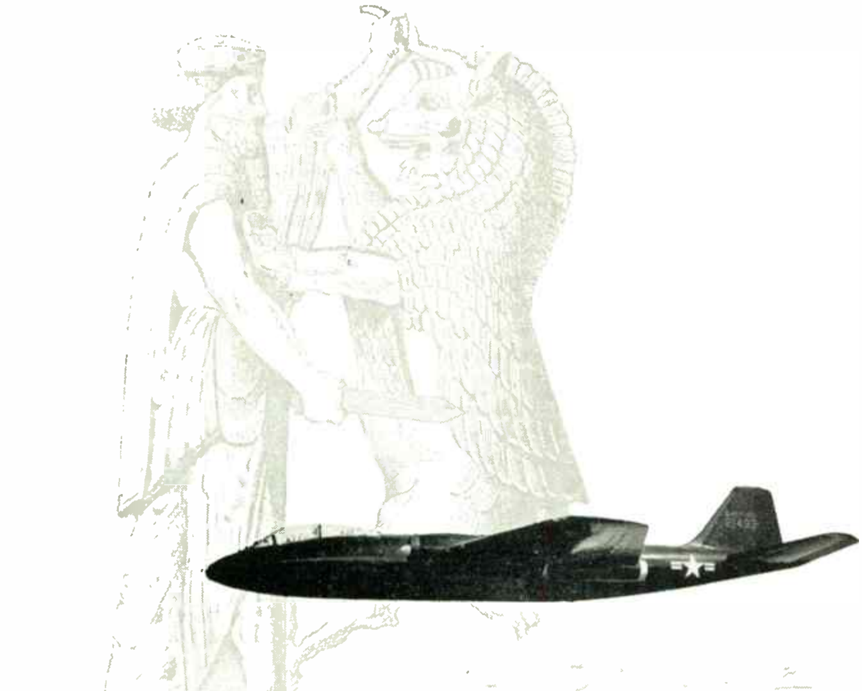


Physicists and engineers able to make significant contributions to the technology of guided missiles are invited to write.

Lockheed MISSILE SYSTEMS DIVISION

research and engineering staff

LOCKHEED AIRCRAFT CORPORATION • VAN NUYS • CALIFORNIA



10,000 years of weapons engineering experience

If you're looking for an opportunity to work with the finest mindpower and facilities in the whole new world of aircraft development...if you want to harness the power of great knowledge to your own technical training...then you should know this:

Martin's engineering staff represents an aggregate of 10,000 man-years of engineering experience, covering every branch of the aeronautical sciences.

And there is—and always will be—a need for outstanding "new blood" in this organization.

If it's only a job you want, the woods are full of them. But if you are one of the few who are destined to go far in this industry, you'd be wise to take an engineer's-eye view of the mindpower and the facilities you'll be working with.

Write to J. M. Hollyday, Box P-2, The Glenn L. Martin Company

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BALTIMORE · MARYLAND

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WITH A LEADER IN
WESTERN ELECTRONICS

An expanding program of:

- *research*
- *development*
- *production*
- *specialized military equipment*
- *advanced commercial design*
- *real creative challenge*

Special receivers and transmitters, DF and DME, various instruments and Transistor applications—special devices. Studies in noise, radar, miniaturization and test equipment. Relocating expenses, good insurance plan, central location, steady advancement.

Send resume to L. D. Stearns
Engineering Employment Manager

Hoffman
LABORATORIES, INC.
(SUBSIDIARY OF HOFFMAN RADIO CORP.)
3761 S. HILL ST., LOS ANGELES, CALIF.

Electrical Engineers and Physicists

- Radar Simulation
- Advanced Circuitry
- Analog Computors
- Ballistics
- Mapping
- Telemetering

Senior and Junior Engineers

*Opportunities Ultd.**

We offer you an opportunity to grow with us . . . an opportunity: for steady advancement . . . individual recognition by working closely with technical management . . . rapid individual development by contact with all phases of projects . . . an interesting and stimulating association with other engineers . . . a suburban location for working and living . . . to ally yourself with a firm with a future. If you are looking for *opportunities unlimited* . . . write:

Industrial Research Laboratories
Dept. B-2, Hilltop & Frederick Rds.
Baltimore 28, Maryland

* Unlimited

Miniaturization Engineers

FOR RESEARCH, DEVELOPMENT AND APPLICATION OF SUBMINIATURIZATION TECHNIQUES

Significant advancements in the fields of guided missiles, airborne electronic systems and commercial electronic computers are requiring further applications of miniaturization techniques in the Hughes Advanced Electronics Laboratory. Positions are open for engineers qualified in this work.

AREAS OF WORK

Techniques involved deal with printed and etched circuits, encapsulation, plastics, metallurgy, dip-soldering, spot-welding, electrochemistry and materials. Development activities are concerned with plug-in units, auto-assembly techniques, potted units, new wiring methods, electromechanical devices, hardware and production techniques. These techniques are used to achieve compactness, reliability, ease of manufacture, serviceability and interchangeability.

How to apply:

Write today, giving details of qualifications and experience. Assurance is required that relocation of the applicant will not cause disruption of an urgent military project.

Scientific and Engineering Staff

Hughes

RESEARCH
AND DEVELOPMENT
LABORATORIES

Culver City,
Los Angeles County,
California

SYLVANIA'S

CALIFORNIA RESEARCH LABORATORY

(San Francisco Bay Area—Near Palo Alto)

Needs Senior Development Engineers for a long range program in circuits research and development and systems analysis. We have specific openings for:

SENIOR MICROWAVE CIRCUITS ENGINEERS

To design and develop microwave components and circuits for use with advanced antennas, tubes and equipment throughout microwave region.

SENIOR TRANSMITTER AND RECEIVER DEVELOPMENT ENGINEERS

Technical degree and related experience at the senior level, preferably in microwaves and pulse techniques, essentiel.

SENIOR FIELD ENGINEERS

To perform advanced engineering field tests of prototype equipment. Engineering degree and substantial experience, preferably with military electronic equipment, essential.

HEAD OF SYSTEMS STUDIES SECTION

To direct a staff of scientists and engineers in the analysis and synthesis of electronic systems.

MECHANICAL ENGINEER

To work on advanced electro-mechanical design problems. Degree in mechanical engineering and 2-5 years experience, preferably in electronic packaging and mechanisms design, essential.

Please send complete resume to

JOHN C. RICHARDS
Electronic
Defense,
Laboratory
Box 205
Mountain View,
California

All inquiries will be answered within two weeks

Sylvania offers the finest facilities and equipment available. We also provide financial support for advanced education, as well as a liberal insurance, pension and medical program.

This Sylvania laboratory is located 5 miles from Palo Alto in the San Francisco Bay area, close to excellent schools and universities, unexcelled living conditions, ideal climate and ample housing.

RELOCATION EXPENSES PAID

ELECTRONIC DEFENSE LABORATORY

A Division of

SYLVANIA

ELECTRIC PRODUCTS INC.

Positions Open

(Continued from page 128A)

ENGINEERS

Several positions for Electrical Engineers available in the development engineering group of a small growing engineering and manufacturing company. Circuit design experience is essential, as the type of work will entail (1) Originating a detailed circuit design to meet written specifications, (2) Testing a breadboard of the proposed circuit to obtain performance characteristics. Experience with any of the following phases will be helpful: radar, computers, simulators, cathode ray displays, industrial automatic controls. Send resume to Penn-East Engineering Corp., Box 240, Kutztown, Pa.

INSTRUCTOR

California State Polytechnic College has one immediate opening for an instructor in the Electronic Engineering Dept to teach courses in fields, waves and antennas. Starting salary $4500 to $5000 for the academic year. Application may be made to Harold P. Hayes, Dean of Engineering, San Luis Obispo, Calif.

ELECTRICAL ENGINEERS

Challenging positions for Electrical Engineers with experience in electronic design. Live in attractive small town with the opportunity of taking graduate work at the Pennsylvania State University. Reply to Personnel Officer, Haller, Raymond and Brown, Inc., State College, Pa.

ELECTRICAL ENGINEER

Graduate Electrical Engineer familiar with pulse systems to act as sales representative in Los Angeles and vicinity. Send resume. Box 793.

ASSOCIATE PROFESSOR

Expansion of a young midwestern technical college requires the addition, by September 1955, of an Assistant or Associate Professor to instruct in electronics, communications and servomechanisms. MSEE degree and teaching, or research experience are minimum requirements. Rank and salary open. Send summary of qualifications and background to Fournier Institute of Technology, Lemont, Illinois.

ENGINEERS

EE Engineers familiar with microwave systems engineering to analyze creative research for invention. Responsible positions open in engine instruments and controls, electrical machinery, microwave devices and electron tubes, and gyroscopic equipment. Patent knowledge beneficial. Liberal salary, unusual employee benefits. Real opportunities for exercise of initiative and advancement. Replies held in confidence. Contact Mr. R. Wathen, Sperry Gyroscope Co. (Div. of the Sperry Corp.) Great Neck, N.Y.

(Continued on page 145A)

1955 Radio Engineering Show
Kingsbridge Armory and
Kingsbridge Palace
New York N.Y.
March 21-24

Developers of the Corporal Guided Missile.

JET PROPULSION LABORATORY

CALIFORNIA
INSTITUTE OF
TECHNOLOGY

Active in all phases of electronics and physics related to guided missiles and jet propulsion.

The nation's foremost guided-missile research and development facility, established in 1940, offers exceptional opportunity for engineers and research scientists in the fields of guidance and control, information theory, computers, electro-mechanical devices, instrumentation, and related aspects of electronic research. The Laboratory offers an ideal blend of academic and industrial environments and maintains a high level of technical competence. Attractive salaries are offered.

A brochure describing opportunities and activities at the Laboratory will be sent upon request.

JET PROPULSION LABORATORY
California Institute of Technology
4800 OAK GROVE DR.,
PASADENA 3, CALIFORNIA

ELECTRONIC ENGINEERS:

INVESTIGATE THESE CREATIVE POSITIONS AT THE WESTINGHOUSE ELECTRONICS DIVISION!

These top-level positions . . . involving advanced research, development and design work with the expanding operation at our Electronics Division . . . offer experienced engineers unlimited opportunity to *create*. Income and other benefits, as well as our professional working atmosphere and conditions, will prove attractive to all qualified applicants. An illustrated brochure will be forwarded promptly, upon receipt of your inquiry.

OPENINGS EXIST FOR—

MAGNETIC AMPLIFIER ENGINEERS

Applied research, development and design of magnetic amplifiers and transformers, reactors and saturable reactors.

UHF COMMUNICATIONS ENGINEERS

Applied research, development and design of military UHF communications apparatus at all power levels, and for both transmitters and receivers.

ANTENNA AND WAVEGUIDE ENGINEERS

Applied research, development and design of antennas and waveguide systems for military communications and radar equipment.

RADAR INDICATOR SYSTEMS ENGINEERS

Planning, studying, proposing, and advanced research, development and design to include search, fire-control and missile guidance systems.

WRITE TODAY TO ARRANGE FOR CONFIDENTIAL INTERVIEW:

R. M. Swisher, Jr.
Employment Supervisor, Dept. 87
WESTINGHOUSE ELECTRIC CORPORATION
2519 Wilkens Avenue
Baltimore 3, Maryland

YOU CAN BE SURE... IF IT'S Westinghouse

SHOULD YOU CHANGE YOUR JOB IN '55?

Several openings for electronics engineers at Gilfillan

The outstanding success of the November-December field tests of the new Gilfillan GCA Quadradar points up the fact that Gilfillan offers engineers real creative opportunity as well as good salaries, rapid advancement and security. If you are thinking of making a change, we suggest you investigate current openings at Gilfillan.

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Gilfillan is a major company, with 7 plants located throughout Southern California, that has been in business more than 40 years.

SATISFACTION

Gilfillan is big enough to handle all phases of engineering research, design and production, yet not so big you get lost. You have the very real satisfaction of following through on your work, getting credit for it, and seeing its achievements in the field.

PRESTIGE

Gilfillan pioneered GCA Radar and all its major improvements; is now engaged in automatic GCA, the new lightweight Gilfillan GCA Quadradar, missile guidance, navigational systems — and a series of highly classified projects involving advanced and unsolved techniques for all branches of the military services.

Work is interesting at Gilfillan because ideas begin here. As a Gilfillan engineer, your value increases — because of the Gilfillan reputation, and because you work in coming fields.

ADVANCEMENT

You go ahead at Gilfillan as fast as you are ready. You are paid and advanced according to ability, not seniority. If you want further formal training, Gilfillan pays your tuition at UCLA or USC. You can be sure your ability will be recognized, because every man in a supervisory capacity at Gilfillan is a qualified engineer.

Write:

R. E. Bell, Gilfillan Bros., Dept 25, 1815 Venice Blvd., Los Angeles, California. Give a brief resume of your background and experience. Interview at a convenient location will be arranged for qualified men.

GCA RADAR AND ELECTRONICS
Gilfillan
LOS ANGELES
GCA
AROUND THE WORLD

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Established manufacturer in the field of Power Tubes, Magnetrons, Klystrons, Thyratrons, etc. has position for man to head its development activity. Candidate must have had a minimum of 10 years experience in tube development and manufacturing field. Must be able to direct the work of a group of engineers and guide the transfer of new products from development into manufacturing. Must have knowledge of applications. Write in confidence, forwarding all particulars.

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Institute of Radio Engineers
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LEAR, INC. will expand its top notch Field Service organization in 1955 to keep pace with increasingly widespread military acceptance of LEAR flight control systems and flight reference systems.

Attractive salary, liberal expense arrangements. Assignments may require travel or residence at assigned stations. Company orientation prior to assignment.

Qualifications include:

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2. **Knowledge or servomechanisms, gyros, electronics.**
3. **Tech. Rep. experience.**

To apply, send resume to:

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ONE MAN

. . . to work with one of the country's outstanding scientists

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and to assume administrative responsibilities as assistant head of a section.

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Please write giving full details of your background to:

Automatic Electric Company
Personnel Director
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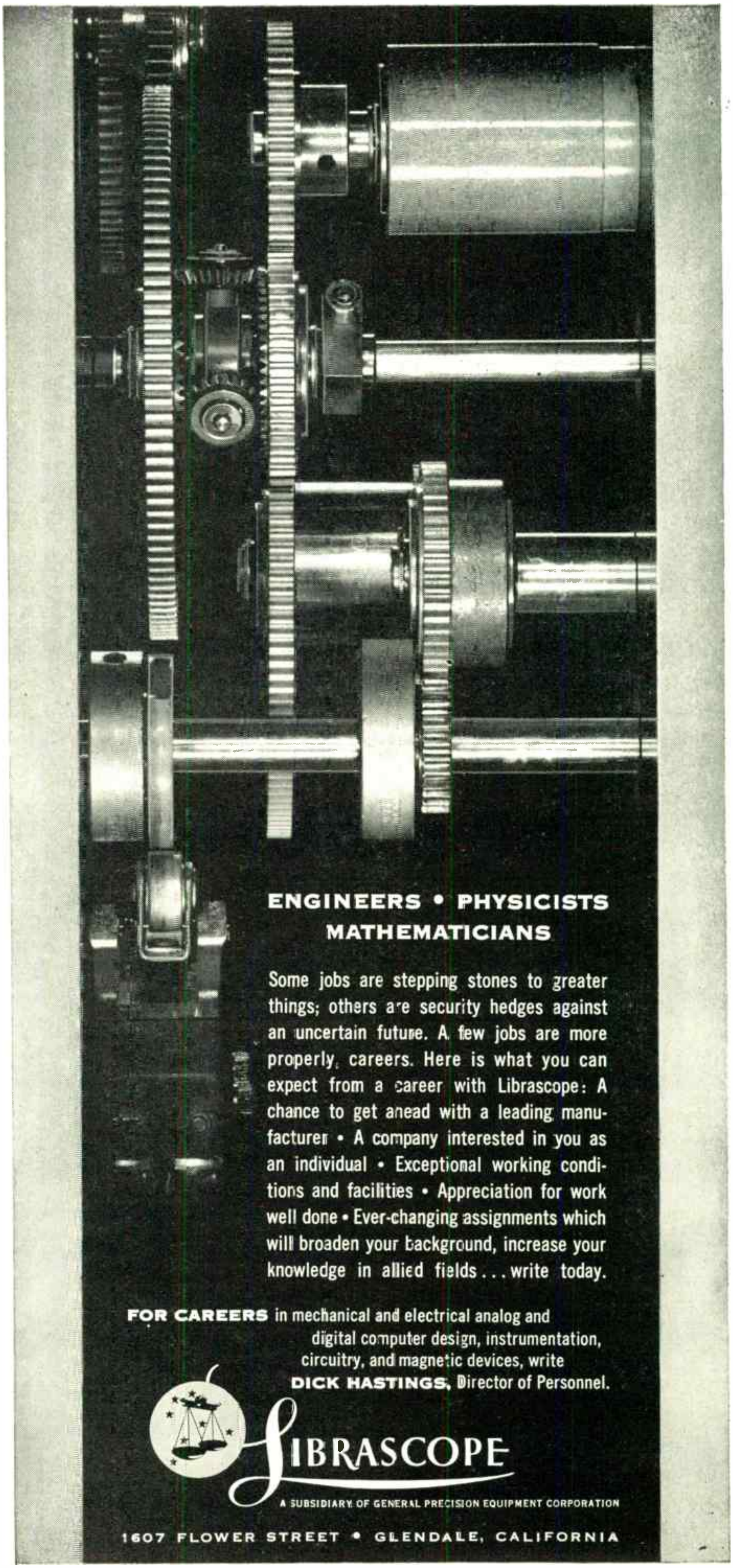

ENGINEERS • PHYSICISTS MATHEMATICIANS

Some jobs are stepping stones to greater things; others are security hedges against an uncertain future. A few jobs are more properly, careers. Here is what you can expect from a career with Librascope: A chance to get ahead with a leading manufacturer • A company interested in you as an individual • Exceptional working conditions and facilities • Appreciation for work well done • Ever-changing assignments which will broaden your background, increase your knowledge in allied fields . . . write today.

FOR CAREERS in mechanical and electrical analog and digital computer design, instrumentation, circuitry, and magnetic devices, write **DICK HASTINGS,** Director of Personnel.

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ENGINEERS

ELECTRONICS BACKGROUND

A few responsible positions available

. . . in systems work associated with navigational computers.

. . . in field service of navigational systems. Some previous experience with electronic and electro-mechanical computers and instruments necessary.

. . . to assist in the preparation of system reports, handbooks, test procedures and specifications.

The modern facilities and congenial atmosphere at Kollsman, designers of America's finest aircraft instruments, provide an environment conducive to truly creative work.

Please submit resumes to Employment Manager. Interviews will be arranged for qualified applicants.

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Elmhurst, L. I., New York

ENGINEERS yours will be a SUCCESS STORY

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AT ELMIRA, NEW YORK

Development & Application Engineers: Receiving, microwave (including traveling waves), image orthicon or vidicon tubes; solid state devices.

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An outstanding opportunity awaits you in our nation-wide **ELECTRONIC COMPUTER** *and* **DATA HANDLING SYSTEMS** *program*

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ENGINEERS

Have you developed a "Success Perspective"?

If a year or two of practical experience has given you the youthful maturity that demands more than just a job, you may be interested in our "career opportunities" in color TV, crystal products and electronic tubes.

Submit resume or address request for personal interview to D. Bellat, Personnel Director.

TUNG-SOL ELECTRIC INC.
200 Bloomfield Avenue
Bloomfield, N.J.

JUNIOR ENGINEER

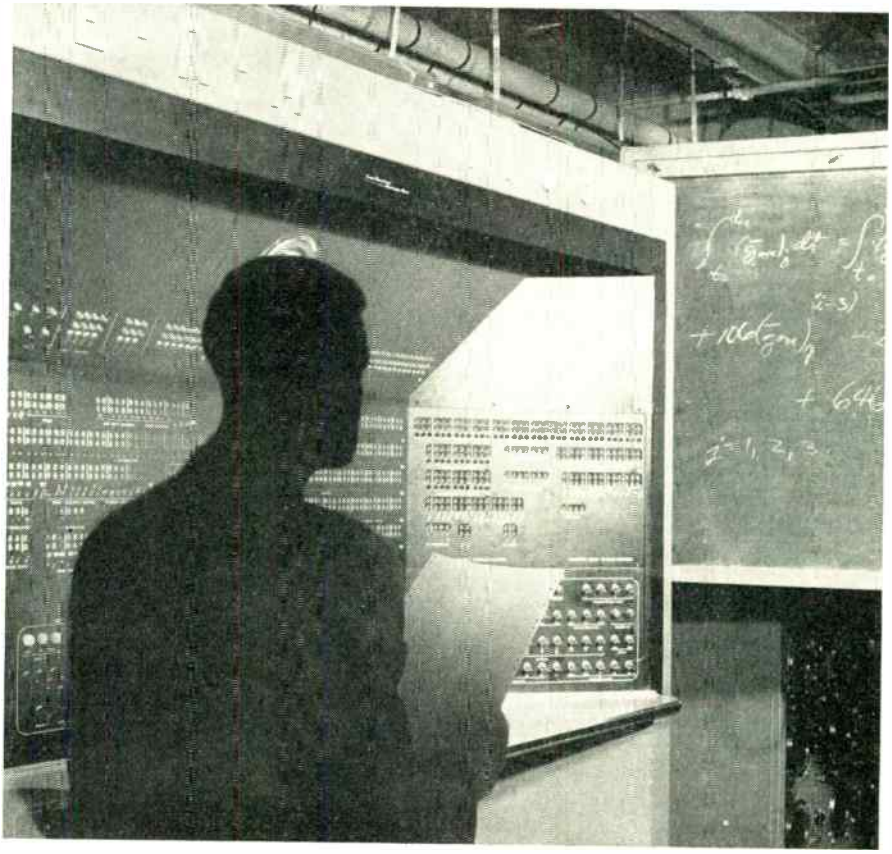
Continental Oil Company

PONCA CITY, OKLAHOMA

Electronic Research Group immediately requires B.S. in Electrical Engineering capable of meeting wide variety of design problems including analog and digital computers plus instrumentation peculiar to petroleum industry. Previous experience preferable but not required. New laboratory. Excellent working conditions. Send resume of education, experience, and salary requirements to Personnel Records Division,

Continental Oil Company
Ponca City, Oklahoma

TO THE FINE ENGINEERING MIND
SEEKING THE CHALLENGING PROJECTS IN



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MATHEMATICIANS AND APPLIED PHYSICISTS with advanced degrees or equivalent experience are offered exceptional career opportunities now at Convair in beautiful San Diego, California. Challenging problems involving theoretical analysis and synthesis of missile guidance systems require highly qualified men in several fields including statistical noise study, information theory, and optimum filter design; microwave propagation studies; synthesis of highly complex control systems involving both analog and digital computing equipment as components; simulation studies of complex control systems using analog and digital computers. Convair's digital* and analog computing facilities rank among the country's best and provide powerful working tools.

CONVAIR offers you an imaginative, explorative, energetic engineering department... truly the "engineer's" engineering department to challenge your mind, your skills, your abilities in solving the complex problems of vital, new, long-range programs. You will find salaries, facilities, engineering policies, educational opportunities and personal advantages excellent.

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H. T. Brooks, Engineering Personnel, Dept. 802

*ERA 1103

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Digital Communication Engineers

with experience in the fields of

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- Miniaturization
- Circuit Development
- Electromechanical Development
- Digital Techniques

Long-Range Information Transmission

New advancements in the field of long-range information transmission are being made at Hughes with digital techniques.

Areas of Work

To further expand work in this area, Hughes Research and Development Laboratories are interested in people with experience in airborne communication systems, digital storage, low frequency measurements, modulation systems, miniaturized packaging, audio, IF and RF circuitry in the HF range, analog to digital—and other data conversion methods.

Scientific and Engineering Staff

Hughes

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AND DEVELOPMENT
LABORATORIES

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LOS ANGELES COUNTY,
CALIFORNIA

Relocation of applicant must not cause disruption of an urgent military project.

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ELECTRONIC ENGINEERS

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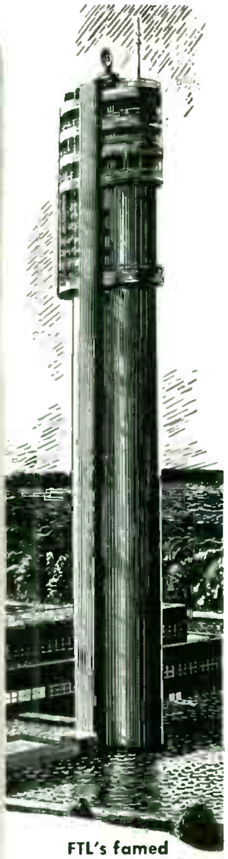
Rectifiers • Computers • Antennas
Telephone and Wire Transmission Systems

SEND RESUME TO:
PERSONNEL MANAGER,
BOX IR-2

Federal Telecommunication Laboratories
A Division of INTERNATIONAL
TELEPHONE AND TELEGRAPH CORPORATION
500 Washington Avenue, Nutley, N. J.



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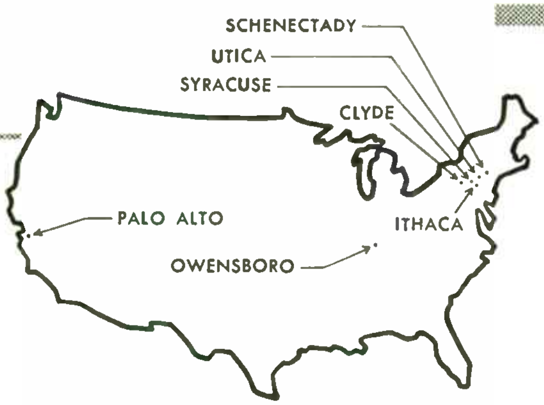
YOUR CALLING CARD FOR A BRILLIANT FUTURE . . .

Bendix Missile Section is a major contractor in the U. S. Navy's guided missile program - - a part of the "new look" in our defense plan. Our expanding program has many opportunities for senior engineering personnel: Electronics Engineers, Dynamicists, Servo-Analysts, Stress Analysts, Project Coordinators, and Designers. Take time now to look into the opportunities which Bendix can offer you. Write Employment Dept. M, 401 Bendix Drive, South Bend, Indiana.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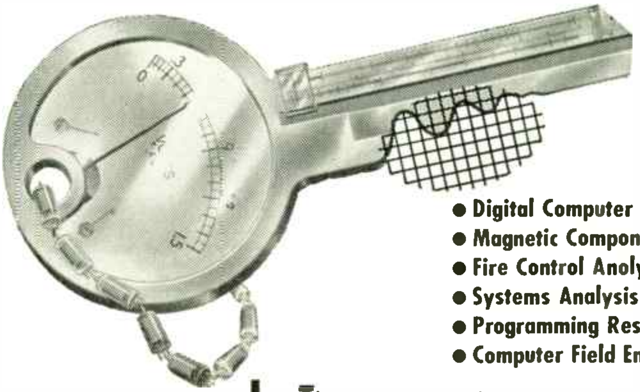

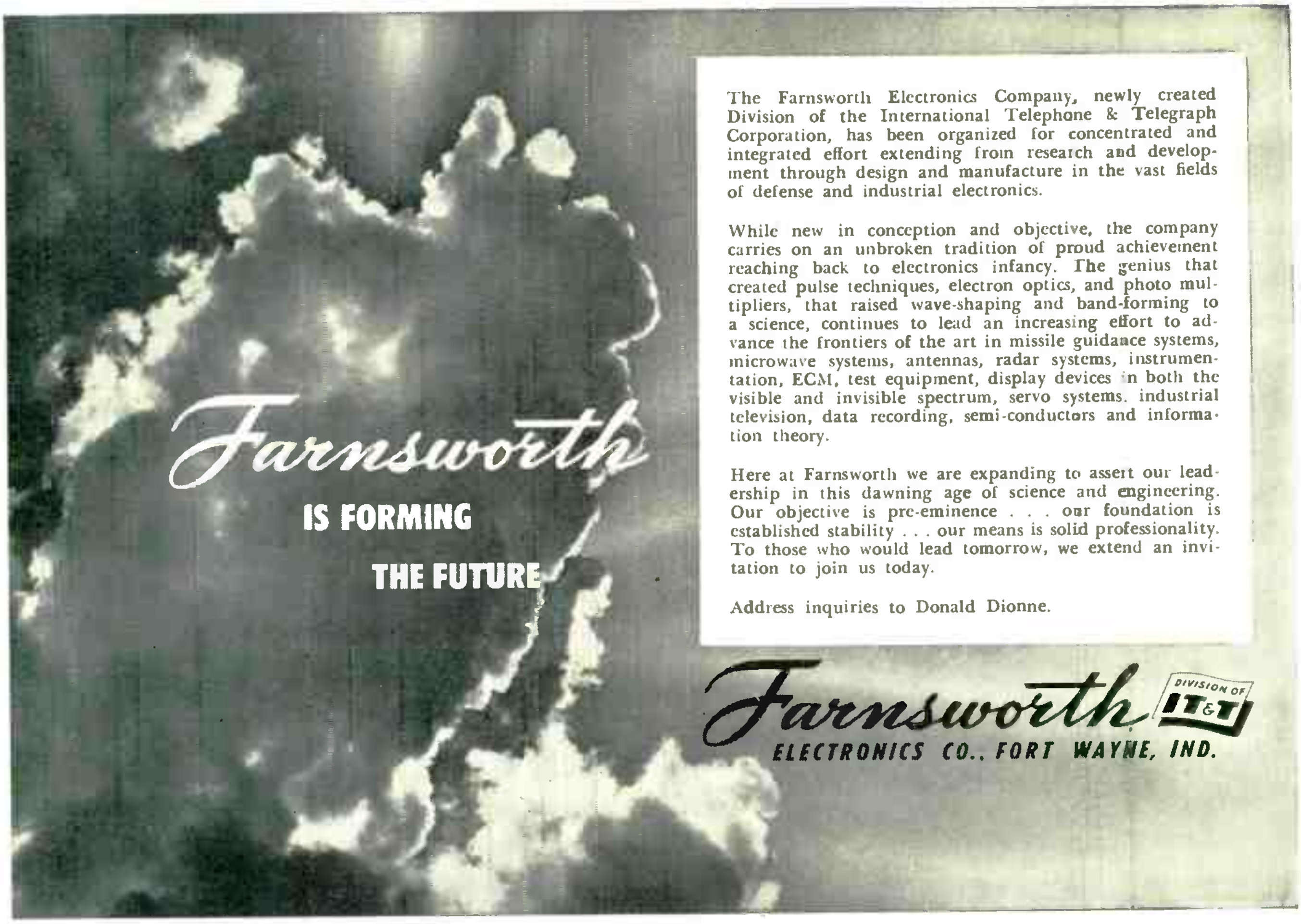

The Farnsworth Electronics Company, newly created Division of the International Telephone & Telegraph Corporation, has been organized for concentrated and integrated effort extending from research and development through design and manufacture in the vast fields of defense and industrial electronics.

While new in conception and objective, the company carries on an unbroken tradition of proud achievement reaching back to electronics infancy. The genius that created pulse techniques, electron optics, and photo multipliers, that raised wave-shaping and band-forming to a science, continues to lead an increasing effort to advance the frontiers of the art in missile guidance systems, microwave systems, antennas, radar systems, instrumentation, ECM, test equipment, display devices in both the visible and invisible spectrum, servo systems, industrial television, data recording, semi-conductors and information theory.

Here at Farnsworth we are expanding to assert our leadership in this dawning age of science and engineering. Our objective is pre-eminence . . . our foundation is established stability . . . our means is solid professionality. To those who would lead tomorrow, we extend an invitation to join us today.

Address inquiries to Donald Dionne.

Farnsworth DIVISION OF IT&T
ELECTRONICS CO., FORT WAYNE, IND.

ELECTRONIC ENGINEERS and PHYSICISTS

We invite you to investigate the fine professional opportunities at Sperry. An enviable record of 43 years consistant growth and expansion plus Sperry's 15 year club of more than 1500 employees is ample evidence of opportunity, good salaries, benefits and fine working conditions that make for a bright future.

Design Engineers — *Klystron and traveling wave tubes, Magnetrons, Image orthicon, Solid state devices, Microwave measuring equipment.*

Production Engineers — *Power tube operation. Knowledge of tube assembly and processing techniques is essential.*

Measurements Engineers — *For microwave measurements on Klystrons and traveling wave tubes.*

- RELOCATION ALLOWANCES
- LIBERAL EMPLOYEE BENEFITS
- ADEQUATE HOUSING IN BEAUTIFUL SUBURBAN COUNTRY TYPE AREA
- TUITION REFUND PROGRAM (9 graduate schools in area of plant)
- MODERN PLANT WITH LATEST TECHNICAL FACILITIES
- ASSOCIATION WITH OUTSTANDING PROFESSIONAL PERSONNEL

SPERRY

Apply in person or submit resume to Employment Office

SPERRY GYROSCOPE CO. *(Division of the Sperry Corp.)*
Marcus Ave. and Lakeville Road, Great Neck, Long Island, New York

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CONVAIR
POMONA
offers
ENGINEERING OPPORTUNITIES

- ELECTRONICS
- DYNAMICS
- AERODYNAMICS
- THERMODYNAMICS

Guided Missiles

Employment Dept.
1675 West 5th St.
P. O. Box 1011, Pomona, Calif.

CONVAIR
A DIVISION OF
GENERAL DYNAMICS CORPORATION
(POMONA)

ENGINEERS

The APPLIED PHYSICS LABORATORY OF THE JOHNS HOPKINS UNIVERSITY offers an exceptional opportunity for professional advancement in a well-established laboratory with a reputation for the encouragement of individual responsibility and self-direction. Our program of

GUIDED MISSILE

RESEARCH AND DEVELOPMENT

provides such an opportunity for men qualified in:

- ELECTRONIC CIRCUIT DESIGN AND ANALYSIS
- DEVELOPMENT AND APPLICATION OF TRANSISTOR CIRCUITRY
- SERVOMECHANISMS AND CONTROL SYSTEM ANALYSIS
- ELECTRONIC EQUIPMENT PACKAGING
- INSTRUMENT DESIGN
- MISSILE SYSTEMS DEVELOPMENT
- FLIGHT TESTING

Please send your resume to

Glover B. Mayfield
APPLIED PHYSICS LABORATORY
THE JOHNS HOPKINS UNIVERSITY
8621 Georgia Avenue
Silver Spring, Maryland

OPPORTUNITIES

FOR YOUR

FUTURE

NO FEE POSITIONS

AVIATION ELECTRONICS	
Suprvsry & Project to Jr.	$7-15,00
MECH LIAISON ENGR, Devel	$14,000
PHYSICISTS, All Fields	$9-16,000
MATHEMATICIANS	$8-13,000
NUCLEAR ENGRS & PHYS	$10-12,000
SATELLITE ENGRS	HIGH
RADAR SYSTEMS	$10-17,000
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INFORMATION THEORY	$8-11,000
UHF & VHF COMMUN	$10-12,000
ANTENNA & WAVEGUIDE	$8-12,000
COMPONENTS	$7,5-14,000
INSTRUMENTATION	$10,800
ELECTRICAL & POWER	$9,000
SYSTEMS ANALYSTS	$8-13,000
DIGITAL-ANALOGUE COMPUT	$9-13,000
DATA RECORDING	$7-9,000
TRANSFORMERS-MAGNETICS	$9,000
CABLE ENGRS	$8-9,000
STANDARDS ENGRS	$8-13,000
SERVO-MECHANISMS	$8-10,000
MECHANISMS ENGRS	$8-12,000
MACHINE DESIGN	$8,000
FIRE CONTROL	$8-10,000
ARMAMENTS	$10,800
TUBE DESIGN	$8-14,000
HIGH FREQ HEATING	$8,000
TEST & INSPECTION	$6-8,500
FIELD ENGRS	$5-8,000
TECH ILLUSTRATORS	$7,200
TECH WRITERS	$8,400
MANUFACTURING ENGRS	$6-7,500
MATERIALS & PROCESS	$8-10,000
OPTICAL ENGRS & PHYS	$10-12,000
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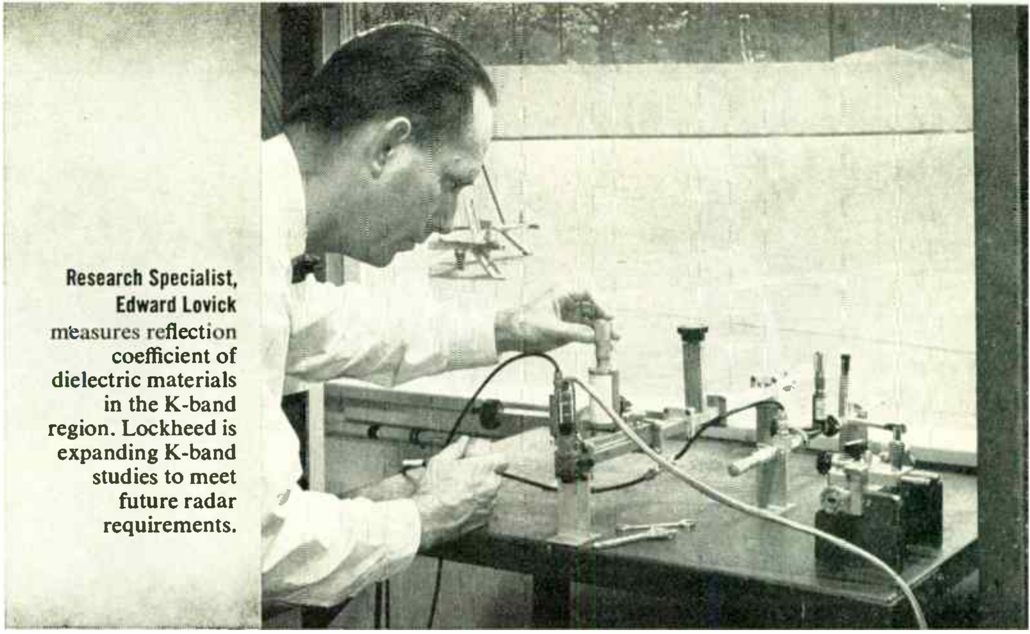
GUILFORD

PERSONNEL SERVICE

308 AMERICAN BLDG. BOX R-1B
Baltimore 2, Md. MUlberry 5-4340



Research Specialist, Edward Lovick measures reflection coefficient of dielectric materials in the K-band region. Lockheed is expanding K-band studies to meet future radar requirements.

Expansion Program Speeds Lockheed Antenna Development

The expansion program covers virtually the entire spectrum of aeronautical endeavor, commercial and military. Antenna research and development is directed at such diverse projects as: supersonic fighters; advanced jet trainers and jet transports; advanced versions of vertical-rising aircraft and bombers; turbo-prop transports; Lockheed's exclusive radar search plane; and a number of significant classified activities.

Electronics Research Engineer T. W. Hancock and Electronics Engineer Irving Alne discuss asymmetry in Super Constellation antenna pattern.

Career Positions at Lockheed

Lockheed's expansion program presents Electronics Engineers and Physicists qualified for airborne antenna design with a wide range of assignments in communication, navigation and microwaves.

Lockheed offers you increased salary rates now in effect; generous travel and moving allowances; an opportunity to enjoy Southern California life; and an extremely wide range of employee benefits which add approximately 14% to each engineer's salary in the form of insurance, retirement pension, sick leave with pay, etc.

Those interested are invited to write E. W. Des Lauriers, Dept. IR-2, for a brochure describing life and work at Lockheed and an application form.

Lockheed AIRCRAFT CORPORATION

BURBANK **California**

A
BRIGHT FUTURE
IN
ORIGINAL RESEARCH
FOR
ELECTRONIC ENGINEERS
PHYSICISTS *and*
MECHANICAL ENGINEERS
WITH
SYLVANIA

It is not surprising that many contributions and advances in the field of electronics have been made by Sylvania engineers. Our company has always placed heavy emphasis on original research, development and product design, offering engineers wide latitude for exploration and creative expression.

As a result, growth opportunities for engineers are virtually unlimited, as Sylvania aggressively advances in its growth tradition.

To aid our engineers in their progress, Sylvania also provides financial support for advanced education, as well as liberal insurance, pension and medical programs.

The following **PERMANENT POSITIONS** are now open at:
BOSTON & BUFFALO ENGINEERING LABORATORIES

Section Heads, Engineers-in-Charge, Senior Engineers, Engineering Specialists and Junior Engineers for Research, Design, Development and Product Design on complex subminiaturized airborne electronic equipment and computers, experienced in:

- Pulse Techniques
- Electro-Mechanisms
- Microwave Techniques
- Microwave Applications
- Circuit Design
- Equipment Specifications
- F. M. Techniques
- Miniaturization
- Servo Mechanisms
- Transistors
- Heat Transfer
- Shock & Vibration
- Technical Writing
- Analytical Problems
- Antenna Design
- Applied Physics
- Systems Development & Testing
- Component Selection
- Component Analysis & Testing
- Component Specifications
- Digital Computer Circuits & Systems
- Mechanical Design

Please forward complete resume to:

MR. CHARLES KEPPLE
SYLVANIA
ELECTRIC PRODUCTS INC.
175 Great Arrow Avenue, Buffalo, New York

ENGINEERS

Countermeasures
Systems
Radar
Servo

BACKGROUND: Responsible positions open for top level development and project engineers with practical and research experience in:

Advanced Electronic Circuits and Systems
Microwave Radar
Microwave Receivers
and Transmitters

MAXSON

Requirements emphasize advanced analytical and/or management experience on highly complex electronic and electro-mechanical systems.

Kindly send resume and salary requirements to

The W. L. MAXSON Corp.
460 W. 34th St., NEW YORK 1, N.Y.

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electronics engineer

A small aircraft instrument division of a major manufacturer of diversified equipment has an opening for an electronics engineer with 6 to 7 years experience in the field of servo-mechanisms and related work

The duties are concerned with the design and development of vacuum tube, magnetic and transistor circuits and their application in systems.

The ability to follow through from the planning stage to the final product is essential. The position also requires the supervision of a group of engineers, and coordination with model shop and drafting sections. An EE degree with a major in electronics is desirable.

The location is in New Jersey adjacent to metropolitan New York City. Please submit complete details, in confidence, including initial salary required.

Advt. Box 2520, Room 1201
230 West 41 St., New York 36, N.Y.

World Radio History

ENGINEERS

DESIGNERS • DRAFTSMEN
Electronic *Mechanical*

THE MELPAR SYMBOL STANDS FOR

Growth - Progress - Leadership

IN RESEARCH AND DEVELOPMENT OF ELECTRONIC EQUIPMENT

Diversified and Challenging Problems

A real appreciation and recognition of the individual's merit and ability

An opportunity for qualified men to join a company that is steadily growing

A location that offers many advantages

Our Technical Personnel Representative will give you complete details of the opportunities available to men qualified in the following fields:

- Network Theory
- Microwave Technique
- UHF, VHF or SHF Receivers
- Analog Computers
- Digital Computers
- Magnetic Tape Handling Equipment
- Radar and Countermeasures
- Packaging Electronic Equipment
- Pulse Circuitry
- Microwave Filters
- Flight Simulators
- Subminiaturization Techniques
- Electro-Mechanical Design

send complete resume to
Technical Personnel Representative,

melpar, inc.

A Subsidiary of the Westinghouse Air Brake Co.
452 Swann Ave., Dept. IRE-14
Alexandria, Virginia
or 11 Galen St., Watertown, Mass.

Representative will be available for interviews in New York during IRE convention.

Admiral

Offers ENGINEERING CAREERS with a future

Positions are available in our organization at all levels for qualified personnel in the following fields:

*Television
Commercial
Military
Monochrome
Color

*Military Communications

*Commercial Radio

*Radar

Our rapidly expanding interests in these and other fields opens many opportunities for experienced electrical engineers as well as recent graduates.

Chicago location offers excellent opportunities for further study and graduate work in the electronics field.

Personal interviews will be arranged at the convenience of qualified applicants.

We suggest you write Mr. Walter Wecker, Personnel Department to get more information on career opportunities, advanced educational plans and other advantages.

ADMIRAL CORPORATION
3800 W. Cortland St.
Chicago 47, Illinois

MICROWAVE ENGINEER

Responsible position for E.E. or physicist familiar with theory and application of microwave components and microwave electron tubes, to analyze creative research for invention. Real opportunity for exercise of initiative and for advancement. Patent knowledge beneficial, but not required. Liberal salary plus full employee benefits.

Interviews can be arranged on Saturday at our plant and may be arranged in your city.

SUBMIT RESUME TO ENGINEERING PERSONNEL DEPT.

SPERRY
Gyroscope Co. (Division of the Sperry Corp.)
Great Neck, Long Island, New York

ELECTRONIC ENGINEERS

Challenging Opportunity
Exists for Senior
Level Positions

Microwave Engineer

with extensive experience in applied microwave circuit design and development. Position involves applications of microwave circuits in the evaluation of modern radar techniques.

Electronic Engineer

with extensive practical experience in the field of analog computers and aerodynamic simulators. Position involves applications in the evaluation of airborne military radar, firecontrol, navigation and human engineering activities.

Servomechanism Engineer

with extensive experience in applied servomechanism design and development. Position involves original applications of servomechanisms in airborne military radar, firecontrol and navigation systems.

CORNELL AERONAUTICAL LABORATORY, INC.
Buffalo 21, New York

RAYTHEON

PHYSICIST or ENGINEER
for
Gas Tube Design & Development

Excellent opportunity in Raytheon's expanding organization for capable engineer or physicist to work on the design and development of VR tubes, rectifiers, thyratrons, GM tubes and allied devices. Minimum requirements: B.S. degree and 3 years' experience in this field.

Write or wire for appointment

G. W. Lewis,
Personnel Mgr.
Raytheon Mfg. Co.
55 Chapel St.,
Newton 58, Mass.

TRANSISTOR & DIGITAL COMPUTER TECHNIQUES

applied to the design, development and application of

AUTOMATIC RADAR DATA PROCESSING, TRANSMISSION AND CORRELATION IN LARGE GROUND NETWORKS

ENGINEERS & PHYSICISTS

Digital computers similar to the successful Hughes airborne fire control computers are being applied by the Ground Systems Department to the information processing and computing functions of large ground radar weapons control systems.

The application of digital and transistor techniques to the problems of large ground radar networks has created new positions at all levels in the Ground Systems Department. Engineers and physicists with experience in the fields listed, or with exceptional ability, are invited to consider joining us.

fields include

TRANSISTOR CIRCUITS
DIGITAL COMPUTING NETS
MAGNETIC DRUM AND CORE MEMORY
LOGICAL DESIGN
PROGRAMMING

VERY HIGH POWER MODULATORS
AND TRANSMITTERS

INPUT AND OUTPUT DEVICES
SPECIAL DISPLAYS
MICROWAVE CIRCUITS

Scientific and Engineering Staff

HUGHES

RESEARCH AND DEVELOPMENT LABORATORIES

Culver City, Los Angeles County, California

Relocation of applicant must not cause disruption of an urgent military project.

ENGINEERS

MICROWAVE

Development of microwave instruments & test equipment

ELECTRONIC

Development of electronic instruments

Precision instrument manufacturer requires men with good academic & practical background. At least 2-3 years design & development experience required. Should exhibit qualities of leadership, with the ability to meet & deal with people. Men who fill the bill will be substantially compensated.

POLYTECHNIC RESEARCH & DEVELOPMENT CO., INC.
202 Tillary St.
Brooklyn 1, New York

SENIOR ELECTRONICS ENGINEERS

EE degree or equivalent experience. Background in communications and navigation desirable. Permanent positions in design and development. Citizenship required. Position at Rochester, New York. Excellent living and recreational conditions in this area.

ADDRESS:

Chief Electronics Engineer
Stromberg-Carlson Company
Rochester 3, New York

Positions Open

(*Continued from page 132A*)

ELECTRONIC ENGINEER OR PHYSICIST

Rapidly growing electronic firm has immediate need for an Electronic Engineer or Physicist in its Research and Development Dept. This work will encompass the work of various digital computer components. These components will include analog to digital computers and high precision digital to analog converter systems. We desire a person with 3 to 5 years experience in electromechanical input and output devices for digital computers. He must have a general knowledge of computer design. Send detailed resume to Technical Employment Manager, 1001 El Centro, South Pasadena, Calif.

INSTRUCTORS

Teaching positions for Sept. 1, 1955 are available at a University in the southeast. Instructors $3,500 $4,300; graduate assistants (M.S. in 12 months) $110.00 per month, tuition free. Box 794.

PROFESSOR—ELECTRICAL ENGINEERING

Professorial appointment at Brown University open for Electrical Engineer with established ability in teaching advanced research. Will have responsibility for organizing and directing theoretical and experimental research program in his fields of interest. Write to D. C. Drucker, Chairman, Div. of Engineering, Brown University, Providence 12, R.I.

REPRESENTATIVES

A growing Massachusetts manufacturer has openings for manufacturers representatives or sales representatives, with sales background, to represent electronic laboratory furniture. Must be qualified to present product to laboratory engineers, executive and authoritative management. All territories open with exception of Illinois, Wisconsin and Massachusetts. Territory assigned; commission basis. Send resume to Formica Metal Products Co., Corporation Way, Medford 55, Mass. stating education, past experience and present employment. All replies confidential.

SALES ENGINEERS OR TRAINEES

Immediate opening for 2 intelligent, personable and imaginative electronic, vacuum or nuclear instrument engineers, with rapidly growing sales engineering organization. Exceptional opportunity for advancement and good earnings for men with initiative. Salary plus incentive compensation. Systematic sales training will be provided for otherwise qualified applicants without prior sales experience. Must be residents of upstate or metropolitan New York. Some travel required. Submit resume (picture if possible), starting salary requirements and availability date with first letter. Box 795.

ELECTRICAL ENGINEERS, MATHEMATICIANS, PHYSICISTS

The Moore School of Electrical Engineering of the University of Pennsylvania has openings for electrical engineers, mathematicians and physicists. Work is available in the fields of digital and analog computers, mathematical analysis, circuit design, information theory, microwaves and systems engineering. Applicants should be U. S. citizens. Salary commensurate with education and experience. For application form write to Director, Moore School, University of Pennsylvania, 200 South 33rd St., Phila. 4, Penn.

(*Continued on page 146A*)

EXPAND YOUR HORIZON!

Bendix Radio
has new, exceptional
opportunities for:

ELECTRONIC ENGINEERS
ELECTRONIC PHYSICISTS

Expand the horizon of your future with Bendix Radio—a leader and pioneer in the electronics field, one that has the knowledge, strength and resources to stay out front during the competitive days ahead! Your part is EASY! Wire, phone, write . . . or send us a post card. Simply state your name, address and phone number, your education and experience. We'll carry the ball from there! All replies held in strictest confidence, and we guarantee speedy action!

Address: Mr. L. H. Noggle
Dept. M
Phone: VAlley 3-2200

Bendix Radio
DIVISION OF BENDIX AVIATION CORP.
Baltimore 4, Maryland

PHYSICIST OR ELECTRICAL ENGINEER

With Ph.D. or comparable training. Knowledge of electrodynamics and microwave analysis is essential. Some experience in microwave measurement techniques is desirable. Proficiency along other lines will be an asset for future work. For aggressive independent research laboratory in midwestern university town. Salary $9,500.

Box 799

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

CAREER OPPORTUNITIES for MICROWAVE ENGINEERS and PHYSICISTS

Capable of engaging in and directing both theoretical and experimental studies related to the propagation of electromagnetic fields through dielectric and semiconducting materials.

Two to five years experience in either antenna design, radome design, microwave circuit design or associated fields is essential. In addition, a knowledge of advanced electromagnetic field theory, electrical characteristics of materials or the techniques of microwave measurements would be highly desirable.

Service facilities include digital and nonlinear computation laboratories, technician service, pattern shop facilities, modern antenna test facilities, excellent library as well as other specialized services.

Send resume or request application from: C. G. Jones, Mgr., Salary Personnel

THE GOODYEAR AIRCRAFT CORPORATION
AKRON 15, OHIO

CAREER OPPORTUNITIES FOR . . .

- mechanical engineers
- electronics engineers
- electrical engineers
- physicists
- mathematicians
- aerodynamicists
- systems engineers

SANDIA CORPORATION, a subsidiary of the Western Electric Company, operates Sandia Laboratory under contract with the Atomic Energy Commission. Sandia engineers and scientists work at the challenging task of designing and developing atomic weapons. Graduate engineers and scientists, with or without applicable experience, will find excellent opportunities in the fields of component development, systems engineering, applied research, testing, and production.

COMPENSATION is competitive with that offered in other industry. Ingenuity and initiative are valued highly, and opportunities for professional advancement are outstanding. Working conditions are excellent, and employee benefits are most liberal.

SANDIA LABORATORY is located in Albuquerque — a modern, cosmopolitan city of 150,000, rich in cultural and recreational attractions and famous for its excellent year-around climate. Adequate housing is easily obtained. For descriptive literature giving more detailed information on Sandia Laboratory and its activities — or to make application for employment — please write:

professional employment
division 1A

SANDIA
Corporation

Sandia Base
Albuquerque, New Mexico

Positions Open

(Continued from page 145A)

ENGINEERS—PHYSICISTS

MECHANICAL, Liaison Engineer, capable of coordinating the mechanical work of several departments in a large multi-plant organization. Paying up to $14,000.

ELECTRONIC, background in Airborne Electronics, on all levels with emphasis on research and development. New project opening opportunities for advancement. $7,000-$15,000. No fee to our applicants on these positions. Guilford Personnel Service, American Bldg., Baltimore 2, Maryland.

TECHNICAL EDITOR

Nationally known, rapidly growing electronic magazine, has an opening for a young, energetic associate editor. Must be a graduate electronic engineer with 2-3 years design experience and have ability to write. Publication experience preferred. Submit resume with salary desired. Box 796.

SALES ENGINEER

To sell advertising space of ELECTRONIC DESIGN to industrial management. This is an exceptional opportunity for a career in industrial marketing and publishing. Young man between 25 and 32, should have technical background, proven sales record and management potential. New England, New York City territory, salary plus expenses and commissions. Send detailed resume to Hayden Publishing Company, Inc. 19 East 62 St., New York 21, N.Y.

ELECTRONIC ENGINEER

Laboratories located in a small midwestern town have an opening for a man experienced in the field of magnetic recording. Must be capable of building and operating a testing laboratory for the development and quality control of magnetic tape. Box 798.

ELECTRONIC ENGINEER

Edgerton, Germeshausen & Grier, Inc. 160 Brookline Ave., Boston, Mass. has a position open for an electronic engineer experienced in the development of instrumentation including oscilloscopic pulse techniques and allied circuitry. Send resume or call Personnel Dept. at COpley 7-3520.

DIGITAL COMPUTER ENGINEERS

Positions require familiarity with digital to analogue data converters, pulse circuits, logical design, sampled data system studies, memory devices. Sperry Gyroscope Co. (Div. of the Sperry Corp.) Great Neck, Long Island, N.Y.

ELECTRONICS ENGINEERS

Electronics manufacturer on San Francisco peninsula has openings for engineers qualified to handle design and development of specialized electronic circuits involving amplifiers, telemetering and related systems. Must have BSEE and at least 2 years experience in related fields. Salary commensurate with experience. Please send resumes to Dalmo Victor Co., 1414 El Camino Real, San Carlos, Calif.

COMPONENTS APPLICATION ENGINEER

Wanted for an intriguing job. *Essentials:* knowledge of military electronics; an interest in and skill at writing technical information; freedom to travel; ability to communicate with other engineers; organizing power and punch. *Opportunity:* this job will make your reputation in an important phase of electronics. *Location:* New York City. Box 804.

COMMUNICATIONS EQUIPMENT CO.

3 CM. ECHO BOX RF 3/AP

Cavity has a "Q" of 30,000 and is tuned by means of an internal 24 vdc motor. Unit is tunable over a range of 80 mc. When motor is left on, the tuning plunger goes thru the tuning range three times per minute. During the tuning motion, an eccentric cam on the mechanism causes an additional flutter action of the tuning disk at approximately 200 cycles per minute. This flutter range curves about 15 mc. This eliminates need of stopping the motor at the peak of the signal, and also gives a characteristic pattern to the echo signal. Input is to type "N" input jack ..**$125.**

MICROWAVE COMPONENTS

10 CM.—RG48/U Waveguide

10CM ECHO BOX: Tunable from 3200-3333 Mc. For checking out radar transmitters, for spectrum analysis, etc. Complete with pickup antenna and coupling devices. $27.50

10 CM ANTENNA ASSEMBLY: 3000-3300 Mc. Parabolic Dish, 29 inch Diam. Fed from dipole Rotation: 360 Deg. Azimuth at speeds of 20 and 10 RPM. Tilt: 20 deg. above and below horizontal. Motor-Driven by 2-28V motors, 4.5 A Total drain. Azimuth info. is fed to selsyn mechanism, and elevation data is obtained from Azimuth potentiometer. Net weight 65 lbs. $78.50

POWER SPLITTER for use with type 726 or any 10 CM Shepherd Klystron. Energy is fed from Klystron antenna through dual pick-up system to 2 type "N" connectors ....$22.50 EACH

LHTR, LIGHTHOUSE ASSEMBLY. Parts of RT39 APG 5 & APG 15, Receiver and Trans. Cavities w/assoc. Tr. Cavity and Type N CPLG. To Recvr. Uses 2C40, 2C43, 1B27. Tunable APX 2400-2700 MCS. Silver Plated $22.50

BEACON LIGHTHOUSE cavity p/o UPN-2 Beacon 10 cm. Mfg. Bernard Rice, each $27.50

MAGNETRON TO WAVEGUIDE Coupler with 721-A Duplexer Cavity, gold plated $45.00

721A TR BOX complete with tube and tuning plungers $12.50

McNALLY KLYSTRON CAVITIES for 707B or 2K28, 2700-2900 Mc. $4.00

WAVEGUIDE TO ⅞" RIGID COAX "DOOR-KNOB" ADAPTER CHOKE FLANGE SILVER PLATED BROAD BAND $32.50

AS14A AP-10 CM Pick up Dipole with "N" Cables $4.50

HOLMDELL-TO-TYPE "N" Male Adapters, W. E. #D167284 ....$2.75

I.F. AMP. STRIP: 30 MC, 30 d.b. gain, 4 MC Band-width, uses 6AC7's—with video detector, A.F.C. less tubes $24.00

BEACON ANTENNA, AS31/APN-7 in Lucite Ball, Type "N" feed $22.50

ANTENNA, AT49A/APR: Broadband Conical, 300-3300 MC Type "N" Feed $12.50

"E" PLANE BENDS, 90 deg. less flanges ...$7.50

3 CM.—RG 52/U Waveguide

3 CM ANTENNA ASSEMBLY: Uses 17" paraboloid dish, operating from 24 vdc motor. Beam pattern: 5 deg. in both Azimuth and elevation. Sector Scan: over 160 deg. at 35 scans per minute Elevation Scan: over 2 deg. Tilt: Over 24 deg. $85.00

Cross-Guide Directional Coupler, UG-40 output flange. Main Guide is 6" Long, with 90 Deg. "E" Plane bend at one end, and is fitted with Std. UG 39/UG 40 flanges. Coupling figure: 20 db Nominal $22.50

FLEX. WAVEGUIDE SECTION. 1 ft. long. With UG-40/UG-39 flanges. Attenuation is less than 0.1 db. at 9375 mc, and VSWR is less than 1.02. Rubber covered $7.50

JAN WAVEGUIDE FLANGES

UG 39/U	$1.10	UG 51/U	$1.65
UG 40/U	$1.25	UG 52/U	$3.40
UG 40A/U	$1.85	UG 52A/U	$3.40

1" x ½" waveguide in 5' lengths, UG 39 flanges to UG40 cover. Silver plated .....**per length $5.00**

Rotating-joints supplied either with or without deck mounting. With UG40 flanges **each, $17.50**

Bulkhead Feed-thru Assembly $15.00

Pressure Gauge Section 15 lb. gauge and press nipple $10.00

Pressure Gauge, 15 lbs. $2.50

Directional Coupler, UG-40/U Take off 20db $17.50

TR-ATR Duplexer section for above $8.50

Rotary Joint choke to choke with deck mounting $17.50

90 degree elbows. "E" plane 2½" radius ..$12.50

Microwave Receiver. 3 CM. Sensitivity: 10-13μ Watts. Complete with L.O. and AFC Mixer and Waveguide Input Circuits, 6 I.F. Stages give approximately 120 DV gain at a bandwidth of 1.7 MC. Video Bandwidth: 2 MC. Uses latest type AFC circuit. Complete with all tubes, including 723A/B Local Oscillator $175.00

ADAPTER, waveguide to type "N", UG 81/U, p/o TS 12, TS-13, Etc. $14.50

ADAPTER, UG-163/U round cover to special btl. Flange for TS-45, etc. ....$2.50 ea.

JAN/UG CONNECTORS

UG 9/U	$1.15	UG 27A/U	$2.50	UG 188/U	$1.20
UG 10/U	1.25	UG 29/U	.95	UG 254/U	1.35
UG 22/U	1.25	UG 58/U	.65	UG 261/U	1.10
UG 22B/U	1.20	UG 85/U	1.25	UG 290/U	1.15
UG 24/U	1.25	UG 102/U	1.85	UG 306/U	2.35
UG 27/U	1.20	UG 176/U	.25		

THERMAL DELAY RELAYS

Stock No.	Heater V	Contact*	Delay (Sec)	Price
30120	6.3	NC	30	$2.25
B-1608	6.3	NO	25	2.40
B-1612	6.3	NO	5	1.85
6C10	6.3	NC	10	1.85
12C5	12	NC	5	1.75
12C10	12	NC	10	1.85
12C45	12	NC	45	2.45
26NO5	24-28	NO	5	2.25
26NO10	24-28	NO	10	2.25
26NO15	24-28	NO	15	2.40
26NO20	24-28	NO	20	2.40
26NO30	24-28	NO	30	2.40
26NO60	24-28	NO	60	2.40

* NO—Normally open. NC—Normally closed. All contact ratings are 3A at 115 VDC or 250 VAC, and are SPST. Units are enclosed in glass tube envelope with octal base.

MAGNETRONS

Type	Peak Range (MC)	Peak Power Out (KW)	Duty Ratio	Price
2J21A	3345-9405	50		$ 8.75
2J22	3267-3333	265		7.50
2J26	2992-3019	275	.002	7.49
2J27	2965-2992	275	.002	13.50
2J29	2914-2939	275	.002	44.95
2J31	2820-2860	285	.002	21.50
2J32	2780-2820	285	.002	21.50
2J38*	3249-3263	5		8.50
2J39*	3267-3333	8.7		8.50
2J48	9310-9320	50	.001	24.50
2J49	9000-9160	50	.001	54.50
2J56*	9215-9275	50	.001	132.50
2J62†	2914-3010	35	.002	32.50
3J31	24-27KMC	50	.001	85.00
4J34	2740-2780	900		87.50
4J38	3550-3600	750	.001	125.00
4J42†	670-730	30	.003	169.50
5J23	1044-1056	475	.001	49.50
700B	690-700	40	.002	22.50
700D	710-720	40	.002	39.75
706EY	3038-3069	200	.001	32.50
706CY	2976-3007	200	.001	32.50
QK259†	2700-2900	800	.001	249.50
QK60†*	2840-3005	.100	CW	65.00
QK61†*	2975-3170	.100	CW	65.00
QK62†*	3135-3350	.100	CW	65.00

*—Packaged with magnet.
†—Tunable over indicated range.

TEST EQUIPMENT

IE 19	TS 34 A	TS 100
IE 36	TS 35 A	TS 110
I-104	TS 56 A	TS 159 TPX
TS 10 A	TS 47 APR	TS 268/U
TS 16	TS 100	TSX 4 SE

POWER TRANSFORMERS

COMBINATION—115V/60 ~ INPUT

CT-133	150-C-150V/65MA, 6.3V/2.5A, 6.3V/0.6A	$1.79
CT-312	290-0-290V/90MA, 5VCT/3A, 6.3VCT/2.8A	3.25
CT-127	900V/25MA PK. 5V/2A, 2V/7.5A	2.79
CT-006	350-0-350V/120MA, 5VCT/3A, 2.5VCT/12.5A, 2.5VCT/3.5A	6.10
CT-965	78V/0.6A, 6.3V/2A	1.95
CT-004	350-0-350V/90MA, 5VCT/3A, 2.5VCT/12.5A	4.60
CT-002	350-0-350V/50MA, 5VCT/2A, 2.5VCT/7.5A	3.65
CT-479	7000V/.018A (2 X Ind. V. Test) 2.5V 5A/17,800 V. Test	29.50
CT-013	450-0-450V @ 200MA, 10V/1.5A, 2.5V 3.5A 5V/3A	6.95
CT-403	350VCT .026A 5V/3A	2.75
CT-931	585VCT .086A 5V/3A, 6.3V/6A	4.25
CT-442	525VCT 75MA 5V/2A, 1CT/2A, 50V/200 MA	3.85

PLATE—115V/60 ~ INPUT

PT 034	125V/45MA	$1.15
PT 157	660-0-660VAC (500VDC) or 550-0-550VAC (400VDC) at 250 MADC	8.70
PT 159	900-0-900 VAC (750VDC) or 800-0-800 VAC (600VDC) at 225 MADC	10.35
PT 167	1400-0-1400 VAC (300MADC) or 1175-0-1175 VAC (1000VDC) at 300 MADC	25.50
PT 168	2100-0-2100 VAC (1750VDC) or 1800-0-1800 VAC (1500VDC) at 300 MADC	33.00
PT 371	210-0-210V at 2.12 Amp.	9.45
PT 133	3140/1570V. 2.36KVA	105.00
PT 801	22,000V/234 MA., 5.35 KVA	135.00
PT 521	7500V/.06A, Half-Wave	85.00
PT 913	2500V/12 MA H'SLD	4.95
PT 12A	280VCT/1.2A	3.95
PT-38-2	37.5/40V AT 750 MA	2.15

PULSE NETWORKS

15A—1-400-50: 15 KV, "A" CKT. 1 microsec. 400 PPS. 50 ohms imp. $24.50

G.E. #3E (3-84-810) 8-2.24-405) 50P4T : 3KV "E" CKT Dual Unit: Unit 1, 3 sections, 0.84 Microsec. 810 PPS, 50 ohms imp.; Unit 2, 8 Sections, 2.24 microsec. 405 PPS 50 ohms imp. $6.50

7-5E3-1-200-67P, 7.5 KV "E" Circuit, 1 microsec. 200 PPS, 67 ohms impedance 3 sections $7.50

7-5E4-16-60, 67P, 7.5 KV "E" Circuit, 4 sections 16 microsec, 60 PPS, 67 ohms impedance $15.00

7-5E3-3-200-67P, 7.5 KV, "E" Circuit, 3 microsec, 200 PPS, ohms imp. 3 sections $12.50

#755: 10KV, 2.2usec., 375 PPS, 50 ohms imp. ...$27.50

#754: 10KV, 0.85usec., 750 PPS, 50 ohms imp. ..$27.50

KS8865 CHARGING CHOKE: 115-150 H @ .02A, 32—40H @ .08A, 21KV Test $37.50

G.E. 25E5-1-350-50 P2T, "E" SKT, 1 Microsec. Pulse @ 350 PPS, 50 OHMS Impedance $69.50

KS9623 CHARGING CHOKE: 16H @ 75 MA, 380 Ohms DCR, 9000 Vac test $14.95

G.E. 6E3-.5-2000 50 P2T: 6 KV., "E" Circuit 0.5 usec /2000 PPS/50 ohms/2 sections $7.50

PULSE EQUIPMENT

MIT. MOD. 3 HARD TUBE PULSER: Output Pulse Power 144 KW (12 KV at 12 Amp). Duty Ratio: .001 max. Pulse duration: 5, 1.0, 2.0 microsec. Input voltage: 115 v. 400 to 2400 cps. Uses: 1-71B, 4-89-B, 3-'72's, 1-'73. New ....Less Cover—$135

ASD Modulator Units, mfd. by Sperry. Hard tube pulser delivers Pk. pulse of 144 kw. Similar to Mod. 3 unit. Brand new, less tubes $85.00

Airborne RF head, model AIA, delivers 50 Kw peak output at 9000 mc, at .001 duty. Complete with pulser unit and all tubes. Used, excel. $185.00

PULSE TRANSFORMERS

Westinghouse 4P37: Primary: 50 ohms imp. 750 v. Sec. 15 kv. 1000 ohms imp. Bifilar filament trans. built in, delivers 12.6 v at 2.5 amp. (pri. 115 v. 400 cy.) $37.50

RAYTHEON WX 4298E: Primary 4KV., 1.0 USEC. SEC: 16KV-16 AMP DUTY RATIO: .001 400 CYCLE FIL. TRANS. "BUILT-IN" $42.50

WECO: KS 9948: Primary 700 ohms; Sec: 50 ohms. Plate Voltage: 18 KV. Part of APQ-13 ......$12.50

GE #K-2449A
Primary: 9.33 KV, 50 ohms Imp.
Secondary: 28 KV, 450 ohms.
Pulse length: 1.0/5 usec @ 635/120 PPS, Pk Power Out: 1,740 KW
Bifilar: 1.5 amps (as shown) ...$62.50

GE #K-2748-A, 0.5 usec @ 2000 Pps. Pk. Pwr. out is 32 KW impedance 40:100 ohm output. Pri. volts 2.3 KV Pk. Sec. volts 11.5 KV Pk. Bifilar rated at 1.3 Amp. Fitted with magnetron well $39.50

K-2745 Primary: 3.1/2.8 KV, 50 ohms Z. Secondary: 14/12.6 KV 1025 ohms Z. Pulse Length: 0.25/1.0 usec @ 600/600 PPS, Pk. Power 200/150 KW. Bifilar: 1.3 Amp. Has "built-in" magnetron well $42.50

K-2461-A. Primary: 3.1/2.6 KV—50 ohms (line). Secondary 14/11.5 KV—1000 ohms Z. Pulse Length: 1 usec @ 600 PPS, Pk. Power Out: 200/130 KW. Bifilar: 1.3 Amp. Fitted with magnetron well .$39.75

K35J45—Pulse Inversion: PRI: 5 KV PK. Pulse Negative. Sec: Pos. Pulse, 4 KV: 1 usec. and .001 DUTY RATIO $6.50

54J318-1—3 wdgs. Ratio: 1:1:1, 1.10 uh. /wdg., 2.5 ohms DCR $3.50

UTAH X-151T-1: Dual Transformer, 2 Wdgs. per section 1:1 Ratio per sec 13 MH inductance 30 ohms DCR $5.00

UTAH X-150T-1: Two sections, 3 Wdgs. per section. 1:1:1 Ratio. 3 MH. 6 ohms DCR per Wdg. $5.00

68G711: Ratio: 4:1 Pri: 200V, Sec. 53V. 1.0 usec Pulse @ 2000 PPS, 0.016 KVA $4.50

TR1049 Ratio 2:1 Pri. 220 MH. 50 Ohms, sec. 0.75 H. DCR 100 Ohms $6.75

K-904695-501: Ratio 1:1, Pri. Imp. 40 Ohm, Sec. Imp. 40 Ohms. Passes pulse 0.6 usec with 0.05 usec rise $8.95

Ray UX 7896—Pulse Output Pri, 5v sec. 41v $7.50

DELAY NETWORKS

D-168184: 0.5 usec. up to 2000 PPS. 1800 ohms .$4.00

D-170499: 0.25/.5/.75/usec. 8 KV., 50 ohms $12.50

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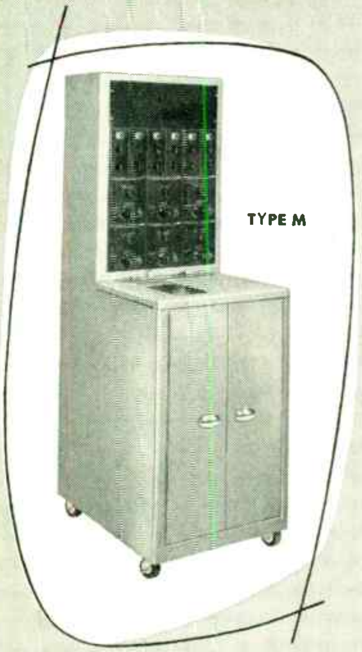

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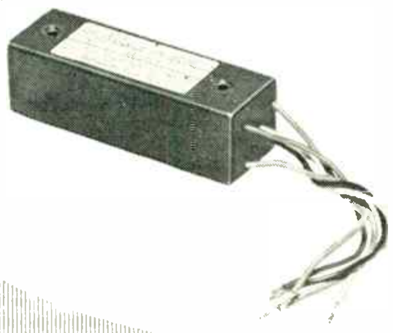

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Varian Associates	101A
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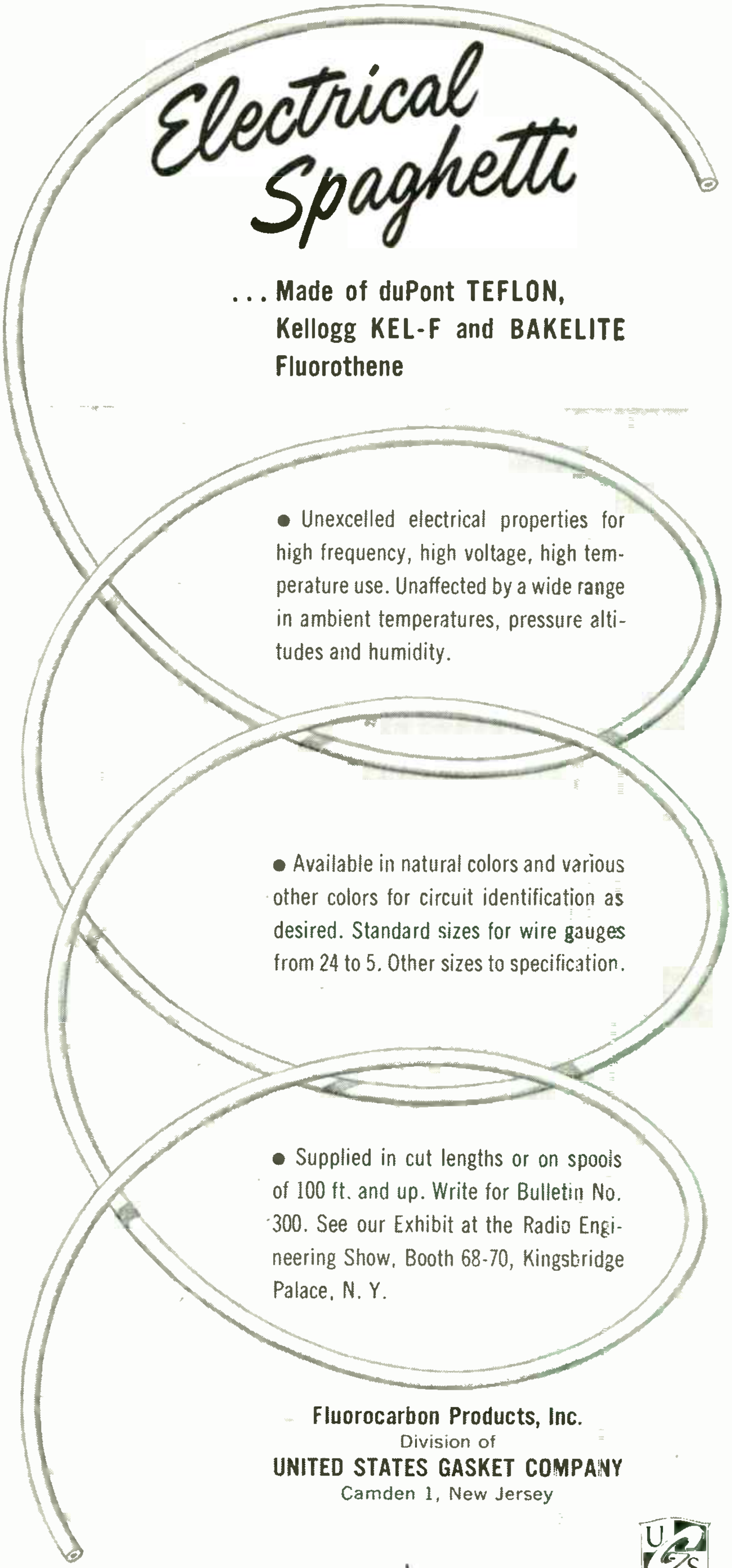

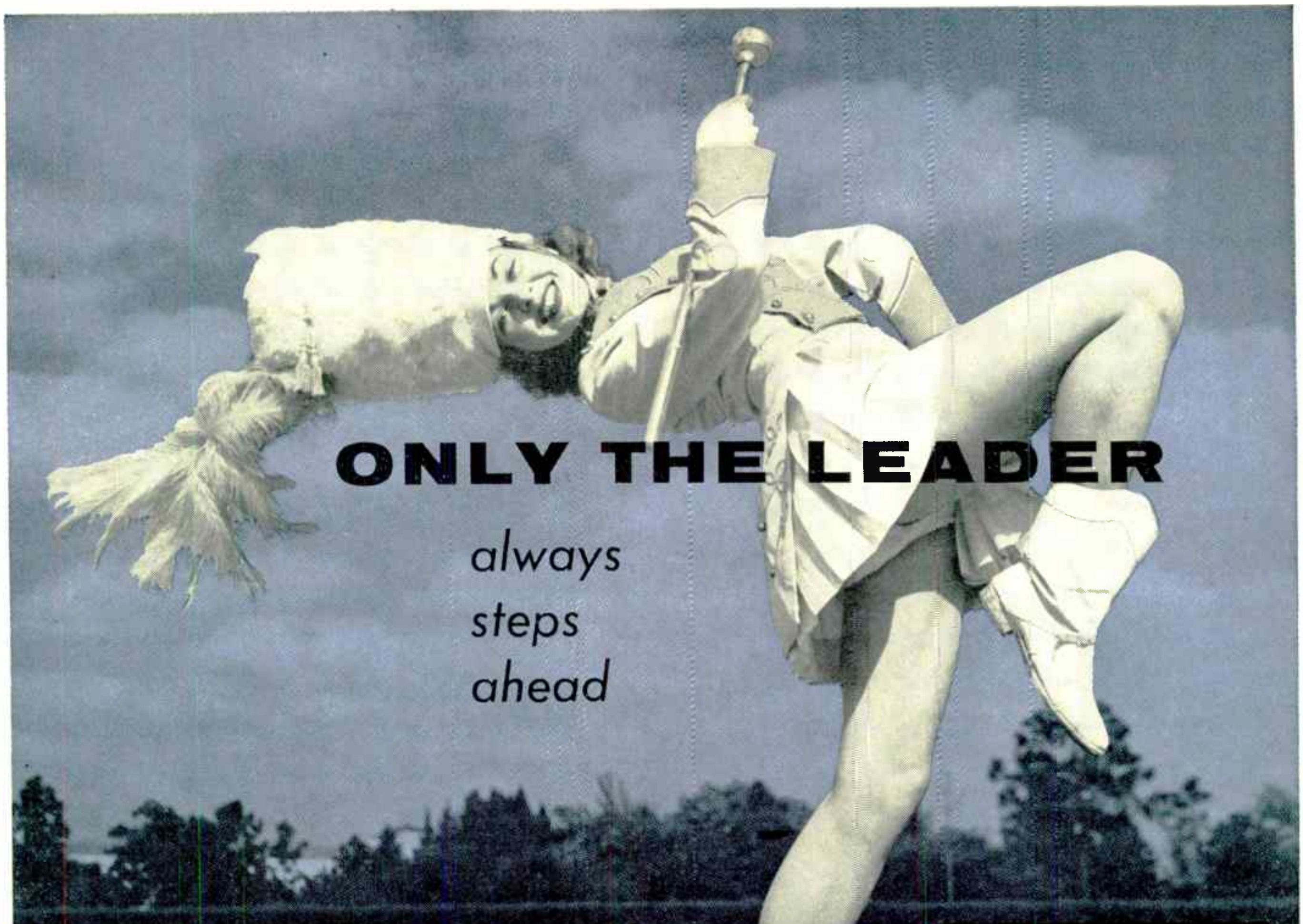

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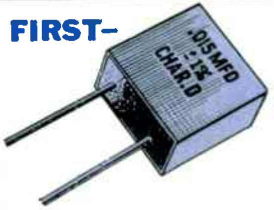

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Wide Frequency Range — 300 to 5000 Mc; useful down to 150 Mc and well over 5000 Mc.

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Minimum Built-In VSWR — line and connectors introduce residual VSWR of less than 1.025 to 1000 Mc, less than 1.07 at 4000 Mc.

Constancy of Probe Coupling—within 1½% along entire 50-cm line — spring-loaded nylon plugs at probe carriage ends bear on outer conductor, practically eliminating "play" and consequent changes in probe coupling.

Precision-Tooled Probe Carriage — made of cast bronze, it slides on tightly fitting bronze bearings — felt washers at ends prevent dirt from entering carriage — oil holes provided for long-lasting lubrication of bearings.

Sturdy Line Construction — outer conductor is rigidly clamped on heavy brass castings and stiffened by two ½" stainless-steel rods — rugged center conductor is of steel tubing with heavy copper and silver plating, supported by two teflon insulators at ends; these insulators are electrically compensated to eliminate reflections.

G-R Universal Type 874 Connector at Ends — this low-loss connector has proven superb for instrument use — its VSWR is less than 1.04 to 4000 Mc; its universal construction permits any Type 874 Connector to plug into any other, materially reducing set-up time and the need for large stocks of male and female components; connections and disconnections are made instantly.

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