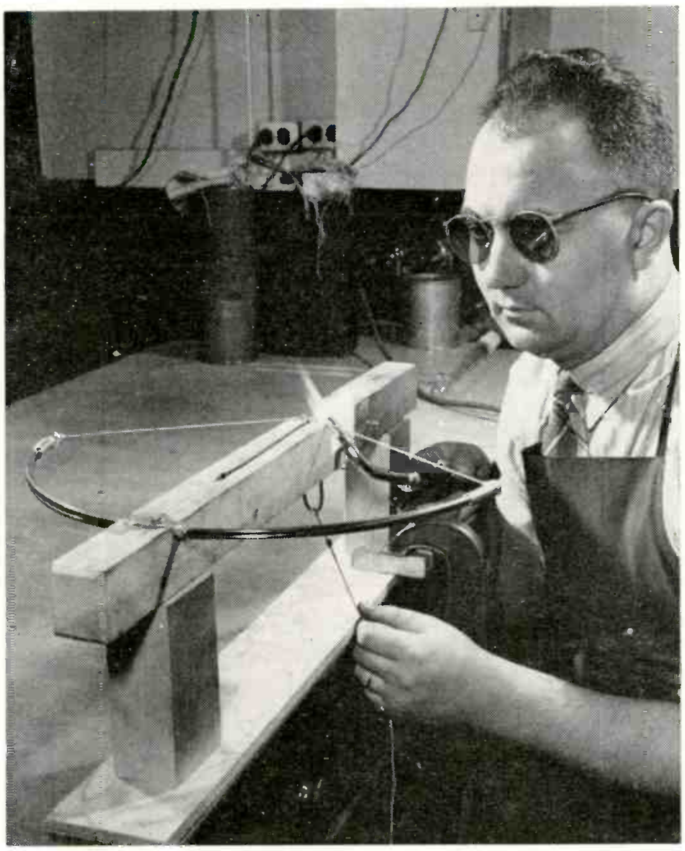
PROCEEDINGS of the I·R·E AND WAVES and ELECTRONS

The Institute of Radio Engineers

INCORPORATED



Westinghouse

ELECTRONIC ARCHER

STEEL CROSSBOW SHOOTS ARROW TO DRAW QUARTZ FILAMENT 1/30,000 OF AN INCH IN DIAMETER FOR ELECTRON-MICROSCOPE CALIBRATIONS.

APRIL, 1946

Volume 34 Number 4

Published in Two Sections

REPORTS of the Theory, Practice, and Applications of Electronics and Electrical Communication

• Radio Communication • Sound Broadcasting • Television • Marine and Aerial Guidance • Tubes • Radio-Frequency Measurements • Engineering Education • Electron Optics • Sound and Picture Electrical Recording and Reproduction • Power and Manufacturing Applications of Radio-and-Electronic Technique • Industrial Electronic Control and Processes • Medical Electrical Research and Applications •

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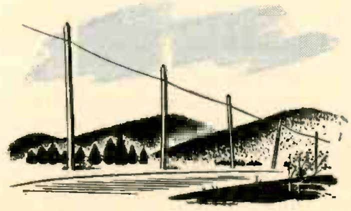
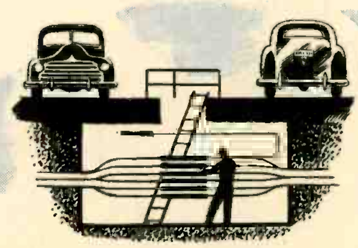
Why

this team is a leader in VHF

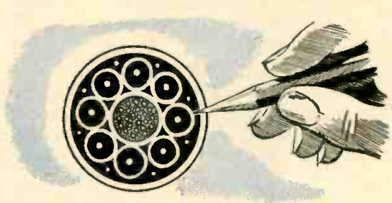


1. *First voice circuits were single iron wires with ground return. Frequency limitations, noise and high losses soon ruled them out.*

2. Big improvement was the all wire circuit—a pair of wires to a message. Later came carrier which stepped up frequency and permitted several messages per circuit.



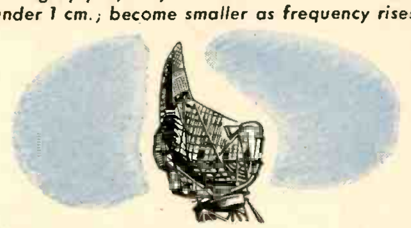
3. Lead covered cable compressed many wire circuits into small space—took wires off city streets. But losses are prohibitive at very high frequencies.



4. Coaxial cable—a single wire strung in a pencil size tube—extended the usable frequency band up to millions of cycles per second and today carries hundreds of messages per circuit, or the wide bands needed for television.

transmission

5. *Wave guides, fundamentally different in transmission principle, channel energy as radio waves through pipes; vary in size from several inches to under 1 cm.; become smaller as frequency rises.*



6. *Late model radar wave guides, similar to that used to feed the antenna above, can carry 3½ cm. waves at more than eight billion cps. Experimental guides for still shorter waves are being tested.*

Back in 1933, Bell scientists established an historic first when they transmitted very high frequency radio waves for hundreds of feet along hollow pipes called wave guides. For them it was another forward step in their long research to make communication circuits carry higher frequencies, broader bands and more messages per circuit.

Continuing Research showed the way

From the days of the single open wire line—through all-metallic circuits, phantoming, cable, carrier systems and coaxials—up to today's wave guides, every improvement has been the result of continuous fundamental study.

When Bell Laboratories started work on wave guides, there was no immediate application for the microwaves they guided. But the scientists foresaw that *some day* wave guides would be needed—so they kept on working until they had developed the wave guide into a practical device.

With the war came radar—and the problem of conducting microwave frequencies. Bell Laboratories had the answer—wave guides—without which radar at the higher frequencies would have been impractical.

What this means to YOU

Year after year, Bell Laboratories have continued to develop methods for handling higher and higher frequencies. Year after year Western Electric has provided equipment putting these scientific advances to work. This team has become the natural leader in the field.

When your requirement dictates the use of VHF—in mobile communications, broadcasting, or point-to-point radio telephony—depend on Western Electric to supply the latest and best equipment for your needs.

BELL TELEPHONE LABORATORIES

World's largest organization devoted exclusively to research and development in all phases of electrical communication.

AMERICAN TELEPHONE & TELEGRAPH CO. BELL SYSTEM AND ASSOCIATED COMPANIES

Western Electric

Manufacturing unit of the Bell System and nation's largest producer of communications and electronic equipment.

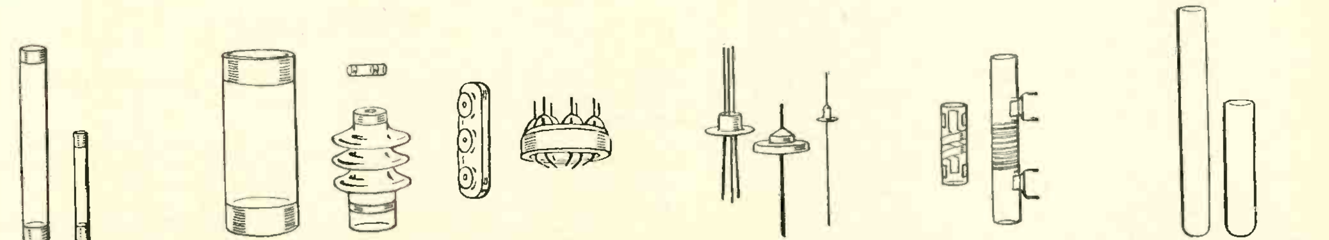
TALKIE SALE!

ONE thing we've learned during the war—almost every small electronic device should be able to work anywhere under any climatic condition. People are going to expect their personal walkie-talkies, plane radios, hearing aids, etc., to be as tough and durable as the stuff the industry developed for the armed forces. The more punishment they take, the better they'll sell.

And that's where these funny-looking little eyelet terminals may be able to do you a lot of good. They're used to carry one or more leads into very small openings. The wires pass through tiny glass beads surrounded by metal collars, which you can solder into place in the twinkling of an eye. They form permanent hermetic seals, resist surface contamination, thermal shock and weathering. They have high mechanical strength and are chemically stable. All standard items are readily produced in quantity.

These Eyelet Terminals are another example of the breadth and versatility of Corning's line of electronic products. Some of them are pictured below with a brief description. Maybe they'll point to a possible solution for a problem that's been bothering you. If so, write, wire or phone The Electronic Sales Department, E-4, Technical Products Division, Corning Glass Works, Corning, New York. One of our engineers will be calling on you in record time to help solve your difficulties.

NOTE—*The metallized Tubes and Bushings, Headers and Coil Forms below are all made by the famous Corning Metallizing Process. Can be soldered into place to form true and permanent hermetic seals. Impervious to dust, moisture and corrosion.*



Metallized Tubes *for resistors, capacitors, etc. 20 standard sizes ½" x 2" to 1¼" x 10". Mass-produced for immediate shipment.*

Metallized Bushings. *Tubes in 10 standard sizes, 5/16" x 25/32" to 1" x 4 7/32" in mass production for immediate shipment.*

Headers — *The best way to get a large number of leads in a small space for assembly in one operation.*

Eyelet Terminals — *Single or multiple eyelets permit design flexibility. Standard items readily available in quantity.*

Coil Forms—*Grooved for ordinary frequencies—metallized for high frequencies. In various designs and mountings.*

VYCOR Brand cylinders—*very low loss characteristics. Stands thermal shock up to 900°C Can be metallized.*

"VYCOR", "CORNING" *and* "PYREX" *are registered trade-marks and indicate maufacture by Corning Glass Works, Corning, N. Y.*

Electronic Glassware

TRADE MARK VYCOR REG. U.S. PAT. OFF.

T.M.REG. CORNING U.S. PAT. OFF.

T.M.REG. PYREX U.S. PAT. OFF.

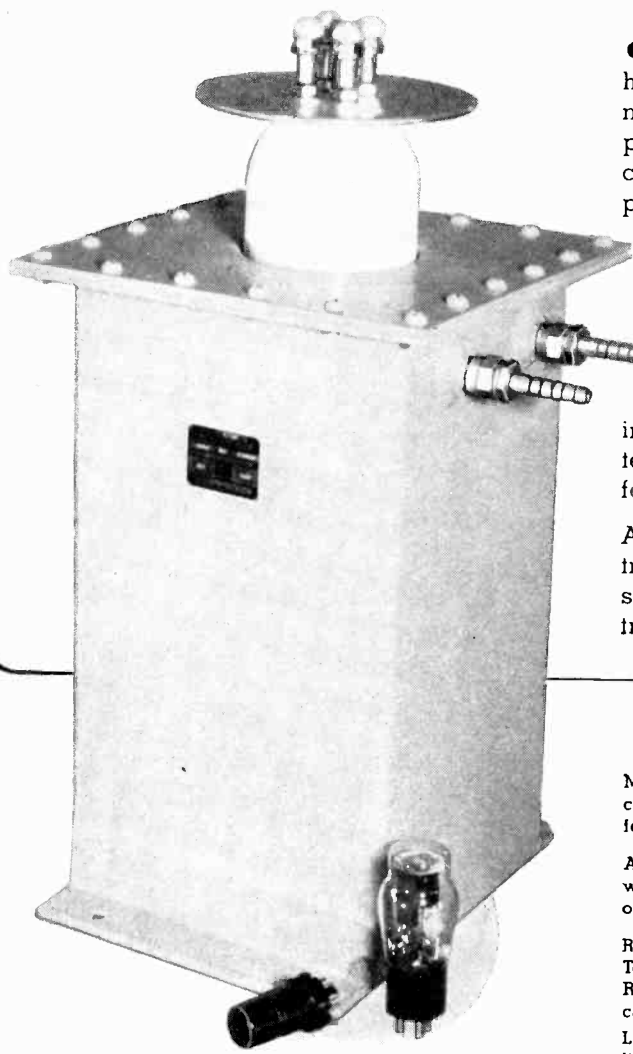
BOOST KVA RATING BY FIVE OR MORE . . .

CUT PRESENT SIZES OF POWER CAPACITORS . . .

AEROVOX SERIES 1780

Water-cooled

MICA CAPACITORS



● This new water-cooled oil-filled mica capacitor handles exceptional KVA loads for its size. This means that more power can be handled than with previous capacitors of similar size or, conversely, capacitor size can be greatly reduced for given power ratings.

Series 1780 capacitors attain their higher KVA ratings in two ways: (1) By exceptional design such as critical arrangement and location of sections; choice of materials; specially-plated parts; large cross-section of conductors; careful attention to details and true craftsmanship in production. (2) By the use of a water-cooling system so designed as to provide maximum heat transfer from capacitor section to cooling coils.

All in all, here is a sturdy, compact, hard-working, trouble-free mica capacitor for extra-heavy-duty service, such as induction furnaces and high-power transmitters.

Featuring . . .

Mica stacks in oil bath. Cooling coils in oil bath for efficient transfer of heat.

Air-cooled operation, 200 KVA; with water-cooling, 1000 KVA—a one-to-five ratio.

Ratings up to 25,000 volts A.C. Test. Capacitances up to .01 mfd. Rated loads up to 1000 KVA. Typical unit: 20,000 V. at .01 mfd.

Lower power factor (.01%). Long life and large factor of safety.

Provisions for making connections with high-current-capacity conductors. Four-stud terminal. Grounded case.

Heavy welded metal case, hermetically sealed. Exceptionally sturdy construction.

Series-parallel mica stack designed for uniform current distribution throughout.

Silver-plated hardware for minimum skin resistance. To minimize or eliminate corona, terminals are finished with large radii of curvature. Steatite insulator shaped to hold gradients below corona limits.

TECHNICAL DATA ON REQUEST

AEROVOX capacitors

FOR RADIO-ELECTRONIC AND INDUSTRIAL APPLICATIONS

AEROVOX CORPORATION, NEW BEDFORD, MASS., U. S. A.

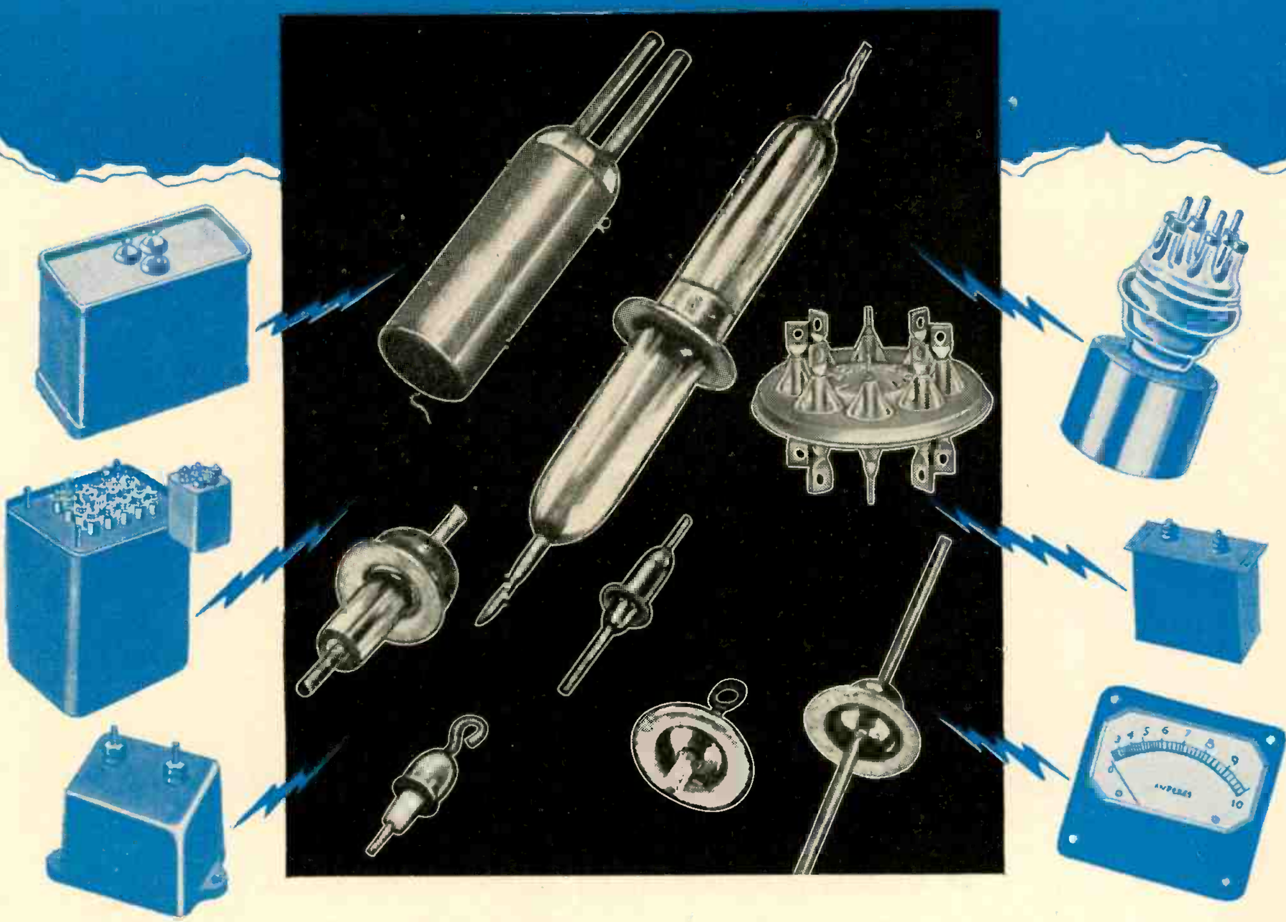
SALES OFFICES IN ALL PRINCIPAL CITIES • Export: 13 E. 40th ST., NEW YORK 16, N. Y.

Cable: 'ARLAB' • In Canada: AEROVOX CANADA LTD., HAMILTON, ONT.

STUPAKOFF HERMETIC SEALS

meet exacting demands of

MODERN ELECTRONIC DEVELOPMENTS



Stupakoff Kovar*-glass seals provide permanently vacuum and pressure tight, insulated electrical lead-ins on products which must be sealed from the atmosphere, even under the most adverse climatic conditions.

Metal-glass terminals are available, or can be made in shapes and sizes to suit your needs . . . with single or multiple, hollow or solid electrodes.

Kovar alloy is also available in the form of sheet, rod, wire, tubing and special shapes for the manufacturers of electronic tubes and others who have their own glass working facilities.

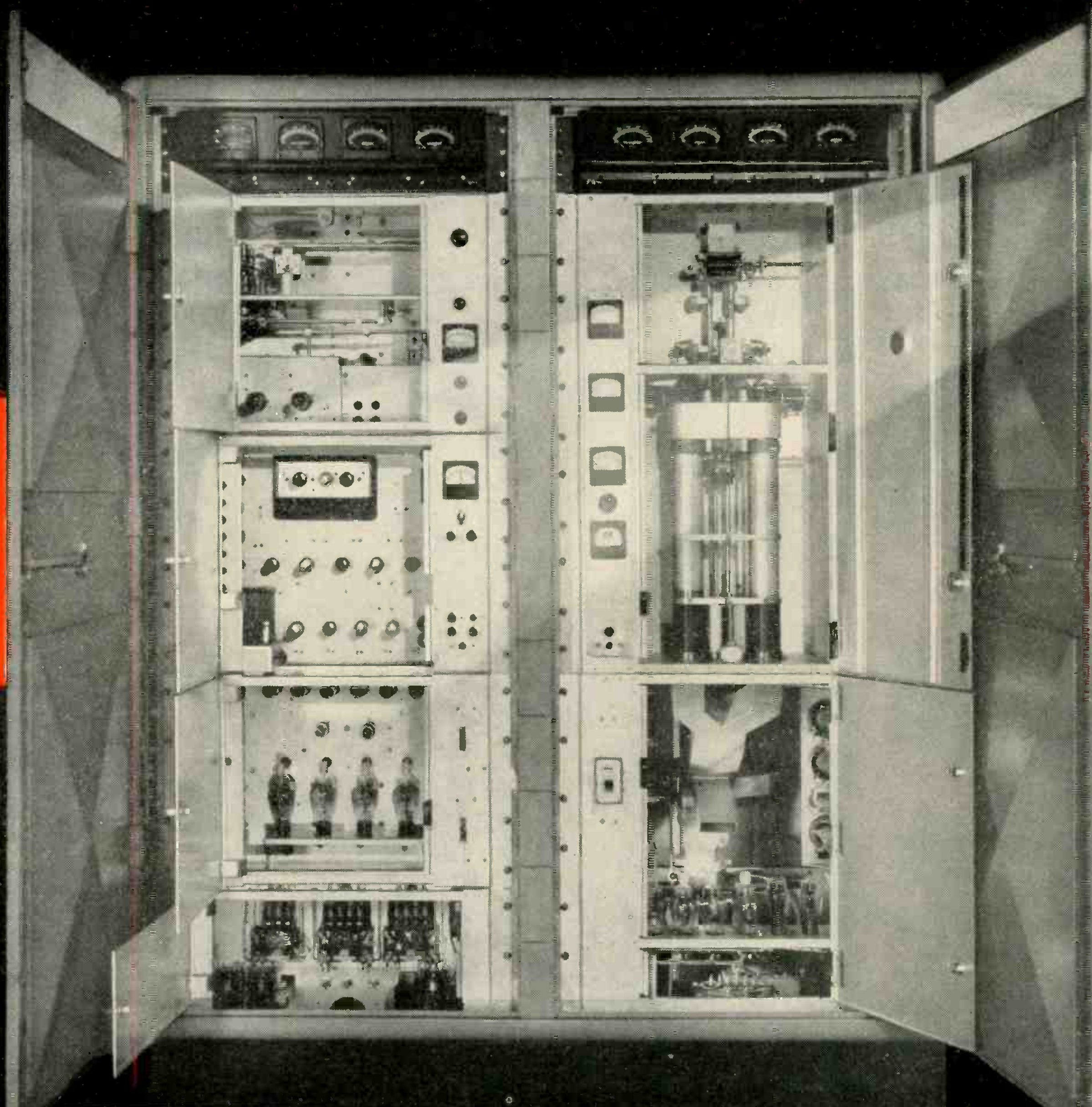
A line from you as to your sealing problems will enable us to make specific recommendations and supply the applicable literature.

*Reg. U. S. Pat. Off. Trade Mark No. 337962

STUPAKOFF

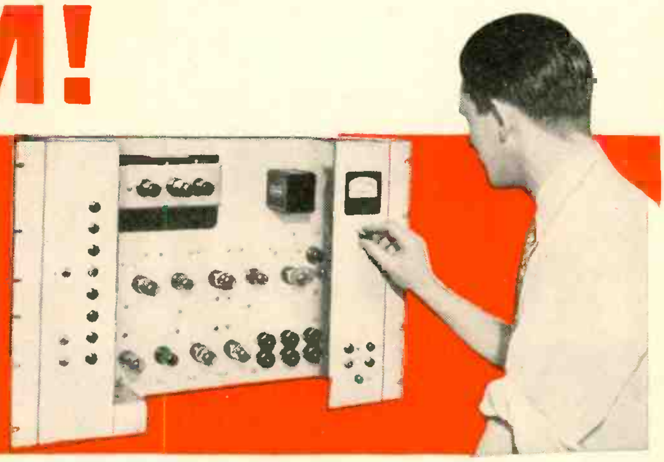
CERAMIC AND MANUFACTURING CO. · LATROBE, PA.

EXPORT DEPARTMENT 13 E. 40TH ST., NEW YORK 16, N. Y. CABLE ADDRESS ARLAB ALL CODES



HERE'S THE BIG NEWS IN FM!

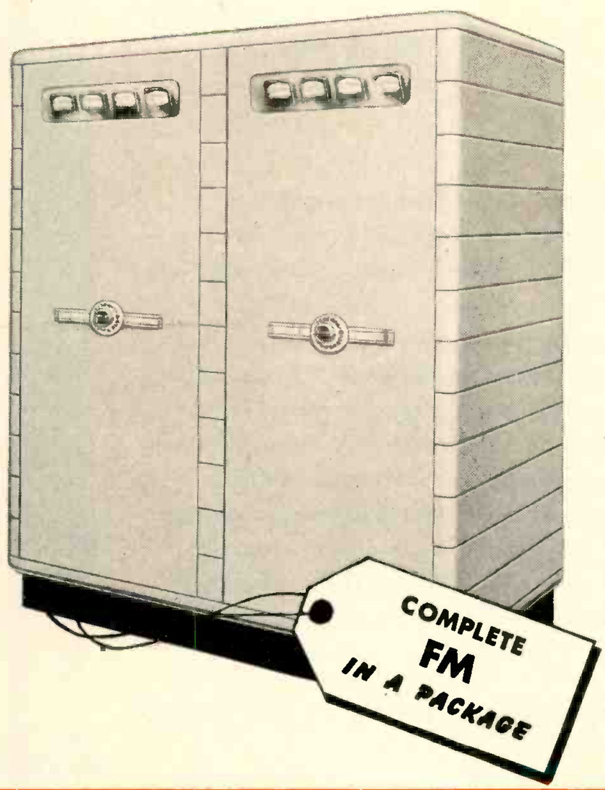
...it's FEDERAL's new "FREQUEMATIC"* MODULATOR



1—3—10 and 50 KILOWATT FM RADIO EQUIPMENT

The "FREQUEMATIC" Modulator takes its place as part of the complete "package" of FM broadcasting equipment offered by Federal. From one source, you get every piece of broadcasting gear to set up operation *now* ... from studio equipment to transmitting tower ... all precision-engineered, all matched, all of highest quality. No more piecemeal assembly of components, and uncertainties of divided responsibility. Federal assumes full responsibility for delivery and *installation* of a complete FM Broadcasting System. For complete details, write: Federal Telephone and Radio Corporation, Newark 1, New Jersey.

*Trade Mark



Telephone and Radio Corporation

Newark 1, New Jersey

Export Distributor:
International Standard Electric Corporation

AN IT&T ASSOCIATE

AMPHENOL

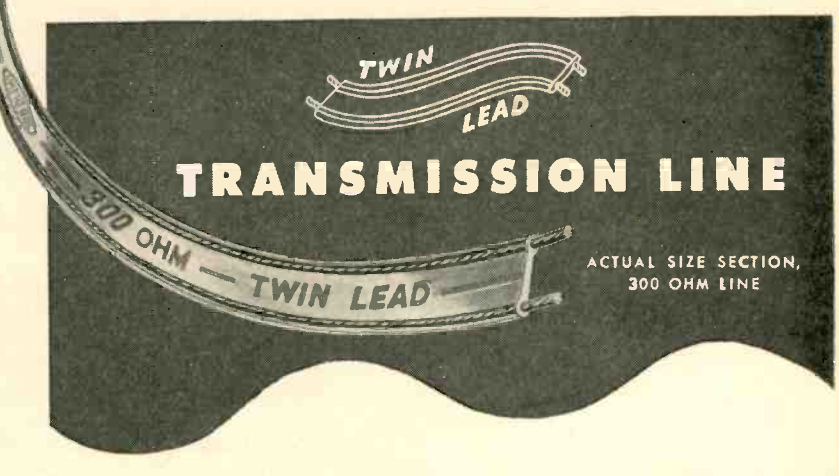
The Perfect Parallel Line Lead-in Wire

Amphenol Twin-Lead is a new type of radio frequency transmission line which combines the low cost of an open line with the excellent dielectric qualities of Polyethylene as a continuous spacer and insulator for the line. It is light and flexible — it can be tacked to a wall and is easy to lead in under a window sash. Its resistance to moisture, cold and heat is far superior to the usual rubber insulated, woven-braid-covered twisted pair used for antennas prior to the war.

Twin-Lead is made in three impedances that serve numerous applications. Selection of type is a simple matter. The *300 ohm* line is the most universal in use, particularly for FM and Television reception. Amateurs are using this line for both antenna and lead-in. The *150 ohm* type is excellent for antennas used mostly for short-wave broadcast reception, and is useful as a link between stages of a transmitter. The *75 ohm* line, originally designed for amateurs who operate in narrow bands of frequency, is also many times better for broadcast reception than the conventional rubber covered or cotton covered wire generally used.

It is to be emphasized that Amphenol Twin-Lead should not be thought of as exclusively for use at ultra-high frequencies. It is THE antenna lead-in for all frequencies.

AMERICAN PHENOLIC CORPORATION
CHICAGO 50, ILLINOIS
In Canada • Amphenol Limited • Toronto



ELECTRICAL DATA

TWIN 300 LEAD — Amphenol "Twin-Lead" Transmission Line is available in 300-ohm impedance value. RMA standardized on 300-ohm lead-in line for Television as the most efficient over broadband operation.

TWIN 150 LEAD — Amphenol also supplies 150-ohm twin-lead to those interested in particular applications and experimental work.

TWIN 75 LEAD — Designed especially for amateurs who operate in very narrow bands of frequency or one particular frequency. Ideal for dipoles with a nominal impedance of 72 ohms at the frequency for which they are cut. This line is also excellent for broadcast reception.

Dielectric constant of Polyethylene — 2.29. Capacities (mmf per ft.): "300" — 5.8; "150" — 10; "75" — 19.

Velocity of propagation (approximately): "300" — 82%; "150" — 77%; "75" — 69%.

Power factor of Polyethylene — up to 1000 Mc — .0003 to .00045.

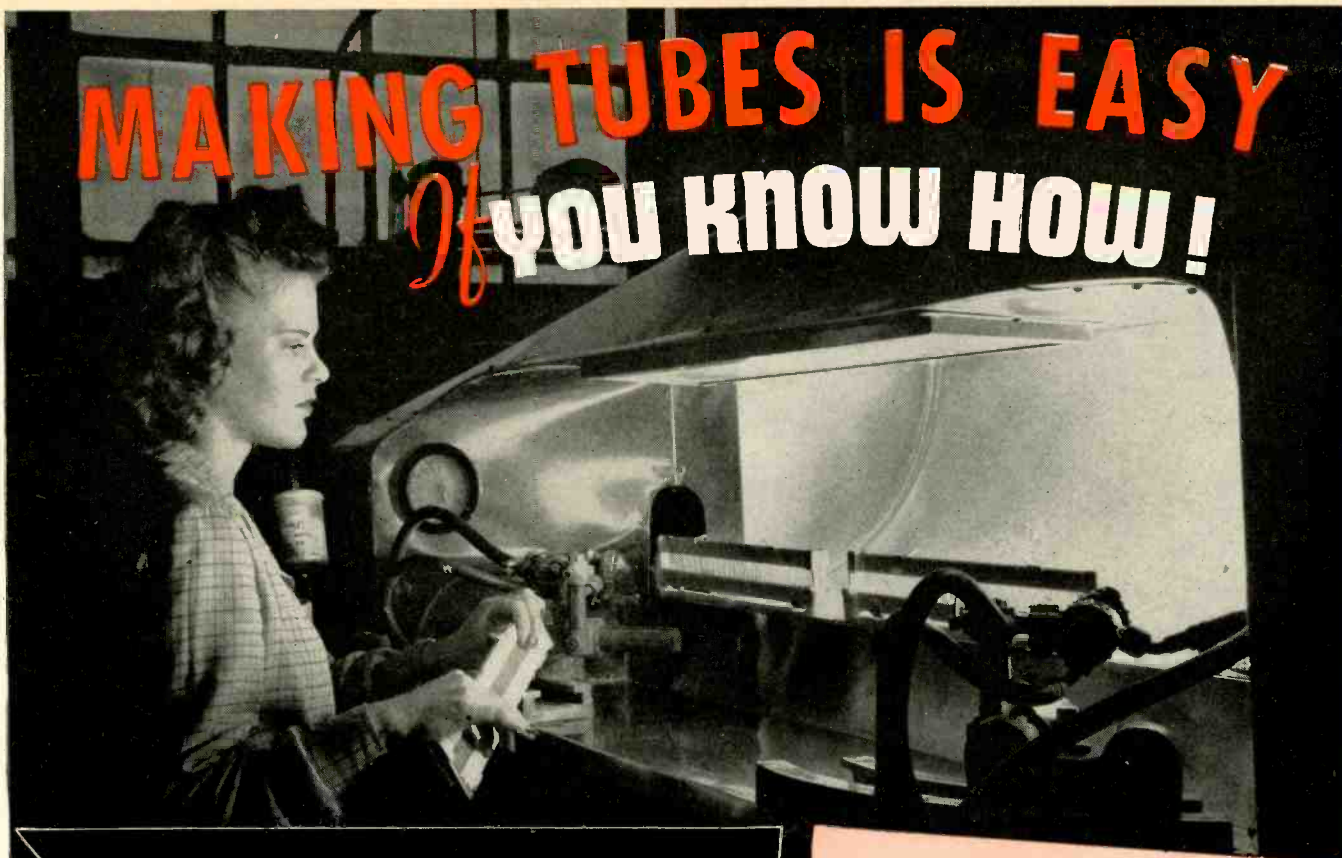
ATTENUATION — FM AND TELEVISION BAND

Megacycles	300-ohm DB per 100 Ft.	150-ohm DB per 100 Ft.	75-ohm DB per 100 Ft.
25	0.77	0.9	1.7
30	0.88	1.03	2.0
40	1.1	1.3	2.5
60	1.45	1.8	3.4
80	1.8	2.25	4.3
100	2.1	2.7	5.0
200	3.6	4.7	8.3

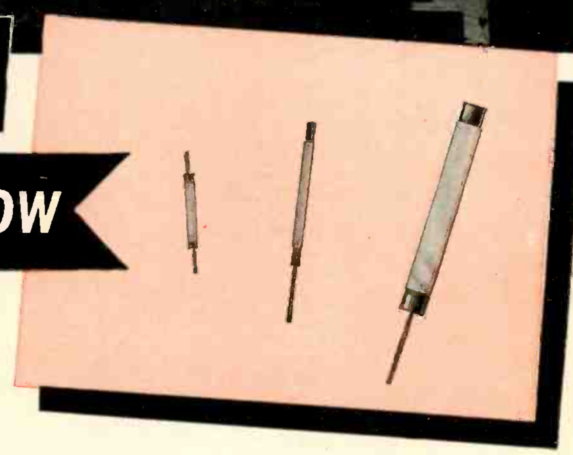
Depend upon AMPHENOL Quality

COAXIAL CABLES AND CONNECTORS • INDUSTRIAL CONNECTORS, FITTINGS AND CONDUIT • ANTENNAS RADIO COMPONENTS • PLASTICS FOR ELECTRONICS

MAKING TUBES IS EASY *If* YOU KNOW HOW!



HERE'S ANOTHER EXAMPLE OF UNMATCHED HYTRON KNOW-HOW



AGAIN a painstaking, tough job is made easy. This Hytron electronically-controlled cathode-spray machine minimizes the element of human error always present with hand spraying. Evenly applied emissive coating of exactly the right weight and density is obtained hour after hour. Number and speed of coating passes, distance from spray guns to cathode sleeves, and intensity of the spray are precisely controlled.

An endless belt, with 8 racks each containing 40–100 bare cathode sleeves, travels before the two spray guns at 37–112 racks per minute. These guns are fired electronically only while racks appear before their nozzles. Each gun can be aimed through an arc of 0–45° to accommodate flat, oval, or round sleeves. Distance between gun and rack is finely adjustable. Number of passes is electronically controlled between 2 and 32.

An ingenious device automatically reverses—at each revolution of the endless belt—the side of a given rack exposed to the guns. A bank of infra-red lamps dries each layer of coating immediately after its application.

Intensity and width of spray are regulated by pressure and nozzle adjustments. A continuously circulating system (instead of suction or gravity feed) maintains the coating fluid in the necessary state of suspension, and prevents clogging by coagulation.

Cathode coatings are held to such close tolerances that they must be measured by weight—on balances capable of reading .1 milligram. Yet this machine can apply accurately over 100,000 of such fine coatings daily. Another example of Hytron's mass production with precision—the Hytron know-how which gives you better tubes.

OLDEST MANUFACTURER SPECIALIZING IN RADIO RECEIVING TUBES

HYTRON

RADIO AND ELECTRONICS CORP.

MAIN OFFICE: SALEM, MASSACHUSETTS

3 RECENT CAPACITOR TYPES *Worth Knowing*

Sprague engineering leadership extends to Mica, Dry Electrolytic and countless Paper Dielectric Capacitor types in addition to those illustrated above. Sprague engineers welcome the opportunity to make recommendations based on your specific requirements.

SPRAGUE

PIONEERS OF ELECTRIC AND ELECTRONIC PROGRESS

*Trademarks Reg. U. S. Pat. Off.

SPRAGUE ELECTRIC COMPANY, NORTH ADAMS, MASS.

Presto Cutting Needles in a "Trouble-Proof" Container

at no extra cost

FOR YOUR CONVENIENCE! Presto Sapphire Recording Needles *now* come to you in a *new* package, designed for utmost needle protection in shipping and handling.

NEW! A transparent lucite container keeps Presto Cutting Needles *safe*. Nothing can harm the precision ground point and cutting edges.

TIGHT! This ingenious chuck holds the needle *tight*—no chance of damage to the point in shipment.

EASY! Just slip used needles (safe in their containers) into this handy mailing bag and send them off to Presto for resharpening.

FREE! To Presto-equipped recording studios: a convenient rack holding six Presto Cutting Needles, with special "point-control" chart recording number of hours each needle is used.

PRESTO Cutting Needles are packed in a Distributor's Carton of six. Each needle container is individually boxed with mailing bag. Order a dozen. Keep 6 in use—6 in transit.

PRESTO

RECORDING CORPORATION

242 W. 55th St., New York 19, N.Y.

WALTER P. DOWNS, LTD., *in Canada*

WORLD'S LARGEST MANUFACTURER OF INSTANTANEOUS SOUND RECORDING EQUIPMENT AND DISCS

NEW power triode with NEW high efficiency, for NEW h-f transmitter circuits

Type GL-592
$15.50

GENERAL ELECTRIC introduces Type GL-592 as a triode which sets entirely new standards of efficiency for power tubes in the high-frequency class.

Operating at frequencies (for max ratings) up to 110 megacycles, a plate input of 600 watts with dissipation of 200 watts gives Type GL-592 preference for both transmitter and electronic heating applications. Here is an h-f tube that really conserves power, with maximum results in usable output!

Small, compact, with solidly mounted and braced filament, grid and plate, Type GL-592 is thoroughly modern in design. All leads are short, and two grid leads to separate side terminals further reduce lead inductance. Fernico metal-to-glass seals make possible (1) elimination of a base with its attendant dielectric losses, (2) the non-soldered plate terminal to withstand high temperatures successfully. All terminal contacts are silver-plated for greater efficiency.

Ask your nearest G-E office or distributor for further facts about this new, *modern* G-E h-f triode. Or communicate direct with *Electronics Department, General Electric Company, Schenectady 5, New York.*

General Electric tube engineers are at your service, to assist you with applications of h-f tubes to your new transmitter and industrial circuits.

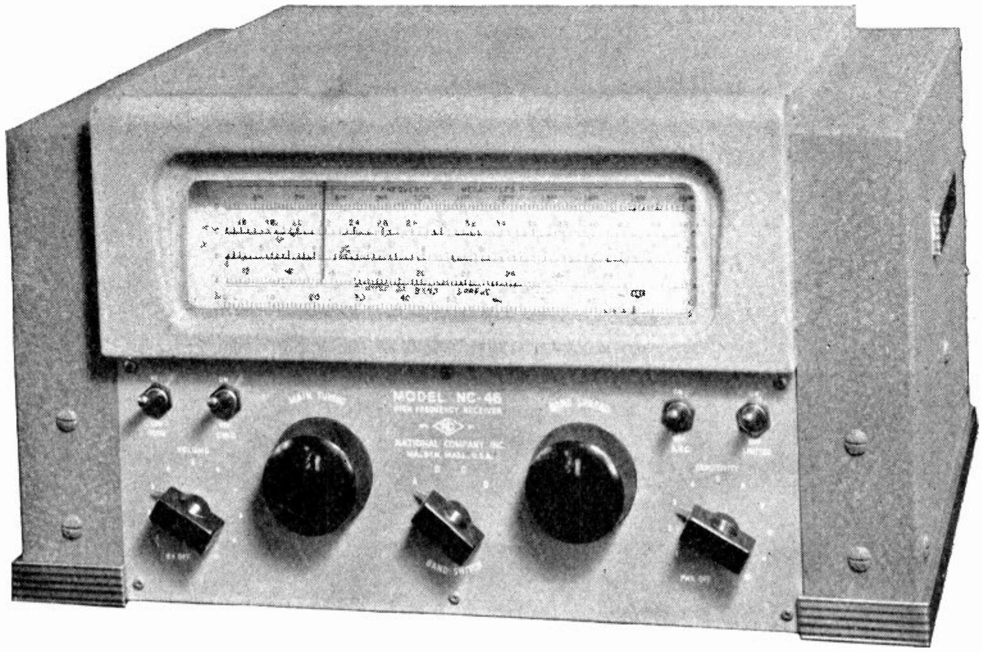
CHARACTERISTICS

FILAMENT VOLTAGE	10 v
FILAMENT CURRENT	5 amp
MAX. PLATE RATINGS, CLASS C TELEGRAPHY	
VOLTAGE	3,500 v
CURRENT	250 ma
INPUT	600 w
DISSIPATION	200 w
PLATE POWER OUTPUT, TYPICAL OPERATION	425 w
TYPE OF COOLING	FORCED-AIR

GENERAL ELECTRIC

161-E5-8850

TRANSMITTING, RECEIVING, INDUSTRIAL, SPECIAL PURPOSE TUBES · VACUUM SWITCHES AND CAPACITORS



THE NC-46

The new National NC-46 Receiver is a fine performer at a moderate price. Ten tubes in an advanced superheterodyne circuit provide excellent sensitivity throughout the receiver's range from 550 KC to 30 MC. Circuit features include an amplified and delayed AVC, series valve noise limiter with automatic threshold control, CW oscillator and separate RF and AF gain controls. The push-pull output provides 3 watts power, and the AC-DC power supply is self-contained.

ARMY E NAVY

ARMY E NAVY

—NATIONAL COMPANY, INC., MALDEN, MASS.

FREQUENCY SHIFT TRANSMITTER MONITORS

by PRESS WIRELESS

MODEL FSTM-1

Frequency Shift Transmitter Monitor Model FSTM-1 is a compact, precision unit designed by Press Wireless engineering laboratories to check the total frequency variations of the carrier of a radio transmitter operating on frequency shift circuits. Although transmitter tuning is not critical in FS circuits even with high-speed keying, the precise adjustments of the shifter unit controls for these carrier variations should be accomplished with rapid accuracy for top operating efficiency. In this single unit both visual meter and aural zero-beat indication facilitate quick determination of the frequency adjustments over a shift range of 400 to 1400 cycles-per-second on any r-f carrier between 2 and 26 megacycles without the necessity for gathering several separate equipments normally required for this frequency shift check. Despite its small size the FSTM-1 contains its own power supply and when rack mounted occupies only 10½ inches of panel space.

The outstanding advantages of r-f carrier frequency shift transmission for mechanized radio circuits are evidenced in the increasing number of FS installations in important telecommunication networks around the world.

PRESS WIRELESS MANUFACTURING
CORPORATION

Executive Offices: 38-01 35th AVENUE, LONG ISLAND CITY 1, NEW YORK

Why are Carbonyl Iron Powders better?

IN ILLUSTRATION, note regularity of pattern. This is due to uniform shape, density, size, and purity of each particle.

These factors account for high "Q" value—the combination of maximum magnetic permeability and minimum power loss. This is why carbonyl iron powders are better.

The following text gives a brief, complete outline of G.A.F. Carbonyl Iron Powders for those desiring more information.

G.A.F. Carbonyl Iron Powders are obtained by thermal decomposition of iron penta-carbonyl. There are five different grades in production, which are designated as "L," "C," "E," "TH," and "SF" Powder. Each of these five types of iron powder is obtained by special process methods and has its special field of application.

The particles making up the powders "E," "TH," and "SF" are spherical with a characteristic structure of increasingly larger shells. The particles of "L" and "C" are made up of homogenous spheres and agglomerates.

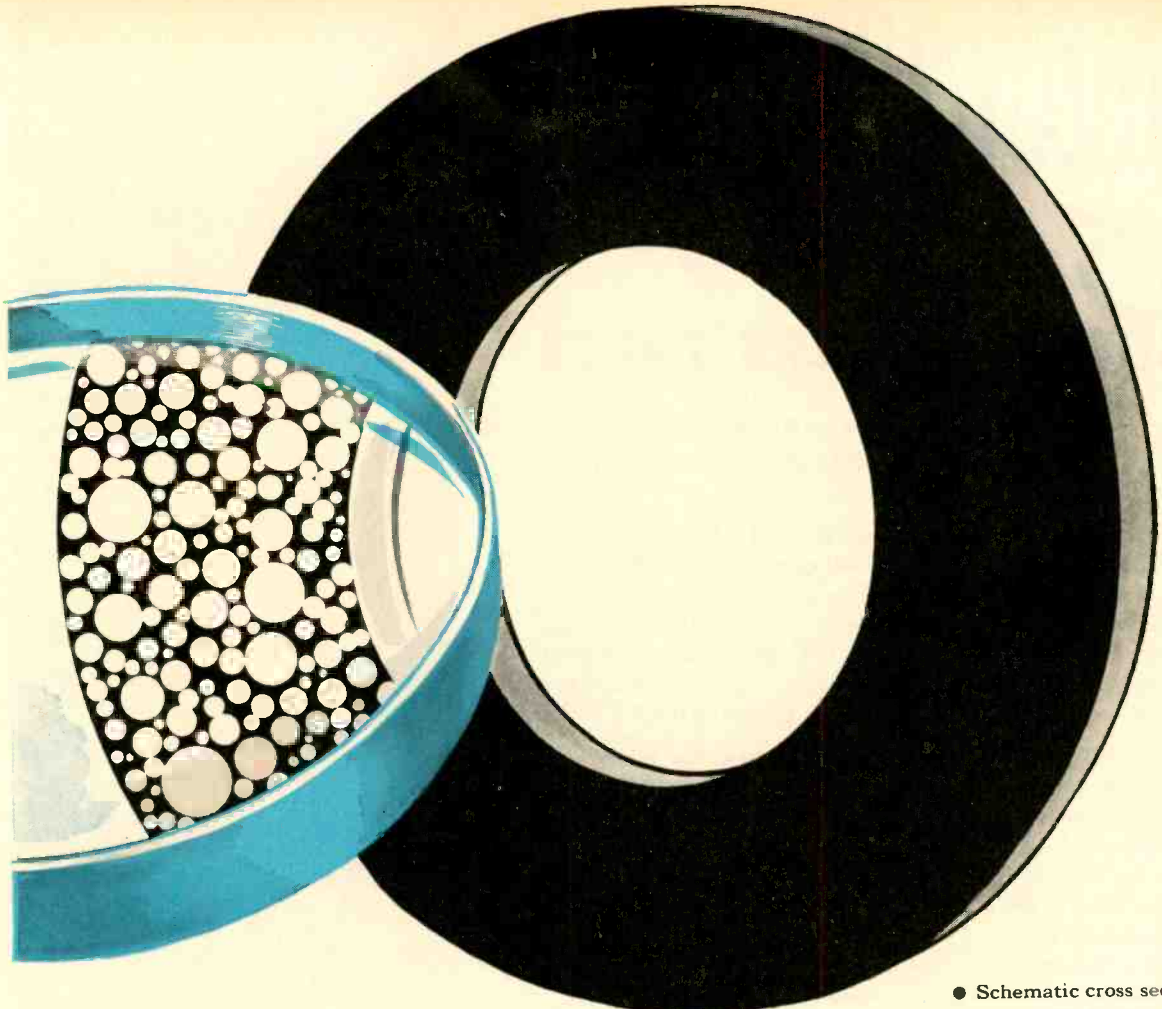
The chemical analysis, the weight-average particle size, the "tap density," and the apparent density are given in the following table for the five different grades:

TABLE 1

Carbonyl Iron Grade	Chemical Analysis % Carbon	% Oxygen	% Nitrogen	Wt. Ave. diameter microns	Tap Density g/cm3	Apparent Density g/cm3
L	0.005—0.03	0.1 —0.2	0.005—0.05	20	3.5—4.0	1.8—3.0
C	0.03 —0.12	0.1 —0.3	0.01 —0.1	10	4.4—4.7	2.5—3.0
E	0.65 —0.80	0.45—0.60	0.6 —0.7	8	4.4—4.7	2.5—3.5
TH	0.5 —0.6	0.5 —0.7	0.5 —0.6	5	4.4—4.7	2.5—3.5
SF	0.5 —0.6	0.7 —0.8	0.5 —0.6	3	4.7—4.8	2.5—3.5

With reference to the chemical analysis shown above it should be noted that spectroscopic analysis shows the rest to be iron with other elements present in traces only.

Carbonyl Iron Powders are primarily useful as electromagnetic material over the entire communication frequency spectrum.



● Schematic cross section of powdered iron core made with carbonyl iron powder.

Table 2 below gives relative Q values (quality factors) and effective permeabilities for the different grades of carbonyl iron powder. The values given in the table are derived from measurements on straight cylindrical cores placed in simple solenoidal coils. Although the data were not obtained at optimum conditions, the Q values as expressed in percentage of the best core give an indication of the useful frequency ranges for the different powder grades.

TABLE 2

Carbonyl Iron Grade	Effective Permeability at 1 kc	Relative Quality Factor at 10 kc	150 kc	200 kc	1 Mc	100 Mc
L	4.16	100	96	90	43	1
C	3.65	94	100	98	72	3
E	3.09	81	94	100	97	30
TH	2.97	81	93	98	100	54
SF	2.17	62	71	78	84	100

(Note: The actually measured Q values can be obtained by multiplying the rows respectively with: 0.78, 1.09, 1.25, 2.63, and 1.62.)

"L" and "C" powders are also used as powder metallurgical material because of their low sintering temperatures, high tensile strengths, and other very desirable qualities. (Sintering begins below 500° C and tensile strengths reach 150,000 psi.)

Further information can be obtained from the Special Products Sales Dept., General Aniline & Film Corporation, 270 Park Avenue, New York 17, N. Y.

G.A.F. CARBONYL IRON POWDERS

LONG SCALE, WIDE RANGE VOLT-OHM-MILLIAMMETER

DOUBLE SENSITIVITY D. C. VOLT RANGES

0-1.25-5-25-125-500-2500 Volts, at 20,000 ohms per volt for greater accuracy on Television and other high resistance D.C. circuits.

0-2.5-10-50-250-1000-5000 Volts, at 10,000 ohms per volt.

A. C. VOLT RANGES

0-2.5-10-50-250-1000-5000 Volts, at 10,000 ohms per volt.

OHM-MEGOHMS

0-400 ohms (60 ohms center scale)
0-50,000 ohms (300 ohms center scale)
0-10 megohms (60,000 ohms center scale)

DIRECT READING OUTPUT LEVEL DECIBEL RANGES

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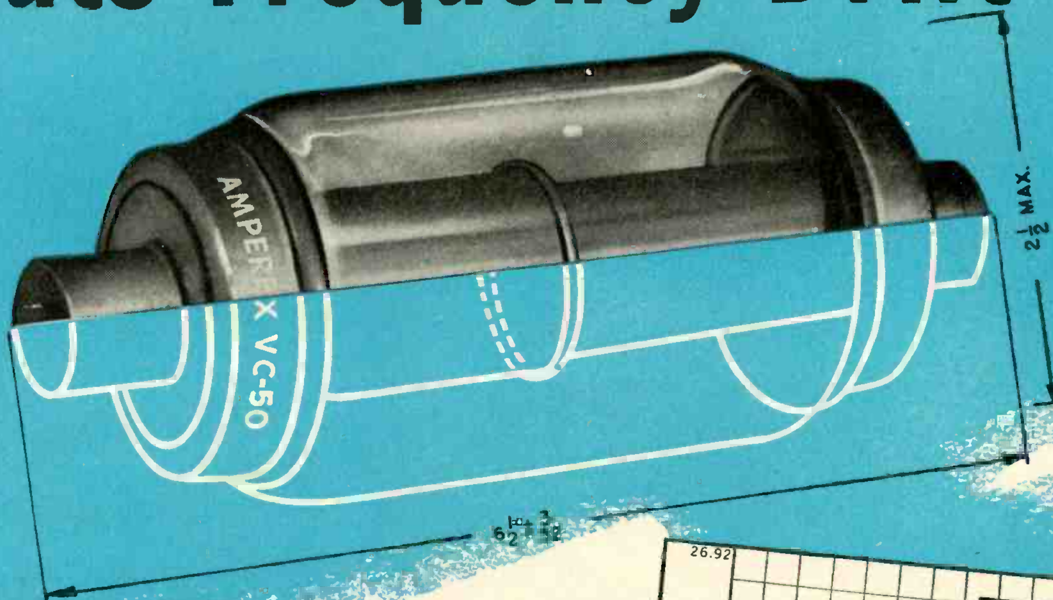

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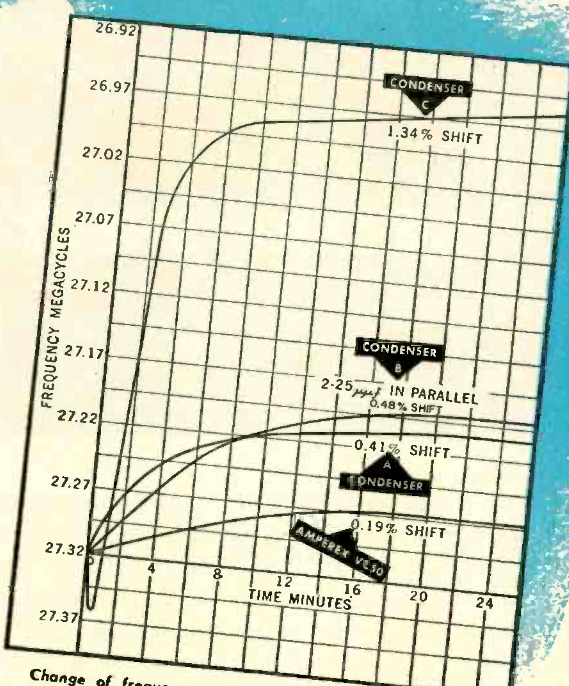

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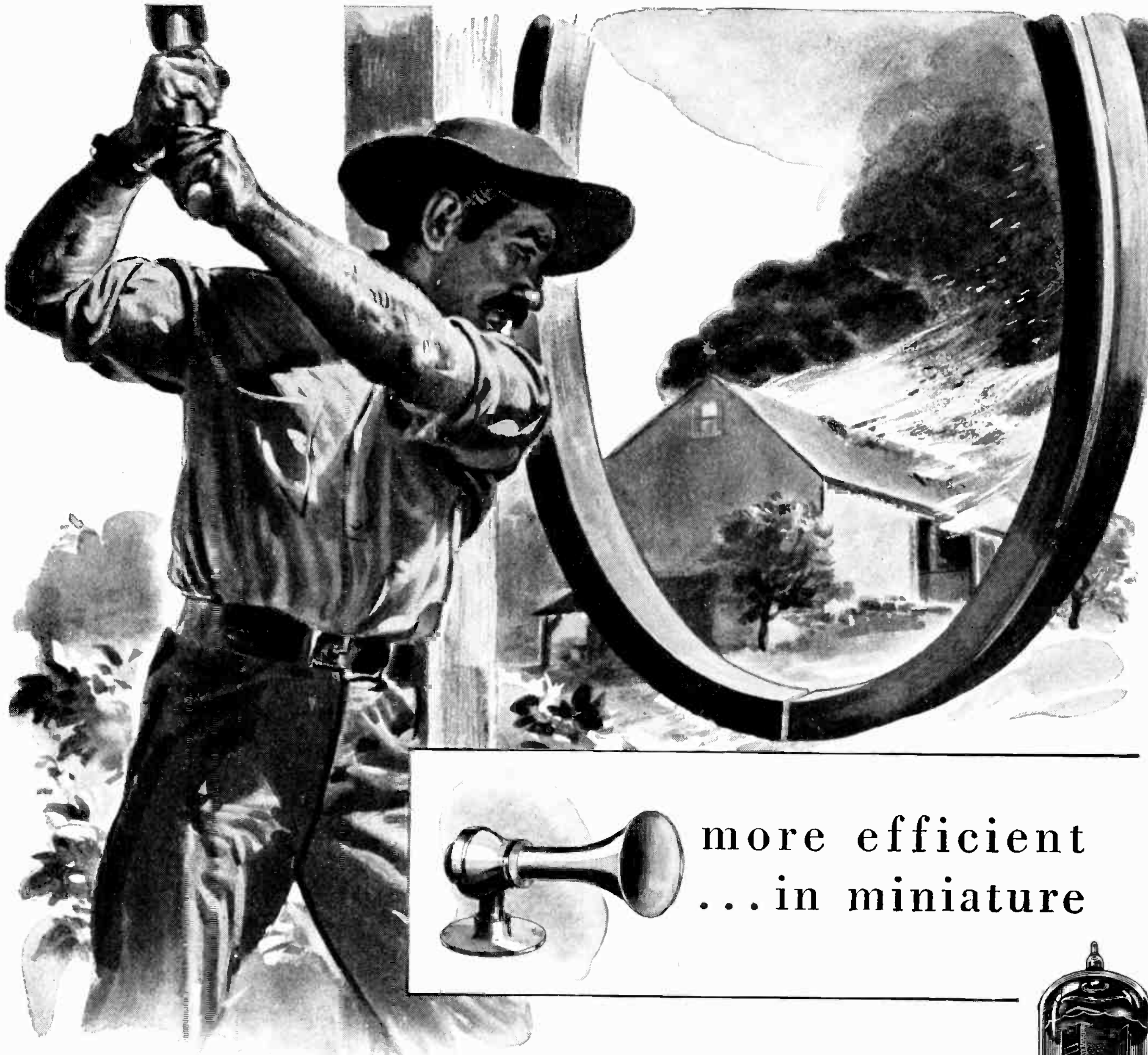

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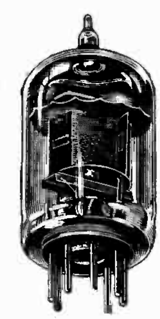

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RCA-5TP4: The RCA-5TP4 (5″ face) metallic film Projection Kinescope more than doubles screen brightness of 16″ x 20″ projected pictures. The "mirror-backed" screen also improves picture contrast and detail. Combined with the Reflective Optical System, the 5TP4 permits viewing at higher ambient light levels.

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	5TP4	10BP4	7DP4	7GP4
Heater Volts	6.3	6.3	6.3	6.3
Heater Amps	0.6	0.6	0.6	0.6
Anode Volts*	27,000	10,000	8,000	4,000
Focus	Electrostatic	Magnetic	Electrostatic	Electrostatic
Deflection	Magnetic	Magnetic	Magnetic	Electrostatic
Deflection Angle	50°	50°	50°	
Raster Size (approx.)	2 3/4″ x 3 5/8	6″ x 8″	4″ x 5 1/2″	4″ x 5 1/2″
Bulb Dia. (max.)	5 1/8″	10 5/8″	7 5/16″	7 1/8″
Length (max.)	12 1/8″	18″	14 7/16″	14 7/8″
Base	Duodecal	Duodecal	Duodecal	Diheptal
Fluorescence	White	White	White	White
Persistence	Medium	Medium	Medium	Medium

*design center maximum value.

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RADIO CORPORATION of AMERICA

HARRISON, N. J.

PROCEEDINGS of the I.R.E. AND WAVES and ELECTRONS

Published Monthly in two sections by
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SECTION I—PROCEEDINGS OF THE I.R.E. SECTION

SECTION II—WAVES AND ELECTRONS SECTION FOLLOWS AFTER PAGE 212 P.

Facing a clouded world future, engineers may properly consider the nature of their contributions to society and the significance of such contributions in relation to the security of their country. Analyzing these timely questions, there follows a discussion, expressive of his own views, by a consultant to the United States War Department. *The Editor*

National Security and a Mechanism for Its Achievement

EDWARD L. BOWLES

Our energies, which for the past several years have been directed solely toward the waging of war, must now be redirected toward the problem of peace. The problem is complex, since war, although it may be decisive as to the issues of mortal combat, is indecisive as to the issues of peace. Victory in war is but a license to give consideration to future security. Victory in peace is the attainment of a state of national security commanding international respect. Enduring peace does not emerge spontaneously from transient negotiations at the end of war, but is, rather, the result of deliberate, sustained effort. If it is to be ours, we must pay the price for it. The cost is small indeed compared with the cost of war.

We were not willing to pay the price of peace after the first world war. National security was an idle abstraction; a malevolent concept of the promoters of war—something too costly of thought and effort. As a nation we held ourselves aloof behind our continental ramparts with a feeling of false security. We watched nations first crawl, then walk, then run headlong into war. Each succeeding step, more clearly than the one before it, portended disaster. Yet, we stood by as if it were of no concern to us.

Having been unwilling to pay the price for peace, we cultivated none of the attributes of security. Consequently, when we did awaken to the danger, it was upon us, and we were in no position to act. Our very existence being thus imperiled, we were obliged once more to pay the price of war.

We now face another period of peace. We are in the midst of concluding negotiations, the real object of which is to clear the way for our main problem, the formulation of a program of national security. We run the risk of being dangerously distracted from this main problem. Contributory to this danger is the more beguiling occupation of disposing of the vanquished—industrialwise, sciencewise, and otherwise. This is a negative aspect of security. It is important, but it is secondary to the problem of what to do at home to consolidate our gains and to establish a positive philosophy with respect to our national welfare and those attributes which command respect among nations.

Fortunately, the job that lies before us is more clearly dictated than it was after the first world war. The recent war was a much longer one, with correspondingly greater opportunity for total mobilization. There was thus more time to develop a philosophy of total warfare. Our people were made more aware of the unconscionable waste, the overwhelming burden, and the horror of war. The war became truly three-dimensional, and the potentialities of retaliation came to full fruition. For this reason a nation cannot henceforth confine war to the territory of its opponents. Containing the enemy's ground forces is but a part of the problem. While thus occupied, the home country is exposed to the force of the enemy's air. A nation can no longer consider itself isolated by natural barriers, such as mountains, bodies of water, air, and polar ice.

The atomic bomb, coming as it did as a climactic *coup de grace* to an already defeated nation, was more than a portent of future physical destruction. It asserted that henceforth war is to be waged totally against a nation—its resources, its people—and not solely against military forces.

We are compelled, then, as never before, to give our attention to factors that make for security and discourage war. Fortunately, in this respect our experience in this war has much to teach. Integration of our three basic resources—the professional military, industrial, and educational assets—is a forceful illustration which should have its counterpart in peacetime. This integration has engendered mutual understanding and confidence. It has broken down barriers between civilian and military. It has demonstrated the potentialities of a peacetime counterpart pattern which, in addition to its obvious contribution to the general welfare of the nation, is readily expandable to meet a national emergency. A pattern of this character is essential to bring our educational and industrial areas as close to the military in peacetime as they have been to each other during the recent war.

In the cultivation of mutual understanding there must be consideration of problems of national and international scope. We must work on these problems by combined effort, so that there may be mutual enlightenment and broad, comprehending solutions. We must bring to bear jointly the talents of the scientist and the technologist, the military and management, the statesman and the scholar.

Popular fancy has it that the natural sciences have been dominant in this war. Scientific effort has become identified uniquely with new weapons. This misconception, for which I think the scientists themselves must take some blame, raises a serious question of balance. In the over-all integration, therefore, greater emphasis is needed on the social sciences and the humanities in this problem of building for peace. Only by the exploitation of our total resources—intellectual and otherwise—can we achieve the first essential of security—a nation economically and socially healthy.

Inescapably, the problem is one of education. It is not one which can be solved by legislative edict or by directive. The process involved is one of evolution. We have the machinery and the talent for the basic job in our educational centers. In these, as the mixing chamber, we must bring together our potential leaders, military and civilian, statesmen and scholars. It is in this atmosphere, the cloisters of the graduate schools, that we must promote research on problems of national scope and importance to acquaint our future leaders one with another, and at the same time with the common problems of the nation and the world. It is this technique which promises the greatest assurance of future security.

Army-Navy Precipitation-Static Project

Natural disturbances of radio reception on airplanes may diminish or destroy quality of communication. The systematic reduction of such disturbances is, accordingly, of fundamental interest in both commercial and civilian aviation. The orderly study of this subject through the joint Army-Navy Precipitation Static Project is presented in a series of six papers, three of which appear in this issue of the PROCEEDINGS OF THE I.R.E. and concluded by the series of three papers which will appear in a subsequent issue. These papers give the principal available methods for the control of the effect of such disturbances to radio communication.

The Editor

Part I—The Precipitation-Static Interference Problem and Methods for Its Investigation*

ROSS GUNN†, ASSOCIATE, I.R.E., WAYNE C. HALL†, AND GILBERT D. KINZER†

Summary—**In order to provide a background for the detailed technical papers of the series, the organization, objectives, and problems of the joint Army-Navy Precipitation Static Project are reviewed. The main lines of attack and the mechanisms responsible for the production of corona and radio interference on aircraft are discussed.**

IT IS clear from the literature summarized in the accompanying bibliography that although there has been wide disagreement as to the causes of precipitation static, its existence and seriousness has long been recognized. Perhaps the best previous review of the subject is that due to Hucke.[1]

Shortly after the beginning of the war, the military services recognized the difficult nature of the precipitation-static problem and, stimulated by the loss of many aircraft and important personnel as a direct result of such interference, determined to set up a research project to investigate its causes and devise a cure. A joint Army-Navy Precipitation-Static Project Committee was organized in May, 1943, to support and prosecute the investigation. Under the terms of organization, the Army provided the necessary research aircraft and arranged for their maintenance and operation through a contract with Northwest Airlines at Minneapolis, Minnesota. Because the Navy was already actively working on the research aspects of the problem, the provision of research facilities and technical direction was made the responsibility of the superintendent of the mechanics and electricity division of the Naval Research Laboratory. To expedite the work, the Navy Bureau of Aeronautics built a giant hangar having a clear space of 220 feet by 135 feet by 70 feet in which special experiments could be conducted. This hangar, shown in Fig. 1, is located at Minneapolis where most of the operational research is centered. The Army assigned civilian engineers and technicians to the Project to represent it and to aid in transferring technical information to that service. The Project has had a maximum of three experimental aircraft, seventeen scientists and engineers, and twenty-two others in the supporting organization. Much of the laboratory experimental work has been carried on in the mechanics and electricity division of the Naval Research Laboratory in Washington, D. C.

The military services have hundreds of millions of dollars invested in aircraft radio-communication and navigational equipment. Frequently the life of the airplane and crew depends on navigational communication with ground stations and other aircraft. But when precipitation static occurs, this valuable equipment is frequently useless, and the failure usually occurs under storm conditions when the pilot and navigator are exceedingly anxious to know just where they are and to receive important information on the extent and duration of the storm. At the beginning of the war the shielded loop mounted under the nose of the airplane was the best antiprecipitation-static device. These devices, carefully installed in accordance with the basic principles to be outlined, are still very valuable. It has been found that except at the very highest frequencies, which are useful only for line-of-sight communication, precipitation static of moderate intensity renders almost all radio equipment useless. The automatic-direction-finder equipment with which most planes are equipped for navigation hunts badly and is generally unreliable or is useless. Another hazard of precipitation static is the psychological effect on the pilot who knows that when his radio fails he must find a small landing field and safely land his airplane under the most unhappy conditions imaginable. The extent of the difficulties encountered in precipitation static may be estimated from the fact that in certain areas of the United States

* Decimal classification: R114.5×R560. Original manuscript received by the Institute, November 19, 1945.
† U. S. Naval Research Laboratory, Washington, D. C.
[1] H. M. Hucke, "Precipitation-static interference on aircraft and at ground stations," PROC. I.R.E., vol. 27, pp. 301–316; May, 1939.

the yearly loss of military aircraft due to precipitation static is more than one per cent of the airplanes assigned to that area. It is evident, therefore, that a considerable expenditure of scientific effort and money is justified to achieve a solution to this difficult problem. This was particularly true because many years had elapsed since the first work on the problem was undertaken and only slight advances had been made toward a practical solution.

Any signal appearing in a radio receiver not synchronous with that emitted by the co-operating transmitter may be classed as interference. There are many sources of interference in radio receivers. Some are man-made and arise from improper design. Others of a more serious nature are associated with natural phenomena such as lightning, and these may shock excite the radio receiver producing serious interference. These crashes and grinders of ordinary static, produced by remote lightning discharges, are intermittent and seldom completely block communication. A more serious interference that may be continuous frequently occurs when an airplane flying through precipitation picks up a high electrical charge and thereby continuously produces corona or small spark discharges on the airplane itself. These cause impulsive disturbances that effectively blanket out all radio communication. In precipitation, such discharges occur more or less regularly with time; frequently the discharge is semimusical or screaming in character, and persists on the airplane as long as adequate charging processes maintain the corona current. Because of the impulsive nature of a corona pulse and because it takes place on the airplane, and, indeed, frequently on the antenna itself, it can and does produce interference of a most severe and continuous type. The pulses following each other, sometimes for hours at a time, effectively block all radio communications for the duration of the corona. We state our conclusion in advance: Precipitation static is produced by these corona pulses whenever they are coupled to the antenna circuit in any manner. Such atmospheric an electric phenomenon is not associated alone with thunderstorms but has been found, particularly on aircraft, to accompany snow, ice, rain, or dust particles which are generally covered under the heading of precipitation.

The radio interference produced by the charging up of small insulated metallic pieces on the airplane with resultant sparking to the airplane proper is already controlled by suitable bonding procedures and involves no serious difficulty. However, if electrical charges are deposited on highly insulated surfaces like the plexiglass windows, or if the airplane as a whole becomes electrically charged, it is necessary that the current deposited by the precipitation shall be dissipated; otherwise, the airplane's potential will rise until sparks to the surrounding air are produced. This means, in general, that corona currents with associated noise will always accompany appreciable electrical-charging processes.

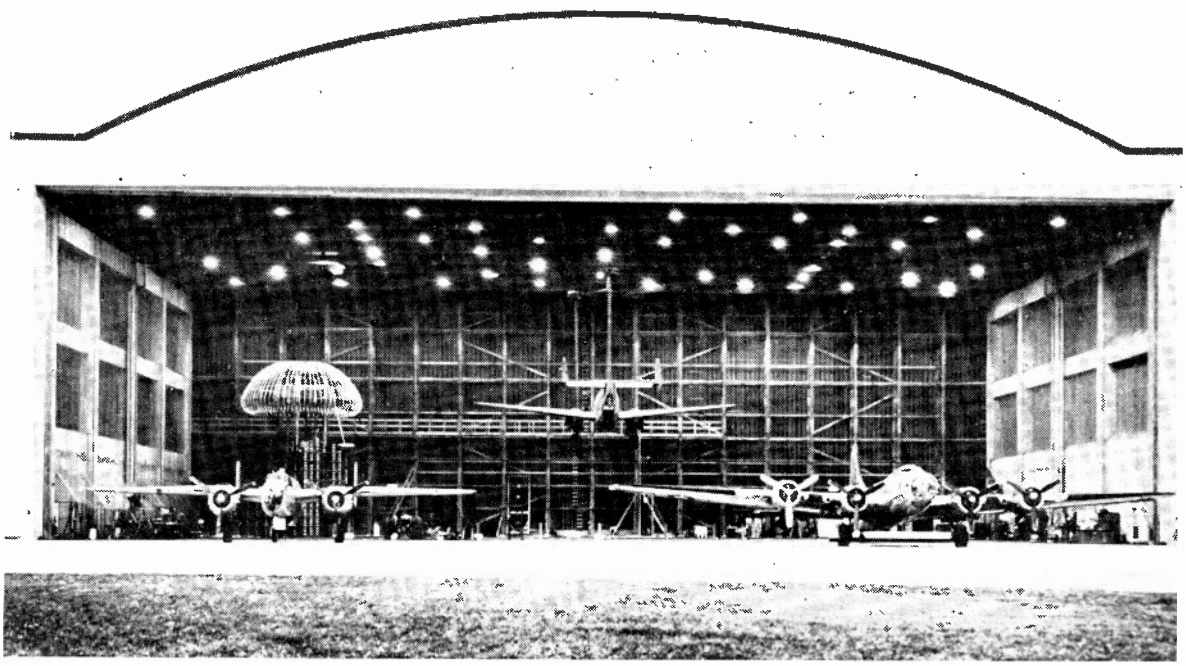

Fig. 1—Research hangar at Minneapolis, Minnesota, showing Project airplanes and high-voltage equipment.

In order that the results of our work could be put upon a quantitative basis, a great many measurements in the air and in the laboratory were necessary. Moreover, the results obtained in the air had to be co-ordinated with the laboratory results before all could be thoroughly understood. One of the great difficulties of this investigation was to find, when needed, natural precipitation-static conditions sufficiently constant and great enough in magnitude to permit the necessary measurements and experiments to be carried on. Because of the difficulty of finding and operating in suitable storms, the laboratory airplanes were completely instrumented and the data systematically recorded so that when suitable conditions were encountered, the complete electrical history of each flight could be brought home for study. The details of the instrumentation of all the laboratory aircraft is reviewed in a companion paper entitled "Aircraft Instrumentation for Precipitation-Static Research." Because of the great variety of conditions that exist in the atmosphere and the constantly changing nature of the charge-producing and charge-transferring mechanisms, some method had to be found for charging the airplane in flight at a constant rate, in order that the performance of various discharge devices could be quantitatively evaluated. Such a device was developed by the Naval Research Laboratory early in 1942 and applied to the Project airplanes with great success. This device reversed nature's process and discharged from the airplane highly charged "rain," thereby building up an electrical charge of opposite sign. By many flights in actual precipitation sufficient experience was gained to make possible the adjustment of the artificial charger to reproduce precipitation-static conditions on the aircraft. Using this artificial charger in flight under fair weather conditions, the electrical properties of the airplane in relation to corona discharge, the current discharged by the engine exhaust, the evaluation of corona threshold for certain areas, and the noise introduced in the airplane's radio receivers under various conditions could be determined. The great advantage of the artificial charger resided in the fact that charge could be placed on the airplane at a constant rate and maintained as long as desirable. The comparison of the various types of discharging devices studied by the Project was easily effected by the use of the artificial charger.

With the object of reducing air operations and saving time in the preparation of various types of aircraft antenna and radio receiving systems, as much of the research work as possible was carried on in the Research Laboratory. A high-voltage machine belonging to the University of Minnesota was set up in one corner of the giant hangar provided for this research. Military airplanes were suspended on long strings of insulators in the middle of the hangar. Direct-current voltages up to 1,200,000 volts were then applied to the airplane and typical precipitation-static interference in the radio receiver installed therein was easily produced. It was found that the threshold of noise and the general behavior of radio equipment in this hangar were generally similar to that encountered in flight, but measurable differences did exist due to the redistribution of space charge, the absence of motion of the airplane, and ions from the engine exhaust. Much attention, therefore, has been given to correlating flight data with laboratory results, and in this correlation, the airplane flying in fair weather and employing an artificial charger was of the utmost value.

Evaluation of the Causes of Precipitation Static

The available published data on precipitation static are hardly consistent, as one may verify by reading the cited references. Many hypotheses have been advanced as to the causes and various cures that should be employed. None of the investigations provided direct observational information which was considered entirely reliable, or which could be correlated with the intensity of the encountered interference. The trend in the development of equipment for control of ordinary "crash and grinder" static has been in the improvement of limiters and volume-control devices. As soon as it became perfectly clear to the research team that the largest share of precipitation-static interference came from corona alone, it was concluded that the improvement to be anticipated by the use of such limiting devices was probably small. It appeared, therefore, that the principal effort should be directed toward controlling the intensity, distribution, or character of the corona discharge in such a way that if radio communication could be maintained for one radio channel it would be maintained for all. In view of this decision, which is now known to be correct, the main job was not circuital, but rather a study of the fundamental electrostatics of the problem and of methods of charging and discharging the airplane so that the corona noise could be effectively suppressed.

The first step in the solution of the problem, therefore, was to evaluate the interference producing conditions by operational flights in every conceivable type of precipitation condition. At first, in co-operation with Northwest Airlines, later with the National Advisory Committee for Aeronautics, and finally in airplanes assigned to the Project, hundreds of flights were made in bad weather conditions that could be expected to produce precipitation-static interference. The encountered magnitudes and distribution of free electrical charge over the airplane were determined by the use of an induction electric field meter especially developed by the mechanics and electricity division of the Naval Research Laboratory for this work. Two of these instruments, whose sensitive elements were mounted one on the top and one on the bottom of the fuselage, were found to be invaluable in describing the electrical state of the airplane in flight. Since the electric field is related to the magnitude of the free charge on the airplane and to the geometry, it is possible not only to determine, by its use, the distribution of charge, but also the potential of the aircraft relative to free space several aircraft diameters away. It was established early in the investigation that the onset and intensity of the encountered radio interference and the magnitudes of the corona currents are reproducibly related to the surface electric field as determined by these instruments.

As a direct result of the operational flights, it soon became evident that essentially all the encountered electrical situations are combinations or examples of two simple conditions. Both of these conditions produce impulsive corona discharges and hence radio interference, but the charging processes that maintain the corona currents arise from two fundamentally different mechanisms. The first and most serious condition arises from the charging of the airplane by the impact of driving snow (and to a much lesser extent, rain) upon the airplane which transfers (usually) negative charge to the airplane; the compensating positive charge being carried away by the precipitation. In this case, the electric field meters show that the field is always toward the plane, and if the amount of snow encountered by the plane is uniform, the electric field is substantially uniform and always of the same sign. This type of airplane self-charging is called autogenous, signifying self-generated.

A less serious condition is encountered even though still higher fields are usually observed, when the airplane is in or closely adjacent to thunderstorm clouds that always produce electric fields. Because, in this case, the electric charge to the plane flows toward the plane on one side and away from it on the other, the electric-field indicators usually exhibit opposite signs. By watching the relative signs and magnitude of the electric-field meters, it is easy to determine the type of charging process to which the airplane is being subjected. In both cases, electrical charge is, for the most part, dissipated by the airplane in the form of a corona discharge that produces interference. However, in the first case, the charge is transferred to the plane by the encountered precipitation, while in the second case, the charge is transferred to the plane by currents conducted from adjacent highly charged thunder clouds. Since this latter type of charging is generated in areas external to the plane, it is called exogenous.

Autogenous Charging

Severe precipitation-static interference is encountered for the longest periods of time when the airplane encounters great areas of dry-snow clouds or ice crystals. The charging current to a typical airplane of the medium bomber class under these conditions may exceed 500 microamperes, and usually approximates 250 microamperes, the charge on the airplane always being negative. The direct-current voltages produced on the plane by these charging currents frequently exceed 500,000 volts. Occasionally, high charging rates are encountered in melting snow and in rain.

The process of charging by dry snow and ice crystals is essentially frictional or triboelectric. A snow crystal strikes the leading edge of the airplane, slides along its surface and, due to the difference in dielectric properties of the metal surface of the plane or its paint, and that of the snow crystals, a charge of one sign is acquired by the airplane while an equal and opposite charge is carried away by the snow. The magnitude of this phenomena was studied in flight by the use of small insulated, metallic areas connected to the frame of the airplane through sensitive microammeters.

Supplementing the use of such localized insulated areas on the airplane in actual flight to study the above phenomena, the research team built up a useful device for moving two streamlined bodies two feet long and nine inches in diameter through the air at the opposite ends of two ten-foot arms arranged to be rotated about a vertical axis. These streamlined bodies and arms were driven by a 40-horsepower gasoline engine at velocities up to 300 miles per hour. The streamlined bodies were carefully insulated in two sections, one a nose section that included most of the entering projected area and the tail section which composed the rest of the aluminum streamlined body. The nose section was arranged so it could be replaced quickly and several were available of various pure metals and aluminum coated with various paints and lacquers. Electrical current-measuring apparatus was provided to measure the charge acquired by these insulated sections as they were rotated at high speed through naturally falling uncontaminated snow.

By check experiments, it was shown that these simulated aircraft sections satisfactorily reproduced under natural snow conditions the electrification encountered by similar streamlined bodies mounted on the laboratory aircraft. By the use of the rotating-arm device in *natural uncontaminated snow*, reliable data could be obtained on the rate of charging of various interesting surfaces and their dependence on speed. The results of these co-ordinated tests are fully described elsewhere in this series of papers but one very significant result may be stated here, namely: that the charging rate depends so critically upon the chemical nature of the surface that the natural oils from one's hand rubbed on the surface being tested can not only change the charging rate by a large factor but, in some cases, can actually reverse its sign. The Project has developed surfaces as a result of these investigations that will charge the airplane positively instead of negatively, and hence permit the exact neutralization of the generated charges. Indeed, thin liquid coatings may be applied on ordinary aluminum that will accomplish this objective. However, because even the best surfaces may be grossly modified by simply passing an oily rag over them, such positively charging materials are not considered to be a practical military solution to the problem. It is clear, moreover, that such treatment will not help in the suppression of corona produced by exogenous electric fields.

There are several less important ways by which a free electrical charge may be transferred to an airplane in flight. Some of these mechanisms require discussion. For example, it has been observed that an airplane in free flight during fair weather acquires a small negative charge that produces a belly electric field of about 7.0 volts per centimeter on a typical plane. Such a small electric field corresponds to some 6000 volts applied to the airplane. By changing the throttle and mixture settings of the engine it is possible to change the magnitude of the field and even to reverse the sign of the accumulated charge. Earlier work has shown that the accumulation of charge is due to the fact that the sign of the charge due to the engine's exhaust is dependent upon the character of the ions and small soot particles ejected. Thus, for example, if an excess positive charge is carried by small soot particles, and these are transferred outward from the airplane by convective processes, then the airplane will acquire a negative charge.

Another way of charging an airplane is by convection. By this we mean that free charge carried on rain, heavy ions, smoke, etc., can be transported to the airplane and there, by simply establishing electrical contact with the airplane, discharge themselves on the airplane. After contact, the particle may be blown away and then be quite free of the original charge. It has been determined that precipitation particles (including even the low-hanging haze found over a city) are frequently highly charged and these, coming in contact with the airplane, often charge it sufficiently to cause mild corona interference. It is evident that, for this particular type of charging, the charge placed on the plane depends only on the magnitude and sign of the charge carried by the original precipitation particles. The process of electrification is reversible and droplets breaking away from the trailing edge of the wing will carry away charge. This latter process is not of great importance.

Another way of charging an airplane is by the breakup of rain splashing against the leading edges. It has been long known that the areas around waterfalls were highly charged, for which this breakup process was responsible. It has been determined that the amount of charge produced by this process increases steadily as the energy of impact on the leading surface increases. The process usually transfers a negative electrical charge to the airplane. All of the above methods of transferring charge to an airplane are normally small, compared to that produced by frictional processes.

Exogenous Charging

The charging of aircraft by free charges generated outside the airplane, as by a thundercloud, is very common. Imagine a large charge of negative electricity concentrated near the center of an active thundercloud. The negative charge will be transferred outward from the area by virtue of the conduction due to ions always present in the air. If a metal object, such as an airplane, is brought into this general area, then because of its low resistance compared to that of air, it is clear that a portion of the current discharged by the negative cloud will enter the airplane on the side closest to the active area and emerge on the far side. The amount of current transferred in this case will depend not at all upon the surface of the airplane or upon the amount of rain intercepted, but *will* depend upon the charge contained in the thundercloud, its geometry in relation to the airplane, and the attitude and size of the airplane. The measured electric fields on the belly of the Project airplanes in thunderclouds have been as great as 3400 volts per centimeter. The currents that can be transferred to the airplane before an actual lightning stroke is initiated have been determined in one case, at least, to approximate ten milliamperes. Currents of one milliampere are frequently encountered under exogenous charging conditions and this current, producing corona both at the entrance and exit areas, can introduce severe interference into the radio circuits. It should be kept in mind that the corona currents conducted to and from the airplane under thundercloud conditions may occur outside of precipitation areas and even in bright sunlight, but in every case the plane must be near an active thunderhead.

Discharge of Free Electricity From Aircraft

In the foregoing paragraphs, the methods by which an airplane may be charged were reviewed. It is important to recognize that in quite ordinary charging conditions the rate of rise of potential is so fast that charging can take place for only a second or so before the airplane will break into corona or spark, and thus discharge the electrical current at exactly the same average rate as it is charged. It is easy to show that in quite ordinary conditions an airplane's potential will rise at a rate of 50,000 volts per second. Therefore, since most planes will break into corona below 200,000 volts, it is clear that the charging process cannot act for long before discharge processes of one kind or another will begin to discharge the electricity as fast as it is supplied and thereby establish an equilibrium. It is the essence of the precipitation-static problem to find means of accomplishing this discharge without the production of radio interference.

Any charged metallic body suspended in the air will lose most of its charge in about 400 seconds due to the presence of atmospheric ions. On an airplane, this discharge, by ordinary conduction, will dissipate some two or three microamperes without the potential rising above the antenna threshold value. The exhaust gases from an airplane engine supply an extremely large number of additional ions and were it not for the large rate of recombination of these ions, the exhaust gases could be depended upon to act as a very efficient discharger. It is a curious fact that the efficiency of the exhaust gases as a discharger depends critically upon the detailed design of the engine exhaust stacks and upon the mixture-control setting.

The most effective method of discharging an airplane is by corona. As soon as the potential of the airplane rises to a high value, areas of corona are built up on the antenna, propellers, wing tip, and empennage. These corona areas produce a copious supply of ions that promote rapid discharge. It is a characteristic of the corona discharge that the current increases much more rapidly than the applied voltage, so that as soon as corona areas are generally produced, the potential of the airplane rises but slowly with increasing charging current.

In studying methods for the reduction of interference, the laboratory made an investigation of many types of discharging devices that might conceivably be useful on aircraft. It was found that a soft cotton wick, treated either with a liquid or by impregnation with colloidal metal to make it slightly conducting, made an ideal discharger of corona current because the resistance and capacity of the outermost fibers can be adjusted easily to make the discharge essentially nonimpulsive. It was found in an investigation of the general performance of all the great variety of dischargers tested, that none was appreciably better than the rest, except perhaps, in relation to the interference they produced. The textile wicks are especially practical because the fraying of the wick in the wind maintains an ever fresh supply of sharp points to promote the corona. By using these wick dischargers on aircraft in flight and by simultaneously measuring the current to each, one may easily determine the detailed character of any outside thunderstorm electric fields. The electrical characteristics and performance of these devices are given elsewhere in this series of papers.

A great many experiments have been directed to the suppression of corona, particularly from the antenna. The textile discharger mounted outside a selected area shields it and protects it from noisy discharges, but is frequently awkward to apply. One of the best methods we have found is to cover the area by a dielectric of such high strength that any probable potential applied across it will not produce a puncture. For example, a polyethylene covering applied to an antenna wire will effectively suppress corona on the antenna and this, together with suitable treatments of the antenna hardware, goes far toward reducing precipitation-static interference.

The series of papers of which this is the opening one will explore the methods outlined above and show in quantitative terms just how severe precipitation static on aircraft may be, and what steps are necessary for its practical suppression.

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Part II—Aircraft Instrumentation for Precipitation-Static Research*

RAMOND C. WADDEL†, RICHARD C. DRUTOWSKI†, AND WILLIAM N. BLATT†

Summary—**Aircraft instrumentation for research on precipitation static is required to provide and record relevant data. It must be rugged and reliable and not constitute a hazard in flight. Electric-field meters and wick dischargers are mounted at various places on the external surfaces of the airplane for measuring intensity and direction of electric fields. An artificial charger provides a means for causing the airplane to assume, in flight, potentials of any desired sign or magnitude, within limits, for simulating natural autogenous charging. A radio-noise meter is used to measure the interference level associated with precipitation static. Search electrodes, termed patches and probes, provide both integrated and detailed information on the charging processes concerned when precipitation strikes solid surfaces. An air-conductivity meter is provided for measuring the conductivity and ion content of the atmosphere. An accelerometer utilizing a telegauge tube measures turbulence. Data from the above and other instruments are brought to a central meter panel and intermittently photographed in flight. This photoobserver is supplemented by a disk voice recorder.**

Introduction

THE FUNCTION of the instrumentation on an airplane used in research on the problem of precipitation static is to provide quantitative data on various phenomena concerned in the electric charging and discharging processes which take place on an airplane during flight. Ideally, instruments should be provided for investigating all phenomena suspected of being relevant to the problem and the data should be permanently and automatically recorded for later analysis. Further, since the weather conditions conducive to precipitation static are not always available on demand there should be means for simulating such conditions at will.

In research on precipitation static the weather sought is that which is usually avoided in normal flying. Airplane, instruments, and personnel are subjected to wide variations in temperature, pressure, humidity, turbulence, vibration, and shock. Portions of the installation external to the airplane are exposed to rain, sleet, snow, and icing. The scientific apparatus must perform its intended functions under rigorous conditions and its installation must not weaken or unduly load the structure of the airplane or constitute a flying hazard in any other way. All of this requires close co-operation between the scientific personnel and those charged with maintenance and flight of the airplane.

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With the above considerations in mind a B-17 Fortress and a B-25 Mitchell bomber have been fitted for flight research on precipitation static. The installations are not identical but most of the apparatus to be described has been installed in both airplanes. The armament was removed after it was ascertained that its presence had no particular bearing on the problem. The interiors were altered, tables installed where possible, and other conveniences for the operating personnel were provided insofar as the natural characteristics of these military airplanes permitted.

The instrumentation has, on the whole, proved very satisfactory and successful flights have covered the United States, Canada, Alaska, Mexico, and Iceland.

Electric-Field Meter

The precipitation static observed in aircraft radio receivers under certain conditions is due, principally, to corona discharges from various parts of the airplane. Initiation of corona requires an electric field. Therefore, measurement of the electric field at selected places on the surface of the airplane is of fundamental importance in the study of precipitation static.

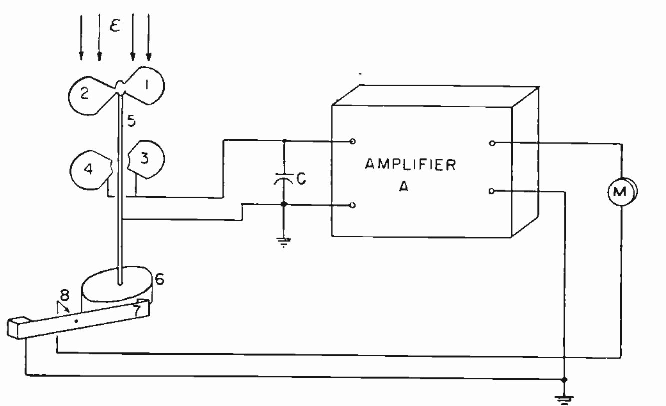

Fig. 1—Principle of electric-field meter. 1, 2 = rotating vanes, or rotor; 3, 4 = fixed vanes, or stator; 5 = grounded-shaft carrying rotor; 6 = ellipsoidal cam; 7 = switch arm; 8 = switch contacts; C = capacitor; A = resistance-capacitance-coupled amplifier; M = center-zero microammeter; $\mathcal{E}$ = electric field.

The instrument developed to measure electrostatic fields during flight is termed an "electric-field meter."[1–3] A block diagram of the device is shown in Fig. 1. A pair of grounded quadrantal rotating vanes 1 and 2, termed the rotor, is driven via a shaft 5 by a small motor at about 1000 revolutions per minute. A pair of insulated fixed quadrantal electrodes 3 and 4, called the stator, are situated a small distance behind the rotor. The stator is connected to ground through a capacitor C. If an electric field $\mathcal{E}$ be applied perpendicular to the electrode system and the motor energized, the stator will be alternately exposed to and shielded from the field. As a consequence, an alternating flow of induced charge takes place between the stator and ground, causing a triangular alternating component of potential difference to appear across capacitor C, whose capacitance is large compared to the stator-rotor capacitance. This potential is applied to a resistance-capacitance-coupled vacuum-tube amplifier A which has an input impedance large compared to the reactance of C.

The amplifier incorporates a large amount of negative feedback and has small amplitude, frequency, and phase distortion in the range from 10 to 50 cycles per second. The amplifier output is converted to direct current by a half-wave synchronous mechanical rectifier. The switch arm 7 (see Fig. 1) carries contacts 8 and is driven by ellipsoidal cam 6, attached to the rotor shaft. The rectified current is read on meter M, a 100-0-100 microampere instrument.

It can be shown that such a system obeys the relation

$$I = 2.86 \times 10^{-7}\, \mathcal{E} S A / C \tag{1}$$

if edge effects and field distortion are neglected. In (1), I is the average value of the rectified current in microamperes; $\mathcal{E}$ is the magnitude of the electric field in volts per centimeter; S (a property of the amplifier and rectifier) is the ratio of I to the peak value of a triangular signal wave applied to the input of the amplifier, in microamperes per volt; A is the maximum area of the stator exposed to the electric field, in square inches; and C is the capacitance of the input capacitor, in microfarads.

In the instrument here described $A = 4.89$ square inches, $S = 715$ microamperes per peak volt (triangular wave), and $C = 0.001$ microfarad. A field $\mathcal{E}$ of 100 volts per centimeter then causes a meter current I of 100 microamperes. Full-scale ranges of 100, 400, 1000, and 4000 volts per centimeter are provided by a potential divider which effectively alters S. The instrument is finally calibrated *in situ* on the airplane by applying known electric fields.

Because of the phase-sensitive property of the synchronous rectifier the device is polarity sensitive; that is, the direction of meter deflection reverses when the field reverses.

A photograph of the electric-field meter is shown in Fig. 2. The instrument is separated into two parts. The "head" carries the rotor-stator system and houses the cam-operated switch, capacitor C, the first amplifier stage (a cathode follower), and a few other small components. The head is, of course, mounted on the outside of the airplane and is subjected to severe weather conditions. The control box houses the amplifier, suitable controls, and a small dynamotor, and is connected by a cable to the head.

Power for the electric-field meter is taken from the 28-volt direct-current airplane system.

Electric-field meters mounted on the nose, on the tail, and on the top and belly of the central fuselage section provide data for mapping the electric-field distribution about the airplane. Fields at other points may be inferred from electrostatic experiments on a scale model of the plane. The instrument functions as described,

[1] Ross Gunn, "Electric field and potential indicator," U. S. Patent No. 1,919,215; July 25, 1933.

[2] P. Kirkpatrick and I. Miyake, "A generating voltmeter for the measurement of high potentials," *Rev. Sci. Instr.*, vol. 3, pp. 1–8; January, 1932.

[3] Ross Gunn, "Principles of a new portable electrometer," *Phys. Rev.*, vol. 40, pp. 307–312; April 15, 1932.

irrespective of whether the fields are autogenous (originating from a net charge on the airplane), exogenous (fields induced by charges external to the airplane), or in combination.

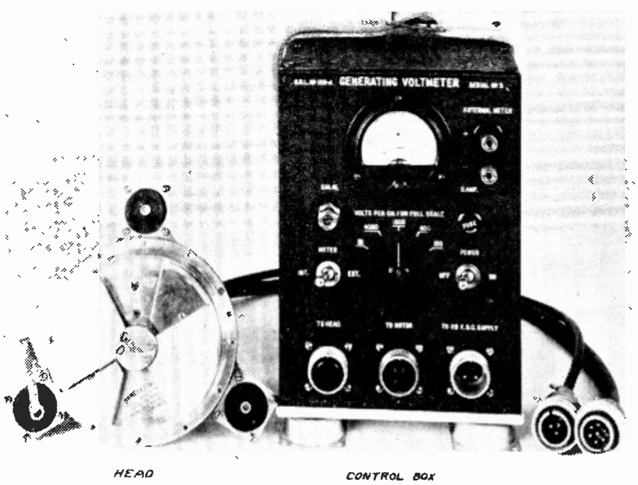

Fig. 2—The electric-field meter. The head, which carries the rotor and stator electrodes and houses the synchronous switch and the first stage of the amplifier, is mounted on the external surface of the airplane. It is connected by a cable to the control box which is located at the instrument-operator's station.

Dischargers

The high interference level usually observed in radio-communication circuits on an airplane when flying in weather conducive to precipitation static can be greatly reduced if the concomitant corona discharges be persuaded to take place from certain special devices called

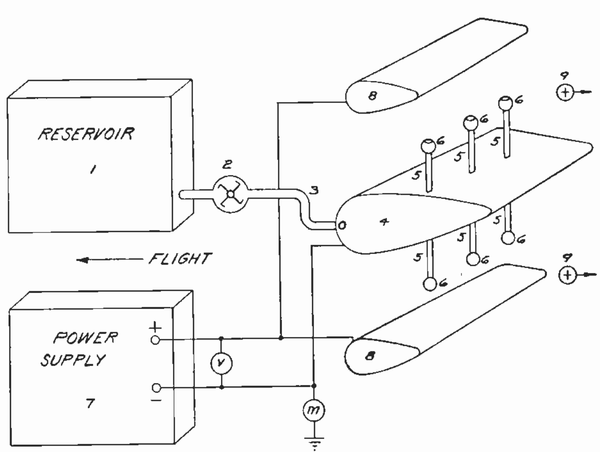

Fig. 3—Principle of the artificial charger. Water from reservoir 1 is forced by pump 2 through pipe 3 into hollow strut 4. Water emerges from jets 5, 6. Power supply 7 maintains an electric field between inducing struts 8 and balls 6. As the water emerges it acquires an induced charge. The charged water droplets 9 are carried away by the slipstream and leave the airplane charged with the opposite sign.

"dischargers." Such devices are not intended to be research instruments, but one type, the "wick discharger," is useful as an adjunct to electric-field meters in studying the electric field about an airplane. The metallized-wick discharger consists of a 12-inch length of heavy cotton yarn rendered slightly conducting by deposition of silver. About one inch of its outer end is frayed and a metal lug, for attaching to the airplane, is fastened to the other end. Except for the ends, the wick is covered by a flexible insulating tube. The discharge takes place from individual fibers at the frayed end.

Normally, these dischargers are mounted in metallic contact with the airplane. For use as qualitative electric-field indicators the mounting bracket is insulated and a lead is run from the wick to a center-zero micro-ammeter on the photoobserver. Such wicks may be easily installed on wing tips and control surfaces where placing electric-field meters would be very inconvenient. They provide information on the direction of the electric field at the place of installation (by observation of the direction of current flow) and provide a qualitative measure of magnitude.

In some wick installations provision has been made for retracting the wicks into a shield. In such cases the wick is attached to a piston working in a cylinder, the piston being remotely controlled by air pressure. Such installations permit rapid and unambiguous demonstration of the efficacy of the wick discharger in reducing the radio-interference level.

Artificial Charger

In research on precipitation static, it is ordinarily necessary to make extended and time-consuming flights to find appropriate weather. A method of simulating autogenous charging of an airplane, developed by the Naval Research Laboratory, which can be employed at will during flight in any weather has been found to be a great convenience. The device used is here termed an "artificial charger."[4] It enables an operator to cause an

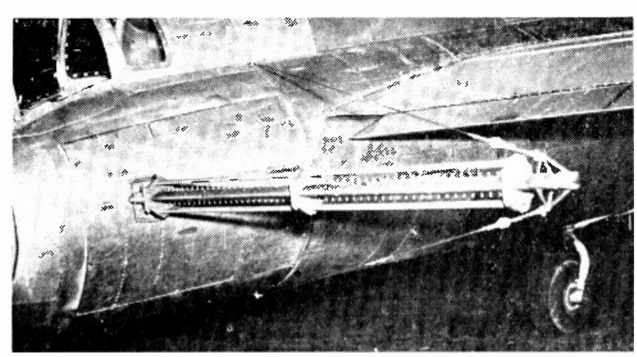

Fig. 4—Rake portion of artificial charger. The rake is shown mounted on a B-17 tail just aft of a horizontal stabilizer. A similar rake extends out from the opposite side of the tail.

airplane to acquire a net charge of controlled polarity and magnitude, within limits. The resulting electric field about and corona discharge from the airplane is not identical with that obtaining in natural autogenous charging but it is sufficiently similar to permit many studies which otherwise would be inconvenient or even impossible.

The essential elements in the artificial charger are shown in Fig. 3.

Water from reservoir 1 is forced by a pump 2 through line 3 to a hollow streamlined strut 4. Projecting from

[4] Naval Research Laboratory Report 0-1919, August 14, 1942.

both top and bottom of strut 4 are a number of small hollow tubes 5, each terminating in a sphere 6. The liquid emerges from these spheres and is torn into small drops by the slipstream in flight. The assembly 4, 5, 6 is termed a "rake" because of its appearance. A photograph of one of the two rakes on a B-17 is shown in Fig. 4. The high-voltage supply 7 (Fig. 3) provides a voltage of either polarity and of controllable magnitude up to 10,000 volts. This potential is applied between the inducing struts 8 and the rake 4, 5, 6. The electric field between struts 8 and balls 6 causes a charge to be induced on the water as it emerges from the balls. This charged water 9 is carried away from the charger, and from the airplane, by the slipstream. The airplane therefore acquires a net charge whose polarity is opposite to that carried away by the water. By this action it is possible to elevate (or depress) the potential of the airplane with respect to the atmosphere and cause various parts of the airplane to exhibit corona discharges, with concomitant static in the radio-receiving system.

The charger is completely insulated from the airplane except for the connection through meter M. This meter thus reads the current which effectively charges the airplane. In equilibrium, this current is equal to the sum of the discharge currents due to corona, atmospheric conduction, and ionized engine-exhaust gas.

When a total of 200 jets (5, 6) and an inducing potential of 10,000 volts are employed a discharge current of about 0.25 milliampere is obtained. This causes, on a B-17, a belly field of about 450 volts per centimeter, or an airplane potential of about 500,000 volts. The rate of water discharge is about 75 gallons per hour.

It is evident that the above device might be used to maintain the airplane potential near zero while flying in autogenous charging conditions. This has been found to be possible, but it is not considered a practical solution for the problem of precipitation static in autogenous charging weather because of the considerable bulk and weight of the device. However, it has been found invaluable in simulating autogenous charging of an airplane in a precisely controlled manner.

Noise Meter

Research in precipitation static requires apparatus for quantitatively measuring the radio-interference level encountered in various kinds of weather and with various treatments of the airplane. The difficulty of designing a direct-reading noise meter whose indications are truly indicative of the interfering property of noise are well known. Radio interference traceable to precipitation static varies from intermittent pops and crackles, through siren-like tones, to a continuous rushing sound. Probably the only technique which would give a true measure of such interference is that of attempting to read nonsense syllables, words, or sentences through the interference level, but such a technique is too slow and difficult in the present problem.

An alternative which has proved fairly satisfactory has been to employ a commercial noise meter (RCA Model 312-B) and to supplement its readings with notes taken during flight.

The RCA 312-B noise meter is ordinarily completely battery powered. Since it was frequently employed for extended periods it was altered for use with a power pack energized from the 28-volt direct-current line on the airplane. The power pack employed gas-tube voltage regulation for the plate supply and a hot-wire-type ballast tube in the filament circuit.

The instrument was ordinarily tuned to 300 or 900 kilocycles. Provision was made for connecting various antennas on the airplane. The relative merits of various types of antistatic antennas could then be evaluated, as well as the effectiveness of other treatments of the airplane. Qualitative estimates of the interference level were also made by listening to the various radio receivers normally installed in the airplane.

Patches and Induction Probe

The detailed theory of the charging process which occurs when a particle of precipitation strikes a solid surface is not known. Apparatus for studying this action under actual flight conditions is highly desirable since the validity of ground experiments is doubtful. Provision was therefore made for exposing insulated metallic surfaces to the slipstream of an airplane in actual flight. These electrodes, called "patches," were streamlined paraboloids of revolution mounted on the under side of the wings near the tips, or disks mounted on supports projecting forward on the nose. Under autogenous charging conditions a current between a patch and the airplane may be observed. These currents vary both with the nature of the surface and the nature of the precipitation and are usually less than 10^{-6} ampere.

Since the above currents are too small to be read directly on instruments that can be flown in an airplane, a four-channel amplifier was constructed. Each channel consists of a double triode, with load resistors in the cathode circuits only. A 100-0-100 microampere meter is connected between cathodes. One grid is grounded through a resistor, the other directly. The current to be measured is passed through the grid resistor, whose value can be adjusted to give full-scale output for input currents of 0.1, 0.4, 1.0, 4.0, 10, and 40 microamperes. Thus currents from about 10^{-9} to 4×10^{-5} ampere can be measured. A potential drop of 0.4 volt is necessary for full-scale deflection. These amplifiers are also used in measuring small currents derived from sources other than patches.

The above method of metering the patches, of course, gives an integrated measure of the charging action of many precipitation particles. An oscilloscope was arranged for study of individual pulses. The oscilloscope (Dumont Model 208) was altered to permit operation at high altitudes and an intensifier voltage supply and single sweep were added. The screen is photographed by a 35-millimeter camera. Convenient controls initiate the single sweep, trip the camera shutter, and advance the film, a tally counter in the field of view of the camera, and a tally counter on the photoobserver. Thus the photography is correlated with other research instruments.

Interpretation of the traces obtained requires consideration of the transient response of the circuit employed.

While it appears that the major cause of charging of an airplane is the separation of charge which occurs when a precipitation particle strikes and leaves the surface of the airplane, as described above, it is also possible for an initially charged particle to deposit charge on the airplane. To study the charge initially resident on precipitation particles, a device termed an "induction probe" was installed.

As shown in Fig. 5, a hollow truncated cone 1, of sheet metal, encloses and shields a short metal cylinder 2. The device is mounted in the air stream, well forward, so that precipitation particles 3 will not have previously

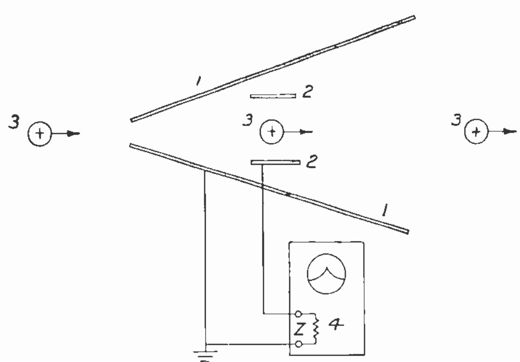

Fig. 5—Principle of induction probe. Probe consists of cone 1 and ring 2. Charged precipitation 3 in passing through ring 2 momentarily induces a charge on the ring. Passage of charge through impedance Z creates a potential difference which is registered on oscillograph 4.

struck any surface of the airplane. Some particles 3 pass through the small opening in the cone, through the short cylinder, and out the large end of the cone. If the particle bears a charge it will, in passing through cylinder 2, cause a charge of opposite sign to be momentarily induced upon it. The passage of this charge from ground (the airplane) through the input impedance Z of the oscilloscope 4 to the cylinder 2 causes a potential difference across Z and a deflection on the oscilloscope screen. Interpretation of the trace involves either a detailed analysis of the circuit or an empirical calibration. The latter was performed by firing charged lead shot through the induction probe by means of an air pistol. The trace was photographed as described previously.

Since in the above measurements it is charge rather than current which is of interest, the input impedance of the oscilloscope was usually made capacitively reactive to all frequencies involved in the pulses.

Air-Conductivity Meter

Among the meteorological conditions of possible relevance in the investigation of precipitation static are conductivity and ion content of the air. An instrument was developed by the Carnegie Institution, Department of Terrestrial Magnetism, Washington, D. C., for making these difficult measurements in flight.

Air conductivity is measured by applying a subsaturation electric field to a continuous sample of air, the rate of air flow being fixed by the use of a constant-volume air pump. The electric field has a known value determined by geometry and applied potential and serves to drive natural ions in the air to a collector electrode and thence to ground (the airplane) through a resistance of about 10^{10} ohms. The potential difference developed is applied to an electrometer-type vacuum tube having a very high input impedance. This tube is followed by several stages of direct-coupled amplification. The amplifier output is fed back to the electrometer tube in degenerative phase in the manner described by Roberts.[5] The feedback voltage is then practically equal to and in opposite phase with the potential developed by the ion current in flowing through the large input resistor. Since it exists at a low impedance level, it can be measured by a conventional voltmeter whose deflections are then directly proportional to ion current.

The instrument is calibrated in an ingenious manner by plugging in to the input an attachment consisting of a small high-voltage battery, a radioactive plaque, and a small ion chamber. The saturation ion current provided by this device is constant so that it acts as a constant-current signal generator for calibrating purposes.

The air conductivity is calculated from the instrument reading, the applied electric field, the rate of air flow, and a factor determined by the use of the calibrating device.

By operating the ion chamber under saturation conditions, it is possible to interpret the instrument readings in terms of ion content of air.

Accelerometer

To measure quantitatively the flight condition generally described by the term "turbulence," a novel instrument was developed. It is a low-range accelerometer utilizing a telegauge tube.[6] The tube is a double diode in which the two plates 1 and 2 are disposed symmetrically with respect to filament 3, as shown in Fig. 6. The plates are mechanically supported by a rod 4, which passes through a flexible metal diaphragm 5, forming one end of the tube envelope. Separate electrical connections are made to the two plates by flexible leads 6 and 7. If a suitably supported mass 8 be attached to the outer end of rod 4 and if the tube mount be subjected to accelerations in the plane of the illustration the diode plates will move with respect to the cathode, causing one plate resistance to increase and the other to decrease.

The external circuit is a direct-current bridge involving resistors 9, 10, and 11, and batteries 12 and 13 to supply plate and filament voltages. A 50-0-50 microammeter M, properly damped, is connected in series with calibrating resistor 14 as the indicator.

The bridge is initially balanced by adjusting resistor

[5] Shephard Roberts, "A feedback micromicroammeter," *Rev. Sci. Instr.*, vol. 10, pp. 181–183; June, 1939.

[6] Ross Gunn, "A convenient electrical micrometer and its use in mechanical measurements," *Jour. Appl. Mech.*, vol. 7, pp. A49–A52; June, 1940.

10. The sensitivity is normally set at 10 microamperes per *g* and may be checked easily by rotating the tube 180 degrees in its mount. This unbalances the bridge and the meter is then made to read a standard value by adjusting resistor 14.

Provision is made for using either a meter on the instrument or one on the photoobserver.

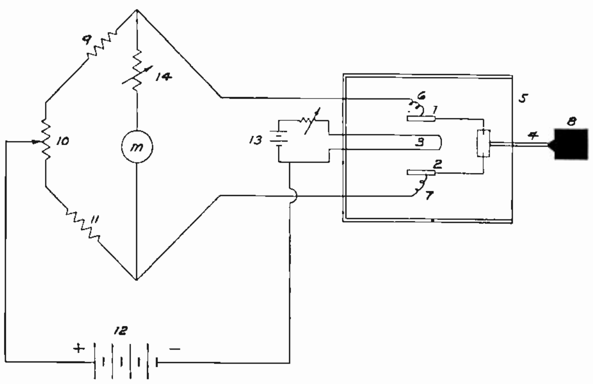

Fig. 6—Accelerometer. A mass 8 is supported on rod 4 which passes through flexible diaphragm 5 of the telegauge tube. Rod 4 supports diode plates 1 and 2, carrying flexible leads 6 and 7. Acceleration of the tube housing causes changes in diode spacings which upsets balanced bridge. Acceleration is read from meter *M*.

Downward accelerations having a value greater than 1 g are found to be correlated with personnel, tools, and other loose articles floating about in mid-air.

Data Recorder

An important accessory to the above described instrumentation is a method of continuously and permanently recording the data furnished by the various instruments. This function is here fulfilled by intermittently photographing a panel on which are mounted meters connected to the instruments involved. This panel is 18 by 24 inches in size and accommodates 23 meters. It is supported by a shock-mounted framework which also carries a 35-millimeter motion-picture camera and a battery of 28-volt incandescent lamps. The camera can be operated either single-frame fashion or at the low continuous rate of two frames per second. The lamp load is about one kilowatt. The location of the lamps is such as to avoid glare from the glass meter fronts. Careful processing of the film is necessary to obtain the required resolution.

Most of the instruments feeding the panel meters have several ranges. In order to record the range in use, two small lamps are installed below each meter. By proper interconnection of these lamps and switch sections in the associated apparatus, four range positions can be indicated. The same arrangement is used when the sensitivity of a meter is varied by shunting.

The instrument panel carries, in addition to the electric-field meters, an altimeter, an air-speed indicator, a clock, and two tally counters.

The above-described device, which is called the "photoobserver," is supplemented by a record-type voice recorder. This recorder is so wired to the airplane interphone system that it becomes operative when the interphone microphones are energized. This permits an operator to record comments and data not shown on the photoobserver. Each time such comment is made, the operator depresses a convenient push button which advances a tally counter on the photoobserver, and mentions the new code number. In this way, the voice-recorded data is correlated with the photoobserver. Incoming and outgoing radio signals can also be recorded.

A multiple-element string oscillograph and automatic-balancing recording potentiometers are also available to supplement the above methods of data recording.

Miscellaneous

In addition to the special-purpose instruments described above, the airplanes used in precipitation-static research are normally equipped with a thermometer for reading external-air temperature, an altimeter for altitude, an air-speed indicator, and a hygrometer for measuring humidity. The latter measurement has been found to be very difficult under flight conditions in sub-zero weather.

The propeller hubs are fitted with slip-ring and retractable brush assemblies to permit metering corona currents from the propellers. The latter are inherently grounded through their bearings but the resistance is sufficient so that a very low resistance meter in shunt with this path carries most of the corona current. The meter readings are corrected by a consideration of the resistances involved.

The main electric-power source for operating the various instruments is the 28-volt, direct-current system in the airplane. This is energized by generators coupled to each of the airplane engines. Under certain operating conditions it is forbidden to use the above generators, in which case the instrument load is shifted to a 28-volt gasoline-engine-driven generator.

A 28-volt direct-current to 115-volt 60-cycle inverter is used to supply power to instruments requiring alternating current. Limited amounts of power at 400 and 800 cycles are also available.

Power at the above levels is distributed to outlets located at convenient points in the airplane.

Interconnection between the various instrument stations and the photoobserver is facilitated by a system of shielded and unshielded distribution lines which terminate at junction boxes at convenient points. This avoids makeshift and hazardous temporary wiring when apparatus is installed or altered.

Although the photoobserver is carefully shock-mounted, meter failures due to vibration and condensation sometimes occur. A device called a "calibrator" is therefore employed before each flight to check the meters. It consists of a controlled source of known currents and potentials which can be applied quickly by suitable switches to each meter. Use of the calibrator, together with frequent checks on the over-all operation of each research instrument, minimizes abortions in which difficulties are discovered after a flight has begun.

Part III—Electrification of Aircraft Flying in Precipitation Areas*

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Summary—**The principal features and mechanisms responsible for the transfer of free electrical charge to aircraft, as it flies through various types of precipitation, are examined. The charging characteristics of a typical airplane flying through dry snow are given and correlated with reliable quantitative data secured on the ground. The critical dependence of charging processes upon the ambient temperature and the character of the airplane's surface is noted, and the possibility of neutralizing this charging by special surfaces is demonstrated.**

The discharge characteristics of the aircraft are evaluated in terms of the charge carried away by the engine-exhaust ions and by corona discharge. It is concluded that under severe precipitation conditions most of the accumulated charge is carried off by corona processes.

The differences between unipolar or autogenous electrification and bipolar or exogenous charging are emphasized. Both types produce serious radio interference and require different treatments for their mitigation.

I. Introduction

Careful studies of the electric behavior of aircraft in flight were not made until after precipitation static became recognized as a serious obstacle to the use of radio communication. As early as 1928, loss of radio communication in rain and snow had annoyed pilots, but the loss was not considered to be important because the general practice at that time was to avoid flying through precipitation. As aircraft construction and instrumentation improved, and as advances in the science of meteorology permitted more all-weather flying this practice gradually disappeared, until, by 1935, trouble with precipitation static had increased to a point where governmental agencies and commercial airlines were searching for ways to eliminate the hazard, and the necessity for understanding the phenomena associated with the electrification of flying aircraft had become recognized.

In a paper on precipitation-static interference written in 1939, Hucke[1] discussed the prevailing opinions of the factors contributing to the electrification of aircraft. It was believed that an airplane might acquire the charge from electrified particles of rain, snow, or dust intercepted along its line of flight. No consideration was given to the possible triboelectric or frictional generation of electricity through contact between intercepted particles of precipitation and the surface of the airplane. Furthermore, it was believed by some investigators that the radio interference might be caused by voltage transients produced when electrified particles struck the airplane or its antennas. This was a theory suggested by Morgan[2] to explain why a metallically shielded loop is less susceptible to static interferences than an open-wire antenna. Hucke made many flights in precipitation areas using aircraft equipped with sharp points projecting from the wing tips, the nose, and the tail. These were connected to the frame of the airplane through recording microammeters and were found to discharge electricity in a manner clearly co-ordinated with the occurrence of precipitation static. Hucke concluded from these flight experiments that the airplane became electrified and that electricity was discharged from the sharp points in the form of corona. After making additional studies on the ground and in the laboratory, Hucke concluded that corona was one of the causes of precipitation static.

Calculations, based upon reasonable estimates of the electric charge resident on particles of precipitation, showed that the rate at which such charge could be collected by an airplane in flight was considerably less than the observed rates of discharge from antennas and other metered areas. This led to the suggestion, now accepted as true, that frictional charging was mainly responsible for the electrification of aircraft.

The early studies of the causes of precipitation static were handicapped by not having an adequate means of measuring the extent of aircraft electrification. As a result, in most of the studies made prior to the introduction of the use of an electric-field meter by Gunn,[3] it was not known how the severity of radio interference was related to the conditions encountered on different flights or, for that matter, to varying conditions found in the same flight. As a further consequence, it was impossible to relate the reports of flight observations made by different investigators in a consistent manner. It is not surprising, therefore, that many early papers on the subject were frequently contradictory. The use of an electric-field meter installed at the surface of an airplane partially solved this problem by permitting the amount of electrification on any given airplane to be measured and to be used as a standard of comparison.

II. Autogenous Charging of Aircraft

Autogenous electrification of aircraft has been defined as the self-charging of aircraft by impact or frictional contact with particles of precipitation. A net

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[1] Herbert M. Hucke, "Precipitation-static interference on aircraft and at ground stations," Proc. I.R.E., vol. 27, pp. 301–316; May, 1939.

[2] H. W. Morgan, "Rain static," Proc. I.R.E., vol. 24, pp. 959–963; July, 1936.

[3] R. Gunn, *Phys. Rev.*, vol. 40, pp. 307–312; 1932.

negative charge is usually left on the airplane and the compensating positive charge remains on the particles after they are swept away in the air flow. The electric field associated with the net charge on the surface of the airplane is known as an autogenous electric field, and it is distributed over the surface according to the surface charge density determined by the geometry of the airplane.

The development of a controlled artificial charger for use on an airplane in flight provided a means of directly measuring the charging rate caused by intercepted precipitation. Since autogenous charging is usually negative, it is only necessary to operate the artificial charger so that the airplane is charged at an equal positive rate. A test of equality of the two opposite charging rates can be made by measuring the surface electric field at some position on the airplane. When the field is zero, there is no surface charge and consequently no net charge, and the natural and artificial charging rates are equal. The most effective artificial charger for this purpose is a device developed by the Naval Research Laboratory.[4] The artificial charger on the B-17 research airplane is limited to about 300 microamperes of positive charging current which corresponds to a moderate natural charging rate. The water jets and the inducing plates were assembled into a rake-like structure and attached to the tail of the B-17. A more complete description of this charger will be found in an accompanying paper[5] on instrumentation.

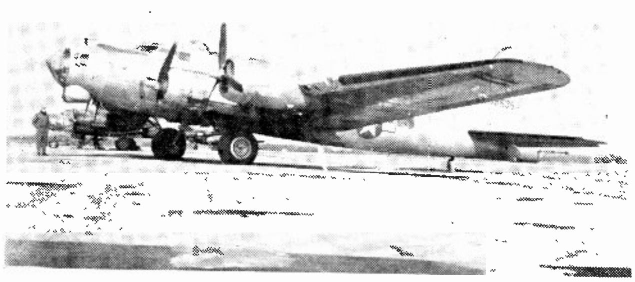

Fig. 1—Position of the electric-field meter on the under side of the B-17 research airplane.

During a flight of the B-17 at an altitude of 8300 feet and at a true airspeed of 200 miles per hour in the vicinity of Yakutat, Alaska, on February 24, 1945, the research meteorologist described the precipitation encountered as light to moderate snow. Using the artificial charger as prescribed, the natural charging rate of the airplane was found to be about 100 microamperes in light snow and about 155 microamperes in moderate snow. Simultaneously, the electric field on the belly was found to be about 175 volts per centimeter in the light snow and about 200 volts per centimeter in the moderate snow. Although this is a particular example, the charging rates and associated electric fields are typical of values measured on many flights of the B-17 during the winter of 1945. The electric-field meter with which these measurements were made had a working range of from 10 to 4000 volts per centimeter. Its location on the bottom of the fuselage of the B-17 is shown in Fig. 1. A full description of the meter also appears in the accompanying paper on instrumentation.[5]

The natural charging rate of an airplane may be measured indirectly by establishing the way in which the electric field at some reference location, such as on the belly, depends upon the charging rate. This method is useful because the electric-field intensity is easily measured. The data just given determined two points on the characteristic curve relating the electric field to the charging rate of the B-17 research airplane. A convenient means of obtaining this curve is provided by flying the airplane in fair weather, operating the artificial charger to produce varying amounts of electrification, and measuring the electric field associated with each value of the charging current.

The curve in Fig. 2 gives the relationship found by this means between the artificial charging current and the electric field on the belly of the B-17. The two points determined during the Yakutat flight fall quite close to this curve, and the slight disagreement is well within the limits of error in measurement. On numerous flights

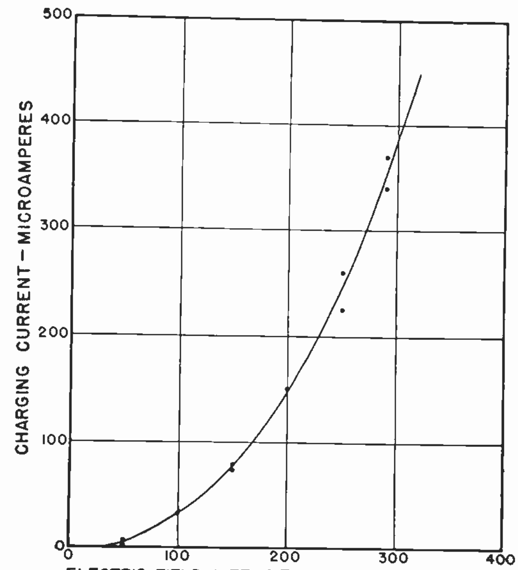

Fig. 2—Relationship between the charging current and the electric field on belly of the B-17 research airplane, airplane charged negatively.

in which heavy snow has been encountered the electric field on the B-17 has been found to rise as high as 400 volts per centimeter. Fields this high, for example, were encountered during a flight in the vicinity of Iceland, on March 13, 1945, and have been encountered numerous times during flights near Minneapolis, Minnesota. Since the calibration curve in Fig. 2 does not extend to electric fields as high as 400 volts per centimeter, it is worthwhile to fit this curve with an empirical formula

[4] Ross Gunn, Naval Research Laboratory Report No. 0-2243; Feb. 23, 1944.

[5] Ramond C. Waddel, Richard C. Drutowski, and William N. Blatt, "Aircraft instrumentation for precipitation-static research," PROC. I.R.E., this issue, pp. 161–166.

which permits extrapolation. A formula that agrees satisfactorily with the curve is given by

$$\log_{10} I = 2.36(\log_{10} E - 1.38) \tag{1}$$

where I is the charging current in microamperes and E is the electric-field intensity in volts per centimeter. Using this formula, a charging current of about 760 microamperes is found to be necessary in order to produce an electric field of 400 volts per centimeter. The extrapolation is believed to be sufficiently reliable to assume that this high charging rate is typical of the B-17 flying in heavy snow.

Measurement of the rate of collection of charge by a chromium electrode mounted on an airplane so that it will intercept uncontaminated snow provides another means of estimating the total natural charging rate. The photograph in Fig. 3 shows the type of chromium electrode that has been used on the B-17 research airplane.

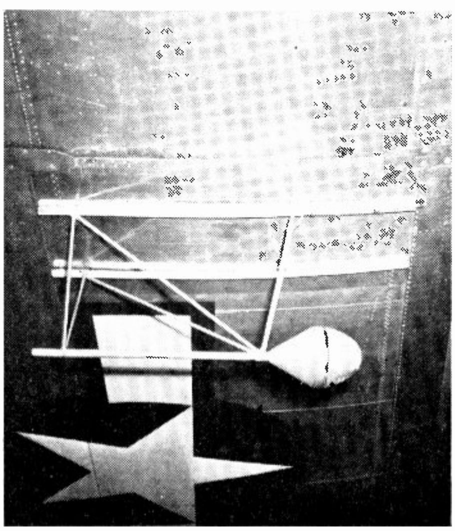

Fig. 3—Chromium electrode used to measure natural charging in precipitation.

The surface of the electrode is a paraboloid of revolution with the vertex placed forward in the line of flight. The electrode is supported about 18 inches below the wing by means of a metal framework, and the whole unit is placed inboard about 4 feet from the wing tip. From close observation in flight it has been determined that no snow coming in contact with any portion of the wing will strike the surface of the electrode. Particles of precipitation strike the electrode near the vertex at nearly normal incidence, but nearer the base, the angle of incidence is almost grazing. This surface is believed to be sufficiently similar in form to most air-foil sections to furnish representative charging currents. A chromium surface was used for two reasons: First, chromium is quite hard and does not suffer from pitting or abrasion under the impinging action of frozen water particles. Softer metals like aluminum or copper show a gradual dulling of polished surfaces when struck repeatedly at high velocities with snow or ice. Second, a well-cleaned chromium surface seems to be more stable in its electric-charging characteristics than other types of surfaces.

In order to calibrate the charging rate of the B-17 equipped with this electrode, it is necessary to measure simultaneously charging currents of both the electrode and the airplane. Charging currents of the airplane were obtained by measuring the electric field and then using the curve of Fig. 2. The charging rate of the chromium electrode was measured by insulating it from the main structure of the airplane, except for a connection through a current amplifier and a photorecording meter.

The charging rate of the chromium electrode during the Yakutat flight was 0.05 microampere when the intercepted snow was light and the total charging current of the airplane was 100 microamperes. When moderate snow was enountered, the charging rate of the electrode increased to about 0.073 microampere while the total charging rate of the airplane increased to 155 microamperes. Thus, it is seen that the charging current of the electrode can be converted into the total natural charging current of the airplane by using a multiplying factor of about 2050.

Many measurements of the electric field on the belly of the B-17 and of the charging current of the chromium electrode have been made simultaneously in all types of weather conditions. The curve shown in Fig. 4 is drawn through points representing data observed during a typical flight when all degrees of snow intensity were

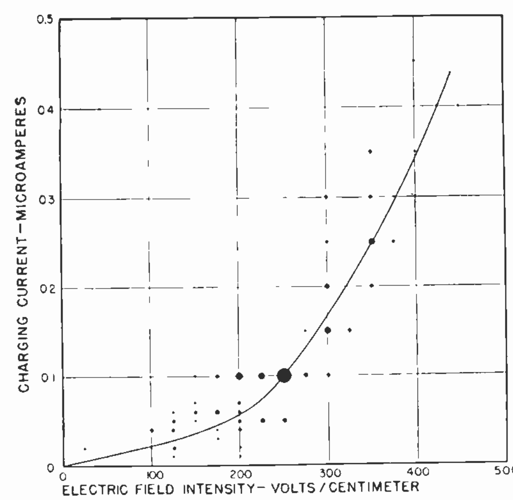

Fig. 4—Relationship between the charging current to the chromium electrode and the electric field on the belly of the B-17 research airplane, airplane charged negatively by precipitation.

encountered. The areas of a given point in this figure are proportional to the number of coinciding readings that fell at this point. It will be noted that the charging current necessary to produce an electric field of 400 volts per centimeter was about 0.34 microampere. Multiplying this electrode current by 2050 gives about 700 microamperes for the total natural charging current. This is in satisfactory agreement with the value of 760 microamperes found by extrapolation from the formula of (1) as necessary to produce an electric field of 400 volts per centimeter.

There is a considerable amount of scatter in the points in Fig. 4, although the trend seems well established. Part of this scatter is known to be due to icing, frequently encountered in precipitation conditions. The type of surface is a highly important factor in autogenous charging, and a later section in this paper is devoted to a discussion of the charging of different types of surfaces. Other factors beside icing can affect the charging rate. The most important of these may be listed as the density of the intercepted snow, the crystalline form of the snow, the angle between the surface and the direction of the impinging snow, the velocity of the aircraft relative to the snow particles, and the temperature.

In a previous example, in light snow the charging rate of a B-17 airplane was about 100 microamperes, while in a moderate snow the rate increased to about 155 microamperes. This shows the effect of snow density upon the charging rate.

Although attempts have been made to relate the charging rates to the type of crystalline form of frozen precipitation, both in flight and in ground experiments, no definite relationship has been established.

The effect of the air temperature has been studied in many flights, but it has not been possible to determine accurately in what manner electrification varies with temperature below freezing. Precipitation at temperatures above freezing are relatively ineffective in producing autogenous charging. Ground experiments described later indicate that many kinds of surfaces show a maximum charging rate at about -7 degrees centigrade.

As the angle between the surface of an airplane and the direction of the impinging snow changes from 90 degrees to smaller values as might be found, for example, at different areas of the nose section, it seems probable that the charging rate decreases. No adequate study of this effect has been made in flight.

When precipitation is encountered in flight, the conditions of electrification never remain sufficiently steady to permit performing the simple experiment of changing the speed of the aircraft and observing the effect upon the charging rate; however, from a careful examination of several hundred flight observations, the conclusion is forced that the charging rate must be proportional to the speed raised to some power higher than the first. In numerous experiments in which the velocity of impinging particles on various types of surfaces has been carefully controlled, the charging rate has been found to increase about as the cube of the velocity. One of these experiments is discussed in a following section of this paper.

Precipitation in the form of snow or particles of ice is not the sole cause of autogenous electrification of aircraft. It is well known, for example, that flight through dust-laden and smoke-filled air will result in a considerable amount of charge accumulation by aircraft. The question of whether or not rain or fog can cause electrostatic charging has been the subject of some dispute, but many flights of the B-17 in rain and fog have been accompanied consistently by a mild autogenous electric field of about 50 volts per centimeter on the belly. The process by which this electrification comes about may be of an entirely different nature than the process of charging by snow or ice particles. The impact of water particles on the leading surfaces of the airplane may result in a spray which possesses a net electric charge, the compensating charge remaining on the airplane.

The charging rates of the propellers of aircraft have been examined to see what portion of the total charging current is collected by the propellers. There is a good reason for making this examination. The tips of the propellers have a velocity relative to the air which is two-to-three times larger than the forward velocity of the airplane, and as mentioned earlier, charging currents are roughly proportional to the cube of the velocity. The propellers might be expected to collect a large portion of the charge found on aircraft in autogenous electrification.

The propeller hubs of the engines of the B-17 research airplane were equipped with slip rings having retractable brushes, following a procedure recommended at a Civil Aeronautics Authority meeting in Indianapolis, in 1942. Measurements of the charging current of the propellers were made by connecting the brushes riding on the slip rings through suitably chosen microammeters to the framework of the airplane. The resistance through the oil film of the engine bearings between the rotating propellers and the framework of the aircraft was measured and found to be roughly 2000 ohms. Accordingly, microammeters having an internal resistance of about 50 ohms were used for measuring the propeller currents in order that the meters not be appreciably shunted by the 2000-ohm resistance of the engine bearings.

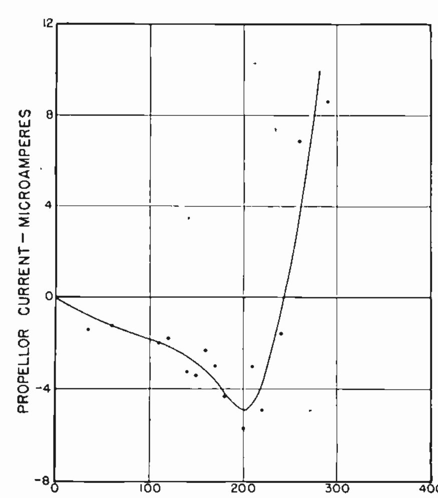

Fig. 5—Propeller current of one propeller of the B-17 research airplane during negative electrification produced by flight in snow.

During a flight on May 7, 1945, at an altitude of 10,000 feet, autogenous charging conditions were encountered in snow which permitted the measurements of propeller charging current plotted in Fig. 5. It will be seen from the curve that an electric field of 200 volts per centimeter accompanied a propeller charging current of 5 microamperes. The total charging current of all four propellers was, accordingly, 20 microamperes. Referring to Fig. 2, the total charging current to the airplane necessary to maintain an electric field of 200 volts per centimeter is about 150 microamperes. Therefore, the propellers contribute about 13 per cent of the total current at this amount of electrification. It will be noted that the negative charging of the propellers displays a reversal in sign as the aircraft becomes more and more electrified. It appears that after a certain amount of charge accumulates on the airplane, the potential reaches a value at which the propellers will begin to discharge. If the airplane potential continues to rise, the propellers will discharge by corona at an increasingly rapid rate that soon exceeds the charging rate.

Autogenous electrification tends to increase continually the quantity of electricity stored on the airplane. It has been found that the potential of an airplane in autogenous electrification can rise very rapidly. The capacity of the B-17 research airplane is approximately 780 micromicrofarads in flight, and when a charging rate of 150 microamperes exists, the voltage of the craft increases at a rate of 192,000 volts per second.

The electrical potential of the airplane would increase indefinitely, were it not that a natural discharging begins. This discharging of the airplane occurs in such a way as to establish an equilibrium potential or state of electrification. A good example of one of the natural discharging processes is the one just mentioned; that is, the discharge by the propellers when the potential of the airplane reaches a value that causes the reversal of current shown in Fig. 5.

Because the frictional charging process is at the very core of the electrification problem when autogenous electrification prevails, an investigation of this little understood phenomenon was initiated. Although it was known that the high-velocity impact between an airplane and precipitation particles could charge up the plane to corona-producing potentials, the dependence of this charging on temperature, snow type, velocity, and character of the striking surface had never been investigated under natural conditions where the precipitation was uncontaminated. Such a study could be expected to yield valuable confirmatory information of the trends that were established roughly in flight observations. It could also be expected to assist in determining the proper treatment of aircraft surfaces for producing minimum charging, and it might lead to information that would enable meteorologists to predict the severity of precipitation-static conditions in advance of a flight.

It was not considered feasible to conduct the experiments in actual flight, since an airplane covers such great distances in a short time that the critical meteorological variables such as temperature, snow type, and snow density cannot possibly remain constant long enough to produce meaningful results. Accordingly, a device was constructed that would simulate aircraft flying through natural uncontaminated snow and which could be set up at a ground station, well away from any cities, in a region of intense and frequent snow falls. This device is pictured in Fig. 6. A good location for its use was found in the Adirondacks, near Saranac Lake,

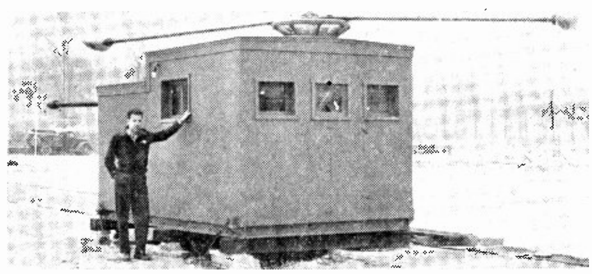

Fig. 6—Device for whirling two nose pieces at controllable speeds up to 300 miles per hour. Nose pieces are interchangeable and coated with various aircraft finishes to permit study of charging factors in falling uncontaminated snow.

New York. As is indicated by the photograph, the essential parts of the device are two arms, each tipped by a tear-shaped electrode. These streamlined electrodes, which are divided into a "nose" and a "body," insulated both from one another and from ground, are rotated at controlled speeds comparable to those of actual flying aircraft. Wires from the two electrodes on the tip of each arm pass down into the house through a brush system, and thence to ground through a current amplifier and recorder. The nose of each streamlined body can be replaced by others, and in this way many different surfaces could be tested in consecutive runs during the same snow storm. Several dozen surfaces were taken to Saranac Lake for investigation in various temperatures and snow types.

It is obvious that a standard is needed for comparing the charging to the type of surface when the snow density varies from snow storm to snow storm. This reduction to a common standard is accomplished experimentally by determining the mass of snow striking a nose per second, and then dividing this quantity into the charge collection rate. The quotient gives a charging factor K, having the unit electric charge divided by mass, and which is a measure of the charging of a particular surface under the impact of one gram of snow. Many different K's thus determined provide an interesting indication of the relative charging of surfaces at different temperatures, speeds of rotation, and snow-type conditions. The value of K changes notably with varying meteorological conditions. If K is expressed in

$$\frac{\text{electrostatic units (meters)}^2}{\text{grams}}$$

then K may reasonably vary from $+10{,}000$ to $-10{,}000$ depending upon the detailed characteristics of the incident snow.

As explained in the preceding paragraph, the charging factor K is given by the relationship

$$K = \frac{I}{W} \tag{2}$$

where I is the charging current to the whirling surface, and W is the mass of snow striking the surface per second. W was obtained through the use of

$$W = PAS \tag{3}$$

in which P is the snow mass per unit volume of air, A is the projected cross-sectional area of the whirling surface, and S is the linear speed of the surface. A and S were known from the design but P must be calculated from two additional measurements. A bucket of known cross-sectional area, B, was tilted so that its longitudinal axis was parallel to the direction of the falling snow, and by a suitable weighing device the mass of the snow N caught per unit time was measured. By means of a recording anemometer, the speed V of the wind-driven snow was obtained. From the relation

$$M = PVB \tag{4}$$

P is obtained, and then W, the mass of snow striking the surface per unit time, is calculated from the final relation,

$$W = \frac{MAS}{VB}. \tag{5}$$

The surfaces taken to Saranac Lake during the winter of 1944 and 1945 could be divided into two groups: (1) Standard aircraft finishes and paints, which normally charge negative; and (2) special surfaces which might increase our knowledge of the charging process. With respect to the special surfaces, it was desired to find very low chargers or positive chargers which, when placed in strategic positions on an airplane, might neutralize the normally negative charging and yield a net airplane current approaching zero.

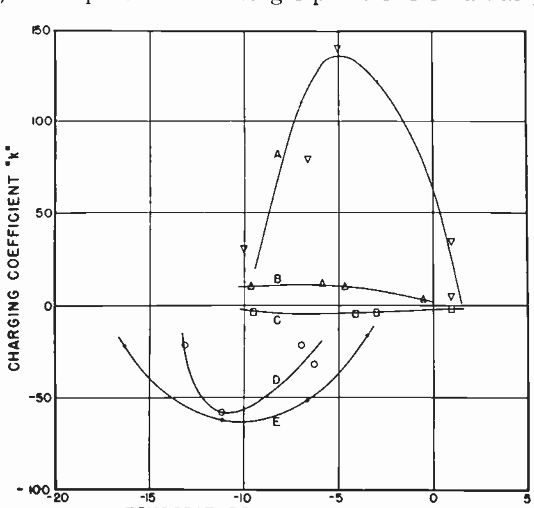

Fig. 7—Charging factor K as a function of temperature for: A—TiO_2, (Anatase Form), thin film; Sol No. 155; B—Colloidal silica No. 155 in Cellulose Nitrate; C—Bare 52-S Aluminum; D—Aircraft wax on 52-S Aluminum; and E—Amphibious Transport Paint.

The charging characteristics of several standard aircraft finishes and two special surfaces are shown in Fig. 7 for one particular snow fall, and an insight is given into the way in which the Saranac data can be interpreted. In Fig. 7 the coefficient is expressed in arbitrary units. The principal information obtained was the following:

A. Bare aluminum is a relatively low negative-charging surface, with little temperature effect discernible.

B. Aircraft wax spread on bare aluminum greatly increases the negative charging, and forms a surface having a maximum temperature effect in the range of -9 degrees centigrade.

C. "Amphibious transport," a common aircraft paint, also charges much higher than bare aluminum, and has a temperature dependence roughly similar to the waxed aluminum.

D. Positive-charging surfaces do exist. The two shown graphically (Fig. 7) possess maxima at around -7 degrees centigrade.

Extensive investigation of the behavior of many other surfaces showed that the paints commonly used on aircraft are consistently high negative chargers relative to bare aluminum. In addition, it was discovered that touching an uncontaminated aluminum surface with the bare hand will raise the charging rate considerably and will reverse the sign of any positive-charging surface. Thus, a thin film of oil on a surface forms an entirely new surface; and this fact provides an explanation for the high charging currents measured on bare aluminum airplanes which, of course, are unavoidably covered with thin oil films.

One of the principal objectives of the Saranac Lake expedition was realized with the discovery of the positive-charging properties of colloidal silica (#115). Spread on aluminum, this substance forms a clear coating which reverses the normal negative-charging sign of the bare metal. It was found that considerable polishing had no effect on the electric characteristics of this unusual surface. Flight experiments at Minneapolis have shown that it is possible to produce a noncharging airplane by coating a certain fraction of the airplane's total surface with colloidal silica. When the B-25 research airplane was covered completely with this unusual substance, and flown in a snow storm unaccompanied by external electric fields, the airplane was observed to accumulate positive charge rather than negative charge. Subsequent mechanical servicing by the ground crew necessitated indiscriminate handling of the surface of the airplane and resulted in a reversal to normal negative charging in latter flights. This obvious effect of contamination is illustrative of one serious difficulty in the way of producing zero charging by a suitable distribution of positive- and negative-charging surfaces on an airplane.

The dependence of the charging on temperature was rather striking. In every case where an effect could be observed, the charging coefficient K showed a maximum in the region of -7 to -9 degrees centigrade. This rule applied, regardless of the sign of charging current to the surface. Such knowledge should enable the meteorologist to warn pilots about probable regions of high electrification and precipitation-static interference.

Information was provided regarding the effect of speed of contact on the magnitude of charging. With temperature, snow type, and snow density constant, it was found that the charging current and the speed were so related that

$$\text{charging current} = \text{a constant} \times (\text{speed})^n. \qquad (6)$$

For most of the surfaces, the average value of the exponent n was approximately 3. A cubic relation of this type shows that a pilot can reduce the severity of electrification by reducing the speed of his airplane.

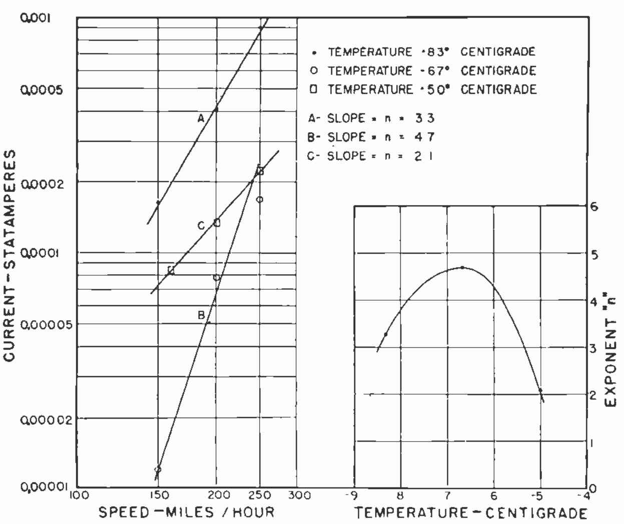

Fig. 8—Temperature effect on exponent n in the equation: Charging current = constant $\times$ (speed)^n. Nosepiece coated with aluminum.

When variations of temperature were taken into account, it was found that the exponent reached its maximum value for a particular surface in the immediate region of -9 degrees centigrade. An illustration of a typical case is shown in Fig. 8. The above-stated relationship between current and speed leads to logarithmic interpretation, since the slope of the curve yields the exponent n. Note the general trend of n with respect to temperature variation. Thus, in addition to the charging coefficient K showing a maximum at -9 degrees centigrade, the effect of speed on charging is most pronounced at this temperature. The difference of snow type was not as clearly marked as was expected. In most cases, it was found that hexagonal plates and powdered snow produced the greatest charging.

III. Processes of Discharge of Aircraft in Autogenous Electrification

Aircraft electrified in flight discharge by natural means. The discharge is produced because a potential relative to the surrounding atmosphere is built up on the airplane. Since the potential will rise rapidly until the discharging rate is nearly equal in magnitude to the charging rate, the airplane may be considered to be always in a state of equilibrium unless extremely fast changes occur in the charging rate. The natural discharging has been found to depend upon such things as altitude, power settings of the engines, conductivity of the air, and the nature of the precipitation encountered in the flight path.

Natural discharging processes may be grouped into four general classes: Discharge due to corona; discharge due to thermal ionization of the exhaust gases of the engines; discharge resulting from convection currents that arise when air or particles come in contact with the surface of the aircraft, receive some of the electric charge on the surface, and then are swept away in the slip stream; and discharge due to the normal conductivity of the atmosphere.

Corona-promoted discharge is by far the most effective means of natural discharging that has been found. As the potential of an airplane rises due to charging by precipitation, a series of values are reached at which the electric fields at the extremities of the aircraft having small effective radii of curvature become so large that these extremities successively break into corona. Such objects as the antennas, the wing tips, the exposed edges of the wing, the tail structure, and the tips of the propellers are especially subject to corona and each has some voltage at which it breaks into corona. These voltages are known as the corona "threshold" voltages. It is important to recognize that every point on an aircraft has a corona-threshold voltage that may be defined as that potential relative to space, many wing-spans distance, for which the electric field at the point in question is just sufficient to cause dielectric breakdown of the air and corona discharge. It is evident that the exposed

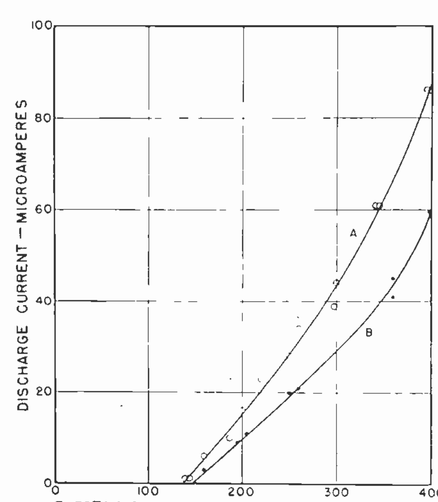

Fig. 9—Relationship between corona discharge current and electric field on the belly of the B-17 research airplane from a $\frac{1}{4}$-inch rod extending out one foot from a wing tip A, and the tip of the vertical stabilizer B. Airplane charged negatively.

extremities of the aircraft which are not shielded by adjacent metallic surfaces and which have the smallest radii of curvature will exhibit relatively low threshold voltages while surfaces having gentle contours and which are shielded will have higher thresholds.

The corona currents plotted in Fig. 9 against the electric field on the belly were obtained from an aluminum rod having a diameter of 0.25 inch rounded at the end to a hemisphere and extended outside a distance of one foot from two different points on the B-17 research airplane. When negative voltage was applied to the airplane in flight by use of the artificial charger, the corona-discharge current from this rod was measured. The general characteristics of corona discharge from any point on an airplane are well illustrated by these curves. It will be seen that there is a definite electric field and airplane potential at which corona starts. For the case when the rod was located at position on the tip of the vertical stabilizer, the threshold electric field was about 155 volts per centimeter. When the rod was located on the right wing tip in position, the threshold was somewhat lower. Another important characteristic of the corona discharge is the fact that once the threshold electric field is reached, the corona current is a steeply rising function of the voltage. Theoretical considerations in Part V of this series indicate that the corona current may be a quadratic function of the electric field.

It should be remembered that the curve of charging current as a function of the electric field shown in Fig. 2 is very nearly the same as the curve of discharge current as a function of the electric field, since equilibrium conditions were established while obtaining this curve.

Were it not for the fact that an airplane takes on a definite potential in autogenous electrification, the thermal ionization of the exhaust gases would not play an important role in discharging the airplane. When the exhaust stacks of the engines are such as to permit the escape of exhaust gases before complete recombination of the ions produced by burning fuel, the electric field of the airplane will capture those ions of opposite sign while simultaneously repelling ions of the same sign. This mechanism serves to transfer free charge on the airplane to the atmosphere.

A careful study was made of the discharge resulting from ionization of the engine exhaust on the B-17 and B-25 research airplanes. This study was made in clear-weather flying using the artificial charger not only as a means of placing a potential on the aircraft but also as a means of determining discharge currents of the aircraft by measuring the charging currents under equilibrium voltage conditions. It was planned originally to conduct these experiments with the aircraft stripped of bare-wire antennas and other projections that might easily break into corona discharge, in order that the main source of discharge would be that of the exhaust gases. It was found in preliminary flights that the exhaust gases did not discharge at a rate sufficient to reduce the potential of the airplane in a short period of time. In order to make the potential of the aircraft more sensitive to the controls of the charger, a discharging element in the form of a cotton wick impregnated with colloidal silver was placed on each wing tip of the B-17, and on the right wing tip of the B-25. This discharging element was the dry-wick discharger described in another paper[6] for use in control of precipitation static. The current discharged by these wicks was measured separately so that it could be subtracted from the total discharge current of the airplane to obtain the discharge current of the exhaust gases. The discharge from these wicks is corona, and it has the same general characteristics as the discharge from the aluminum rod shown in Fig. 9.

In order to test the validity of subtracting the discharge current of the wicks from the total discharge current of the airplane to obtain the discharge of the exhaust, a flight was made with the B-25 without attached wicks, in which the discharge from the airplane

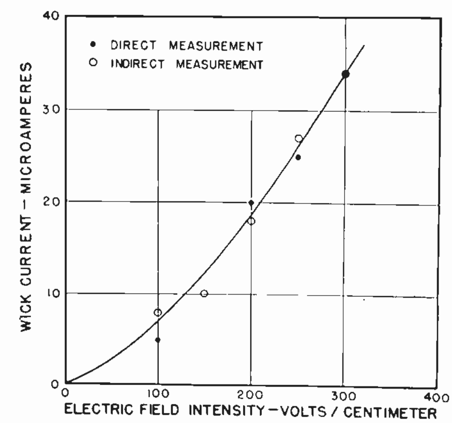

Fig. 10—Corona-discharge current of a single wick as a function of the belly electric field. Wick mounted on the right wing tip of B-25 research airplane. Airplane charged negatively.

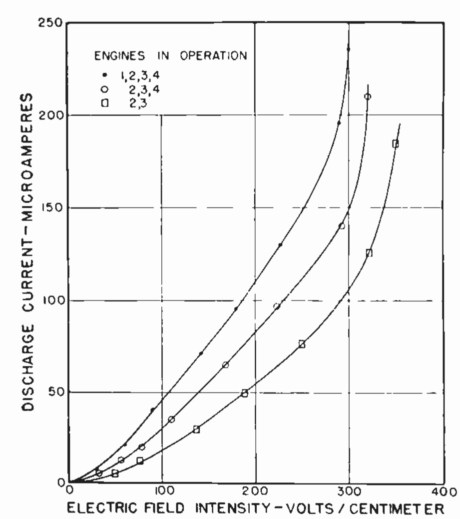

Fig. 11—Total discharge current of B-17 research airplane as a function of the belly electric field. Airplane charged negatively.

was measured. Then another flight was made with wicks added and the discharge from the airplane was measured. The former measurement was subtracted from the latter and the difference compared to the measured discharge current of the wicks. The results are shown in Fig. 10, and it appears that the two determinations of the wick-discharge current agree. It was concluded from this test that the subtractive process is justifiable.

[6] Part V of this series, to be published.

The results of the study of the exhaust discharge of the B-17 research airplane are shown in Figs. 11 to 13. The family of curves in Fig. 13 show the total discharging currents with all four engines of the B-17 in operation, with the two inboard and one of the outboard engines operating, and finally with only the two inboard engines operating. When the wick current shown in Fig. 12 is subtracted from the total discharge currents, the curves in Fig. 13 are obtained.

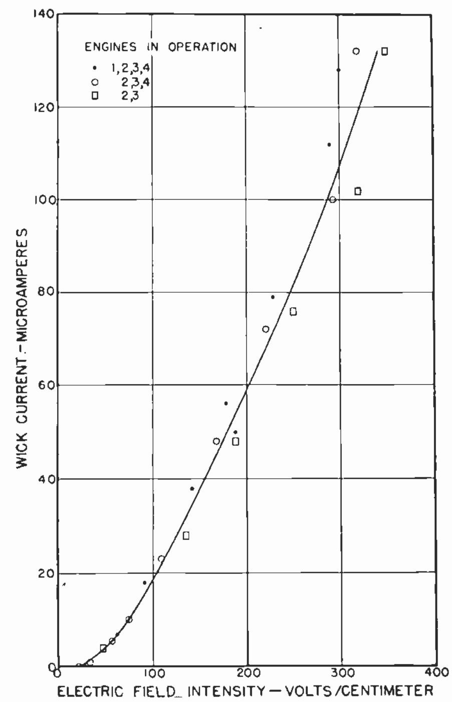

Fig. 12—Total discharge current of two wicks mounted one on each wing tip of B-17 research airplane. Airplane charged negatively.

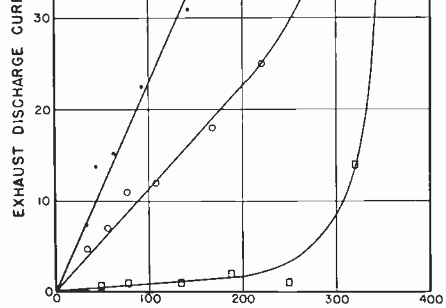

Fig. 13—Exhaust discharge current of B-17 research airplane engines as a function of the belly field. Airplane charged negatively.

Several features of the last set of curves are worth comment. The point of transition to a nonlinear variation is interpreted to be the point at which corona discharge from the airplane begins. The voltage of the airplane at this point is the corona-threshold voltage. It is believed that the discharge occurring prior to this degree of electrification is almost entirely exhaust discharge, discharge due to convection and conductivity of the air being considered negligible for reasons which will be discussed later. If this interpretation is correct, then the exhaust discharge obeys Ohm's Law. It will be noted that the two outboard engines of the B-17 are better dischargers than the two inboard engines. This is due, perhaps, to the fact that the amount of recombination of ions in the stacks of the outboard engines may be considerably less than in the stacks of the inboard engines, since the latter are at least twice as long as the former.

If a linear extrapolation of the curves in Fig. 13 be permissible then, when the electric field on the belly of the B-17 is equal to 400 volts per centimeter the engine exhausts should discharge about 93 microamperes. It has been stated previously that this amount of electrification should correspond to a charging current of about 750 microamperes and would be found in severe autogenous electrification. Thus the engine exhausts seem to be capable of discharging about 12 per cent of the total aircraft discharge under this condition. It may be concluded that when the electrification of aircraft is such that the equilibrium potential is below the corona-threshold voltage, the engine current is important as a discharging process; but that, once corona sets in, the corona current greatly exceeds the former as the voltage rises. The measurements of the exhaust currents of the B-25 verify the conclusions drawn for the B-17.

There is some evidence that an airplane can be discharged by convection. When an airplane is flown through rain, some of the water impinging on the frontal surfaces runs back over the wings and the fuselage and is then blown off at the trailing edges by the slip stream. If the airplane is charged, then these drops will be blown off in the presence of the electric field along the trailing edges. There will then be an induced charge on the water droplets just before they break contact with the surface of the airplane. It will be recognized that this provides a means of charging the drops in much the same manner as that employed by the artificial charger using a water spray, except that in this case, the water carries away charge of the same sign as that on the aircraft, whereas with the artificial charger the charge carried away may be opposite in sign to that remaining on the aircraft. Although no measurements have been made of this phenomenon, the small amount of autogenous electrification encountered in even the most severe rains perhaps indicates that such a mechanism may discharge electricity in appreciable quantities.

The air surrounding an airplane in flight has a finite, though small, conductivity, and it is well known that because of this conductivity an electrified object will lose its charge in about 400 seconds. It is apparent, therefore, that a charged airplane can discharge slowly by this means. The decay time for the discharge of the

B-25 airplane in flight by the exhaust gases has been found, as described later in the paper, to be about 2.8 seconds. It may be inferred from this that the air conductivity produces a discharge current which is many times smaller than the discharge current of the exhaust gases and which must be insignificant compared to corona-discharging currents.

Since the discharging current of the exhaust gases has been found to be the second most important means by

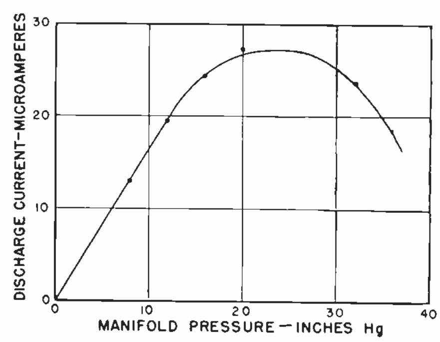

Fig. 14—Exhaust-discharge current of B-25 research airplane as a function of the manifold pressure.

which an airplane in flight can discharge itself naturally, an investigation was made to determine how the discharge rate was effected by the power output of the en-

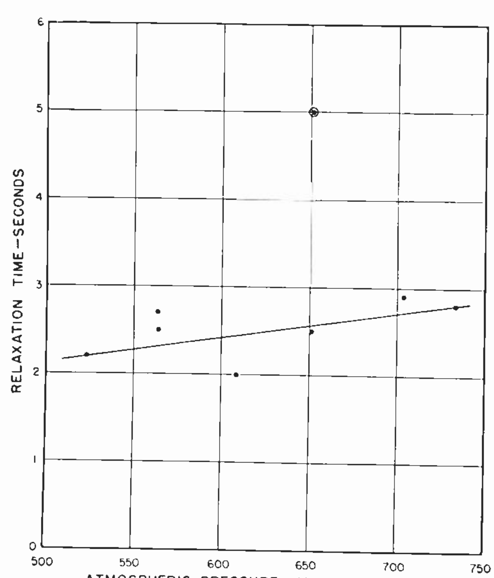

Fig. 15—Relation between relaxation time of the B-25 research airplane and atmospheric pressure. Two-engine operation furnished points along the straight line. Single-engine operation indicated at single point above.

gines. This experiment was carried out using the B-25 research airplane. The results are shown in Fig. 14, in which the discharged current is plotted as a function of the manifold pressure, a direct indicator of the power output when the engine speed is held constant. The amount of electrification and the flight conditions were maintained as nearly constant as possible. The curve in Fig. 14 shows that the discharging current displays a maximum at about 28 inches of mercury manifold pressure. It is obvious that if the curve be extrapolated back to zero manifold pressure the discharging current should also approach zero, for there would be no fuel consumption. It is not so obvious that at an increased manifold pressure above 28 inches the exhaust-discharge current should again decrease. The fuel-and-air mixture of the particular Wright engines used on the B-25 grows richer in fuel content as the manifold pressure is increased above 28 inches, and it is suspected that the falling off of the discharge current is associated with this in some manner.

To determine the variation with altitude, that is with atmospheric pressure, of the exhaust-discharging characteristics of the airplane at low electric fields, a series of relaxation-time measurements were made at altitudes from 1000 feet to 10,000 feet with the B-25. These relax-

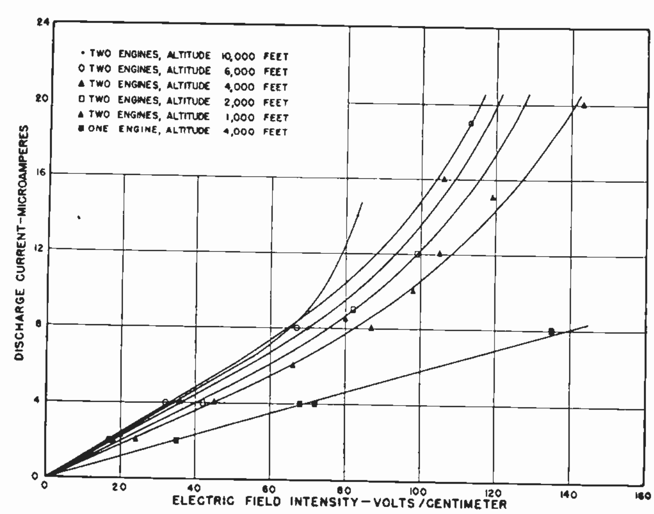

Fig. 16—Discharge current at various altitudes of the B-25 research airplane as a function of belly electric field. Airplane charged negatively.

ation times were taken as the time in seconds required for the electric field on the B-25 to decay from approximately 75 volts per centimeter to $1/\epsilon$ of the initial value, and the results of these measurements are plotted in Fig. 15. A set of curves giving the exhaust-discharge current of the B-25 at low electric fields through the same range of altitudes as were employed in determining the relaxation times is shown also in Fig. 16. It should be pointed out that although the airplane during this set of measurements was equipped with two bare-wire antennas having a diameter of 0.04 inch, and had a dry-wick discharger installed on the right wing tip, the voltage of the airplane did not exceed the corona-threshold voltages of these objects except when the electric field in Fig. 16 exceeded 80 volts per centimeter.

IV. The Airplane in Exogenous Electrification

Extensive experience, flying in all types of weather, has shown that not only thunderstorms but all convective activities in the air are capable of causing charge separations that produce atmospheric electric fields. The electrification found in thunderstorms and rain showers, however, is generally more intense than the electrification found in convective-type snow storms. When aircraft fly through regions of this type of meteorological activity they are subject to the influence of the strong electric fields and have charges of opposite polarities induced on the extremities. The electric fields have all possible orientations and magnitudes, depending on the distribution of the electric charge in the atmosphere. The electrification of an airplane resulting from the influence of these atmospheric electric fields has been defined as exogenous electrification.

It is important to recognize that an airplane may acquire a net electric charge from autogenous charging mechanisms at the same time that it experiences exogenous electrification. Since autogenous electrification has been covered earlier in the paper, only the latter will be discussed in the following. Furthermore, since both types of electrification produce many common effects, the discussion will be limited to those features which are different.

In an atmospheric electric field, an all-metal airplane takes on the mean potential of the space that it spans, since its surface determines a new constant-potential surface. The original potential distribution becomes highly modified in the vicinity of the airplane, depending upon the geometry of the electrified atmospheric areas and upon the attitude of the airplane. The electric fields encountered by aircraft near thunderclouds may rise to very high values, so high, indeed, that lightning intervenes. During a flight of the B-25 research airplane in a thunderstorm, an exogenous field was encountered on one occasion that produced a lightning strike. The electric field on the belly of the B-25 was measured just before and just after the strike occurred. It rose in a matter of ten seconds to 3400 volts per centimeter just before the flash, then dropped in the succeeding three seconds to zero. Estimates of the amount of distortion of the electric field by the airplane lead to the conclusion that the electric field well clear of the airplane at the time of strike was about 1500 volts per centimeter.

The electric discharges taking place when an airplane has an exogenous electrification include the four general types discussed under autogenous electrification. There are, however, some important differences.

It has been pointed out that the polarity of an airplane in autogenous charging is usually negative, and the discharge current, whether it be by corona or by other means, is negative. The discharge associated with exogenous electrification, on the other hand, has both positive and negative currents, the former coming from one portion of the aircraft and the latter from an electrically opposed portion. The discharge of electricity under autogenous electrification acts to limit the potential of the airplane, but the potential of the airplane in exogenous electrification is determined by its span, and the magnitudes of the discharge currents are generally dependent solely upon the external distribution of atmospheric charge. The airplane has little influence on the atmospheric-charge distribution, except when a stroke of lightning is promoted. The electric fields on the surface of aircraft and the resulting discharge currents in exogenous electrification have been found generally to be of greater magnitude than those encountered in autogenous electrification.

A time record of the electric fields encountered with a B-17 research airplane during a flight in the vicinity of Greenland, on March 13, 1945, is shown in Fig. 17. Both

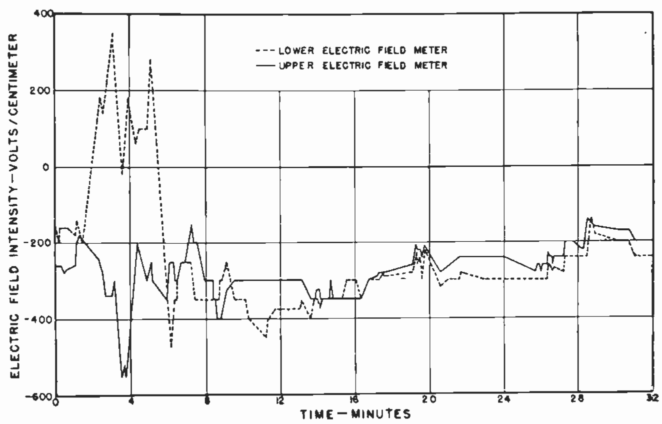

Fig. 17—Time record of the electric fields encountered by the B-17 research airplane during a flight in the vicinity of Greenland on March 13, 1945.

autogenous and exogenous electrification were encountered during this flight. Two electric-field meters were used in this flight, one mounted in the usual position beneath the fuselage and the other mounted directly above, on top of the fuselage. Nearly pure autogenous charging existed during those times when the electric-field meter mounted above showed the same sign and magnitude of electric field as the meter below. On the other hand, during the time when the two meters showed definitely different fields or fields of opposite sign, exogenous conditions existed. It is important to observe that autogenous charging exists as a steady condition lasting for many minutes and sometimes hours, whereas exogenous electrification is highly variable and usually lasts for relatively short periods of time. For this reason, the operational hazards due to autogenous charging are notably greater than those caused by thunderstorms.

The Effect of Rain upon the Propagation of Waves in the 1- and 3-Centimeter Regions*

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Summary—**This paper presents some experimental results which show the effect of rain upon the transmission of electromagnetic waves in the region between 1 and 4 centimeters.**

At a wavelength of 1.09 centimeters, the waves are appreciably attenuated, even by a moderate rain. Attenuations in excess of 25 decibels per mile have been observed in rain of cloudburst proportions.

The attenuation of waves somewhat longer than 3 centimeters is slight for moderate and light rainfall. During a cloudburst, however, the attenuation may approach a value of 5 decibels per mile.

I. Introduction

Radio research during the past decade has succeeded in producing suitable techniques for the generation and detection of wave lengths in the region below 10 centimeters. Before the future prospects of these short wavelengths can be properly evaluated, it becomes necessary to consider the transmission properties of the medium.

For some time it has been suspected that, in the progression to shorter and shorter wavelengths, transmission losses due to rainfall, water vapor, and molecular absorption of the atmospheric gases would some day assume serious proportions. In extending an early investigation of Mie in 1930,[1] Stratton[2] predicted that rainfall might appreciably attenuate waves of 5 centimeters or less. An experimental investigation of particular significance was described by Wolf and Linder[3] in 1935. They were unable to find any appreciable atmospheric attenuation of 9-centimeter waves over line-of-sight distances up to 16 miles. Their measurements also indicated that the attenuation caused by rain, even approaching cloudburst intensity, was less than 0.1 decibel per mile. Calculations based upon a recent analysis of Fränz[4] indicate that wavelengths between 1 and 3 centimeters will be seriously attenuated by both rain and fog. Experimental results for wavelengths in the 1- and 3-centimeter region have not, however, previously been published.

II. Experimental Method

Aware of the need for more definite information, the writers set up a rather simple experiment early in 1942, designed to measure the influence of rain upon centimeter-wave propagation.

In a problem of this nature, the question arises as to what length of transmission path should be used for the experiment. If the path length is very great, variations in attenuation become large and can be measured with considerable precision, but the rain distribution is not likely to be uniform. On the other hand, if the path is short the rain will be more nearly uniform, but the variation in attenuation becomes too small to be measured accurately. Accordingly, the choice of path length is necessarily a compromise. For these experiments a distance of 1260 feet was chosen for the 1.09-centimeter tests and an existing installation over a path of 900 feet was used for the 3.2-centimeter experiments.

For the 1.09-centimeter circuit the transmitter consisted of a continuous-wave generator associated with an electromagnetic-horn radiator having an absolute gain[5] of 31 decibels and a beam width of approximately 3.5 degrees between half-power points. A similar horn was employed as a receiving antenna and connected to a double-detection receiver. The antennas were oriented to produce a vertically-polarized beam.

Likewise, a continuous-wave source was used at the 3.2-centimeter transmitter. This was connected to a radiator consisting of a 30-inch parabolic reflector excited by an open-ended wave-guide horn placed at the focus. The transmitting antenna had a beam width of 3 degrees and an absolute gain of 35 decibels. At the 3.2-centimeter receiving station an electromagnetic horn having a gain of 23 decibels and a beam width of approximately 10 degrees was connected to a double-detection receiver. The polarization in this case was horizontal.

Rain was prevented from falling on the antennas by suitable protecting structures. Both transmitters were provided with circuits for continuously monitoring the radiated field intensity.

Variations in the received signals were measured by means of a receiver output meter calibrated in decibels. In addition to the output meter, it was found convenient to employ an auxiliary intermediate-frequency attenuator, also calibrated in decibels, for measuring changes in received signals which were too large to be read directly with the output meter alone.

The rain gauge consisted of a funnel 30 centimeters in diameter mounted above the roof of a small shack. The funnel was connected to a graduate in the room below. The amount of water collected in the graduate was

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† Bell Telephone Laboratories, New York, N. Y.

[1] G. Mie, "Beiträge zur Optik trüber Medien, speziell kolloidaler Metallösungen," Ann. der Phys., vol. 25, pp. 377–445; 1908.

[2] J. A. Stratton, "The effect of rain and fog on the propagation of very short radio waves," Proc. I.R.E., vol. 18, pp. 1064–1075; June, 1930.

[3] Irving Wolf and E. G. Linder, "Transmission of 9-centimeter electromagnetic wave," *Broadcast News*, no. 18, pp. 10–13; December, 1935.

[4] K. Fränz, "Die Schwachung sehr kurzer electrischen Wellen beim durchgang durch Wolken und Nebel," Hochfrequenz. und Electroakustic," vol. 55, pp 141–143; May, 1940.

[5] Gain referred to a nondirectional source.

recorded by an observer at intervals of approximately one minute. During periods of light rainfall, however,

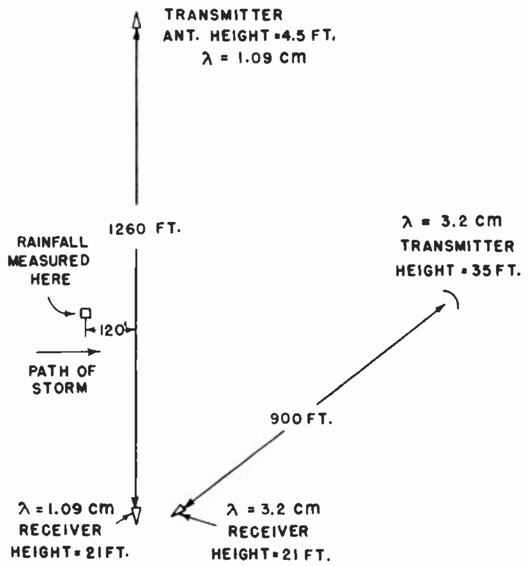

Fig. 1—Arrangement of apparatus used in studying the effect of rainfall upon microwave radio propagation.

observations were made at somewhat longer intervals. For heavy rainfall, or where the rate of fall appeared to be changing rapidly, the intervals were often shorter than one minute, at the discretion of the observer. From

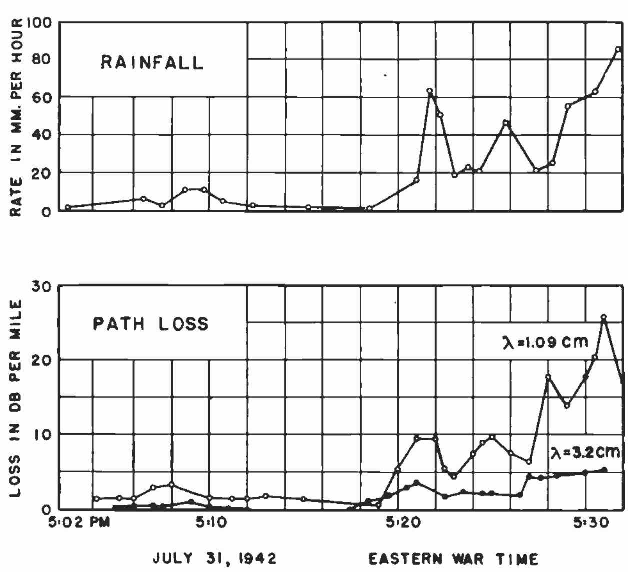

Fig. 2—Curves showing the variation of rainfall (above) and the corresponding variation in path loss (below).

these data it was, of course, possible to compute the average rate of fall expressed in millimeters per hour during any interval. The timepieces of all other observers were synchronized with that of the rainfall observer.

For the data taken on July 31, 1942, and shown in Fig. 2, the rain gauge was located at the 1.09-centimeter transmitter site. However, for the later data of Fig. 3, taken on August 10, 1942, the rain gauge was moved to a position intermediate to the terminals of the 1.09-centimeter path so as to provide better average rainfall data for the entire path. This new location, together with the relative disposition of the 1.09- and 3.2-centimeter terminal equipment, is shown in Fig. 1. The local terrain was a level, open field located at Holmdel, New Jersey.

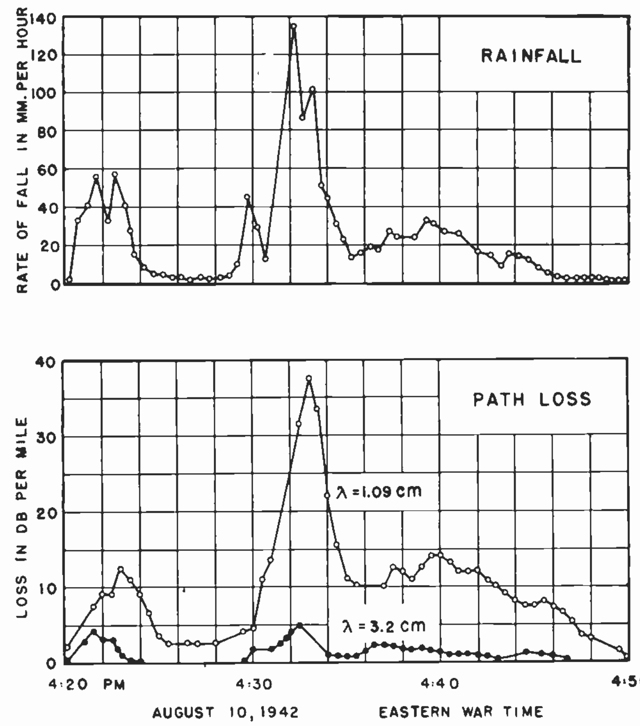

Fig. 3—Curves showing the variation of rainfall (above) and the corresponding variation in path loss (below).

III. Experimental Results

In the summer of 1942, two favorable opportunities were afforded for studying the effect of rainfall on the propagation of microwaves. In the afternoon of July 31, 1942, the rainfall varied over a wide range of intensities little short of a cloudburst. Precipitation and path loss data were taken continuously during the storm. In Fig. 2 the path loss due to rain is plotted as additional attenuation in decibels per mile; rainfall is expressed in millimeters per hour.

On August 10, 1942, another rainstorm occurred which afforded an opportunity for further study. Measurements were made as before and the data are shown in Fig. 3. The correlation between rainfall and additional path loss is very evident.

A number of points from Figs. 2 and 3 have been replotted in Figs. 4 and 5, illustrating the correspondence between path loss and rainfall. While the correlation is very evident, there are, however, some apparent discrepancies which possibly may be due to one or more of the following causes:

(1) The data for the points on the rainfall curve represent the average fall over discrete periods of approximately one minute, while the data for points on the path-loss curve are instantaneous values.

(2) The rainfall was not necessarily uniform in intensity over the entire path.

(3) The effect of the size of the raindrops has not been evaluated.

(4) Exact data for low values of rainfall were difficult to obtain with the type of rain gauge used.

(5) Attenuations of less than 1 to 2 decibels per mile were difficult to measure precisely. For the accurate measurement of attenuations during light rainfall, the length of path selected was found to be somewhat short. This was particularly true for the lower attenuations prevailing at 3.2 centimeters. Under these circumstances it would be required to measure the received signal variations to a precision of a few hundredths of a decibel, which was of the same order of magnitude as the random variations in receiver output. Consequently, these low values are in some doubt.

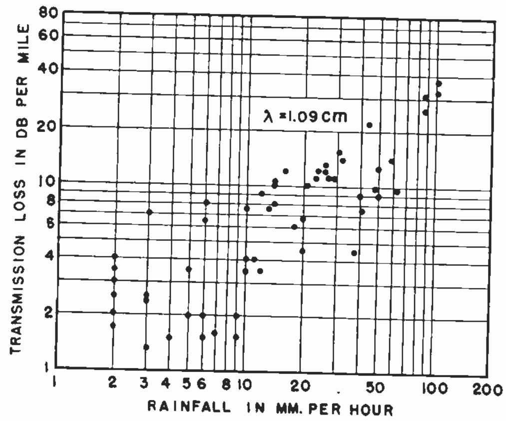

Fig. 4—1.09-centimeter mass plot of transmission or path loss with respect to rainfall.

IV. Conclusions

Certain general conclusions can be drawn from the data collected in the course of these experiments. In Table I these are summarized in terms of Humphrey's[6] classification of rainfall.

In interpreting the data, greater weight has been given to measurements made during periods of rainfall which exceeded 10 millimeters per hour than to the values obtained for lower rates of rainfall. The latter are limited in accuracy for the reasons already set forth in the preceding section.

[6] W. J. Humphreys, "Physics of the Air," McGraw-Hill Book Company, New York, N. Y., 1940.

TABLE I

	Light Rain (1 millimeter per hour)	Moderate Rain (4 millimeters per hour)	Heavy Rain (15 millimeters per hour)	Cloudburst (100 millimeters per hour)
Centimeters	Attenuation—Decibels per Mile	Attenuation—Decibels per Mile	Attenuation—Decibels per Mile	Attenuation—Decibels per Mile
$\lambda=3.2$	?	<0.5	<1	4 to 5
$\lambda=1.09$	<1	1 to 2	4 to 10	30 to 40

As a working figure, it may be concluded that the added path loss at 3.2 centimeters is approximately 0.05 of a decibel-per-mile per millimeter-per-hour of precipitation. At a wavelength of 1.09 centimeter the figure is roughly 0.3 of a decibel-per-mile per millimeter-per-hour.

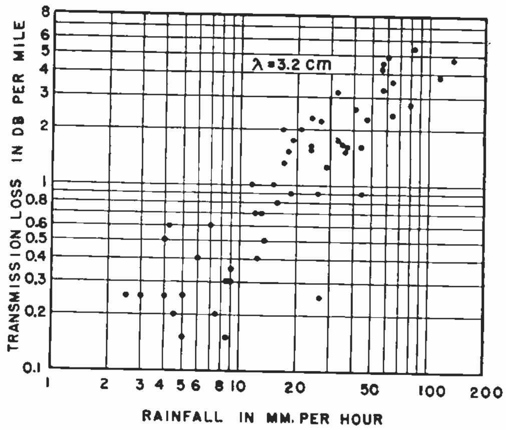

Fig. 5—3.2-centimeter mass plot of transmission or path loss with respect to rainfall.

It may be concluded, therefore, that with 3.2-centimeter waves the periods where the radio transmission will be appreciably attenuated by rainfall should be extremely rare, on a percentage basis, even where considerable distances are involved. However, at the 1-centimeter wavelength, one can expect rather large path losses at the time of heavy or even moderate rains, particularly if the distances are large. These higher losses will be partially offset by the greater antenna gains which can be realized at these very short wavelengths.

Propagation of 6-Millimeter Waves*

G. E. MUELLER†, ASSOCIATE, I.R.E.

Summary—**One step in the exploration of a new band of frequencies for communications purposes is a study of the transmission properties of the medium involved. This paper describes the methods and results of measurements of attenuation due to rainfall and atmospheric gases at a wavelength of 0.62 centimeter.**

The one-way attenuation due to moderate rains at 0.62 centimeter is roughly 0.6 decibel-per-mile per millimeter-per-hour. The gas attenuation is probably less than 0.2 decibel per mile.

Introduction

INVESTIGATORS during the last decade have continuously improved techniques for producing and using electromagnetic waves in the centimeter region. One of the steps in the development or exploration for communication purposes of a new band of frequencies is a study of the transmission properties of the medium involved. These studies include the effects of gases, of rain, and of other liquid or solid constituents of the atmosphere, and a knowledge of the effects on propagation of reflection and refraction due to various sections of the atmosphere. The present paper deals with a few simple measurements of the first of these effects made at a wavelength of 0.62 centimeter ($f=4.8\times10^{10}$ cycles). The measurements of rain were patterned on those made earlier at 1 centimeter and 3 centimeters by Robertson and King,[1] and by Wolf and Linder.[2] The measurements of atmospheric absorption were made by observing the path attenuation for several path lengths and comparing this with the theoretical inverse-square-law relation between power and distance.

Method

The measurements reported below were made using a modulated signal generator with a single-detection crystal receiver followed by an audio amplifier, a second rectifier, and a microammeter. The location employed was a long flat field at Holmdel, New Jersey.

The signal generator was a 1.24-centimeter velocity-variation oscillator. The cathode voltage of the oscillator was derived from the output of a square-wave amplifier, the duty cycle was 1:2, and the fundamental modulation frequency used in the tests was 10,000 cycles. The second-harmonic output was obtained from a harmonic generator and was fed directly to a paraboloidal antenna 18 inches in diameter with a gain of 45 decibels above a spherical radiator and a half-power beam width of 0.8 degree. It was located about 25 feet above the ground. The waves were horizontally polarized. The transmitted power was monitored by means of an auxiliary detector which intercepted part of the energy radiated by the antenna. The receiving antenna was a similar paraboloid located at approximately ground level at a point 1200 feet distant from the transmitter. Both antennas were shielded from the rain by structures outside the path of the beam.

The detector was developed by R. S. Ohl of the Bell Telephone Laboratories and is a silicon-crystal rectifier. The output of the receiving detector was sent through an amplifier, a rectifier and finally appeared on a microammeter. A wave-guide radio-frequency attenuator, previously calibrated against a standard intermediate-frequency attenuator in a double-detection set, was used to determine the added attenuation due to rain. In use, the receiver was adjusted for maximum received power and then radio-frequency attenuation was introduced until the received power was about twice the first-circuit noise power. As the rain introduced loss in the path, the radio-frequency attenuation was withdrawn so as to keep the output-meter reading constant. The actual amount of rain was measured at the receiving end by means of a funnel and graduate. The accuracy was such as to permit readings of rate of rainfall of about 0.3 millimeter per hour, while the path attenuation could be read to 0.1 decibel. Simultaneous readings were taken of attenuation and of rainfall, usually once a minute, but for high rates of precipitation, at half- or even quarter-minute intervals.

Atmospheric attenuation was measured by means of the same apparatus. Since it was necessary to make observations at various distances, the receiving antenna was mounted about 8 feet above the ground on a post supported on a truck. The rest of the receiving equipment was placed inside the truck. In taking the data the antennas were aligned with one another at each of the points of observation. It was possible to vary the height of the receiving antenna above the ground, and this was done at several points to check for the presence of ground reflections. No multipath effects were observed.

The method of measurement placed stringent requirements on drifts in the over-all measuring system but adequate voltage regulation and attention to details resulted in satisfactory stability. The over-all gain ordinarily varied less than 0.1 decibel per hour after the initial warm-up period. The total systems gain was such as to provide a 14-decibels working margin which proved to be adequate for the heaviest rain encountered.

It was necessary to interpret the rainfall data in light of the method of measurement. The data on rate of rainfall were based on the amount of rain water

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† Bell Telephone Laboratories, New York, N. Y.

[1] Sloan D. Robertson and Archie P. King, "The effect of rain upon the propagation of waves in the 1- and 3-centimeter regions," Proc. I.R.E., this issue, pp. 178–181.

[2] Irving Wolf and E. G. Linder, "Transmission of 9-centimeter electromagnetic waves," *Broadcast News*, no. 18, pp. 10–13; December, 1935.

collected over one-minute intervals, whereas the attenuation reading was the instantaneous value taken at the end of each interval. In order to compare the two measurements properly, it was necessary to average the values of attenuation over at least one-minute intervals. Also, since the rainfall measurements were made at one end of the path, the peak rainfall did not always coincide with the peak of attenuation. To take care of this displacement, sections of the data were selected which satisfied two criteria. First, the rainfall was substantially uniform over the interval chosen. Second, the edges of the interval were well defined. Samples of the data and method of averaging are shown in Fig. 1. Here the light vertical construction lines indicate the boundaries of the averaging intervals, and the horizontal lines indicate the average value chosen. For convenience of comparison, the corresponding intervals of rainfall and attenuation are numbered consecutively. The points plotted in Fig. 2 were obtained from some thirty such intervals taken from the data covering the rainfall on three days (15, 24, and 27) in April, 1944. This method of reducing the data leads to a considerable decrease in the scattering of points, largely due to the improved correlation of the two types of data. However, it does introduce a possibility of error, for it integrates out the effects of variation in drop size taking place during any one averaging interval.

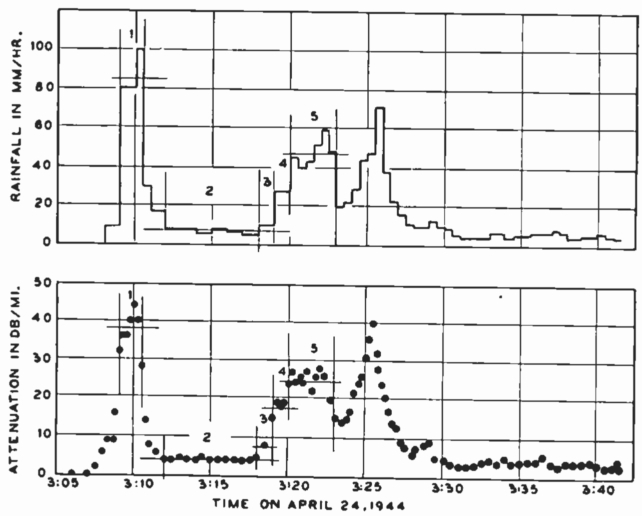

Fig. 1—Sample of data and method of interpretation.

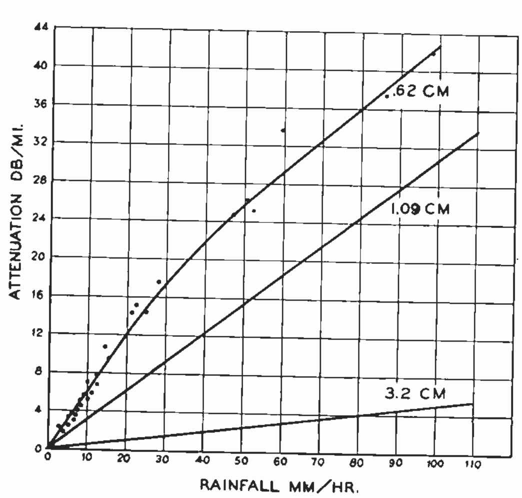

Fig. 2—Attenuations due to rainfall.

Results

In Fig. 2 the attenuation in decibels per mile due to rainfall at 0.62 centimeter is shown. Comparison curves for 1-centimeter and 3-centimeter wavelengths from the paper of Robertson and King[1] are included.[3] The effect of a change in wavelength for a given rainfall is made more evident by Fig. 3 which is a rearrangement of the data of Fig. 2 on an attenuation-wavelength basis.

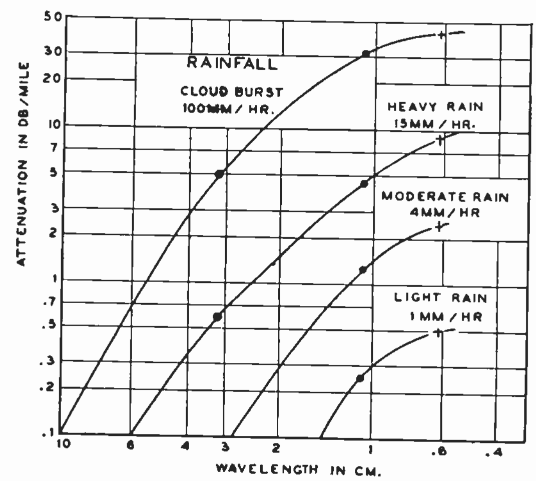

Fig. 3—Effect of wavelength on attenuation due to rain.

It is apparent from the data of Robertson and King[1] that the decibel attenuation for a given rain at 1 centimeter is six or seven times as large as that at 3 centimeters. If the attenuation increased at the same rate, for a given rainfall the loss at 0.6 centimeter would be almost three times the 1-centimeter loss while the measurements show it to be approximately twice as large. This drop in the rate of increase of attenuation may be explained as follows.

From the theoretical work of Mie,[4] Fränz,[5] and Stratton[6,7] it would seem that the attenuation due to rain is composed of two parts The first is due to scattering and the second is due to absorption by the water in the drop.

[3] It will be noted that the measurements of Robertson and King used horizontal polarization at 3.2 centimeters while they used vertical polarization at 1.09 centimeters. The present measurements used horizontal polarization. It is believed that the attenuation due to rain is independent of the spatial orientation of the polarization. This is a consequence of the fact that individual raindrops are very nearly spherical.

[4] G. Mie, "Beiträge zur Optik trüber Medien, speziell kolloidaler Metallösungen," Ann. der Phy., vol. 25, pp. 377–445; 1908.

[5] K. Fränz, "Die Schwachung sehr kurzer electrischen Wellen beim durchgang durch Wolken und Nebel," Hochfrequenz. und Electroakustic, vol. 55, pp. 141–143; May, 1940.

[6] J. A. Stratton, "The effect of rain and fog on the propagation of very short radio waves," Proc. I.R.E., vol. 18, pp. 1064–1074; June, 1930.

[7] J. A. Stratton, "Electromagnetic Theory," McGraw-Hill Book Company, New York, N. Y., p. 563; 1941.

The water resonance which causes the absorption loss lies in the vicinity of 2 centimeters and, although it is very broad, in going from 1.0 to 0.6 centimeter there should be a decrease in the second derivative of the absorption loss with respect to wave length. Scattering loss varies directly with the dielectric constant, with the power factor, and with the ratio of drop diameter to wave length. In the 0.6-centimeter region, the dielectric constant and power factor are decreasing with wave length while the drop diameter, in wavelengths, is increasing. These factors tend to balance so that the scattering loss should not increase rapidly with shorter wavelengths. Qualitatively then, one would expect further decreases in the rate of increase of attenuation as one goes to still shorter wavelengths.

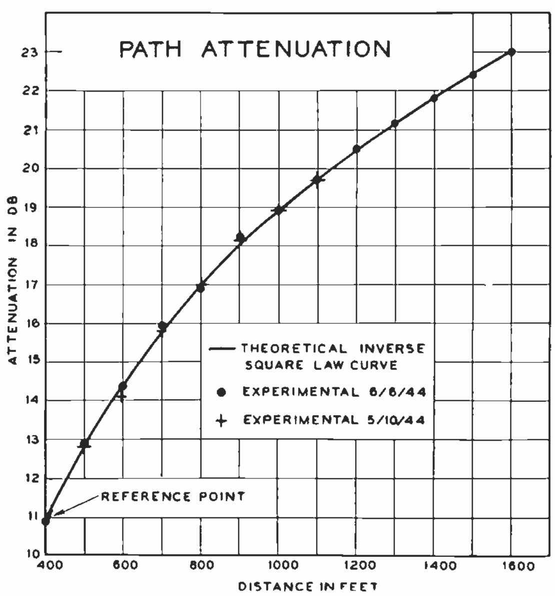

Fig. 4—Curve showing path attenuation.

In Fig. 2, it may be seen that for large values of rainfall the slope of the 0.6-centimeter attenuation seems to be comparable with that at 1 centimeter. The amount of data is small and the errors may, in fact, be large enough to account for the change in slope. One of the more likely causes is uneven rainfall over the transmission path. It should be noted, however, that this path was only a quarter-mile long and that it was directed at right angles to the prevailing storm winds.

The scattering of points on the graph is probably due in large part to the variation in drop size. Experimental errors, the unevenness of rainfall discussed above, and the method of interpretation also contribute to the spread of the points. The scattering is somewhat less than that obtained in the earlier 1-centimeter measurements, but this is almost wholly a result of the averaging process used in reducing the data.

The results of the atmospheric absorption measurements are shown as points in Fig. 4. The solid curve is a plot of the inverse square law using as a reference the signal received at 400 feet. If attenuation had been present the experimental points would have fallen above the theoretical curve, in effect increasing the rate of increase of attenuation with distance. No trend of this kind can be observed. The standard deviation of the observed results from the theoretical curve has been calculated and found to be 0.035 decibel. Since the longest path change is a quarter mile, this corresponds to a probable error of ± 0.14 decibel per mile. Assuming there are no systematic errors, it is reasonable to set the value of the upper limit of any atmospheric absorption that may be present at twice the standard deviation, or 0.28 decibel per mile. Since there was no definite indication of atmospheric absorption, no attempt was made to assess the relative effects of humidity and of gases.

Conclusions

The attenuation of 0.6-centimeter waves by moderate rainfalls is approximately twice that of 1 centimeter. However, this statement should be correlated with the frequency at which given rains occur before its seriousness is evaluated. In terms of the average rainfall in the middle temperate zone, the one-way loss will be less than 0.5 decibel per mile 97 per cent of the time, less than 1.5 decibels per mile 98 per cent of the time, and less than 6 decibels per mile 99 per cent of the time. Stated in terms of intensity, the one-way attenuation for most rains will be roughly 0.6 decibel-per-mile per millimeter-per-hour. An attenuation of 40 or more decibels per mile may be obtained in cloudbursts of 100 millimeters per hour rate of fall.

The attenuation due to atmospheric absorption is probably less than 0.2 decibel per mile, which is small in comparison with the losses due to rain.

Superheterodyne Frequency Conversion Using Phase-Reversal Modulation*

E. W. HEROLD†, SENIOR MEMBER, I.R.E.

Summary —In radio reception using the superheterodyne principle the incoming signal is changed in frequency by the converter stage of the receiver to a new and lower frequency known as the intermediate frequency. The electron tubes used in the converter stage have been characterized in the past by poor performance as compared with that of tubes used for amplification. This paper describes a new principle whereby frequency conversion may be accomplished with substantially improved performance over that available from conversion methods heretofore used.

The principle of conversion herein described is to reverse the phase of the signal output periodically at a rate which differs from the signal frequency by the intermediate frequency. This may be done either by continuous variation of phase or by continuous variation of tube transconductance from positive to negative. The result is a conversion transconductance which is twice as high as had heretofore been believed ideal. Furthermore, if the phase-reversal rate is made by any integral multiple of an applied local-oscillator frequency, equally good conversion is obtained at a harmonic of the local oscillator without spurious responses at any other harmonic than the one chosen. An electron tube with a multihumped characteristic has been devised as a means to this end since the transconductance characteristic will then vary from positive to negative as the control voltage is varied. An analysis of such a tube is carried out in detail, including the effect of fluctuation noise.

The analysis shows that the new conversion method doubles the conversion gain possible in a tube with a given maximum transconductance. In an ideal case with no second-stage noise, the signal-to-noise ratio is as good as with the same tube used as amplifier; even in practical cases, the mixer is only 10 per cent to 20 per cent poorer than the amplifier. This is in contrast with conventional mixer methods in which the signal-to-noise ratio is from two to three times poorer than when the same tube is used as an amplifier.

Conversion at a harmonic may also be achieved with high gain but it is found that the signal-to-noise ratio is not as favorable as with fundamental operation.

I. Introduction

THIS PAPER will describe an improved method of frequency conversion as utilized in superheterodyne reception. The latter method of reception has been almost universally adopted in modern communication because of its ease of tuning, its excellent and constant selectivity, and its high sensitivity. In the superheterodyne receiver, an incoming-signal frequency is combined with a local-oscillator frequency to produce a difference frequency which is subsequently amplified and utilized. The heart of the superheterodyne may be said to be the converter or mixer,[1] the electron tube wherein the signal frequency is changed to a so-called intermediate frequency. However, it has been found in the past that each new and improved *converter* or *mixer* tube developed during the progress of the tube art has a lower amplification and a poorer signal-to-noise ratio than *amplifier* tubes which include contemporary and parallel technological improvements. For this reason, it has been necessary in receivers designed for the very best performance, to utilize a stage of amplification at the original signal frequency between the antenna and the converter stage. Such amplification is frequently difficult to obtain and is usually expensive to include in a receiver. The object of the work to be described in this paper was to overcome this limitation of the converter tube to a great extent, so as to place the converter on a more nearly equal footing with amplifier tubes of a similar degree of refinement.

The converter stage of the usual superheterodyne operates by the process of modulation.[2] A received signal of frequency f_s is combined with the output of a local oscillator of frequency f_0 in a modulating device which produces the intermediate frequency (f_0-f_s). The modulation process differs from that used in a radio transmitter in only two respects: first, only one sideband frequency is used in the output of the superheterodyne converter; and second, the received signal amplitude is so small compared to that of the local oscillator that the modulation percentage must be considered extremely small compared with that of the transmitter. Ordinarily, in the superheterodyne the local-oscillator frequency is of the same order as that of the signal so that (f_0-f_s) is considerably lower than the signal frequency.

With most devices used for frequency conversion it is found that, even though the local oscillator is a pure sine wave of frequency f_0, there is an appreciable output at the frequencies (nf_0-f_s) where n is any integer. If one of these, with $n\neq 0$, is chosen as our intermediate frequency, then the frequency conversion may be thought of as occurring at the nth harmonic of the local oscillator. It is clear that when the intermediate frequency is low this mode of operation permits the use of a local-oscillator frequency which is of the order of $1/n$ times the signal frequency; i.e., the local-oscillator frequency is much lower than would normally be the case. This is of advantage at ultra-high frequencies when strength and stability of oscillation are difficult to obtain. In the past, conversion at $n=2$ and $n=3$ have sometimes been used, but, because the operation becomes poorer as n is increased, conversion at higher harmonics than the third has not been considered practicable. In the work to be

* Decimal classification: R148.41. Original manuscript received by the Institute, November 1, 1945.

† RCA Laboratories, Radio Corporation of America, Princeton, New Jersey.

[1] A converter is usually defined as a frequency-changing tube which contains its own local oscillator. If a separate source is used for the local oscillator, the frequency-changing tube is known as a mixer.

[2] A description of converter-stage operation together with a comprehensive bibliography will be found in E. W. Herold, "The operation of frequency converters and mixers for superheterodyne reception," Proc. I.R.E., vol. 30, pp. 84–103; February, 1942.

described, it will be shown that the decrease in performance for larger values of n can be overcome to a large extent by the use of a new principle of frequency conversion.

It has been stated that the superheterodyne converter or mixer operates by the process of modulation. In the past, the type of modulation which has been used was basically *amplitude* modulation; i.e., the *amplitude* of one of the frequencies involved was changed by the other. It is known, however, that phase or frequency modulation also produces sideband frequencies. It occurred to the writer some years ago that possibly the use of these other forms of modulation was advantageous in the superheterodyne frequency changer. By thinking of the conversion process from this new point of view, interesting basic principles were evolved which offer the possibility of greatly improved converter and mixer-tube design.

II. A Physical Picture of Frequency Conversion

The purpose of the converter stage of a receiver is to convert the incoming signal to a lower frequency called the intermediate-frequency. Obviously, the greater the amount of intermediate-frequency voltage produced by a given signal, the better the converter operates. The ratio of intermediate-frequency output current to signal-input voltage, is known as the conversion transconductance and is frequently used as a measure of the performance. It is analogous in every way to the transconductance of amplifier tubes. It has frequently been proved that the conversion transconductance depends directly on the amplifier transconductance in a given electron tube. Thus, it may be stated without serious error that the best converter consists of the best amplifier, with its amplification periodically varied at oscillator frequency. In the past, the upper limit to the conversion transconductance obtained by this means was believed to be $1/\pi$, or 32 per cent, of the maximum possible amplifier transconductance.[3] Currently available tubes give values of conversion transconductance when used at oscillator fundamental, between 25 and 30 per cent of their amplifier transconductance and considerably less than this for second- or third-harmonic operation.[2] The new principles of conversion to be discussed in this paper will permit a great improvement in these ratios of conversion transconductance to amplifier transconductance.

The best understanding of the converter or mixer is probably obtainable by mathematical methods. However, it is possible to give simple physical pictures[4] which clarify the operation of converters or mixers under ideal conditions. Let us first consider converter operation as it has been used in the past. We picture an electron-tube converter or mixer with an applied signal and a local-oscillator voltage which periodically varies the signal-frequency output to an output electrode. Thus, looking upon the operation as that of amplitude modulation, we may say the local-oscillator voltage varies periodically the amplitude of the signal-frequency output. One of the sidebands of the modulation process will be the intermediate frequency. In the ideal case, the local oscillator will fully modulate the signal; i.e., it will vary the signal output from its maximum value to zero.

In Fig. 1(a) is shown a sine wave of arbitrary frequency which may be considered to be the output current at signal frequency of our converter or mixer tube

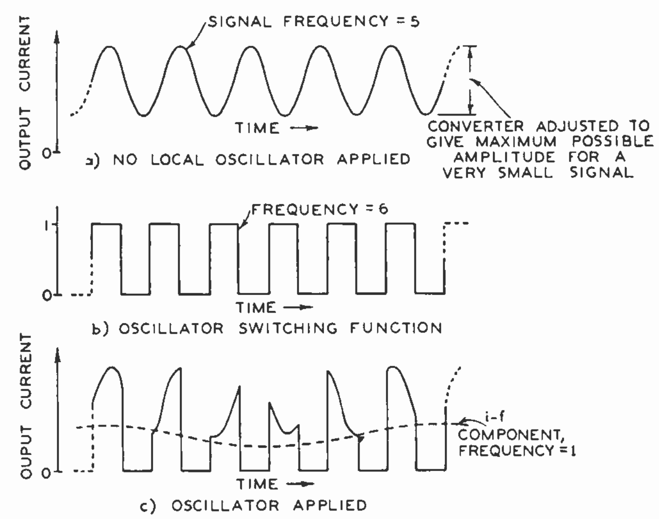

Fig. 1—Diagram showing frequency-changing action by prior methods. The intermediate-frequency component is 32 per cent of the original signal-frequency component.

with a small applied signal voltage and when the oscillator voltage is *not* present. The tube is assumed to be adjusted to the point of maximum signal-electrode transconductance so that Fig. 1(a) represents the maximum alternating current for the given small signal voltage of which the tube is capable. It represents also, therefore, the maximum amplification point of the tube considered as an amplifier. The effect of an applied local oscillator at a frequency 20 per cent higher than that of the signal may be considered, in an ideal case, as switching the signal on and off. This condition has been believed, in the past, to represent the maximum possible modulation of the signal by the oscillator.[3] A suitable oscillator switching function is shown in Fig. 1(b). When the function of Fig. 1(b) is zero, it represents the oscillator as cutting off the signal-frequency current completely; when it reaches unity, the signal-frequency current is permitted to have its maximum value (i.e., the value shown by Fig. 1(a)). The result of applying the switching function is shown in Fig. 1(c) which represents the output current when the oscillator is applied. The intermediate-frequency (difference-frequency) component, as may be verified by a Fourier analysis, is just 32 per cent ($1/\pi$) of the original signal-frequency current of Fig. 1(a). This figure, therefore, represents the action

[3] C. F. Nesslage, E. W. Herold, and W. A. Harris, "A new tube for use in superheterodyne frequency conversion systems," Proc. I.R.E., vol. 24, pp. 207–218; February, 1936.

[4] E. Peterson, and F. B. Llewellyn, "The operation of modulators from a physical viewpoint," Proc. I.R.E., vol. 18, pp. 38–48; January, 1930.

of a converter or mixer which, in the past, has been considered the ideal.

It will be observed that, during half of the time, in Fig. 1(c), the converter or mixer tube is virtually inoperative. By broadening the idea of modulation to include phase modulation, the writer found that the maximum intermediate-frequency output does not occur with this condition of local oscillator switching the signal current on and off but, on the other hand, occurs when the local oscillator switches the phase of the signal current by 180 degrees, periodically, at oscillator frequency. With the latter state of affairs, the frequency-changing tube is no longer inoperative during half the time but, on the contrary, is always operative but with a changing phase. In Fig. 2(a) is shown the signal current with oscillator removed and in Fig. 2(b) the oscillator switching function to accomplish the desired result.

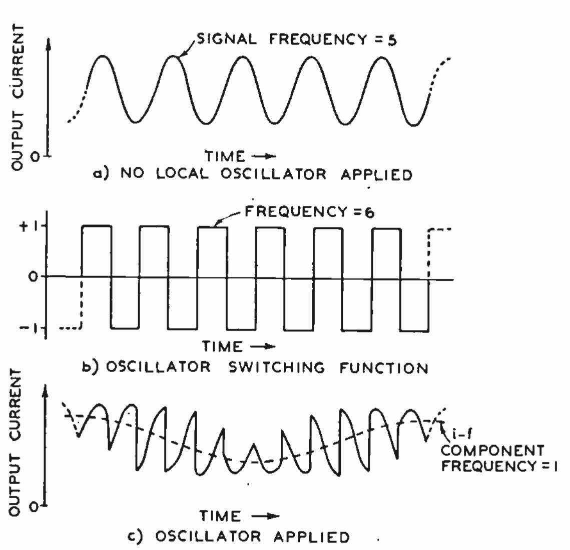

Fig. 2—Frequency changing by phase reversal. The intermediate-frequency component is 64 per cent of the original signal-frequency component; i.e., twice as high as with prior methods.

The latter function now varies from $+1$ to -1 and thus varies the signal current, not in amplitude, but in phase only. The output current, after application of the switching function, is shown in Fig. 2(c). The difference-frequency intermediate-frequency component is again recognizable and comparison with Fig. 1(c) shows clearly that it is greater in magnitude than in the latter illustration. As may be verified by Fourier analysis, the intermediate-frequency component of Fig. 2(c) is just 64 per cent $(2/\pi)$ of the original signal-frequency current. A tube operating according to the principles of Fig. 2 will give, therefore, just twice as much intermediate-frequency output for a given maximum signal-electrode transconductance as a tube operating along the conventional principles of Fig. 1.

At this point it may be well to remember that the switching of signal-frequency current from one phase to an opposite phase is equivalent to switching from a transconductance of one sign to a transconductance of opposite sign. Tubes having positive transconductance as well as tubes having negative transconductance have been known for many years[5] and, in fact, a number of tubes exhibit both characteristics at different points on their characteristic curves. Furthermore, closer analysis indicates that, in practical cases, there are only minor differences in conversion efficiency between a converter or mixer whose transconductance is varied in phase from, let us say, $+90$ to -90 degrees by a change in phase with no change in magnitude (i.e., whose phase passes through 0) and a converter whose transconductance is varied from positive to negative accompanied by a change in magnitude (i.e., whose magnitude passes through 0). In Fig. 2, of course, since the switching is done instantaneously by an ideal switching function, the two types of variation are indistinguishable.

Practicable tubes for the attainment of high conversion efficiency by these methods have been described[6] and will also be discussed later in this paper. It will be seen that a tube whose transconductance changes from positive to negative in correspondence to the oscillator voltage by changing the magnitude only may have advantages over one whose transconductance is varied by changing the phase only.

To conclude this preliminary physical picture of conversion, it may be understood from Fig. 2 that if, by any means, the switching represented by Fig. 2(b) and having the relative frequency 6 can be accomplished by a local oscillator of frequency $6/n$, equally good conversion may be obtained at the nth harmonic of the local oscillator. This requires that, for each cycle of the local oscillator, the signal-electrode transconductance must be switched from positive to negative n times. This is theoretically possible in special tube structures wherein the tube characteristic consists of n pulses having alternately positive and negative transconductances. In practice, it is doubtful if sufficient advantage is obtained by harmonic operation above the third to justify the more complex tube characteristics necessary. These aspects will be made clearer by the subsequent discussion.

III. Elementary Mathematical Analysis

The physical pictures which have been given of frequency conversion correspond to idealized conditions. A more exact analysis is readily made mathematically by using concepts established on a physical basis.[4] Let us consider a converter or mixer device, such as some form of electron tube, which produces an output current in response to a very small signal input voltage. Ordinarily, as has already been mentioned, one considers only amplitude modulation by the local oscillator so that one would write the alternating part of the output

[5] E. W. Herold, "Negative resistance and devices for obtaining it," Proc. I.R.E., vol. 23, pp. 1201–1223; October, 1935.

[6] E. W. Herold, United States Patent No. 2,294,659, applied for May 17, 1941.

current as

$$i = g_m e_s \sin \omega_s t$$

where $e_s \sin \omega_s t$ is the applied signal voltage and g_m is the so-called transconductance of the device. Since the device is a converter, not an amplifier, we may consider g_m as varied by the local oscillator and easily find the conversion transconductance. However, let us now take the more general case in which the local oscillator may vary either the amplitude or the phase of the signal-frequency current. Thus we write

$$i = g_m e_s \sin (\omega_s t + \phi) \tag{1}$$

where g_m and ϕ are both variable in time and periodic at the local-oscillator frequency ω_0. In cases of practical importance, the zero of time may always be chosen so that g_m and ϕ are even functions so that, without loss of generality, we may write them each as a cosine series

$$g_m = \sum_{n=0}^{\infty} a_n \cos n\omega_0 t$$

$$\phi = \sum_{n=0}^{\infty} q_n \cos n\omega_0 t.$$

If we attempt to use this expansion for ϕ in (1) we soon run into difficulties should many terms be involved in the expansion. However, (1) may be written

$$i = g_m e_s (\sin \omega_s t \cos \phi + \cos \omega_s t \sin \phi) \tag{1a}$$

and we see that it is not really ϕ which should be expanded in a Fourier series but instead it is $\cos \phi$ and $\sin \phi$ which are desired. Writing them as Fourier series, we obtain

$$\cos \phi = \sum_{n=0}^{\infty} b_n \cos n\omega_0 t$$

$$\sin \phi = \sum_{n=0}^{\infty} c_n \cos n\omega_0 t.$$

If ϕ has large values, $\cos \phi$ and $\sin \phi$ will go through many positive and negative excursions in a single period and their Fourier series will contain many high-order terms. Our series expansions, when substituted in (1a) will permit us to find the desired intermediate-frequency output.

Although we have now formally solved our problem by a completely general analysis, the results can hardly be interpreted without some restrictions on the variations of g_m and ϕ. For the purposes of this paper, it will be sufficient to consider either a time variation of g_m, or one of ϕ, separately and assume they do not both occur together. That is, we shall design our converter device so that the local oscillator varies periodically either g_m or ϕ but not both simultaneously.

A. Conversion by Variation of Phase Angle

Let us consider first variations in ϕ only. Then

$$i = g_m e_s \sin \omega_s t \sum b_n \cos n\omega_0 t + g_m e_s \cos \omega_s t \sum c_n \cos n\omega_0 t.$$

The terms of interest to us are those containing the intermediate frequency, which we shall choose to be $(n\omega_0 - \omega_s)$. Thus

$$i_{i-f} = g_m e_s [b_n \cos n\omega_0 t \sin \omega_s t + c_n \cos n\omega_0 t \cos \omega_s t]$$

$$= g_m e_s \left[\frac{b_n}{2} \sin (\omega_s - n\omega_0)t + \frac{c_n}{2} \cos (\omega_s - n\omega_0)t\right] + \cdots . \tag{2}$$

The conversion transconductance is

$$g_{c_n} = \left|\frac{i_{i-f}}{e_s}\right| = \frac{g_m}{2}\sqrt{b_n^2 + c_n^2}. \tag{3}$$

We may estimate the maximum value which g_{c_n} may have by examination of the Fourier coefficients b_n and c_n. These are given by

$$b_n = \frac{1}{\pi}\int_0^{2\pi} \cos \phi \cos n\omega_0 t d(\omega_0 t), \qquad n \neq 0$$

$$c_n = \frac{1}{\pi}\int_0^{2\pi} \sin \phi \cos n\omega_0 t d(\omega_0 t), \qquad n \neq 0.$$

Since the maxima of either $\cos \phi$ or $\sin \phi$ fluctuate between $+1$ and -1, the integrals will be a maximum if $+1$ is maintained at all times when $\cos n\omega_0 t > 0$ and if -1 is maintained whenever $\cos n\omega_0 t < 0$. In the case of b_n, we wish $\cos \phi = +1$ from $n\omega_0 t = -\pi/2$ to $n\omega_0 t = +\pi/2$ and we wish $\cos \phi = -1$ from $n\omega_0 t = \pi/2$ to $n\omega_0 t = 3\pi/2$. Thus we find that the highest value of b_n occurs with a variation of $\cos \phi$ similar to that shown in Fig. 3(a).

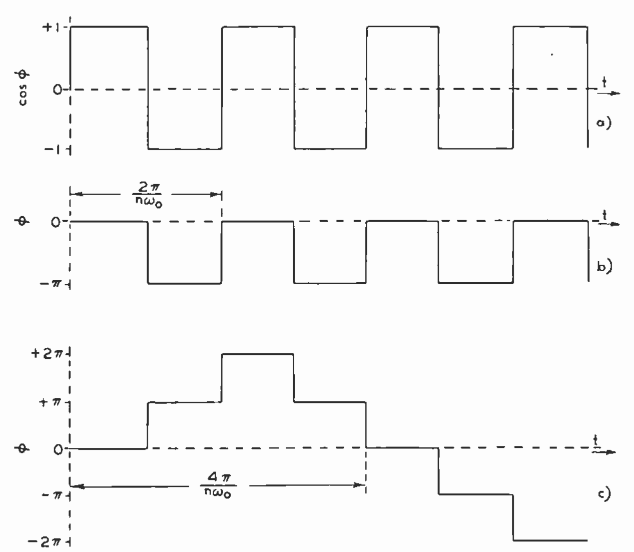

Fig. 3—(a) Time variation of $\cos \phi$ which leads to maximum conversion transconductance;
(b) one possible time variation of ϕ which leads to $\cos \phi$ variations as in (a);
(c) another possible time variation of ϕ which also gives $\cos \phi$ variations as in (a).

There are many possible variations of ϕ which will give us such a variation in $\cos \phi$. Two possibilities are given in Figs. 3(b) and 3(c). The last of these, Fig. 3(c), is interesting in that it shows a lower fundamental frequency in the variation of ϕ may, nevertheless, give a maximum value for b_n. Obviously, if $\cos\phi$ varies in the manner shown in Fig. 3(a), then $\sin\phi$ will be a constant. Thus, when b_n is a maximum, $c_n=0$. In a similar way, if c_n is made a maximum, $b_n=0$. We have shown, therefore, that

$$\text{maximum } b_n = \frac{2}{\pi}\int_{-\pi/2}^{\pi/2} \cos n\omega_0 t d(\omega_0 t)$$
$$= 4/\pi$$

and, similarly, the maximum value of c_n is also $4/\pi$. Finally, we see by reference to (3) that the maximum conversion transconductance is given by

$$\text{maximum } g_{c_n} = \frac{2}{\pi} g_m.$$

This maximum is just twice that which had previously been considered as ideal. Furthermore, it is seen that the same conversion transconductance may be attained no matter what value we assign to n.

A clearer picture of conversion by phase-angle variation is obtained by analysis of a type of variation which is suggested by the preceding considerations. Let us assume that the phase angle is varied by the local oscillator in the manner depicted in Fig. 4. Thus, since ϕ varies from $+\theta$ to $-\theta$, the function $\sin\phi$ varies from $\sin\phi$ to $-\sin\phi$. Since $\cos\phi$ is an even function, $\cos\phi$ does not vary with time and so is a constant. Our Fourier series for $\sin\phi$ is the usual one for a square wave and may be written

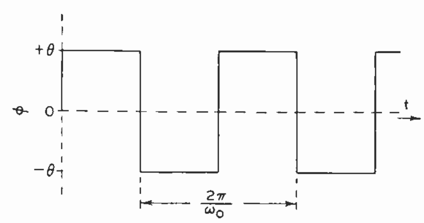

Fig. 4—An assumed time variation of phase angle which leads to a simple treatment of conversion by phase-angle variation.

$$\sin\phi = \frac{4}{\pi}\sin\theta\sum_{k=1}^{\infty}(-1)^{k-1}\frac{\cos(2k-1)\omega_0 t}{2k-1}. \quad (4)$$

Substituting this value for $\sin\phi$ in equation (1a) and remembering that $\cos\phi=$constant, we obtain

$$i = g_m e_s \sin\omega_s t\cos\theta$$
$$+\frac{4}{\pi}\sin\theta\cos\omega_s t\sum_{1}^{\infty}(-1)^{k-1}\frac{\cos(2k-1)\omega_0 t}{2k-1}. \quad (5)$$

The usual intermediate frequency (at oscillator fundamental) is $(\omega_0-\omega_s)$. This frequency is given by the term containing the product $\cos\omega_0 t\cos\omega_s t$; i.e., the first term of the summation. The intermediate-frequency output is

$$i_{i-f} = g_m e_s\frac{4}{\pi}\sin\theta\frac{\cos(\omega_0-\omega_s)t}{2}$$

so that the conversion transconductance is

$$g_{c_1} = \frac{2}{\pi} g_m\sin\theta. \quad (6)$$

The conversion transconductance has a maximum when $\theta=\pi/2$. It is seen that a periodic switching of phase angle from $+\pi/2$ to $-\pi/2$ (i.e., a periodic 180-degree phase reversal) will give rise to a maximum conversion transconductance. This case is similar to the one treated in Fig. 2.

B. Conversion by Variation of Transconductance

If only the transconductance is varied by the local oscillator, we may disregard the phase angle ϕ and write

$$i = g_m e_s\sin\omega_s t$$
$$= e_s\sin\omega_s t\sum_{n=0}^{\infty}a_n\cos n\omega_0 t$$
$$= a_0 e_s\sin\omega_s t+\frac{e_s}{2}\sum_{1}^{\infty}a_n\sin(n\omega_0+\omega_s)t$$
$$-\frac{e_s}{2}\sum_{1}^{\infty}a_n\sin(n\omega_0-\omega_s)t. \quad (7)$$

The intermediate frequency is chosen as one of the terms in the second summation. Thus, the conversion transconductance is

$$g_{c_n} = \frac{i_{i-f}}{e_s} = \frac{a_n}{2} \quad (8)$$

and conversion is said to be at the nth harmonic of the applied local-oscillator frequency ω_0. Thus far, our analysis is the same as that used in prior work.[2] We interpret the results in a new way, however, by including the possibility of negative transconductance. The value of a_n is

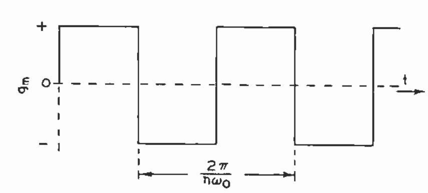

Fig. 5—A possible time variation of transconductance which leads to maximum conversion transconductance.

$$a_n = \frac{1}{\pi}\int_0^{2\pi} g_m\cos n\omega_0 t\, d(\omega_0 t), \qquad n\neq 0.$$

If negative values of g_m are excluded, the first coefficient a_1 would have a maximum value of $(2/\pi)g_{m_{max}}$ and the conversion transconductance would be $(1/\pi)g_{m_{max}}$ as previously found.[3] When negative values are included, however, these values may be twice as great. Analogous to the result in maximizing the Fourier coefficient for the phase-modulation case, a_n will be a maximum if the transconductance has a maximum positive value from

$n\omega_0 t = -\pi/2$ to $n\omega_0 t = +\pi/2$ and has a maximum negative value from $n\omega_0 t = +\pi/2$ to $n\omega_0 t = +3\pi/2$. The time variation of the transconductance, which is desired, is shown in Fig. 5. Since one period of the local oscillator occurs in the time $2\pi/\omega_0$, we see that for each periodicity of the local oscillator, there must be n changes from maximum positive to maximum negative transconductance. If the maximum positive and maximum negative transconductance values are equal, it is found that

$$a_n = \frac{4}{\pi} g_{m_{\max}}$$

where $g_{m_{\max}}$ is the maximum value. The conversion transconductance is then

$$g_{c_n} = \frac{2}{\pi} g_{m_{\max}}. \tag{9}$$

For $n = 1$ the operation is shown in Fig. 2 and is basically indistinguishable from a periodic 180-degree phase-angle variation as analyzed above.

IV. Mixer Design Using Phase-Reversal Conversion

We have seen that the conversion transconductance of a device may be made a maximum if the device periodically reverses the phase of the signal-frequency output. It is immaterial whether this change is made by phase or amplitude modulation, so that a sufficiently descriptive title is to call the process phase-reversal conversion.

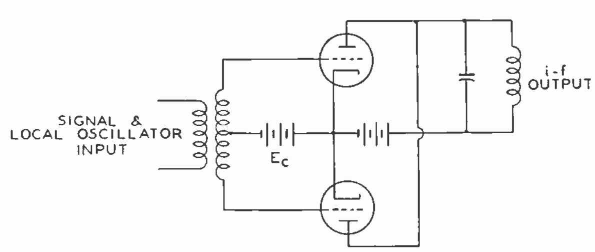

Fig. 6—A balanced modulator circuit which is similar in behavior to phase-reversal conversion.

Tubes operating along conventional principles are not particularly well suited for phase-reversal conversion, so that it is necessary to consider somewhat unconventional tube designs. However, there is a well-known circuit using conventional tubes which may be considered to bridge the gap between the old and the new ways of frequency conversion. The arrangement referred to is a particular form of the so-called balanced, or push-pull, modulator or mixer. In Fig. 6 is shown a circuit of two tubes whose anodes are connected together and whose grids are driven in push-pull. The bias battery E_c may be considered as biasing the tubes somewhere near cutoff. The local-oscillator voltage, which is applied in push-pull to the grids, along with the signal, is much larger than the signal voltage and alternately permits first one tube and then the other to operate. Since the signal voltages on the two grids are in opposite phase, the alternating plate currents of the tubes are also in opposite phase. The local-oscillator voltage, then, switches operation from one tube (i.e., one phase) to the other tube (i.e., opposite phase). Actually, this circuit for frequency conversion has little advantage over use of a single tube, inasmuch as it is necessary to drive two control grids and the output is basically the same as from two tubes in parallel. However, it does illustrate how, by circuit means, one may artificially create a phase reversal of signal for conversion purposes.

Let us next consider how a single tube having a negative and a positive transconductance may be used for conversion by phase reversal. Let us assume that a tube can be made with a curve of anode current versus control voltage such as shown in Fig. 7(a). The transconductance of such a tube will then be similar to that shown in 7(b). If a local oscillator voltage, of not too large an amplitude, is applied, with a bias so that it swings about point A, it is seen that the transconductance is periodically altered from positive to negative. If a small signal is also applied, the operation is equivalent to a periodic reversal in phase of the signal-frequency output current, one reversal occurring for each reversal of the local-oscillator voltage. Such a tube would be useful chiefly when operating at oscillator fundamental.

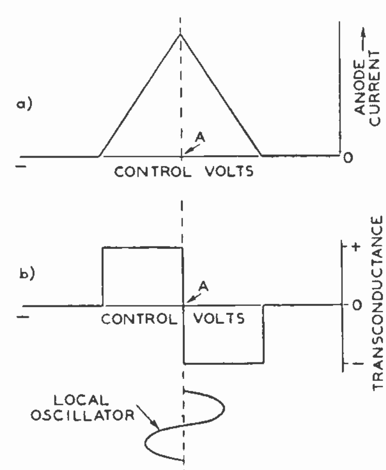

Fig. 7—The characteristic of a single tube which is needed to provide idealized phase-reversal conversion.

A practicable form of tube, which may be designed to give a characteristic resembling that of Fig. 7, consists of a multigrid structure dimensioned to permit formation of a virtual cathode between two of the grids.[7] The grid arrangement and circuit for such a tube are shown in Fig. 8(a). A cathode is surrounded by four grids and an anode. The grid adjacent to the cathode G_1 is used as the control electrode, while the remaining grid electrodes serve only to maintain a particular potential distribution in the tube. The signal and local-oscillator voltages are both applied to the control electrode, and the intermediate frequency is taken from the anode.

[7] B. J. Thompson, United States Patent No. 2,141,673.

When the potential of the control electrode G_1 is raised sufficiently in the positive direction, a large electron current is permitted to pass through the second grid G_2. Since G_3 is at a low potential, as indicated, the tube may be designed so that the space-charge effects of a large current flow in the region between G_2 and G_3 will depress the potential in that region approximately to cathode potential. Such a potential minimum is known as a virtual cathode, and its behavior has been studied in detail in the literature.[8] An increase in current through G_2, beyond that needed to form a virtual cathode, causes a shift in position of the potential minimum towards G_2, so as to decrease the current reaching G_3 and passing through it to the anode. A curve of anode current versus the voltage on grid G_1 is then similar to that shown in Fig. 8(b). The current maximum is found at approximately that voltage on G_1 which permits just enough current to flow to create a virtual cathode. Further increase in the potential of G_1 shifts the virtual cathode toward G_2 and the anode current decreases. The shape of the curve of Fig. 8(b) resembles to some extent the suggested ideal curve of Fig. 7(a).

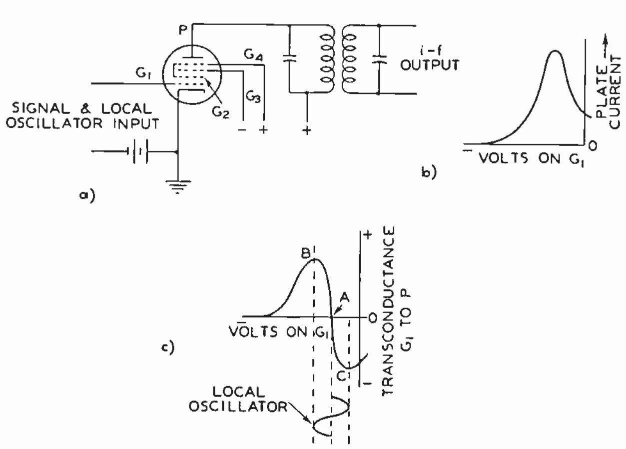

Fig. 8—A type of mixer tube with a second space-charge region which is suitable for phase-reversal conversion. Signal and oscillator voltages are applied to the same grid.

The transconductance of the tube is simply the derivative of Fig. 8(b) and is plotted in Fig. 8(c). This curve forms the basis for analysis of converter operation. If we apply a local-oscillator voltage and bias to the point A, it is seen that, with the amplitude of local-oscillator voltage shown, the transconductance is altered from positive (point B) to negative (point C). The difference between the curve of the practicable tube and the suggested one of Fig. 7(b) is mainly in the fact that the transconductance gradually changes in magnitude from point B to point C, instead of varying discontinuously as in the suggested case. Application of the theory given in the previous section indicates that a conversion transconductance of about 50 per cent of the maximum transconductance is attained with a curve similar to the one shown.

A multigrid tube utilizing the virtual-cathode phenomenon may be used in another way to accomplish phase-reversal conversion at oscillator fundamental. Referring to Fig. 9(a), a hexode tube is shown in which

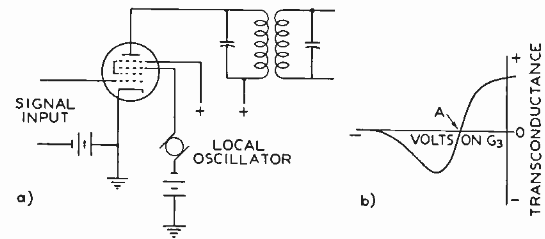

Fig. 9—A multigrid mixer with outer-grid oscillator injection which can be designed so as to give phase-reversal conversion by using a second space-charge region.

the signal input is connected to the grid adjacent to the cathode, whereas the local-oscillator voltage is connected to grid G_3. This circuit is the same as the one commonly used with outer-grid injection mixers. The design of the tube, however, is altered so as to permit the formation of a strong virtual cathode between grids G_2 and G_3 when G_3 is at its maximum negative excursion in potential. When G_3 is at its maximum positive excursion, on the other hand, there is no virtual cathode. As we have seen in connection with Fig. 8, the virtual cathode will give rise to a negative transconductance between the signal electrode G_1 and the anode. Thus if our local oscillator periodically varies the potential of G_3 so as periodically to build up and remove the virtual cathode, the transconductance of grid G_1 to anode will be altered periodically from negative to positive. A curve of the signal-grid transconductance plotted against oscillator-electrode voltage will be similar to Fig. 9(b). Application of the local oscillator to G_3 with a bias at point A will periodically reverse the transconductance of the signal grid and so give rise to phase-reversal conversion. As in the previous instance, only one phase reversal occurs for each reversal in local-oscillator voltage, so that high conversion transconductance is achieved only by operation at oscillator fundamental.

One of the most interesting practicable methods for phase-reversal conversion consists of an electron tube with an electron beam which is controlled by means of deflection.[6] If we refer back to Fig. 7(a), it would be a comparatively simple matter to apply the control voltage across a pair of deflecting electrodes, so as to sweep an electron beam back and forth over a final aperture and an anode. For example, Fig. 10(a) shows a tube arrangement which may be used for this purpose.[9] An electron gun produces a beam of electrons which passes between a pair of deflecting electrodes to be deflected through a final aperture. The anode current and transconductance characteristics of such a tube are indicated

[8] B. Salzberg and A. V. Haeff, "Effects of space charge in the grid-anode region of vacuum tubes," *RCA Rev.*, vol. 2, pp. 336–374; January, 1938.

[9] H. Alfven, "An investigation of an amplifier tube using transverse field control," *Zeit. für Hochfrequenz.*, vol. 38, pp. 27–29; July, 1931.

in Figs. 10(b) and 10(c). If the electron beam were made of square or rectangular cross section and had a uniform current density, the characteristics would more nearly approach the suggested rectilinear ones of Fig. 7. Mixer operation is accomplished by application of both signal and local-oscillator voltages across the deflection plates, and best conversion occurs with the bias adjusted at approximately the midpoint of the characteristic.

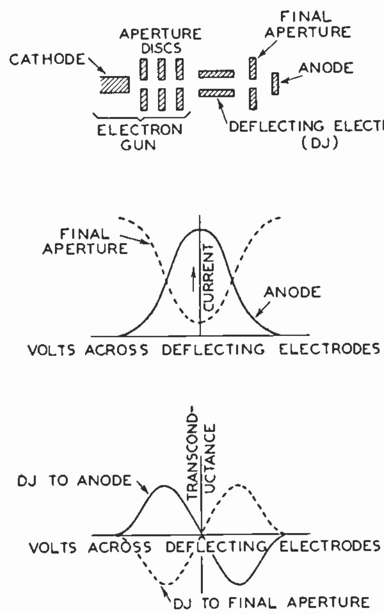

Fig. 10—A beam-deflection type of tube which can be used for phase-reversal conversion.

In the actual use of converter or mixer tubes, it is highly desirable to minimize the unavoidable fluctuation noise due to shot effect in the electron current. In many instances, these fluctuations are proportional to the magnitude of the current which flows in the tube.[10] In a mixer or converter, the noise fluctuations must be averaged over an oscillator cycle so that one frequently wishes a low average anode current.[11] Referring to Fig. 10, this tube operates as a mixer about the midpoint of the characteristic so that the average anode current is high. We could, however, invert the connections of final aperture and anode and use the final aperture as the output electrode. In this case the characteristic which applies is the dotted-line curve of Fig. 10(b), and the average current for mixer operation is small. Since the transconductance characteristic is the same, except for a reversal in sign, there is no loss in conversion transconductance. The reduced noise due to a small anode current over part of the oscillator cycle indicates an advantage over any device which accomplishes phase-reversal conversion by a shift in *phase* only without reduction in current.

[10] W. Schottky, "Spontaneous current fluctuations in various conductors," *Ann. der Phys.*, vol. 57, pp. 541–567; December 20, 1918.

[11] E. W. Herold, "Superheterodyne converter system considerations in television receivers," *RCA Rev.*, vol. 4, pp. 324–337; January, 1940.

The use of deflection control also enables tubes to be designed for phase-reversal conversion at an oscillator harmonic.[6] To understand this, let us refer to Fig. 11(a) which shows in idealized form a tube characteristic suitable for phase-reversal conversion at fundamental, at oscillator second harmonic, and at oscillator third harmonic. The transconductance characteristic is shown in Figs. 11(b), 11(c), and 11(d) where the method of operation for fundamental-, second-, and third-harmonic conversion are shown. Looking at Fig. 11(b) we see that there is a one reversal of the transconductance for each

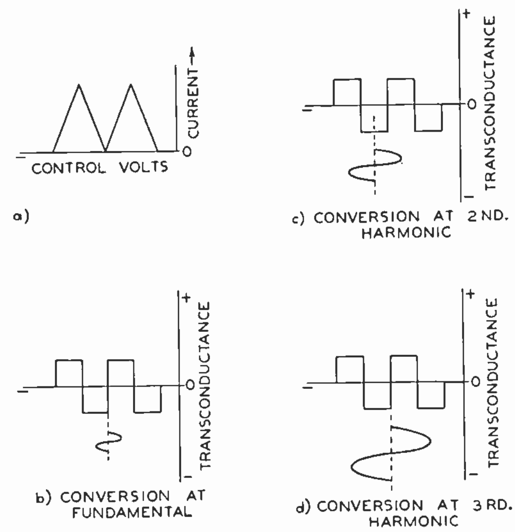

Fig. 11—Idealized form of tube characteristic to give the same maximum conversion-transconductance fundamental, second, or third harmonic of the local oscillator.

reversal of local oscillator voltage. If the bias is shifted slightly and a larger local-oscillator voltage is used, as in Fig. 10(c), it is seen that there are two reversals of transconductance for each reversal in local-oscillator voltage. This operation is suitable for second-harmonic conversion. Third-harmonic conversion is accomplished by biasing at the center and using a still larger local-oscillator voltage as in Fig. 11(d). It is seen that each reversal of the local-oscillator voltage results in *three* reversals in sign of the transconductance.

An interesting point in connection with harmonic operation is that, in the idealized case, there is no component of current flow to the output electrode at the harmonic of the local oscillator which is being used for conversion. In other words, the frequency which is being used for conversion is not actually present anywhere in the conversion system. Furthermore, there is no conversion at harmonics other than the desired one, so that the spurious responses ordinarily encountered in harmonic-conversion superheterodynes are not present when this method of conversion is used. The conversion transconductances for harmonic conversion are phenomenally high compared with those usually found in conventional tubes. The conventional tube has a conversion transconductance which approaches 32 per cent of the transconductance for fundamental operation, 16 per cent for second-harmonic conversion and 10 per cent for third-harmonic conversion. The conversion transconductance for all three conversions shown in Fig. 11 is substantially the same and equal to approximately 64 per cent (i.e., $2/\pi$) of the maximum transconductance.

Conversion at any desired higher harmonic of the local oscillator is theoretically possible by increasing the number of "humps" in the output-electrode versus control-electrode characteristic. For optimum conversion at the nth harmonic, the transconductance characteristic should have the shape of the Lissajous figure compounded by a sine wave of local-oscillator frequency and a square wave of frequency n times as great.

If the characteristics of Fig. 11 are to be approached in a tube of the deflection type it will be necessary to use an output anode with several openings or an anode with an adjacent aperture having several openings. Deflection tubes with a multiplicity of humps in the characteristic of anode current versus control-electrode voltage have been suggested for harmonic generation and there would appear to be no basic difficulty in such design.[6,12] In practicable tubes, the characteristic of Fig. 11(a) would probably be approached only very roughly and one would expect something more nearly resembling Fig. 12.

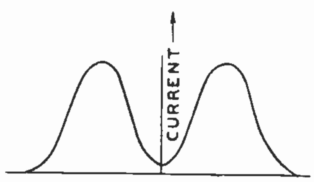

Fig. 12—A practicable characteristic of a beam-deflection tube with an anode having an adjacent aperture with two openings.

Because of the promising nature of conversion at oscillator harmonics by tubes having the general characteristics of Fig. 12, it has appeared worth while to analyze the behavior more completely. This analysis is the subject of the following section.

V. Analysis of Phase-Reversal Conversion Using Multihumped Characteristics

The exact behavior of tubes having characteristics similar to those of Figs. 10 and 12 can be analyzed readily. The analysis is most conveniently made by expressing the volt-ampere characteristic in the form of a trigonometric polynomial, using the method of Barrow to reduce the number of terms needed.[13] Thus, for an analysis of a tube similar to that of Fig. 10, we may artifically extend the actual characteristic indefinitely on either side as shown in Fig. 13. The trigonometric polynomial representing the characteristic is a Fourier series of which we use a limited number of terms to approximate the tube characteristic. The results will be valid for the tube of Fig. 10 as long as our applied voltages do not exceed the limits B and C. Since conversion at oscillator harmonics is of considerable interest, we may as well permit voltage excursions over two humps; i.e., from B to D of Fig. 13. In this case we are able to analyze a device having the characteristic of Fig. 12. Thus it is seen that, by expressing our characteristic as a

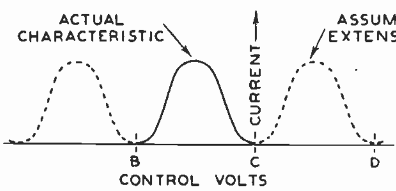

Fig. 13—Extension of a tube characteristic to permit representation by a Fourier series.

Fourier series, the analysis of a multihumped characteristic is made. By restricting the voltage swings over one or two of these humps, the behavior of simpler tubes is given.

If we include many terms of the Fourier series for the characteristic, an analysis may be made to any required degree of accuracy. In the illustrative analysis to be given here, we shall restrict ourselves to cases of symmetrical characteristics and include only two terms beyond the constant term of the Fourier series. The symmetry restriction eliminates even harmonics in the Fourier expansion so we use simply a series of the form

$$I_b = I_{b_0} - d_1 \cos k(E - E_c) + d_3 \cos 3k(E - E_c) \quad (10)$$

where I_b is the output-electrode current, I_{b_0} is the constant term needed to avoid negative-current values, E is the control-electrode voltage, and E_c is the direct-current bias on the control electrode. Since there is no

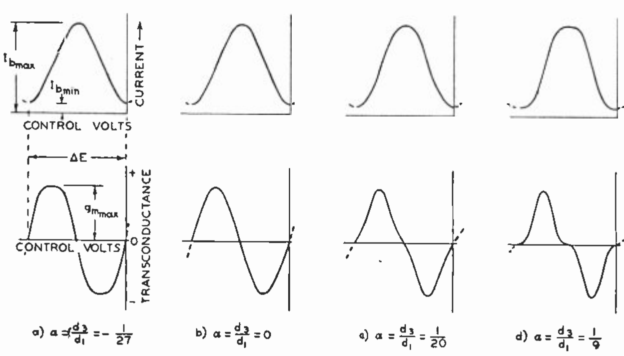

Fig. 14—Range of current and transconductance characteristics covered by the analysis using three terms of a Fourier series.

particular interest in tube characteristics having double maxima and minima for each main rise and dip, we may further restrict ourselves to small values of d_3. An investigation shows that d_3/d_1 must lie between $-1/27$ and $+1/9$ if both the transconductance and the volt-ampere characteristics are to rise monotonically.

The analysis will include, therefore, characteristics ranging between those shown in Fig. 14(a) to 14(d). The

[12] N. C. Jamison, "A cathode-ray frequency multiplier," *Physics*, vol. 2, pp. 217–224; April, 1932.

[13] W. L. Barrow, "Contribution to the theory of nonlinear circuits with large applied voltages," Proc. I.R.E., vol. 22, pp. 964–981; August, 1934.

shapes of the derivative curves (i.e., the transconductance characteristics) show more clearly the differences between the characteristics than do the current curves. Thus, in an application to an actual case by inspection only, it is advantageous to have a transconductance characteristic, in addition to a current characteristic, so that the best approximation can be made. Of course, the values of d_1 and d_3 may be found exactly by the usual Fourier-analysis methods. Here again, however, the transconductance characteristic is of advantage because of the greater accuracy of an evaluation of the higher-order term.

It should be noted that the residual current $I_{b\min}$ of Fig. 14 is included to account for a possible basic defect in the device under consideration. It plays no role in the conversion process but does represent a source of additional fluctuation noise, either due to stray electrons in an electron tube, or to an equivalent contribution by a following intermediate-frequency amplifier and circuit. Ordinarily, it will be a very small fraction of the maximum current $I_{b\max}$ and this will be assumed here.

We may put (10) in more useful form by noting that the maximum output-electrode current (see Fig. 14) is

$$I_{b\max} = I_{b_0} + (1 - \alpha)d_1 \tag{11}$$

where α is the ratio d_3/d_1. The minimum current is

$$I_{b\min} = I_{b_0} - (1 - \alpha)d_1. \tag{12}$$

Solving (11) and (12) gives

$$d_1 = \frac{I_{b\max} - I_{b\min}}{2(1 - \alpha)} \quad \text{and} \quad I_{b_0} = \tfrac{1}{2}(I_{b\max} + I_{b\min}).$$

Since we are usually concerned with those cases in which $I_{b\min} \ll I_{b\max}$, we may call $I_{b\min}/I_{b\max} = \beta$ and treat β as a small number. Then

$$d_1 = \frac{I_{b\max}}{2(1 - \alpha)}(1 - \beta) \quad \text{and} \quad I_{b_0} = \frac{I_{b\max}}{2}(1 + \beta)$$

so that (10) may be written as

$$I_b = \frac{I_{b\max}}{2}\left[(1 + \beta) - \frac{(1 - \beta)}{(1 - \alpha)} \cos k(E - E_c) + \frac{\alpha(1 - \beta)}{(1 - \alpha)} \cos 3k(E - E_c)\right].$$

Finally, we know that α lies between $-1/27$ and $+1/9$ so that it may also be treated as a small number. Hence,

$$I_b = \frac{I_{b\max}}{2}(1 + \alpha - \beta)[(1 + 2\beta - \alpha) - \cos k(E - E_c) + \alpha \cos 3k(E - E_c)]. \tag{13}$$

Differentiation of (13) gives the transconductance

$$g_m = \frac{dI_b}{dE} = k\frac{I_{b\max}}{2}(1 + \alpha - \beta)[\sin k(E - E_c) - 3\alpha \sin 3k(E - E_c)]. \tag{14}$$

The maximum transconductance (see Fig. 14) is

$$g_{m\max} = k\frac{I_{b\max}}{2}(1 + \alpha - \beta)(1 + 3\alpha).$$

Substituting this in (14) gives

$$g_m = \frac{g_{m\max}}{1 + 3\alpha}[\sin k(E - E_c) - 3\alpha \sin 3k(E - E_c)]. \tag{15}$$

Thus far, all the basic characteristics of our curves of Fig. 14 have been identified in (13) and (15) except the base voltage ΔE. Obviously, however,

$$k = \frac{2\pi}{\Delta E}$$

so that all the information required is now given. Actually, if $I_{b_{\max}}$, $I_{b_{\min}}$, $g_{m_{\max}}$, and ΔE are all given, it can be shown that α is already determined and is given by

$$\alpha = \frac{1}{4}\left[\frac{\Delta E}{\pi}\frac{g_{m\max}}{I_{b\max}} + \beta - 1\right]. \tag{16}$$

It is interesting to note that (16) indicates (for $\beta = 0$)

$$2.7\frac{I_{b\max}}{\Delta E} < g_{m\max} < 4.3\frac{I_{b\max}}{\Delta E}$$

as long as α lies between $-1/27$ and $+1/9$. Hence if $g_{m_{\max}}$ is actually found to be outside of these limits, the relationships between (13) and (15) will not be valid. In this event, the analysis may be made most accurate for mixer operation by finding α from a Fourier analysis of the transconductance curve without regard to the actual values of plate current. In any event, analyses of the type suggested here are of chief importance in indicating basic trends and behaviors, rather than for getting accurate quantitative data. The latter are always most convincing when obtained by direct measurement.

We are now in a position to apply a local-oscillator voltage and analyze converter operation. We will be interested in the average output electrode current (for fluctuation noise analysis) and in the conversion transconductances. Let

$$E = E_0 \sin \omega_0 t \tag{17}$$

be the applied local-oscillator voltage. Then the plate current will be given by (13) as

$$\begin{aligned} I_b &= \frac{I_{b\max}}{2}(1+\alpha-\beta)\{(1+2\beta-\alpha) - \cos(kE_0 \sin \omega_0 t - kE_c) + \alpha \cos(3kE_0 \sin \omega_0 t - 3kE_c)\} \\ &= \frac{I_{b\max}}{2}(1 + \alpha - \beta)\{(1 + 2\beta - \alpha) - [\cos kE_c][\cos(kE_0 \sin \omega_0 t)] - [\sin kE_c][\sin(kE_0 \sin \omega_0 t)] \\ &\quad + \alpha[\cos 3kE_c][\cos(3kE_0 \sin \omega_0 t)] + \alpha[\sin 3kE_c][\sin(3kE_0 \sin \omega_0 t)]\}. \end{aligned} \tag{18}$$

We may make use of the familiar expansions[14]

$$\cos(x \sin \phi) = J_0(x) + 2\sum_{r=1}^{\infty} J_{2r}(x) \cos 2r\phi$$

$$\sin(x \sin \phi) = 2\sum_{r=1}^{\infty} J_{2r-1}(x) \sin(2r-1)\phi$$

where $J_n(x)$ is the Bessel function of the first kind, of order n. Substituting these in (18) and rearranging terms we find

$$\begin{aligned} I_b = \frac{I_{b\max}}{2}&(1+\alpha-\beta)[(1+2\beta-\alpha) - J_0(kE_0)\cos kE_c \\ &+ \alpha J_0(3kE_0)\cos 3kE_c] \\ &- \frac{I_{b\max}}{2}(1+\alpha-\beta)[2J_1(kE_0)\sin kE_c \\ &- 2\alpha J_1(3kE_0)\cos 3kE_c]\sin\omega_0 t \\ &- \frac{I_{b\max}}{2}(1+\alpha-\beta)[2J_2(kE_0)\cos kE_c \\ &- 2\alpha J_2(3kE_0)\cos 3kE_c]\cos 2\omega_0 t \\ &- \frac{I_{b\max}}{2}(1+\alpha-\beta)[2J_3(kE_0)\sin kE_c \\ &- 2\alpha J_3(3kE_0)\sin 3kE_c]\sin 3\omega_0 t \\ &+ \cdots . \end{aligned} \tag{19}$$

The terms of (19) are arranged to give the direct-current, fundamental oscillator frequency, and second- and third-harmonic components of output current. Of these, only the first term is of interest to us. Writing the average output current, as read on a direct-current meter after application of the local-oscillator voltage, as $\overline{I_b}$ we see

$$\begin{aligned} \overline{I_b} = \frac{I_{b\max}}{2}&(1+\alpha-\beta)[(1+2\beta-\alpha) - J_0(kE_0)\cos kE_c \\ &+ \alpha J_0(3kE_0)\cos 3kE_c]. \end{aligned} \tag{20}$$

The conversion transconductances at the various oscillator harmonics are given by one half of the coefficients of the Fourier series of the transconductance, as we saw in (7) and (8) of Section III above. The transconductance, after application of the local-oscillator voltage, is given by substitution of (17) in (15),

$$\begin{aligned} g_m &= \frac{g_{m\max}}{1+3\alpha}[\sin(kE_0\sin\omega_0 t - kE_c) \\ &\quad - 3\alpha\sin(3kE_0\sin\omega_0 t - 3kE_c)] \\ &= \frac{g_{m\max}}{1+3\alpha}[\sin(kE_0\sin\omega_0 t)\cos kE_c \\ &\quad - \cos(kE_0\sin\omega_0 t)\sin kE_c \\ &\quad - 3\alpha\sin(3kE_0\sin\omega_0 t)\cos 3kE_c \\ &\quad + 3\alpha\cos(3kE_0\sin\omega_0 t)\sin 3kE_c] \\ &= \frac{g_{m\max}}{1+3\alpha}[-J_0(kE_0)\sin kE_c + 3\alpha J_0(3kE_0)\sin 3kE_c] \\ &\quad + 2\frac{g_{m\max}}{1+3\alpha}[J_1(kE_0)\cos kE_c \\ &\quad - 3\alpha J_1(3kE_0)\cos 3kE_c]\sin\omega_0 t \\ &\quad - 2\frac{g_{m\max}}{1+3\alpha}[J_2(kE_0)\sin kE_c \\ &\quad - 3\alpha J_2(3kE_0)\sin 3kE_c]\cos 2\omega_0 t \\ &\quad + 2\frac{g_{m\max}}{1+3\alpha}[J_3(kE_0)\cos kE_c \\ &\quad - 3\alpha J_3(3kE_0)\cos 3kE_c]\sin 3\omega_0 t \\ &\quad + \cdots . \end{aligned} \tag{21}$$

[14] Whittaker and Watson, "Modern Analysis," Cambridge University Press, London, England, fourth edition, p. 379, 1927.

The conversion transconductances at oscillator first, second, and third harmonics are therefore given by

$$g_{c1} = \frac{g_{m\max}}{1+3\alpha}[J_1(kE_0)\cos kE_c - 3\alpha J_1(3kE_0)\cos 3kE_c] \tag{22}$$

$$g_{c2} = \frac{g_{m\max}}{1+3\alpha}[-J_2(kE_0)\sin kE_c + 3\alpha J_2(3kE_0)\sin 3kE_c] \tag{23}$$

$$g_{c3} = \frac{g_{m\max}}{1+3\alpha}[J_3(kE_0)\cos kE_c - 3\alpha J_3(3kE_0)\cos 3kE_c]. \tag{24}$$

A quantity of considerable interest is the equivalent noise resistance, which gives a measure of the relative fluctuation-noise output compared with useful intermediate-frequency output of a converter or mixer. This quantity is obtained by equating the actual output noise produced by the tube to that which would have been produced in the output by thermal agitation noise in an input circuit of resistance R_{eq}. For the present purposes, we may assume that our converter or mixer device operates by electronic conduction and that the electron current arriving at the anode is a result of a completely random arrival of electrons. In this case, the mean-squared output noise fluctuations for a steady current I_{b_0} are[10]

$$\overline{i_{p_n}^2} = 2eI_{b_0}\Delta f$$

where e is the charge of the electron and Δf is the effective-noise bandwidth.[15] Operation as a mixer or converter requires that we use the value of these fluctuations averaged over the time of one local-oscillator cycle.[11] Thus, the mixer or converter noise is

$$\overline{i_{p_n}^2} = 2e\overline{I_b}\Delta f$$

where $\overline{I_b}$ is given by (20). The equivalent noise resistance, for operation at the nth harmonic, is

[15] Effective noise bandwidth is discussed in Part V of B. J. Thompson, D. O. North, and W. A. Harris, "Fluctuations in space-charge limited currents at moderately high frequencies," *RCA Rev.*, vol. 5, pp. 505–524; April, 1941; and vol. 6, pp. 115–124; July, 1941.

$$R_{\mathrm{eq}_n} = \frac{\overline{i_{p_n}^{\,2}}}{4kT_R\Delta f g_{c_n}^{\,2}} = \frac{2e\overline{I_b}}{4kT_R g_{c_n}^{\,2}}$$

where k is Boltmann's constant in joules per degree Kelvin and T_R is room temperature in degrees Kelvin. Very closely, $2e/4kT_R=20$ so that

$$R_{\mathrm{eq}_n} = \frac{20\overline{I_b}}{g_{c_n}^{\,2}}. \tag{25}$$

Substituting (20) and making use of (22), (23), and (24) we find

$$R_{\mathrm{eq}_1} = 10\,\frac{I_{b\max}}{g_m^{\,2}}\left(1+\frac{7}{2}\alpha-\frac{\beta}{2}\right)^2\left\{\frac{(1+2\beta-\alpha)-J_0(kE_0)\cos kE_c+\alpha J_0(3kE_0)\cos 3kE_c}{[J_1(kE_0)\cos kE_c-3\alpha J_1(3kE_0)\cos 3kE_c]^2}\right\} \tag{26}$$

$$R_{\mathrm{eq}_2} = 10\,\frac{I_{b\max}}{g_{m\max}^{\,2}}\left(1+\frac{7}{2}\alpha-\frac{\beta}{2}\right)^2\left\{\frac{(1+2\beta-\alpha)-J_0(kE_0)\cos kE_c+\alpha J_0(3kE_0)\cos 3kE_c}{[J_2(kE_0)\sin kE_c-3\alpha J_2(3kE_0)\sin 3kE_c]^2}\right\} \tag{27}$$

$$R_{\mathrm{eq}_3} = 10\,\frac{I_{b\max}}{g_{m\max}^{\,2}}\left(1+\frac{7}{2}\alpha-\frac{\beta}{2}\right)^2\left\{\frac{(1+2\beta-\alpha)-J_0(kE_0)\cos kE_c+\alpha J_0(3kE_0)\cos 3kE_c}{[J_3(kE_0)\cos kE_c-3\alpha J_3(3kE_0)\cos 3k^2E_c]}\right\}. \tag{28}$$

Lowest relative fluctuation noise and highest signal-to-noise ratio is given when the equivalent noise-resistance values are small. We are, therefore, in a position to estimate roughly how the tube should be operated for best results. First of all, the highest ratio of $g_{m\max}^{\,2}/I_{b\max}$ is desirable. This depends on the tube design and is beyond the scope of this paper. For fundamental and third-harmonic operation, it is desirable to choose $kE_c=0$ or π to obtain the highest conversion transconductance (i.e., the denominator of (26) and (28)). In choosing between these two values, however, one should preferably choose $E_c=0$ for fundamental operation and $kE_c=\pi$ for third-harmonic operation, since it will be found that in these cases the numerator becomes smallest. This is equivalent to operation at a point of minimum output electrode current for fundamental conversion and at a point of maximum current for third-harmonic conversion. For second-harmonic operation, on the other hand, $kE_c=\pi/2$ will give best results. This is equivalent to operation at a point of maximum transconductance. These conclusions check the expected ones as indicated previously in connection with Fig. 11. Obviously, oscillator excitation is also of importance and should be increased until the relation for R_{eq_n} is at a minimum. Although formally the relations (26), (27), and (28) could be maximized, this process leads to equations which cannot readily be interpreted. It is more convenient to plot the various factors as functions of the local-oscillator voltage so as to study the behavior. This will be carried out in the next section.

VI. Discussion of Results

A. Tube Characteristics Approaching Sine Wave in Shape; $\alpha=0$

Let us first treat the simple case when the tube characteristics are sinusoidal in shape. If α is set equal to zero in (22) and (24) we see that optimum conversion transconductance is obtained for g_{c_1} and g_{c_3} when $\cos kE_c=\pm 1$. This occurs at $kE_c=0$, π, 2π, etc., which is equivalent to operation at either a minimum or a maximum of output-electrode current. Inspection of the plate-current relation, (20) shows that lowest plate current for small oscillator excitation (i.e., fundamental operation), will probably occur when $\cos kE_c=+1$ rather than when $\cos kE_c=-1$. It will be seen that the reverse is true for the higher oscillator excitations which will be needed for best third-harmonic conversion. Thus we will prefer to choose $kE_c=0$ for fundamental operation since this gives us lowest plate current with high conversion transconductance. This was to be expected on physical grounds, of course, as discussed in connection with Fig. 10. Thus, we will set $E_c=0$ when considering operation at oscillator fundamental and we will examine third-harmonic conversion both at $kE_c=0$ and at $kE_c=\pi$.

The optimum condition for second-harmonic operation is seen from (23) to require $\sin kE_c=\pm 1$. This is equivalent to $kE_c=\pm n/2$ or a bias

$$E_c = \pm\frac{\pi}{2}\,\frac{1}{k} = \pm\frac{\pi}{2}\,\frac{\Delta E}{2\pi} = \pm 1/4\Delta E.$$

With this value of bias, the output electrode current is constant and equal to approximately half the maximum current. The bias is equivalent to operation at one of the points of the characteristic which has maximum transconductance.

On Fig. 15, curves have been plotted showing the average output electrode current, conversion transconductance, and equivalent noise resistance for three values of minimum current (i.e., three values of β). The curves are plotted as a function of the oscillator excitation E_0. The scale of abscissas corresponds to values of kE_0. Thus, since

$$k = \frac{2\pi}{\Delta E},$$

values are readily transformed to an actual oscillator voltage or vice versa. The output electrode current is shown as a fraction of $I_{b\max}$ the maximum current. Similarly, the conversion transconductances are shown as fractions of $g_{m_{max}}$, the maximum transconductance. The equivalent noise resistance values are plotted on a relative scale which will give actual values if the ordinates are multiplied by $I_{b_{max}}/g_{m_{max}}^2$.

We see that, as the oscillator excitation is increased, the conversion transconductance at oscillator fundamental g_{c_1} increases to a maximum of 58 per cent of the maximum transconductance and then decreases again.

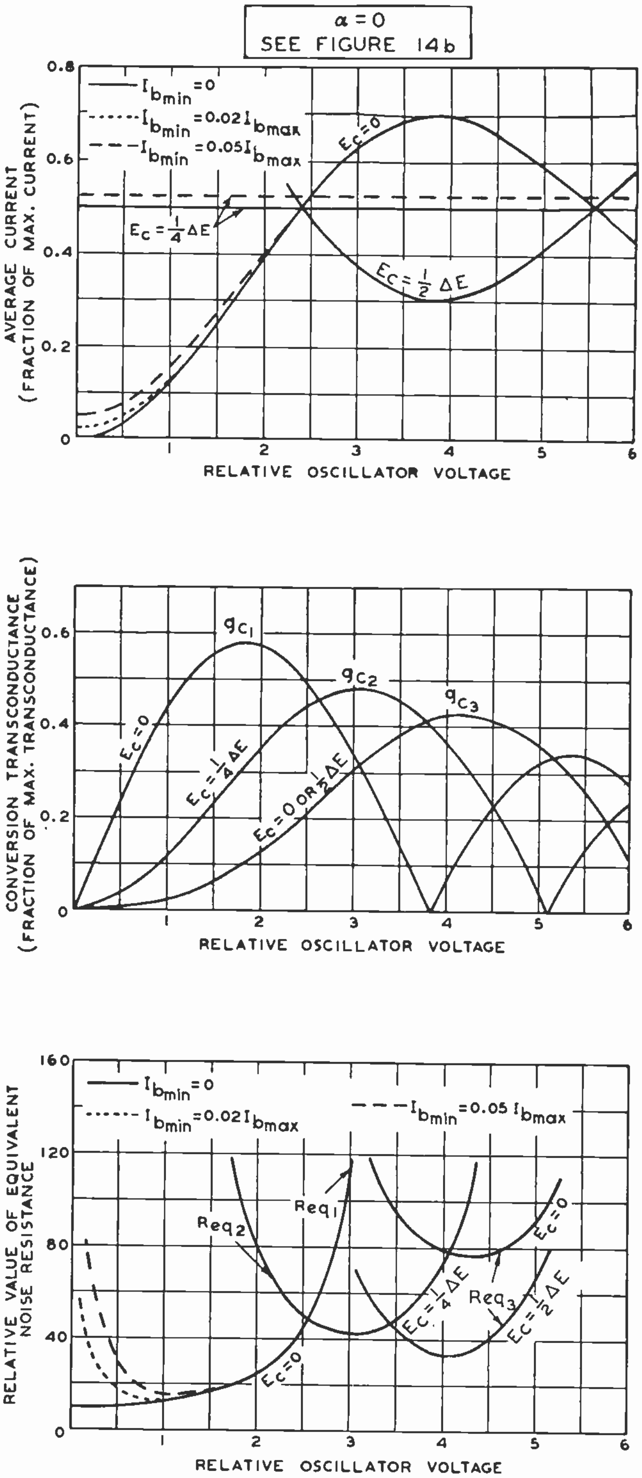

Fig. 15—Performance of a mixer tube having an assumed characteristic similar to (b) of Fig. 14. The minimum equivalent noise resistance of such a tube as an amplifier has a relative value of 10.

We may compare this curve with similar ones for conventional tubes[2] which reach a maximum value of only 28 per cent of the maximum transconductance.

Examination of the second-harmonic conversion transconductance g_{c_2} curve shows that a larger oscillator excitation is required, just as has been expected (see Fig. 11). The bias is changed to a point of maximum transconductance for second-harmonic conversion. The optimum conversion transconductance is 48 per cent of the maximum transconductance. This compares with an optimum of only 14 per cent using conventional tubes for second-harmonic conversion. The curve for g_{c_3}, the conversion transconductance at third harmonic, requires either a bias $E_c=0$ or $E_c=\frac{1}{2}\Delta E$, and a still larger oscillator swing is needed for best conversion. The value attained is 43 per cent of the maximum transconductance. This is nearly five times as high a figure as that which can be reached with conventional tubes for third-harmonic conversion. Furthermore, it will be observed that conversion at fundamental is substantially zero at the point of best third-harmonic conversion, and the bias is such that second-harmonic conversion is also zero. Thus, spurious responses will be absent, in contrast to conventional methods.

So far the analysis has shown that the new principle has led to a very considerable improvement in gain (i.e., conversion transconductance) over conventional methods and the mixer or converter is placed very much closer to the amplifier in performance. In many applications, however, the signal-to-noise performance is of more significance than gain alone. We have yet to see what the analysis shows in this respect. Let us examine the equivalent noise resistance of a tube of this kind as an *amplifier*. We will then be able to compare the result with the bottom set of curves of Fig. 15 and evaluate the signal-to-noise performance.

A tube having $I_{b_{min}}=0$ and of the kind under discussion, when operated at the point of maximum transconductance and used as an amplifier, will have a direct plate current

$$I_b = \frac{I_{b_{max}}}{2}$$

and a transconductance

$$g_m = g_{m_{max}}.$$

The equivalent noise resistance is then

$$\text{Amplifier } R_{eq} = \frac{20 I_b}{g_m^2}$$

$$= 10 \frac{I_{b_{max}}}{g_{m_{max}}^2}.$$

Returning to Fig. 15, we see that in the case of $I_{b_{min}}=0$, the fundamental equivalent noise resistance, R_{eq_1}, approaches this same value at small oscillator excitations. With any appreciable value of $I_{b_{min}}$, the equivalent noise resistance is somewhat greater, and a minimum value is found at a definite oscillator excitation.[16] This particular oscillator excitation for fundamental operation will give rise to an average plate current approximately 15 per cent of the maximum plate current. The conversion transconductance is slightly less than optimum. Looking at the values, we see that the minimum R_{eq_1} increases as $I_{b_{min}}$ increases.

It will be seen from Fig. 15 that the equivalent noise

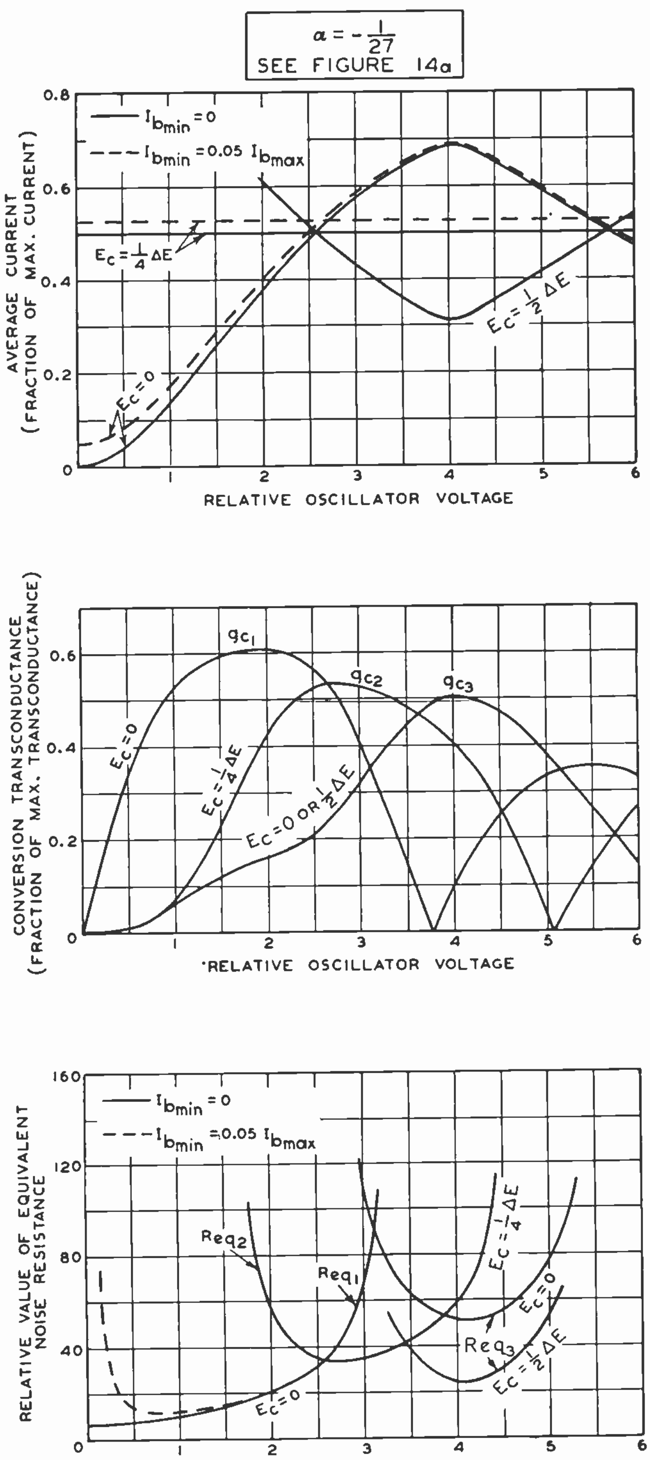

Fig. 16—Performance of a mixer tube having an assumed characteristic similar to (a) of Fig. 14. The equivalent noise resistance of such a tube as an amplifier has a relative value of 10 when operated at maximum gain.

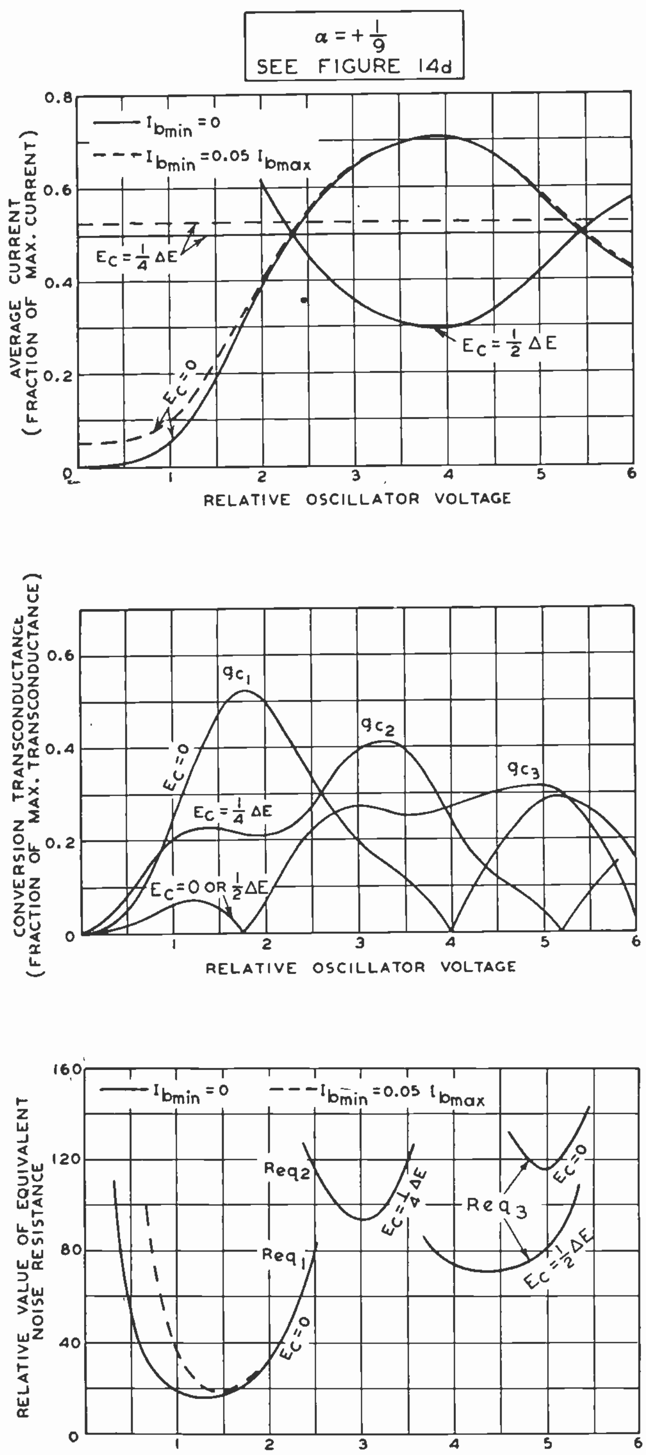

Fig. 17—Performance of a mixer tube having an assumed characteristic similar to (d) of Fig. 14. The equivalent noise resistance of such a tube as an amplifier has a relative value of 10.

resistance for third-harmonic operation is lowest when the bias is chosen at $E_c = \frac{1}{2}\Delta E$ because the average anode current is then lowest. Both second- and third-harmonic equivalent noise resistances are somewhat higher than

[16] It should be remembered that $I_{b_{min}}$ has its chief significance as equivalent to a residual source of noise, either from the stray electrons in a mixer tube or possibly from the succeeding tubes and circuits. In the latter case, of course, $I_{b_{min}}$ will not be read on a direct-current meter and the current curves at the top of Fig. 15 will appear as if $I_{b_{min}} = 0$.

for fundamental operation so that the signal-to-noise ratio is not as good. This is true even though the conversion transconductance (i.e., the gain) remains high. It is seen that, when $I_{b_{min}}$ is zero, the equivalent noise resistance as a mixer at fundamental approaches that of the same tube used as amplifier; i.e., a value of 10 on the relative scale used on the figure. Practically, $I_{b_{min}}$ is never zero (particularly if interpreted as equivalent to a noise contribution from the following tubes and circuits) and the mixer noise-resistance curve has a minimum which is slightly higher than the amplifier value. However, it is clearly demonstrated that the new principle largely wipes out the inherent advantage in signal-to-noise ratio hitherto maintained by amplifiers.

B. Tube Characteristics with Flattened-Top Transconductance: $\alpha = -1/27$

Curves similar to Fig. 15 have been plotted in Fig. 16 for the case when $\alpha = -1/27$ (see Fig. 14). The tube characteristic giving these results is the one with the output-electrode current characteristic which approaches a triangle, and the transconductance characteristic is somewhat flat topped. The results show a higher ratio of conversion transconductance to amplifier transconductance than with $\alpha = 0$ and the curve against oscillator excitation has a flatter top. The equivalent noise-resistance values are smaller, and, for $I_{b_{min}} = 0$ would even appear to be less than under amplifier conditions. This is not actually the case, inasmuch as, by sacrificing gain in the amplifier, the plate current may be reduced faster than the transconductance. Thus the amplifier noise equivalent may be improved somewhat over the figure of 10 heretofore mentioned.

Fig. 16 shows that harmonic conversion is also improved over the characteristic assumed for Fig. 15. This is only reasonable, since $\alpha = -1/27$ represents a closer approach to the ideal one than the sine-wave shape used for the curves of Fig. 16.

C. Tube Characteristics With Flattened-Top Current: $\alpha = +1/9$

Since the flat-topped current characteristic of Fig. 14(d) is also of interest, curves have been plotted for this case and are shown on Fig. 17. By a comparison with Figs. 15 and 16, it is made clear that this shape of characteristic is disadvantageous. Fundamental operation is more critical and harmonic conversion much poorer than with the more nearly ideal characteristics of Figs. 14(a) and 14(b) which were used for Figs. 15 and 16.

VII. Conclusions

It has been shown that phase-reversal conversion leads to the possibility of greatly improved converter operation. The detailed analysis of various tube characteristics shows that, for conversion at oscillator fundamental, the conversion transconductance is more than half of the transconductance of the same tube used as an amplifier. The equivalent noise resistance in the limit approaches the same value as the amplifier and in practical cases is only slightly higher. These comparisons are much more favorable than can be obtained with tubes of conventional design and use.

Harmonic conversion is also favorable from the point of view of gain, but is somewhat poorer from the point of view of equivalent noise resistance.

Acknowledgment

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Conjugate-Image Impedances*

SHEPARD ROBERTS†, MEMBER, I.R.E.

Summary—**A load having the conjugate impedance of the signal generator to which it is connected receives the maximum amount of power and is said to be matched on the conjugate-image basis. This method of impedance matching, when applied to active and passive four-terminal networks, is shown to be especially suitable for determining the limits of power amplification or loss. In contrast, an analysis on the usual image basis gives these results only if the image impedances happen to be pure resistances. The maximum power gain of a given network and the impedance terminations for achieving it are derived and are expressed in concise form. The effects of impedance mismatching are likewise treated.**

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† Massachusetts Institute of Technology, Cambridge, Massachusetts. This paper is based on work done for the Office of Scientific Research and Development under contract OEMsr-262 with the Radiation Laboratory, Massachusetts Institute of Technology.

I. Introduction

In proposing the conjugate-image method of network analysis, we have in mind impedance-matching problems such that the conservation or amplification of power is the primary consideration. For example, to evaluate the suitability of a given device for a specific application, one may need to know between what impedances, real or complex, the device will operate most efficiently and what proportion, greater or less than one, of the input power will be delivered to the output under these conditions. Also, one may need to know how this power will be affected if the terminating impedances differ from the optimum values.

When these problems are treated by the methods of network analysis on the usual image basis, as they have sometimes been in the past, one finds that the results are significant only if the image impedances are pure resistances. In order to analyze the operation of a device with complex image impedances, one has two alternatives. Either one may first tune the device by adding appropriate reactances at its input and output terminals and then continue the analysis on the usual image basis, or combine both steps in one operation and derive the results directly on the conjugate-image basis. The results by either method should be the same.

As a matter of practical significance, many common devices used in communication circuits, such as telephone cables and transformers, do have complex image impedances. The problem of determining the optimum impedances between which passive devices such as these may operate has been described by Johnson.[1] We are here concerned with systematizing and simplifying this analysis and extending it to more general cases, such as amplifiers with feedback and various types of mixers[2] which cannot be treated as passive networks.

II. Generators, Loads, and Available Power

In the radio art, one often finds examples where a source of signal energy can be represented as a constant-voltage source in series with an impedance, or a constant-current source in parallel with an impedance. When the signal originates in a linear network, these representations are justified by Thévenin's and Norton's theorems, respectively.[3] A device to which these representations are applicable will be called a generator in the following discussion.

A load impedance connected to a source of signal, or a generator, is in many applications "matched" to the impedance of the generator or vice versa. If the load impedance is matched on the usual image basis, it is made equal to the impedance of the generator. The maximum amount of power will be delivered into a load matched on this basis, provided that the generator impedance is purely resistive. If the maximum power from a generator having complex impedance is desired, it is not sufficient to match the load as above. One should first add enough reactance in series to tune out the reactance of the generator. This is another way of saying that for maximum power transfer, the load impedance should be the complex conjugate of the generator impedance. Impedance matching to secure maximum-power transfer will, therefore, be called matching on the conjugate-image basis. The power delivered from a generator to a load, when matched on this basis, will be called the available power[4] P_0 of the generator.

[1] K. S. Johnson, "Transmission Circuits for Telephonic Communication," D. Van Nostrand Company, Inc., New York, N. Y., chap. VII, sec. 721.

[2] L. C. Peterson and F. B. Llewellyn, "The performance and measurement of mixers in terms of linear-network theory," Proc. I.R.E., vol. 33, pp. 458–476; July, 1945.

[3] W. L. Everitt, "Communication Engineering," McGraw-Hill Book Company, New York, N. Y., 1932, chap. II.

The power delivered from a generator having an impedance Z_0 to a load impedance Z_1 may be derived with reference to Fig. 1. In this derivation and others to fol-

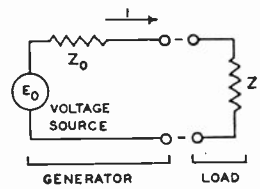

Fig. 1—Equivalent circuit of generator and load.

low, the asterisk is used to denote the conjugate of a complex quantity; thus, Z_0^* is the conjugate of Z_0.

$$\begin{aligned} P = ii^*R_1 &= \frac{e_0}{(Z_1+Z_0)}\cdot\frac{e_0^*}{(Z_1^*+Z_0^*)}\cdot\frac{(Z_1+Z_1^*)}{2} \\ &= \frac{e_0e_0^*}{2(Z_0+Z_0^*)}\cdot\frac{(Z_0+Z_0^*)(Z_1+Z_1^*)}{(Z_1+Z_0)(Z_1^*+Z_0^*)} \\ &= \frac{e_0e_0^*}{4R_0}\left[1-\frac{(Z_1-Z_0^*)(Z_1^*-Z_0)}{(Z_1+Z_0)(Z_1^*+Z_0^*)}\right] \end{aligned} \tag{1}$$

where R_0 and R_1 are the real parts of Z_0 and Z_1.

Equation (1) can also be written

$$P/P_0 = 1 - \alpha_{10}\alpha_{10}^* \tag{2}$$

where

$$\alpha_{10} = \frac{Z_1 - Z_0^*}{Z_1 + Z_0} \tag{3a}$$

and

$$P_0 = \frac{e_0e_0^*}{4R_0}. \tag{3b}$$

By analogy with transmission lines, α_{10} is called the "reflection coefficient" of the load as viewed from the generator. It differs from the corresponding reflection coefficient on the ordinary image basis in that the numerator contains the complex conjugate of Z_0. It is zero when the load and generator are matched on the conjugate-image basis, and its absolute value is always less than unity if Z_0 and Z_1 have positive resistance components. The reflection coefficient α_{01} of the generator, as viewed from the load, has the same magnitude as α_{10}, but a different phase angle as can be seen by interchanging Z_0 and Z_1 in (3a).

Impedance matching on the conjugate-image basis over a wide band of frequencies is not likely to be a simple matter. One is faced with the contradiction that all physically realizable impedances are analytic functions of frequency and that the conjugate of a complex analytic function is not analytic. However, the conjugate of a given impedance function can be realized exactly at a specific frequency, and approximately in a relatively small adjacent band of frequency.

[4] H. T. Friis, "Noise figures of radio receivers," Proc. I.R.E., vol. 32, pp. 419–422; July, 1944.

For this reason, the method of impedance matching described above may be useless in some applications, such as in telephone circuits, where the width of the frequency band to be used is a large fraction of the highest frequency in the band. On the other hand, this method finds useful applications in radio-communication circuits, and is sometimes known more familiarly by the name "tuning."

III. Conjugate Image Impedances of Four-Terminal Networks

The application of conjugate-image-impedance matching, outlined above for two-terminal loads and generators, may also be extended to more complicated arrangements, such as four-terminal impedance networks. Impedance matching of a four-terminal dissymmetrical network on this basis can be illustrated by an infinite

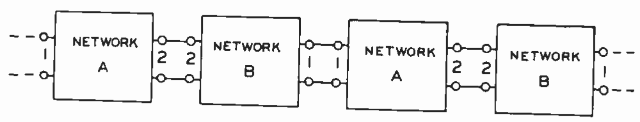

Fig. 2—Cascade of networks illustrating conjugate-image impedance matching.

cascade of networks, a portion of which is shown in Fig. 2. In this figure, network A is the given network and network B is identical to network A except that the impedance coefficients[5] of network B are conjugates of those of network A. Furthermore, each network B is reversed so that similar terminals are connected to network A at each junction. In an infinite cascade of this sort, provided there is some dissipation, it can be shown easily that at any junction of two networks the impedance looking to the right will be the conjugate of the impedance looking to the left. Fig. 2 may be compared with the corresponding cascades of networks on the iterative basis and on the normal image basis.[6]

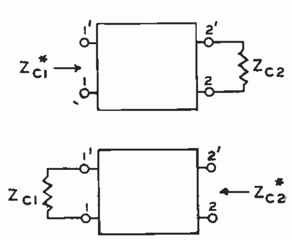

Fig. 3—Input impedances of network with matched terminations.

The following statement will serve as a definition of the conjugate-image impedances of a network. If a four-terminal network is so connected between such a generator and load that the impedance looking into the network from the generator is the conjugate of the generator impedance, while the impedance looking back at the network from the load is the conjugate of the load impedance, then the generator and load impedances are the conjugate-image impedances of the network. This is shown in Fig. 3, where Z_{c1} and Z_{c2} are the conjugate-image impedances.

The conjugate-image impedances can be expressed in terms of the usual network parameters. For example, the current and voltage relations in a four-terminal network may be stated in the form of a set of simultaneous equations such as the following:

$$\begin{aligned} e_1 &= z_{11}i_1 + z_{12}i_2 \\ e_2 &= z_{21}i_1 + z_{22}i_2. \end{aligned} \tag{4}$$

The voltages and currents e_1, e_2, and i_1, i_2 are indicated in Fig. 4. In equation (4) z_{11}, z_{12}, z_{21}, and z_{22} are complex impedance coefficients which characterize the network. These coefficients can be determined by known procedures from impedance measurements on the terminals of the device.[7]

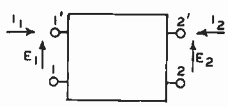

Fig. 4—Terminal currents and voltages in four-terminal network.

The input impedances indicated in Fig. 3 can be calculated from the impedance coefficients of the network and its terminating impedances. If we let $e_2 = -i_2Z_{c2}$ and solve (4) for e_1/i_1 ($=Z_{c1}^*$), we get

$$Z_{c1}^* = z_{11} - \frac{z_{12}z_{21}}{z_{22} + Z_{c2}}; \tag{5a}$$

similarly

$$Z_{c2}^* = z_{22} - \frac{z_{12}z_{21}}{z_{11} + Z_{c1}}. \tag{5b}$$

For nondissipative networks (5b) becomes identical with (5a). This case will be discussed later.

For dissipative networks this set of simultaneous equations can be solved for Z_{c1} and Z_{c2}. This is done by clearing fractions in (5a) and (5b) thus obtaining two independent expressions for $z_{12}z_{21}$. Letting $z_{11} = r_{11} + jx_{11}$ etc., we can equate the real and imaginary parts of the two expressions for $z_{12}z_{21}$, deriving the following ratios which serve as definitions of θ_r and θ_x:

$$\begin{aligned} \frac{R_{c1}}{r_{11}} &= \frac{R_{c2}}{r_{22}} = \theta_r \\ \frac{X_{c1} + x_{11}}{r_{11}} &= \frac{X_{c2} + x_{22}}{r_{22}} = \theta_x. \end{aligned} \tag{6a}$$

The conjugate-image impedances can now be expressed in terms of θ_r and θ_x.

$$\begin{aligned} Z_{c1} &= r_{11}(\theta_r + j\theta_x) - jx_{11} \\ Z_{c2} &= r_{22}(\theta_r + j\theta_x) - jx_{22}. \end{aligned} \tag{6b}$$

[5] See equation (4).
[6] E. A. Guillemin, "Communication Networks," vol. II, John Wiley and Sons, Inc., New York, N. Y., 1936; Figs. 52, 54.
[7] Chapter IV, of footnote reference 6.

Putting (6b) into either expression for $z_{12}z_{21}$ derived from (5a) or (5b) one obtains

$$z_{12}z_{21} = r_{11}r_{22}(1 - \theta_r + j\theta_x)(1 + \theta_r + j\theta_x). \quad (7a)$$

The values of θ_r and θ_x may be derived directly from (7a).

$$\theta_r = \sqrt{\left(1 - \frac{r_c^2}{r_{11}r_{22}}\right)\left(1 + \frac{x_c^2}{r_{11}r_{22}}\right)}$$
$$\theta_x = \frac{r_c x_c}{r_{11}r_{22}} \quad (7b)$$

where

$$r_c + jx_c = \sqrt{z_{12}z_{21}}.$$

θ_r is ordinarily a positive real number. It is meaningless if imaginary, for reasons discussed in section V. θ_x is real and may be either positive or negative.

IV. Gain of Four-Terminal Networks

The principal application of network analysis on the conjugate-image basis is in the determination of the power gain of a network. We shall use the symbol for gain proposed by Friis,[4] but shall modify his definition slightly. The gain is defined here as the ratio of the power delivered to the load impedance connected at the output terminals to the power available from the generator connected at the input terminals. This ratio is called "gain", irrespective of whether it is greater or less than one. It may be expressed alternatively in decibels, but will be stated here as a ratio except when otherwise specified.

(A) Ultimate Gain G_{21}

The "ultimate" gain G_{21} is the gain when a generator of impedance Z_{c1} is connected to terminals $1-1'$, while a load Z_{c2} is connected to terminals $2-2'$. If a generator of impedance Z_{c2} is connected to terminals $2-2'$, etc., the corresponding ultimate gain is called G_{12} to distinguish it from G_{21}.

Under the conditions described above the ultimate gain G_{21} is

$$G_{21} = \frac{i_2 i_2^* R_{c2}}{i_1 i_1^* R_{c1}}. \quad (8)$$

Putting $e_2 = -i_2 Z_{c2}$, we have from (4)

$$\frac{i_2}{i_1} = \frac{-z_{21}}{z_{22} + Z_{c2}} \quad (9)$$

hence

$$G_{21} = \frac{R_{c2}}{R_{c1}} \cdot \frac{z_{21}z_{21}^*}{(z_{22} + Z_{c2})(z_{22}^* + Z_{c2}^*)}. \quad (10)$$

Making use of (6b) we obtain

$$G_{21} = \frac{z_{21}z_{21}^*}{r_{11}r_{22}} \cdot \frac{1}{(1 + \theta_r)^2 + \theta_x^2}. \quad (11a)$$

Similarly

$$G_{12} = \frac{z_{12}z_{12}^*}{r_{11}r_{22}} \cdot \frac{1}{(1 + \theta_r)^2 + \theta_x^2}. \quad (11b)$$

Multiplying (11a) and (11b) and substituting the value of $z_{12}z_{21}$ given by (7a) we have

$$G_{12}G_{21} = \frac{(1 - \theta_r)^2 + \theta_x^2}{(1 + \theta_r)^2 + \theta_x^2}. \quad (12)$$

This can be simplified further if we define a coefficient α_c as follows. The importance and significance of α_c will be demonstrated in subsequent examples.

$$\alpha_c = \frac{1 - \theta_r + j\theta_x}{1 + \theta_r + j\theta_x} = \frac{z_{11} - Z_{c1}^*}{z_{11} + Z_{c1}} = \frac{z_{22} - Z_{c2}^*}{z_{22} + Z_{c2}}. \quad (13)$$

The second and third equalities in (13) may be derived from the first by means of (6a).

Then

$$G_{12}G_{21} = \alpha_c\alpha_c^*. \quad (14)$$

Also from (11)

$$\frac{G_{21}}{G_{12}} = \frac{z_{21}z_{21}^*}{z_{12}z_{12}^*}. \quad (15)$$

Therefore

$$G_{21} = \left|\alpha_c \frac{z_{21}}{z_{12}}\right| \quad (16a)$$

$$G_{12} = \left|\alpha_c \frac{z_{12}}{z_{21}}\right|. \quad (16b)$$

(B) Actual Gain G_{21}'

A similar analysis can be applied in determining the gain G_{21}' of the network when operating between the arbitrary generator impedance Z_0 connected to terminals $1-1'$ and a load impedance Z_2 connected to terminals $2-2'$. Reflection coefficients α_1 and α_2 for the generator and load, respectively, may be defined as follows:

$$\alpha_1 = \frac{Z_0 - Z_{c1}}{Z_0 + Z_{c1}^*}$$
$$\alpha_2 = \frac{Z_2 - Z_{c2}}{Z_2 + Z_{c2}^*}. \quad (17)$$

The current and voltage relations are

$$e_1 = i_1 z_{11} + i_2 z_{12} = e_0 - i_1 Z_0$$
$$e_2 = i_1 z_{21} + i_2 z_{22} = -i_2 Z_2. \quad (18)$$

Solving for i_2 we have

$$i_2 = \frac{-e_0 z_{21}}{(Z_0 + z_{11})(Z_2 + z_{22}) - z_{12}z_{21}}. \quad (19)$$

The power delivered to the load is then

$$P_2 = \frac{e_0 e_0^* z_{21}z_{21}^* R_2}{|(Z_0 + z_{11})(Z_2 + z_{22}) - z_{12}z_{21}|^2}. \quad (20)$$

Applying (3b) and the definition of gain we have

$$G_{21}' = \frac{4z_{21}z_{21}^* R_0 R_2}{\left|(Z_0 + z_{11})(Z_2 + z_{22}) - z_{12}z_{21}\right|^2}. \qquad (21)$$

Solving (17) for Z_0 and substituting the value given by (6b) for Z_{c1} we obtain

$$Z_0 = r_{11}\left(\theta_r \frac{1+\alpha_1}{1-\alpha_1} + j\theta_x\right) - jx_{11} \qquad (22a)$$

and the real part of Z_0 is

$$R_0 = r_{11}\theta_r \frac{1 - \alpha_1\alpha_1^*}{(1-\alpha_1)(1-\alpha_1^*)}. \qquad (22b)$$

If we take the ratio of G_{21}' given by (21) to G_{21} given by (11a), substitute the above expressions for Z_0 and R_0 and similar expressions for Z_2 and R_2 along with the value for $z_{12}z_{21}$ given by (7a) and simplify with the aid of (13) we obtain

$$\frac{G_{21}'}{G_{21}} = \frac{(1-\alpha_1\alpha_1^*)(1-\alpha_2\alpha_2^*)}{(1-\alpha_1\alpha_2\alpha_c)(1-\alpha_1^*\alpha_2^*\alpha_c^*)}. \qquad (23)$$

The various factors in (23) can be interpreted readily. If α_1 and α_2 are both zero, the gain becomes equal to the ultimate gain, which is the maximum value it can have. If α_1 and α_2 are not both zero, the factors in the numerator account for mismatch of the generator and/or load.[8] And if neither α_1 nor α_2 is zero, the denominator accounts for interaction between the power reflections from the load and generator. This interaction may either help or hinder the transfer of power.

(C) Available Gain G_{21}''

In accordance with Friis' definition, the "available" gain G_{21}'' is specified to be the ratio of the available power output from the network to the available power from the generator connected to its input terminals. The available output from terminals $2-2'$ is attained when the load Z_2 connected to these terminals is the conjugate of the impedance Z_2' seen looking back into these terminals with the generator impedance Z_0 connected to terminals $1-1'$. The value of Z_2' is found by letting $e_1 = -i_1Z_0$ and solving (4) for e_2/i_2.

$$Z_2' = z_{22} - \frac{z_{12}z_{21}}{Z_0 + z_{11}} \qquad (24)$$

The reflection coefficient for Z_2' with respect to the conjugate image impedance Z_{c2} is

$$\alpha_2' = \frac{Z_2' - Z_{c2}^*}{Z_2' + Z_{c2}}. \qquad (25a)$$

By substituting in (25a) the values of Z_{c2} given by (6b) and Z_2' as given by (24), in which $z_{12}z_{21}$ is determined by (7a) and Z_0 by (22a), we can simplify this equation thereby obtaining

$$\alpha_2' = \alpha_1 \frac{1 - \theta_r + j\theta_x}{1 + \theta_r + j\theta_x} = \alpha_1\alpha_c. \qquad (25b)$$

Furthermore, if Z_2 is to be the conjugate of Z_2', equation (17) becomes

$$\alpha_2 = \frac{Z_2'^* - Z_{c2}}{Z_2'^* + Z_{c2}^*} = \alpha_2'^* = \alpha_c^*\alpha_1^*. \qquad (26)$$

Putting this value in (23) we get the available gain of the network with a generator of arbitrary impedance Z_0.

$$G_{21}'' = G_{21}\frac{1 - \alpha_1\alpha_1^*}{1 - \alpha_1\alpha_1^*\alpha_c\alpha_c^*}. \qquad (27)$$

We have now defined three different concepts of gain, each of which has its specific application. The ultimate gain G_{21} corresponds to the condition that impedance match on the conjugate-image basis exists at both input and output terminations, or $\alpha_1 = \alpha_2 = 0$. The available gain G_{21}'' corresponds to the situation that impedance-match exists at the output termination, or $\alpha_2 = \alpha_1^*\alpha_c^*$. The actual gain G_{21}' corresponds to the general case in which a match may not exist at either termination. Under these conditions, and if α_1 is the same in the last two cases, (27) and (23) indicate that $G_{21} \geqq G_{21}'' \geqq G_{21}'$.

V. Special Cases

The analysis presented above applies specifically to dissipative networks. For a nondissipative network, or one with purely reactive impedance coefficients in (4), equations (5a) and (5b) become identical, as previously pointed out, and it is not possible to obtain unique solutions for two unknowns with only one independent equation. If, under these conditions, a state of impedance match exists at either the load or the generator; that is to say, the impedance looking to the right is the conjugate of the impedance looking to the left, then such a state exists at both. This important property of a nondissipative network is obviously true if the network is passive, in other words if $x_{12} = x_{21}$. In this case the power output must equal the power input. If the generator is putting out as much power as it possibly can, then the load must be receiving as much power as it possibly can, or vice versa.

The concept of available power and all the foregoing analysis can become meaningless if negative resistances are present. A generator which, when represented according to Thévenin's theorem, has a negative resistance component of impedance does not have a maximum power output in the sense referred to above. Instead, with a load impedance equal and opposite in sign to the generator impedance, the total impedance presented to the constant-voltage-signal source is zero. This means that power can theoretically be delivered to the load even when the signal voltage is vanishingly small. In other words, the device can operate as an oscillator.

Under certain conditions, a four-terminal network can exhibit the property of negative resistance and in such

[8] Compare with equation (2).

cases it is impossible to apply conjugate-image-impedance matching. If, for example, r_{11} or r_{22} is negative, the impedance measured at one pair of terminals with the other pair on open circuit has a negative resistance component. Negative terminal resistances are also possible if the quantity under the square-root sign in (7b) is negative, or if $r_c^2 > r_{11}r_{22}$, which is conceivable even if none of the resistance coefficients of the network is negative. In this case it can be shown that the impedance looking into terminals $1-1'$ will have a negative resistance component if terminals $2-2'$ are terminated in the reactance $j(r_{22}\theta_x - x_{22})$. The sign of the quantity under the square-root sign is thus an index as to whether or not the device is potentially an oscillator.

The analysis in the preceding sections, which has been worked out on the impedance basis, can just as well be done on the admittance basis. Starting with (28), we can proceed in exactly the same manner and obtain similar results, expressed in admittances instead of impedances.

$$\begin{aligned} i_1 &= y_{11}e_1 + y_{12}e_2 \\ i_2 &= y_{21}e_1 + y_{22}e_2. \end{aligned} \tag{28}$$

All of the derived equations are valid on the admittance basis if we simply replace r and x by g and b, where $y_{11} = g_{11} + jb_{11}$, etc. It should be borne in mind, however, that the phase angle of a reflection coefficient determined on the admittance basis is different from that of the corresponding coefficient determined on the impedance basis.

VI. Examples

A. To illustrate the comparison between conjugate-image impedances and normal image impedances we shall apply this analysis to a repeating coil having the following characteristics at a frequency of 1000 cycles per second:

$$Z_{1oc}' = 575 + j4848 \text{ ohms} = z_{11} \text{ (secondary open circuit)}$$
$$Z_{1sc}' = 80.5 + j62 \text{ ohms} \quad \text{(secondary short circuit)}$$
$$Z_{2oc}' = 863 + j7272 \text{ ohms} = z_{22} \text{ (primary open circuit).}$$

The problem is to determine the conjugate-image impedances and ultimate gain of this transformer.

We have

$$z_{12} = z_{21} = \sqrt{z_{22}(z_{11} - Z_{1sc}')} = z_c$$
$$= 655 + j5900 \text{ ohms.}$$

From (7b) we obtain

$$\theta_r = 3.10$$
$$\theta_x = 7.79.$$

Then from (6b)

$$Z_{c1} = 1784 - j370 = 1823\underline{/12.0 \text{ degrees}}$$
$$Z_{c2} = 2675 - j552 = 2730\underline{/11.9 \text{ degrees.}}$$

From (13) we have

$$\alpha_c = \frac{1 - 3.10 + j7.79}{1 + 3.10 + j7.79} = 0.959\underline{/36.8 \text{ degrees.}}$$

Then from (16)

$$G_{12} = G_{21} = 0.959 = -0.18 \text{ decibels.}$$

For comparison with Z_{c1} and Z_{c2}, the normal image impedances are

$$Z_{I1} = 346.5 + j612 = 705\underline{/60.58 \text{ degrees}}$$
$$Z_{I2} = 509.5 + j920 = 1056\underline{/60.58 \text{ degrees.}}$$

The contrast between the normal image impedances and the conjugate-image impedances is here very striking. It indicates the magnitude of the discrepancies one may encounter in not using the conjugate-image method of analysis for problems involving power transfer.

B. As another example let us investigate the stability of an intermediate-frequency amplifier circuit. We want to determine how small the grid-plate capacitance should be, so that the amplifier cannot oscillate regardless of how it is tuned. Let us analyze the simplified circuit of Fig. 5 as a four-terminal network. The plate

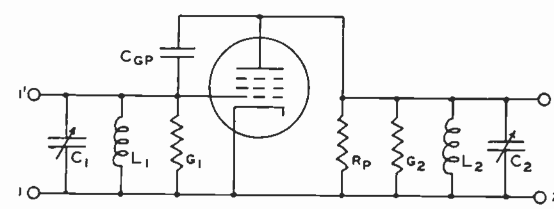

Fig. 5—Equivalent circuit of amplifier stage.

resistance r_p of the tube and its grid-plate capacitance C_{gp} are included as separate elements in this diagram.

This circuit may be analyzed on the admittance basis, referring to (28). The conductances and susceptances, expressed in micromhos, are as follows:

$$g_{11} = g_1 = 4$$
$$g_{22} = g_2 + \frac{1}{r_p} = 4 + 1 = 5$$
$$g_{12} = 0$$
$$g_{21} = g_m = 1500$$
$$b_{12} = b_{21} = \omega C_{gp}.$$

Where C_{gp} is in microfarads,

$$\omega = 2\pi \cdot 465 \text{ kilocycles.}$$

We have shown that the condition for oscillation is $g_c^2 > g_{11}g_{22}$. The minimum value of g_c for which oscillations are possible is then $g_c = \sqrt{g_{11}g_{22}}$.

We have

$$g_c + jb_c = \sqrt{y_{12}y_{21}} = \sqrt{jb_{12}(1500 + jb_{12})}$$
$$\cong \sqrt{j1500b_{12}} = \sqrt{750b_{12}} + j\sqrt{750b_{12}}$$

assuming

$$b_{12} \ll 1500.$$

Then

$$g_c = \sqrt{750 b_{12}}$$

and

$$\sqrt{750 b_{12}} = \sqrt{20}, \qquad b_{12} = -0.0266 \text{ micromhos}$$

or

$$C_{gp} = 0.0091 \text{ micromicrofarads.}$$

This low value indicates the importance of shielding in high-gain amplifiers. It should be emphasized that an amplifier with capacitance greater than this value does not necessarily oscillate and may, in fact, be perfectly satisfactory for a specific application. However, if one tunes such an amplifier for maximum gain at a single frequency, disregarding its band-pass characteristics, one will eventually bring the amplifier into oscillation. Tuning with the aid of an oscilloscope and frequency-modulated oscillator generally avoids this difficulty.

This example illustrates that the analysis on the conjugate-image basis may be useful even in problems not directly concerned with impedance matching or power gain.

A Theory for Three-Element Broadside Arrays*

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Summary—**The vector relationship between the voltages that must be applied across the terminals of a three-element array, to maintain input currents of the same amplitude and phase, is determined. Each antenna is of half-length h, and of radius a. The spacing between antennas is b. Two broadside arrays having the following dimensions are analyzed numerically: (a). $h=\lambda/2$, $b=\lambda/2$, and $\Omega=2\ln(2h/a)=20$; (b). $h=\lambda/4$, $b=\lambda/2$, and $\Omega=20$. The results of these calculations are supplied in the form of vector diagrams.**

BY DEFINITION a broadside array consists of a number of identical antennas, oriented in the following geometrical manner:

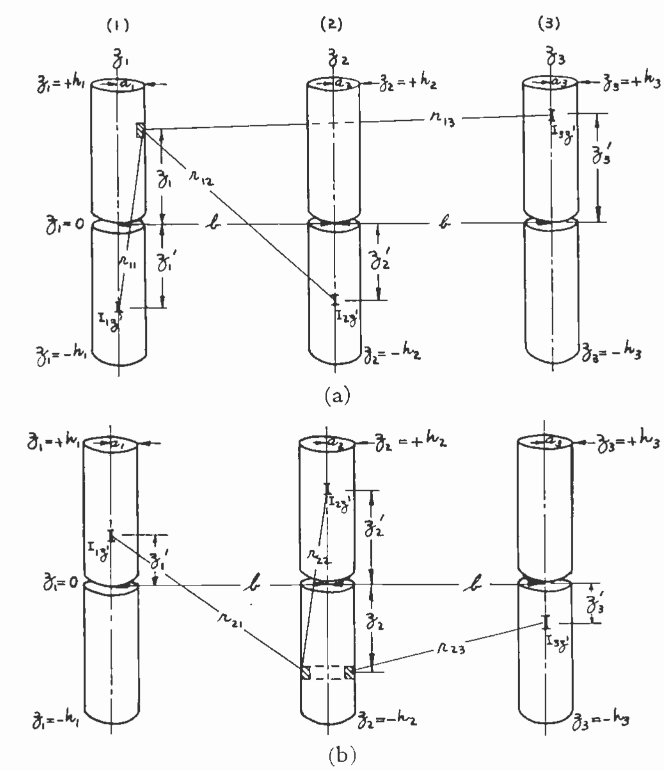

Fig. 1—Three-element broadside array. Two views of the same array are shown in order to lessen the possibility of confusing the various distance lines.

(a). The antennas lie in the same plane.

(b). The axis of each antenna makes a right angle to a straight line connecting their centers.

(c). The antennas are equally spaced.

Electrically the definition requires the currents flowing at the input terminals to be of equal amplitude and of the same phase.

Fig. 1 illustrates a three-element broadside array. The antennas are consecutively numbered from left to right. Each has a half-length $h=h_1=h_2=h_3$, and radius $a=a_1=a_2=a_3$. The spacing between elements is b. Fig. 2

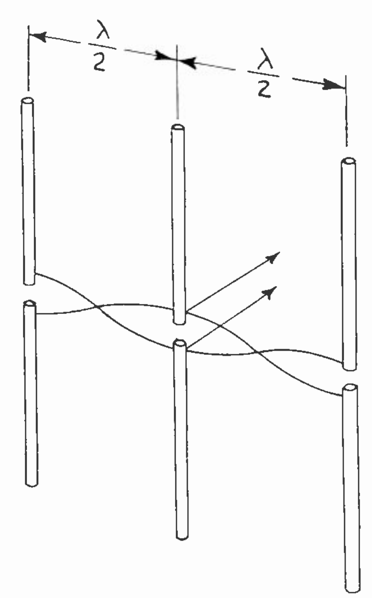

Fig. 2—Three-element array driven by crossed $\lambda/2$ transmission lines.

shows a common method of driving a three-element broadside array, when the spacing is such that crossed half-wave transmission lines may be employed.

Returning to Fig. 1, a moment's reflection is sufficient to see that the input impedance of antenna (1) does not equal the input impedance of antenna (2), for the antennas occupy different geometrical positions in the

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array. Thus for equal applied voltages, the currents flowing at the input terminals are unequal, and the definition for a broadside array cannot be satisfied.

The intent of the present paper is to determine analytically the vector relationship between the applied voltages necessary to establish identical driving-point currents in all antennas. The theory is utilized to calculate conditions obtaining in three-element broadside arrays having the following dimensions: (1). $h=b=\lambda/2$ and $h/a\approx 11{,}013$. (2). Same as (1) but for $h=\lambda/4$. The possibility of feeding this array in the required manner by use of a feed system comparable to that shown in Fig. (2), is considered briefly.

It can be shown that the distributions of current along antennas (1) and (2) respectively, may be written[1,2]

$$I_{1z} = -\frac{j4\pi}{\Omega_1 R_c}\left\{C_1 \cos\beta z_1 + \tfrac{1}{2}V_{10}^e \sin\beta|z_1|\right\} - \frac{1}{\Omega_1}\left\{I_{1z}\ln\left(1-\frac{z_1^2}{h_1^2}\right) + I_{1z}\delta_1 + \int_{-h_1}^{+h_1}\frac{I_{1z'}e^{-j\beta r_{11}} - I_{1z}}{r_{11}}dz_1' + \int_{-h_2}^{+h_2} I_{2z'}\frac{e^{-j\beta r_{12}}}{r_{12}}dz_2' + \int_{-h_3}^{+h_3} I_{3z'}\frac{e^{-j\beta r_{13}}}{r_{13}}dz_3'\right\} \tag{1}$$

and

$$I_{2z} = -\frac{j4\pi}{\Omega_2 R_c}\left\{C_2 \cos\beta z_2 + \tfrac{1}{2}V_{20}^e \sin\beta|z_2|\right\} - \frac{1}{\Omega_2}\left\{I_{2z}\ln\left(1-\frac{z_2^2}{h_2^2}\right) + I_{2z}\delta_2 + \int_{-h_2}^{+h_2}\frac{I_{2z'}e^{-j\beta r_{22}} - I_{2z}}{r_{22}}dz_2' + \int_{-h_1}^{+h_1} I_{1z'}\frac{e^{-j\beta r_{21}}}{r_{21}}dz_1' + \int_{-h_3}^{+h_3} I_{3z'}\frac{e^{-j\beta r_{23}}}{r_{23}}dz_3'\right\}. \tag{2}$$

The following notation is used:

$$\Omega = 2\ln\frac{2h}{a} \tag{3}$$

$$R_c = 376.7 \approx 120\pi \text{ ohms} \tag{4}$$

C_1 and C_2 are arbitrary constants to be determined later.

V_{10}^e and V_{20}^e are the voltages applied to the input terminals of antennas (1) and (2), respectively.

[1] Ronold King and Charles W. Harrison, Jr., "Mutual and self-impedance for coupled antennas," *Jour. Appl. Phys.*, vol. 15, pp. 481–495; June, 1944.

[2] Charles W. Harrison, Jr., "Symmetrical antenna arrays," PROC. I.R.E., vol. 33, pp. 892–896; December, 1945.

$$\delta = \ln\left\{\frac{1}{4}\left[\left(1+\left(\frac{a}{h-z}\right)^2\right)^{1/2}+1\right]\cdot\left[\left(1+\left(\frac{a}{h+z}\right)^2\right)^{1/2}+1\right]\right\} \tag{5}$$

$$r_{11} = \left\{(z_1-z_1')^2 + a_1^2\right\}^{1/2} \approx |z_1 - z_1'| \tag{6}$$

$$r_{12} = \sqrt{(z_1-z_2')^2 + b^2} \tag{7}$$

$$r_{13} = \sqrt{(z_1-z_3')^2 + 4b^2} \tag{8}$$

$$r_{22} = \sqrt{(z_2-z_2')^2 + a_2^2} \approx |z_2 - z_2'| \tag{9}$$

$$r_{21} = \sqrt{(z_2-z_1')^2 + b^2} \tag{10}$$

$$r_{23} = \sqrt{(z_2-z_3')^2 + b^2}. \tag{11}$$

The current I_{10} flowing at the input terminals of antenna (1) may be obtained from (1) by writing $z_1=0$ throughout. Thus

$$I_{10} = -\frac{j4\pi}{\Omega_1 R_c}\{C_1\} - \frac{1}{\Omega_1}\left\{\int_{-h_1}^{+h_1}\frac{I_{1z'}e^{-j\beta l_{11}} - I_{10}}{l_{11}}dz_1' + \int_{-h_2}^{+h_2} I_{2z'}\frac{e^{-j\beta l_{12}}}{l_{12}}dz_2' + \int_{-h_3}^{+h_3} I_{3z'}\frac{e^{-j\beta l_{13}}}{l_{13}}dz_3'\right\}. \tag{12}$$

Similarly the current I_{20} flowing at the input terminals of antenna (2) is given by (2) with $z_2=0$. Thus

$$I_{20} = -\frac{j4\pi}{\Omega_2 R_c}\{C_2\} - \frac{1}{\Omega_2}\left\{\int_{-h_2}^{+h_2}\frac{I_{2z'}e^{-j\beta l_{22}} - I_{20}}{l_{22}}dz_2' + \int_{-h_1}^{+h_1} I_{1z'}\frac{e^{-j\beta l_{21}}}{l_{21}}dz_1' + \int_{-h_3}^{+h_3} I_{3z'}\frac{e^{-j\beta l_{23}}}{l_{23}}dz_3'\right\}. \tag{13}$$

In (12) and (13), the l's are derived directly from the r's (see (6) through (11)), by requiring $z_1=z_2=0$.

The antenna currents vanish at $z_1=\pm h_1$ and $z_2=\pm h_2$. For these conditions, (1) and (2) become

$$0 = -\frac{j4\pi}{\Omega_1 R_c}\left\{C_1\cos\beta h_1 + \tfrac{1}{2}V_{10}^e\sin\beta h_1\right\} - \frac{1}{\Omega_1}\left\{\int_{-h_1}^{+h_1} I_{1z'}\frac{e^{-j\beta d_{11}}}{d_{11}}dz_1' + \int_{-h_2}^{+h_2} I_{2z'}\frac{e^{-j\beta d_{12}}}{d_{12}}dz_2' + \int_{-h_3}^{+h_3} I_{3z'}\frac{e^{-j\beta d_{13}}}{d_{13}}dz_3'\right\} \tag{14}$$

and

$$0 = -\frac{j4\pi}{\Omega_2 R_c}\left\{C_2\cos\beta h_2 + \tfrac{1}{2}V_{20}^e\sin\beta h_2\right\} - \frac{1}{\Omega_2}\left\{\int_{-h_2}^{+h_2} I_{2z'}\frac{e^{-j\beta d_{22}}}{d_{22}}dz_2'\right.$$

$$+\int_{-h_1}^{+h_1} I_{1z'} \frac{e^{-j\beta d_{21}}}{d_{21}} dz_1'$$
$$\left. + \int_{-h_3}^{+h_3} I_{3z'} \frac{e^{-j\beta d_{23}}}{d_{23}} dz_3' \right\} . \tag{15}$$

Here the d's are derived from the r's (see (6) through (11)), by requiring $z_1 = +h_1$ and $z_2 = +h_2$.

In solving (1) or (2), a process of iteration is used. For instance, the expression[3]

$$(I_{1z})_0 = -\frac{j4\pi}{\Omega_1 R_c}\left\{C_1 \cos\beta z_1 + \tfrac{1}{2}V_{10}^e \sin\beta|z_1|\right\} \tag{16}$$

is conveniently selected as the zeroth-order approximation for the distribution of current along antenna (1), and this is substituted in the appropriate integrals when computing a first-order correction to the current in either antenna. Theoretically this procedure may be extended indefinitely, but in practice only two terms in the expansion for the current are ordinarily retained. In the present analysis terms of higher order will be neglected.

If the voltage V_{30}^e, applied to the input terminals of antenna (3), is equal in magnitude and phase to V_{10}^e, then for reasons of symmetry

$$I_{1z} = I_{3z} \tag{17}$$

and

$$C_3 = C_1. \tag{18}$$

Here C_3 is the arbitrary constant involved in the expression for I_{3z}. Upon taking cognizance of (17) and (18), it is clear that one may choose

$$(I_{3z})_0 = -\frac{j4\pi}{\Omega_1 R_c}\left\{C_1 \cos\beta z_3 + \tfrac{1}{2}V_{10}^e \sin\beta|z_3|\right\} \tag{19}$$

to represent the leading term in the distribution of current along antenna (3).

By adopting an appropriate shorthand, and observing that the antennas comprising the array are of the same length and radius, (12), (13), (14), and (15), taken in consecutive order, may be written

$$I_{10} = -\frac{j4\pi}{\Omega R_c}\left\{C_1\left\{1 + \frac{1}{\Omega}(F_1(0) + J_1(0))\right\}\right.$$
$$+ \tfrac{1}{2}V_{10}^e \frac{1}{\Omega}\{G_1(0) + K_1(0)\}$$
$$\left. + \frac{1}{\Omega}\{C_2 P_1(0) + \tfrac{1}{2}V_{20}^e Q_1(0)\}\right\} \tag{20}$$

$$I_{20} = -\frac{j4\pi}{\Omega R_c}\left\{C_2\left\{1 + \frac{1}{\Omega}F_1(0)\right\} + V_{10}^e \frac{1}{\Omega}Q_1(0)\right.$$
$$\left. + \frac{2}{\Omega}C_1 P_1(0) + \frac{V_{20}^e G_1(0)}{2\Omega}\right\} . \tag{21}$$

$$C_1\left\{\cos\beta h + \frac{1}{\Omega}\{F_1(h) + J_1(h)\}\right\}$$
$$+ \tfrac{1}{2}V_{10}^e\left\{\sin\beta h + \frac{1}{\Omega}\{G_1(h) + K_1(h)\}\right\}$$
$$+ \frac{1}{\Omega}\{C_2 P_1(h) + \tfrac{1}{2}V_{20}^e Q_1(h)\} = 0 \tag{22}$$

$$C_2\left\{\cos\beta h + \frac{1}{\Omega}F_1(h)\right\}$$
$$+ \tfrac{1}{2}V_{20}^e\left\{\sin\beta h + \frac{1}{\Omega}G_1(h)\right\}$$
$$+ V_{10}^e \frac{1}{\Omega}Q_1(h) + \frac{2}{\Omega}C_1 P_1(h) = 0. \tag{23}$$

The following notation is employed:

$$F_1(0) \approx -\int_{-h}^{+h} \frac{\cos\beta u \, e^{-j\beta|u|} - 1}{|u|} du \tag{24}$$

$$F_1(h) \approx -\int_{-h}^{+h} \cos\beta u \frac{e^{-j\beta|h-u|}}{|h-u|} du \tag{25}$$

$$G_1(0) \approx -\int_{-h}^{+h} \sin\beta|u| \frac{e^{-j\beta|u|}}{|u|} du \tag{26}$$

$$G_1(h) \approx -\int_{-h}^{+h} \sin\beta|u| \frac{e^{-j\beta|h-u|}}{|h-u|} du \tag{27}$$

$$P_1(0) = -\int_{-h}^{+h} \cos\beta u \frac{e^{-j\beta\sqrt{u^2+b^2}}}{\sqrt{u^2+b^2}} du \tag{28}$$

$$P_1(h) = -\int_{-h}^{+h} \cos\beta u \frac{e^{-j\beta\sqrt{(h-u)^2+b^2}}}{\sqrt{(h-u)^2+b^2}} du \tag{29}$$

[3] In (1), $I_{1h} = 0$ when $z_1 = \pm h_1$. If this substitution is made, and the result is subtracted from (1), the following expression is obtained:

$$I_{1z} = -\frac{j4\pi}{\Omega_1 R_c}\left\{C_1\{\cos\beta z_1 - \cos\beta h_1\} + \tfrac{1}{2}V_{10}^e\{\sin\beta|z_1| - \sin\beta h_1\}\right\}$$
$$-\frac{1}{\Omega_1}\left\{I_{1z}\ln\left(1 - \frac{z_1^2}{h_1^2}\right) + I_{1z}\delta_1 + \int_{-h_1}^{+h_1}\frac{I_{1z'}e^{-j\beta r_{11}} - I_{1z}}{r_{11}} dz_1'\right.$$
$$\left.-\int_{-h_1}^{+h_1} I_{1z'}\frac{e^{-j\beta d_{11}}}{d_{11}} dz_1'\right\} - \frac{1}{\Omega_1}\left\{\int_{-h_2}^{+h_2} I_{2z'}\frac{e^{-j\beta r_{12}}}{r_{12}} dz_2'\right.$$
$$-\int_{-h_2}^{+h_2} I_{2z'}\frac{e^{-j\beta d_{12}}}{d_{12}} dz_2' + \int_{-h_3}^{+h_3} I_{3z'}\frac{e^{-j\beta r_{13}}}{r_{13}} dz_3'$$
$$\left.-\int_{-h_3}^{+h_3} I_{3z'}\frac{e^{-j\beta d_{13}}}{d_{13}} dz_3'\right\} .$$

This is analytically more rigorous than (1) because I_{1h} now vanishes for all values of βh_1, whereas when $z_1 = \pm h_1$ is substituted in (1), the term involving C_1 disappears if $\cos\beta h_1 = 0$. Thus it is not possible to make the right side zero as required.

The usual procedure is to choose

$$(I_{1z})_0 = -\frac{j4\pi}{\Omega_1 R_c}\left\{C_1\{\cos\beta z_1 - \cos\beta h_1\} + \tfrac{1}{2}V_{10}^e\{\sin\beta|z_1| - \sin\beta h_1\}\right\}$$

to represent the zeroth-order approximation for the current distribution along antenna (1) in lieu of (16). Investigation reveals that results obtained using (16) with (1) differ only a few per cent from those obtained with the more correct forms, even for $\beta h = \pi/2$. The employment of (16) has the obvious advantage of greatly reducing the number of integrals encountered in the analysis, and additionally, the functions Cuv δ and Suv δ, defined in the appendix of footnote reference 1, are entirely avoided.

Although the notation is similar to that previously used in papers on antenna theory, the present selection of leading term in the expansion for the current implies a difference in the analytical form of the functions $F_1(0)$, $F_1(h)$, $P_1(0)$, $P_1(h)$, etc., defined later.

$$Q_1(0) = -\int_{-h}^{+h} \sin\beta|u| \frac{e^{-j\beta\sqrt{u^2+b^2}}}{\sqrt{u^2+b^2}}\,du \tag{30}$$

$$Q_1(h) = -\int_{-h}^{+h} \sin\beta|u| \frac{e^{-j\beta\sqrt{(h-u)^2+b^2}}}{\sqrt{(h-u)^2+b^2}}\,du \tag{31}$$

$$J_1(0) = -\int_{-h}^{+h} \cos\beta u \frac{e^{-j\beta\sqrt{u^2+4b^2}}}{\sqrt{u^2+4b^2}}\,du \tag{32}$$

$$J_1(h) = -\int_{-h}^{+h} \cos\beta u \frac{e^{-j\beta\sqrt{(h-u)^2+4b^2}}}{\sqrt{(h-u)^2+4b^2}}\,du \tag{33}$$

$$K_1(0) = -\int_{-h}^{+h} \sin\beta|u| \frac{e^{-j\beta\sqrt{u^2+4b^2}}}{\sqrt{u^2+4b^2}}\,du \tag{34}$$

$$K_1(h) = -\int_{-h}^{+h} \sin\beta|u| \frac{e^{-j\beta\sqrt{(h-u)^2+4b^2}}}{\sqrt{(h-u)^2+4b^2}}\,du. \tag{35}$$

Values for the above integrals are listed in the appendix.

Equations (20), (21), (22), and (23) form the basis for the writer's solution of the three-element broadside array problem. Readers should bear in mind that each expression is valid only through the first-order approximation. Assuming the problem can be solved to satisfactory accuracy by using the present technique, C_1 and C_2 must be determined from a simultaneous solution of (22) and (23). This is conveniently accomplished by writing the coefficients of the constants and voltages in magnitude phase-angle form. In the following calculations C_1 and C_2 are evaluated directly by substituting numerical values in (22) and (23).

The necessary vector relationship between V_{10}^e and V_{20}^e to insure broadside operation is established by equating (20) to (21). Thus

$$\begin{aligned} C_1&\left\{1 + \frac{1}{\Omega}\{F_1(0) + J_1(0) - 2P_1(0)\}\right\} \\ &+ \tfrac{1}{2}V_{10}^e\frac{1}{\Omega}\{G_1(0) + K_1(0) - 2Q_1(0)\} \\ &+ \tfrac{1}{2}V_{20}^e\frac{1}{\Omega}\{Q_1(0) - G_1(0)\} \\ &+ C_2\left\{-1 + \frac{1}{\Omega}\{P_1(0) - F_1(0)\}\right\} = 0. \end{aligned} \tag{36}$$

The problem of the three-element broadside array may easily be formulated in terms of mutual and self-impedance. The circuit relations of interest are the following:

$$V_{10}^e = I_{10}Z_{s1} + I_{20}Z_{12} + I_{30}Z_{13} \tag{37}$$

$$V_{20}^e = I_{20}Z_{s2} + I_{10}Z_{21} + I_{30}Z_{23}. \tag{38}$$

Here Z_{s1} and Z_{s2} are the self-impedances of antennas (1) and (2), respectively. Z_{12}, Z_{13}, etc. are mutual impedances.

Since for broadside operation the terminal currents are identical, (37) and (38) become

$$V_{10}^e = I_{10}\{Z_{s1} + Z_{12} + Z_{13}\} \tag{39}$$

$$V_{20}^e = I_{10}\{Z_{s2} + Z_{21} + Z_{23}\}. \tag{40}$$

Hence

$$V_{20}^e = V_{10}^e\left\{\frac{Z_{s2} + Z_{21} + Z_{23}}{Z_{s1} + Z_{12} + Z_{13}}\right\}. \tag{41}$$

Values for mutual and self-impedance have appeared in the literature,[1] but these have been derived on the premise that only two antennas comprise the array. Even though it is theoretically unsound to employ such impedances in the solution of antenna problems involving more than two radiators, good results are often obtained by their use in analyzing multielement radiating systems composed of relatively thick half-wave dipoles.

As the first numerical illustration of the present theory, consider a three-element broadside array for which $h=\lambda/2$, $b=\lambda/2$, and $\Omega=20$. For this case, (42) to (56) give

$$\begin{aligned} F_1(0) &= 2.438 + j1.418 \\ F_1(h) &= -1.557 - j0.7461 \\ G_1(0) &= -1.418 + j2.438 \\ G_1(h) &= -0.6720 + j0.8810 \\ P_1(0) &= 0.3268 + j0.3360 \\ P_1(h) &= -0.0490 - j0.3962 \\ Q_1(0) &= 0.9980 - j0.4180 \\ Q_1(h) &= 0.2619 - j0.3962 \\ J_1(0) &= -0.0615 - j0.1310 \\ J_1(h) &= -0.1080 + j0.0880 \\ K_1(0) &= -0.5910 + j0.1339 \\ K_1(h) &= -0.2960 + j0.3020. \end{aligned}$$

Substituting these values in (22) and (23), and solving simultaneously, one obtains

$$C_1 = V_{10}^e\{-0.0213+j0.0282\} + V_{20}^e\{0.0054-j0.0096\}$$
$$C_2 = V_{10}^e\{-0.0149+j0.0163\} + V_{20}^e\{0.0178-j0.0186\}.$$

Finally, upon employing (36), and requiring $V_{10}^e\{=V_{30}^e\} = 1.0+j0.0$ volts,

$$V_{20}^e = 1.843 + j0.3576 = 1.877 \text{ volts} \underline{|+11.0 \text{ degrees.}}$$

A plot of this result is shown in Fig. 3(a).

As a second illustration, require $h=\lambda/4$, $b=\lambda/2$, and $\Omega=20$. For this case, one obtains from (42) to (56),

$$\begin{aligned} F_1(0) &= 1.648 + j1.852 \\ F_1(h) &= -0.7090 + j1.219 \\ G_1(0) &= -1.418 + j1.648 \\ G_1(h) &= 1.815 + j1.143 \\ P_1(0) &= 0.6190 - j0.0440 \\ P_1(h) &= 0.4990 - j0.2090 \\ Q_1(0) &= 0.5920 - j0.1027 \end{aligned}$$

$$Q_1(h) = 0.4557 - j0.2120$$
$$J_1(0) = -0.3159 + j0.0120$$
$$J_1(h) = -0.2955 + j0.0670$$
$$K_1(0) = -0.3120 + j0.0279$$
$$K_1(h) = -0.2852 + j0.0775.$$

Employing these values in (22) and (23), and solving the equations simultaneously, one finds that

$$C_1 = V_{10}^e\{2.488 + j6.814\} + V_{20}^e\{-0.6656 + j2.768\}$$
$$C_2 = V_{10}^e\{-1.331 + j5.518\} + V_{20}^e\{1.849 + j8.266\}.$$

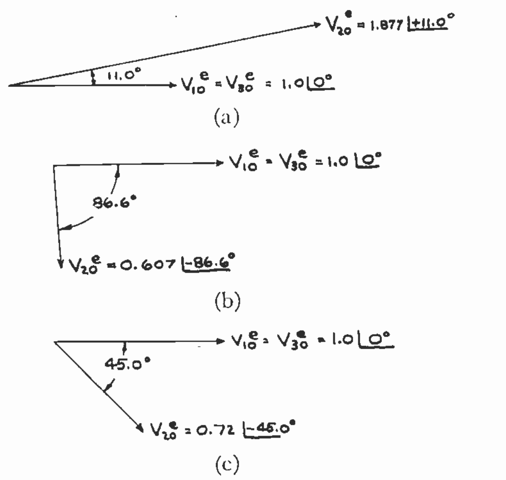


Fig. 3—Three-element broadside-array vector diagrams.

Finally, upon substituting the values for these constants in (36), and requiring $V_{10}^e\{=V_{30}^e\} = 1.0 + j0.0$ volts,

$$V_{20}^e = 0.0350 - j0.6060 = 0.607 \text{ volts} \underline{\left|-86.6 \text{ degrees.}\right.}$$

A plot of this result is shown in Fig. 3(b).

If the assumption is made that the distribution of current in all antennas is sinusoidal, then it is legitimate to employ values for mutual and self-impedance based on Poynting vector methods. When $h=\lambda/4$ and $b=\lambda/2$,

$$Z_{s1} = Z_{s2} = 73.13 + j42.50 \text{ ohms.}$$
$$Z_{12} = Z_{21} = Z_{23} \approx -12.0 - j30.2 \text{ ohms.}$$
$$Z_{13} \approx 4.2 + j18.5 \text{ ohms.}$$

Requiring $V_{10}^e\{=V_{30}^e\} = 1.0 + j0.0$ volts, and substituting the above impedance values in (41), the result is

$$V_{20}^e = 0.51 - j0.51 = 0.72 \text{ volts} \underline{\left|-45.0 \text{ degrees.}\right.}$$

A plot is shown in Fig. 3(c).

In carrying out the above calculations, great care was taken to avoid errors. Whereas the analysis for a broadside array appears to be a rather formidable task if the present theory is used, the writer found that an array can be analyzed in approximately four hours, provided a fully automatic calculating machine and necessary mathematical tables are available.

It is difficult to draw any positive conclusions regarding the accuracy of the present theory, inasmuch as no experimental evidence is available to the author. Clearly, an arrangement to produce identical voltages across the input terminals of an array (as shown in Fig. 2), cannot be trusted to insure broadside operation, unless the elements are individually tuned. This might be appropriately accomplished by a slight adjustment of the dimensions h and b, or a small change in the length of the center radiator alone may suffice. Nevertheless, considerable doubt exists as to the possibility of securing simultaneously input currents of the same *amplitude* as well as of the same *phase*, by employing crossed transmission lines.

The effect of changing the dimensions of antenna (2), on the performance of the array, may be studied with little additional labor.

Frequently in practice it is desirable to minimize the amplitude of the side lobes in the radiation field pattern of a given array. For the array pictured in Fig. 1, for example, this may be achieved by reducing the input-current amplitude in antennas (1) and (3) as compared to the current amplitude existing in antenna (2). Suppose one arbitrarily chooses $I_{10} = I_{20}/9$. Then a study of this array with "tapered feed" devolves simply into multiplying (20) by 9, and equating the result to (21).

The importance of the present theory lies in its adaptability to the analysis of more advanced arrays. As an illustration, the problem of the four-element broadside array is handled just as easily as the problem of the three-element array. Referring to Fig. 4, clearly for reasons of symmetry $I_{1z} = I_{4z}$ and $I_{2z} = I_{3z}$. Accordingly, only two arbitrary constants will appear in the solution of this problem, and they may be determined in exactly the same way as for three antennas.

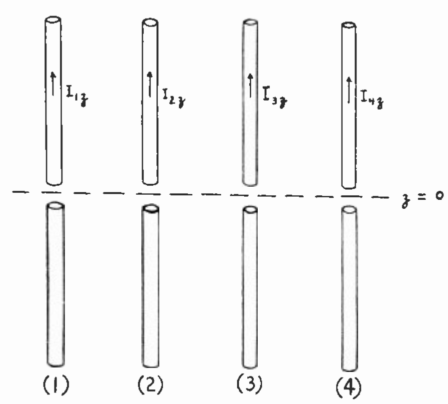


Fig. 4—Four-element broadside array.

Three arbitrary constants will appear in the analysis of a five-element broadside-array problem. No increase in complexity results if the current amplitude in the individual radiators is required to conform to a Gauss error curve (or any other type of distribution) provided symmetry with respect to the center of the array obtains.

Occasionally a broadside array consisting of a large number of radiators must be analyzed. In this case it is legitimate to assume that identical currents exist in all antennas that are well removed from the ends of the array. A great simplification in the problem is thus realized.

An obvious way to remove array "end effects" altogether is to locate the antennas at the vertices of regular polygons. For identical antennas carrying currents of equal amplitude, only one arbitrary constant appears in the analysis of any such radiating system. Furthermore, an appropriate progressive phase shift from one antenna to the next is easily taken into account.[2]

Appendix

The integrals (24) to (35) have the following values:

$$F_1(0) \approx \overline{\mathrm{Ci}}\ 2\beta h + j\ \mathrm{Si}\ 2\beta h \tag{42}$$

$$\begin{aligned} F_1(h) \approx\ & \tfrac{1}{2}\cos\beta h\{\overline{\mathrm{Ci}}\ 4\beta h + j\ \mathrm{Si}\ 4\beta h\} \\ & - \tfrac{1}{2}\sin\beta h\{\mathrm{Si}\ 4\beta h - j\ \overline{\mathrm{Ci}}\ 4\beta h\} \end{aligned} \tag{43}$$

$$G_1(0) \approx -\ \mathrm{Si}\ 2\beta h + j\ \overline{\mathrm{Ci}}\ 2\beta h \tag{44}$$

$$\begin{aligned} G_1(h) \approx\ & -\tfrac{1}{2}\cos\beta h\{\mathrm{Si}\ 4\beta h - 2\ \mathrm{Si}\ 2\beta h \\ & - j\ \overline{\mathrm{Ci}}\ 4\beta h + j2\ \overline{\mathrm{Ci}}\ 2\beta h\} \\ & - \tfrac{1}{2}\sin\beta h\{\overline{\mathrm{Ci}}\ 4\beta h + j\ \mathrm{Si}\ 4\beta h - j2\ \mathrm{Si}\ 2\beta h \\ & - 2\ \overline{\mathrm{Ci}}\ 2\beta h - 4\ln 2\} \end{aligned} \tag{45}$$

$$\begin{aligned} P_1(0) =\ & -\ \mathrm{Ci}\ \beta(x+h) + \mathrm{Ci}\ \beta(x-h) \\ & - j\ \mathrm{Si}\ \beta(x-h) + j\ \mathrm{Si}\ \beta(x+h) \end{aligned} \tag{46}$$

$$\begin{aligned} P_1(h) =\ & -\tfrac{1}{2}\cos\beta h\{\mathrm{Ci}\ \beta(y+2h) - \mathrm{Ci}\ \beta(y-2h) \\ & - j\ \mathrm{Si}\ \beta(y+2h) + j\ \mathrm{Si}\ \beta(y-2h)\} \\ & + j\tfrac{1}{2}\sin\beta h\{2\ \mathrm{Ci}\ \beta b - j2\ \mathrm{Si}\ \beta b \\ & - \mathrm{Ci}\ \beta(y-2h) - \mathrm{Ci}\ \beta(y+2h) \\ & + j\ \mathrm{Si}\ \beta(y-2h) + j\ \mathrm{Si}\ \beta(y+2h)\} \end{aligned} \tag{47}$$

$$\begin{aligned} Q_1(0) =\ & j\{2\ \mathrm{Ci}\ \beta b - j2\ \mathrm{Si}\ \beta b - \mathrm{Ci}\ \beta(x+h) \\ & - \mathrm{Ci}\ \beta(x-h) + j\ \mathrm{Si}\ \beta(x+h) \\ & + j\ \mathrm{Si}\ \beta(x-h)\} \end{aligned} \tag{48}$$

$$\begin{aligned} Q_1(h) =\ & \frac{j}{2}\{e^{-j\beta h}(2\ \mathrm{Ci}\ \beta(x-h) - j2\ \mathrm{Si}\ \beta(x-h) \\ & - \mathrm{Ci}\ \beta(y-2h) + j\ \mathrm{Si}\ \beta(y-2h) \\ & - \mathrm{Ci}\ \beta b + j\ \mathrm{Si}\ \beta b) + e^{j\beta h}(2\ \mathrm{Ci}\ \beta(x+h) \\ & - j2\ \mathrm{Si}\ \beta(x+h) - \mathrm{Ci}\ \beta(y+2h) \\ & + j\ \mathrm{Si}\ \beta(y+2h) - \mathrm{Ci}\ \beta b + j\ \mathrm{Si}\ \beta b)\}. \end{aligned} \tag{49}$$

In the above

$$\mathrm{Ci}\ z = \int_\infty^z \frac{\cos u}{u}\,du \tag{50}$$

$$\mathrm{Si}\ z = \int_0^z \frac{\sin u}{u}\,du \tag{51}$$

$$\overline{\mathrm{Ci}}\ z = \int_0^z \frac{1-\cos u}{u}\,du = 0.5772 + \ln z - \mathrm{Ci}\ z \tag{52}$$

$$x = \sqrt{(h)^2 + (b)^2} \tag{53}$$

$$y = \sqrt{(2h)^2 + (b)^2}. \tag{54}$$

Observe that $J_1(0)$ is similar to $P_1(0)$, $J_1(h)$ is similar to $P_1(h)$, $K_1(0)$ is similar to $Q_1(0)$, and $K_1(h)$ is similar to $Q_1(h)$. For example to obtain $K_1(h)$ from $Q_1(h)$, replace x by

$$\bar{x} = \sqrt{(h)^2 + (2b)^2} \tag{55}$$

and replace y by

$$\bar{y} = \sqrt{(2h)^2 + (2b)^2}. \tag{56}$$

Also write Ci βb and Si βb as Ci $2\beta b$ and Si $2\beta b$, respectively.

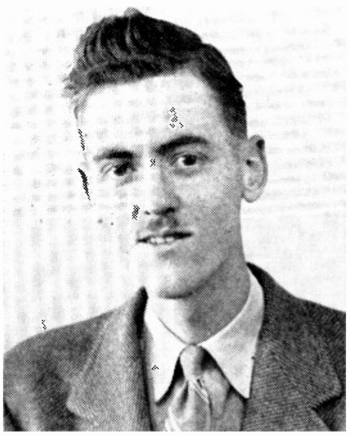
Acknowledgment

This paper has been reviewed by Professor Ronold King, Cruft Laboratory, Graduate School of Engineering, Harvard University. The writer expects to use the material in a thesis on antennas at some future date.

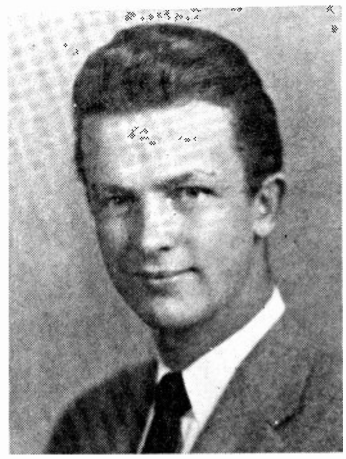
Correction

Edward Leonard Ginzton and Arthur E. Harrison have brought to the attention of the Editor an error which appeared in their paper "Reflex-Klystron Oscillators," Proceedings of the I.R.E., vol. 34, pp. 97–114, March, 1946. Fig. 5, which is shown on page 101P, should be Fig. 6; Fig. 6, which appears on page 102P, should be Fig. 5.

Contributors to Proceedings of the I.R.E. Section



William N. Blatt



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He is a member of Eta Kappa Nu and Tau Beta Pi.

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Ross Gunn (A'35) was born at Cleveland, Ohio, in 1897. He received the degrees of B.S.E.E. and M.S. in physics from the University of Michigan in 1920 and 1921, and the Ph.D. degree from Yale in 1926. He was a wireless operator on the Great Lakes during 1915–1917, and was a special instructor in radio courses at the University of Michigan in 1918. From 1920 to 1922 he was an instructor in physics at the University of Michigan, and became a radio research engineer in the U. S. Air Service in 1922–1923. From 1923 to 1927, he served as an instructor in physics at Yale University, and was in charge of the high frequency laboratory during 1926–1927.

In 1927 he joined the staff at the Naval Research Laboratory, where his present duties as chief physicist include: technical adviser to the Director, superintendent of the mechanics and electricity division, superintendent of the aircraft electrical research division, and technical director of the Army-Navy Precipitation-Static Project.

Mr. Gunn has specialized in the invention and development of new electrical instruments and electronic devices, including early radio control apparatus for airborne missiles. He was recently cited by the Secretary of the Navy for Distinguished Civilian Service, in connection with the development of the atomic bomb.

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Wayne C. Hall was born at Reading, Kansas, in 1909. He attended the University of Kansas from 1927 to 1935 and received his B.S. degree in electrical engineering, and M.S. and Ph.D. in physics. From 1931 to 1935, he was part-time instructor in the Physics Department of the University of Kansas.

He has been employed by the Naval Research Laboratory since 1935, working on electrical, electrochemical, and magnetic problems. Currently he is assistant superintendent of the aircraft electrical research division of the Naval Research Laboratory, Washington, D. C.

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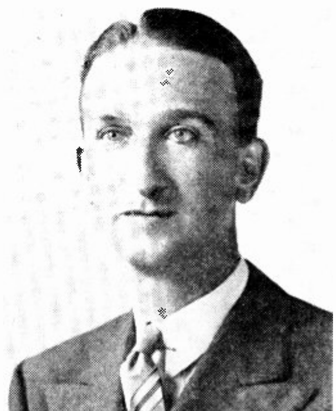
Charles W. Harrison, Jr. (J'30–A'36–M'44) was born in Virginia in 1913. The years 1932 to 1936 were spent in the United States Naval Academy Preparatory School and in the Academy. In 1939 Mr. Harrison received the S.B. degree in engineering, and in 1940 the degree of electrical engineer, from the University of Virginia. In 1942 he

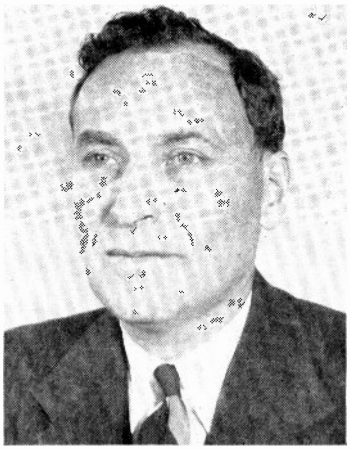


Wayne C. Hall

Charles W. Harrison, Jr.

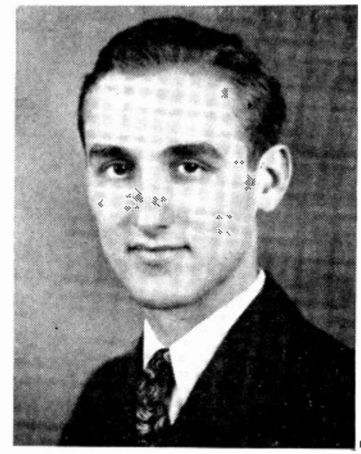
E. W. Herold

Contributors to Proceedings of the I.R.E. Section



Archie P. King

Gilbert D. Kinzer



G. E. Mueller

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was graduated with the S.M. degree in communication engineering from Cruft Laboratory, Harvard University, and completed the Navy course in radar engineering at the Massachusetts Institute of Technology. From the fall of 1942 to the spring of 1944 he was engaged in lecturing to officers of the Armed Forces assigned to the radar schools at Harvard and Princeton Universities. His experience includes amateur, naval, and broadcast-station operation, in addition to some three years of research work at the Navy Department and the United States Naval Research Laboratory. He was advanced to the rank of lieutenant commander early in 1944.

Commander Harrison is at present senior representative of the United States Navy at the Evans Signal Laboratory, Belmar, New Jersey. He is a member of the American Physical Society and Sigma Xi, and is a registered electrical and radio engineer in Virginia.

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E. W. Herold (A'30–M'38–SM'43) was born on October 15, 1907, in New York City. He received the B.S. degree from the University of Virginia in 1930, and the M.S. degree from Polytechnic Institute of Brooklyn in 1942.

From 1924 to 1926, Mr. Herold was with the Bell Telephone Laboratories, and from 1927 to 1929 with E. T. Cunningham, Inc. In 1930 he entered the research and engineering department of the RCA Manufacturing Company, at Harrison, N. J. Since 1942, he has been associated with the RCA Laboratories at Princeton, N. J. He is a member of Phi Beta Kappa and Sigma Xi.

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Archie P. King (A'30–SM'45) was born at Paris, France, May 4, 1901. He received the B.S. degree from California Institute of Technology in 1927. From 1927 to 1930 he was in the seismological research department of the Carnegie Institution of Washington. Since 1930, he has been with Bell Telephone Laboratories.

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Gilbert D. Kinzer was born at Ottawa, Illinois on November 2, 1909. He received the degrees of B.S. in electrical engineering in 1931, and the Ph.D. in physics in 1936, from the University of Illinois. He was an instructor in physics and mathematics at St. Viator College, at Bourbonnais, Illinois, from 1937 to 1938, and is now a physicist at the Naval Research Laboratory, in Washington, D. C.

❖

G. E. Mueller (S'39–A'42), was born at St. Louis, Missouri, on July 16, 1918. He received the B.S. degree in electrical engineering from the Missouri School of Mines and Metallurgy in 1939, the M.S. degree in engineering from Purdue University in 1940. Since that time, Mr. Mueller has been a member of the technical staff of the Bell Telephone Laboratories, engaged in television and radio research.

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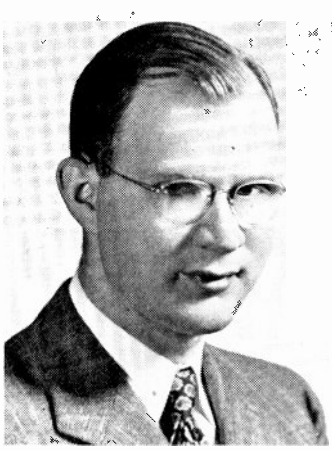
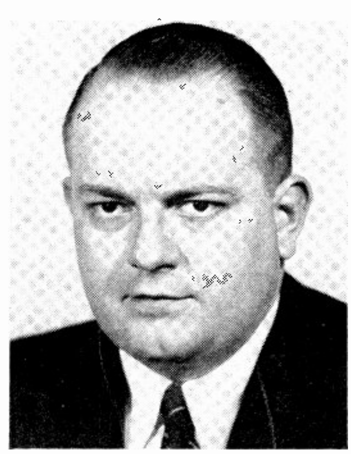


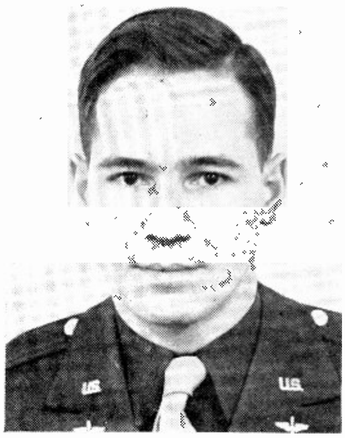
Shepard Roberts



Sloan D. Robertson

Emery H. Rogers

Contributors to Proceedings of the I.R.E. Section



Ronald G. Stimmel

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Shepard Roberts (A'44–M'45) was born in New Rochelle, New York, on April 12, 1915. He received the S.B. degree in 1938 and the S.M. degree in 1939 from the Massachusetts Institute of Technology. From 1939 to 1940 he was a research assistant in the Laboratory for Insulation Research at Massachusetts Institute of Technology, where he worked on dielectric measurements in the range of microwaves. From 1940 to 1945 he was a staff member of the Radiation Laboratory. In 1941, in the Advanced Developments Group, he experimented with new waveguide techniques and shorter wavelengths. A major part of his subsequent work in this laboratory was concerned with testing and standardization of crystal rectifiers for radar receivers. Since 1945, he has been a research associate and graduate student in the department of electrical engineering at Massachusetts Institute of Technology. He is a member of Sigma Xi.

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Sloan D. Robertson (S'37–A'41–SM'45) was born at Aurora, Missouri, on August 8, 1915. He received the B.E.E. degree in 1936 from the University of Dayton. He then attended the Ohio State University and was awarded the M.Sc. degree in 1938 and the Ph.D. degree in 1941. He was a Stillman W. Robinson Fellow at Ohio State University from 1937 to 1939.

In 1940, Mr. Robertson taught electrical engineering at the University of Dayton. Since 1940 he has been a member of the technical staff of Bell Telephone Laboratories where he has been engaged in microwave radio and radar research. He is a Member of the American Physical Society, Tau Beta Pi, Eta Kappa Nu, and Sigma Xi.

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Ramond C. Waddel

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Emery H. Rogers was born at Los Angeles, California, March 31, 1921. He received his A.B. in physics at Stanford University in 1943, and served as assistant instructor at Stanford University from 1942 to 1943. From 1943 to 1945 he was employed by the Naval Research Laboratory. At present he is National Research Council Fellow in Physics at Stanford University.

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Ronald G. Stimmel was born August 27, 1921, at Columbus, Ohio. He received the degree of B.Sc. in physics from Ohio State University in 1942. Since graduation, he has been associated with the Aircraft Radio Laboratories, Wright Field, Ohio, and is now production, design, and research officer. Since 1943, Mr. Stimmel has been engaged as the Army technical representative with the joint Army-Navy Precipitation Static Research Project, in Minneapolis, Minnesota.

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Ramond C. Waddel was born on July 17, 1909, at Whiteson, Oregon. He received the A.B. degree in 1931 from Willamette University, and the Ph.D. degree in 1940 from New York University. From 1931 to 1940 he taught and was engaged in graduate work at New York University, Washington Square College. In 1940, Dr. Waddel went to the Naval Research Laboratory, Washington, D. C., where he is now a consultant to the mechanics and electricity division. He is a member of the American Physical Society.

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Franklin E. Waterfall was born at Columbia City, Indiana, in 1918. In 1941, he received the B.S. degree in physics from the University of Indiana, and was a student at the graduate school during 1941 and 1942, serving as assistant instructor in physics. He was employed as physicist at the Naval Research Laboratory from 1942 to 1945. At present, Mr. Waterfall is engaged as associate scientist in the electrical engineering department at the University of Minnesota.

Franklin E. Waterfall

PROCEEDINGS of the I.R.E. AND WAVES and ELECTRONS

Published Monthly
by
The Institute of Radio Engineers, Inc.

April, 1946

SECTION II—WAVES AND ELECTRONS SECTION

Institute News and Radio Notes

Books

SECTION I—PROCEEDINGS OF THE I.R.E. SECTION CONTENTS ON PAGE 153 P

The future of science and technology are independent in considerable measure upon the major journals in these fields. In their pages are presented the advances in these fields. The stimulating educational effect and the practical results of such publications are of major importance.

It has accordingly seemed appropriate to present guest editorials from the Editors who are leaders of thought in these fields of publication. There accordingly follows a guest editorial by the Editor of the *Review of Scientific Instruments*, a publication of the American Institute of Physics.

The Editor

Journals in Science

G. P. Harnwell

A most striking feature of our citizen Army and Navy was the level of technical talent and individual competence in dealing with electrical and mechanical devices exhibited by the men who came into all ranks. It was a war of technology to a degree never before known, and the skilled employment of military devices and instruments by men with a flair for their maintenance and operation made their efforts more effective and saved many American lives. Resource and initiative based on an innate aptitude for contrivances of all sorts, shared by designers, manufacturers, and GI users, surmounted obstacles of production and overcame inadequacies in the field by ingenious improvisation.

The same facility with instruments and devices will in turn accelerate reconversion and the resumption of our material and industrial progress when the human and economic problems in which we have not demonstrated comparable dexterity are solved. Not only will the application of perfected machines and techniques improve our standards of health and living, but the stimulus to our thought and ingenuity will accelerate future research and exploration. Our broad educational base has enabled our insatiable scientific curiosity and the urge of individual and corporate competition to create such a body of scientists and technologists in our country as has never before been known.

The technical periodicals, through which advances in basic research and technical application to engineering and industry are disseminated, constitute the circulatory system upon which the great body of scientists depends for stimulus and integration. Our common technical strength exceeds the sum of the separate abilities of each laboratory and enterprise, because of the fertilizing flux of knowledge and information constantly emerging from laboratories and plants that reaches us through journals sponsored by societies and institutes. The obligation of the scientist and engineer to society is not discharged until a record of his technical achievements is published and made a part of that common knowledge from which he has himself drawn in making his contribution.

The vigor of our technical periodicals is a measure of the strength of our scientific growth. The ability to continue to improve upon our present material facilities for peacetime living and to maintain and enhance our standards in competition with all is contingent upon our recognition of the role of technical publication in our society. We owe a great debt to the broad vision of our scientific predecessors who established media for the dissemination of scientific ideas and maintained the standards of excellence for them of which we may be justly proud. It is our obligation as members of the vital scientific subcommunity within our nation to support our journals both as subscribers and contributors and to maintain thereby the enviable technical tradition of which we are the inheritors.

Virgil Miller Graham

Board of Directors—1946

Virgil Miller Graham was born in Rochester, New York, on January 22, 1902. In the early days of radio broadcasting, 1921–1922, he manufactured and sold components such as "single-layer" coils, to replace the currently popular honeycomb coils in tuners, and reactance-coupling units for radio-frequency amplifiers. In 1923 he joined the engineering department of the Stromberg-Carlson Telephone Manufacturing Company and had a part in the design and production of the first broadcast receivers manufactured by that company. He became engineer in charge of the broadcast receiver design, which position he held until 1935. In 1925 Mr. Graham became interested in radio standardization with the radio division of the, then newly formed, National Electrical Manufacturers Association and continued active in this work during the life of that division until around 1928. During this time he did the editorial work on the NEMA Handbooks of Radio Standards that were published. In 1930 he was appointed standards chairman in the RMA Engineering Committee until 1934 when he became assistant director of the RMA Engineering Department, and since 1942 he has been associate director. In the fall of 1935 he joined the Hygrade Sylvania Corporation and became director of the tube-application department in Emporium, Pennsylvania. Until the war he was engaged to a large degree in foreign sales promotion and patent defense work, in addition to the domestic commercial engineering activities of his department. At the start of the defense program, he organized the application engineering department at Emporium for a circuit and equipment developmental program for the Armed Services. This department evolved into a manufacturing plant in 1942 and in July of that year he was appointed plant manager. In the Spring of 1944 this plant was moved to Williamsport, Pennsylvania.

Mr. Graham has been chairman of the Rochester Fall Meeting Committee since its inception in 1929. He joined the Institute in 1924 as an Associate, became a Member in 1927, and a Fellow in 1935. During his membership he has held many committee appointments and was a member of the Board of Directors from 1935 to 1941. He became a Member of the Institution of Radio Engineers, Australia, in 1936 and was awarded a Fellowship in that organization in 1941. He is a member of the Acoustical Society of America, the Society of Illuminating Engineers, the Société des Radioélectriciens, and the Rochester Engineering Society.

Radio Progress During 1945*

Introduction

THE YEAR 1945, with the cessation of hostilities, saw the beginning of publication of information about some of the uses to which radio communication systems and related techniques had been put during the war years.

The gradual relaxation in military restrictions has resulted in the revelation of some new advances, either by implication or through semitechnical papers, although security reasons have, to some extent, still held back the publication of many interesting and significant developments. It seems probable that, with the publication of fuller technical details, it will become possible to include more of these developments in next year's review. The year 1946 should see a volume of technical publications of outstanding interest.

During the last half of the year, radio engineers have been devoting major attention to the problems of applying the most advanced technical knowledge to the requirements of peacetime commercial activities.

Striking developments which have been disclosed in general terms but which have not yet been fully covered in technical publications are various applications of pulse methods of radio transmission, such as radar systems of many types and a system of navigational aids known as "loran."

During the year, the Federal Communications Commission continued with the holding of hearings on frequency allocation begun in 1944. As a result, the Commission issued a report on May 25, 1945, supplemented on June 27, 1945 and on November 19, 1945, allocating frequency bands in the range of 25 megacycles to 30,000 megacycles to radio services in the United States. In this portion of the spectrum, comparatively new to practical utilization, allocations were made for frequency-modulation broadcasting and television broadcasting and for many new services including telephone communication with mobile units, such as trucks, busses, taxicabs, and railroad rolling stock, radio-relay systems, aviation-radio devices, civilian two-way radio telephony, and for medical and industrial electronic applications. The Commission, on May 21, 1945, issued a proposed reallocation of frequency bands in the range of 10 to 25,000 kilocycles.

Radio Transmitters

Activity in the field of radio transmitters for commercial and civil applications was greatly stimulated coincident to the ending of the war. The extensive research and development of electronic circuits and vacuum tubes for military use during the war were already giving rise, before the close of 1945, to new and promising transmitting-apparatus designs.

Renewed interest was being expressed in the use of transmitter powers greater than 50 kilowatts for amplitude-modulation broadcasting. Several new transmitter developments for frequency-modulation broadcasting at power levels ranging from 250 watts to 50 kilowatts were announced as a result of the reallocation of the frequency-modulation broadcast band to the region of 100 megacycles. Transmitters for television broadcasting in the channels below 90 megacycles were being manufactured by several suppliers and the development of television transmitters for operation in the region of 200 megacycles was going forward with accelerated interest. Much activitity and interest was developing over the possibilities of pulse-position or pulse-time-modulated transmitters for point-to-point and radio-relay transmission at microwave lengths, and several experimental installations were being made.

TABLE I
RADIO BROADCAST STATIONS FOR WHICH LICENSES AND CONSTRUCTION PERMITS ISSUED BY THE FEDERAL COMMUNICATIONS COMMISSION WERE OUTSTANDING ON DECEMBER 31, 1945

Class of Broadcast Station	Number of Licenses and Construction Permits
Standard	1004
Commercial high-frequency (frequency-modulation)	282*
Experimental high-frequency	1
Commercial television	9
Experimental television	54
International	38
Facsimile	3
Noncommercial educational	15
Developmental	38

* Including 229 conditional grants.

Many instructive papers dealing with radio transmitters appeared throughout the year 1945.

A twelve-channel radio multiplex circuit spanning the Chesapeake Bay and comprising a part of the network of the Chesapeake and Potomac Telephone Company, installed in 1941, was described in four papers; viz,

(1) N. F. Schlaack and A. C. Dickieson, "Cape Charles-Norfolk ultra-short-wave multiplex system," PROC. I.R.E., vol. 33, pp. 78–83; February, 1945.
(2) Charles R. Burrows and Alfred Decino, "Ultra-short-wave multiplex," PROC. I.R.E., vol. 33, pp. 84–94; February, 1945.
(3) D. M. Black, G. Rodwin, and W. T. Wintringham, "Ultra-short-wave receiver for the Cape Charles-Norfolk multiplex radiotelephone circuit," PROC. I.R.E., vol. 33, pp. 95–100; February, 1945.
(4) R. J. Kircher and R. W. Friis, "Ultra-short-wave transmitter for the Cape Charles-Norfolk multiplex system," PROC. I.R.E., vol. 33, pp. 101–106; February, 1945.

A feature of the transmitter of especial interest was the design of the circuit employing 40 decibels of envelope feedback, the basic method of feedback design, and the

* Decimal classification: R090. Original manuscript received by the Institute, January 30, 1946. This report is based on material from the 1945 Annual Review Committee of The Institute of Radio Engineers, as co-ordinated and edited by Laurens E. Whittemore, Keith Henney, H. A. Wheeler, I. S. Coggeshall, and J. Warren Horton.

technique of practical application was given in considerable detail.

In one paper the desirability of specifying quartz crystals in terms of their intrinsic properties, instead of the desired performance of the set, was stressed and contrasted with present practice.

(5) K. S. VanDyke, "The standardization of quartz-crystal units," Proc. I.R.E., vol. 33, pp. 15–20; January, 1945.

When it becomes the practice to use circuit properties of crystals, when convenient instruments for impedance measurement are available, and when formal treatment of oscillator-circuit design is extended to include crystal-controlled types, there will naturally follow the convenient cataloging and standardization of a relatively few types.

An improved amplifier for single-sideband transmission of one or two channels was described.

(6) C. F. P. Rose, "A 60-kilowatt high-frequency transoceanic-radiotelephone amplifier," Proc. I.R.E., vol. 33, pp. 657–662; October, 1945.

Of interest is the means described for the rapid change of frequency between assigned frequencies within the range from 4.5 to 22 megacycles.

Circuit features, typical operating conditions, and distortion characteristics were given for an experimental triode amplifier operating at 140 megacycles.

(7) R. J. Kircher, "A coil-neutralized vacuum tube amplifier at very high frequencies," Proc. I.R.E., vol. 33, pp. 838–843; December, 1945.

A survey of multichannel communication systems which make use of modulated pulse change was given in one paper.

(8) F. F. Roberts and J. C. Simmonds, "Multichannel communication systems," *Wireless Eng.*, vol. 22, pp. 538–549; November, 1945; pp. 576–580; December, 1945.

The principles underlying the system were considered at some length and the advantages as compared with conventional multichannel systems were discussed. Experimental apparatus employing amplitude-modulated pulses was described which gave seven good-quality speech channels in a bandwidth of 110 kilocycles.

In one paper,

(9) "PT modulation for multiple transmission," *Electronic Indus.*, vol. 4, pp. 90–91; November, 1945,

a system was described whereby the time of occurrence of carrier pulses is advanced for positive and retarded for negative portions of the signal wave. This method permits the transmission of intelligence by means of a series of pulses of about one-half-microsecond duration, each separated from the other by a time interval of about 5 microseconds. Their time of recurrence can be advanced or retarded over a range of approximately one microsecond. Converting the modulated pulses to amplitude modulation is accomplished by means of a cyclophone which is similar to a cathode-ray tube except that the target end of the tube has a metal plate with radially disposed slits behind which is another plate which is the target for the cathode ray.

A system of pulse-position modulation was described in which, by clipping sine waves into square form, altering their length and differentiating, pulses are obtained at varying times.

(10) "Pulse position modulation technique," *Electronic Indus.*, vol. 5, pp. 82–87, and 180, 182, 184, 186, 188, 190; December, 1945.

The radio transmitter converts position-modulated positive impulses derived from transmitting multiplex equipment into impulses of ultra-high-frequency power. The final wave form of the radiated ultra-high-frequency impulses may be pictured as a series of eight groups of 5000-megacycle oscillations each emitted from the antenna for a period of approximately 1 microsecond, plus a 4-microsecond marker impulse. For the production of a wave shape of this type, the transmitter included an ultra-high-frequency oscillator excited by momentary power impulses from a modulator.

The following summarizes the explanation of pulse-time modulation given in one paper.

(11) E. M. Deloraine and E. Labin, "Pulse time modulation," *Elec. Commun.*, vol. 22, pp. 91–98; 1944.

Pulse-time modulation consists essentially in the transmission of signals by pulses of constant amplitude, the instantaneous amplitude of the voice being translated into a variation of time intervals of successive pulses; the rate of this variation corresponds to the instantaneous frequency of the signal period. Important advantages include improvement of the signal-to-noise ratio as the bandwidth increases and the possibility of adding repeaters without increasing distortion. Thus this method of modulation appears particularly promising for application to multichannel radio and coaxial-cable transmission systems and to ultra-high-frequency broadcasting and television sound channels. High spots relating to the conception and development of pulse-time modulation were included in the paper to complete the historical record.

Technical details of the radio station at Delano, California, for putting three short-wave broadcast programs on the air simultaneously were given in a paper by

(12) Robert N. DeHart, "OWI-CBS 200-kw west coast transmitters," *Electronic Indus.*, pp. 82–85, 148, 150, 152, 154, 156; April, 1945.

A high-power radio-frequency converter designed for use with frequency-modulated broadcast transmitters permitting operation in either one of two frequency bands or simultaneous operation in both bands was described in a paper by

(13) Frank A. Gunther, "Power frequency converter for FM," *FM and Television*, vol. 3, pp. 53–54, 78–79; August, 1945.

One paper described 250-, 1000-, and 3000-watt frequency-modulation broadcast transmitters for operation in the 88- to 108-megacycle band. The transmitters employed reactance control tubes as modulators, electromechanical control of the center frequency independent of the modulation action, and grounded-grid power amplifiers.

(14) C. M. Lewis, "Data on RCA FM broadcast equipment," *FM and Television*, vol. 5, pp. 28–35; November, 1945.

The Signal Corps of the United States Army has described a world-wide communication network utilizing a multichannel radiotelegraph system of which noteworthy features are stability of transmission and economy of frequency utilization.

(15) "Army Service Forces, Annual Report for fiscal year, 1945," pp. 42–43.
(16) Major General Harry C. Ingles, Chief Signal Officer, U. S. Army, "Electrical communications in world-wide warfare—I. On the ground," *Bell Tel. Mag.*, vol. 24, pp. 54–72; Summer, 1945.

Frequency Modulation

During 1945 the developments in frequency modulation moved ahead very rapidly, first in anticipation of the end of the war, and later through reconversion programs. Early in the year, intense discussions took place between industry and the Federal Communications Commission in the United States to determine frequency allocations to be made, among other services, for frequency-modulation broadcasting. An outstanding series of discussions of radio-transmission considerations as bearing on the frequency-allocation problem took place at the I.R.E. Winter Technical Meeting in January, 1945. These discussions have been reproduced as a special pamphlet by the Institute. The Federal Communications Commission, in August, made definite frequency allocations for frequency-modulation broadcasting, designating the band from 88 to 92 megacycles for educational and noncommercial frequency-modulation broadcasting, and designating the band from 92 to 106 megacycles for commercial frequency-modulation broadcasting. At the end of the year the industry was applying itself at top speed to make available both receivers and transmitters for use in this new band.

One paper published during the year emphasized the availability of broad-band telephone systems to produce high-fidelity transmission, on many routes providing an 8000-cycle band, and on routes utilizing types J, K, and L carrier systems providing a 15,000-cycle band. Thus the frequency-modulation broadcasters will be able to operate networks with high fidelity when desired.

(17) H. S. Osborne, "Transmission networks for frequency modulation and television," *Elec. Eng.*, vol. 64, pp. 392–397; November, 1945.

At the end of 1944, further developments in the use of a synchronized oscillator as a combined limiter and amplifier were reported. This locked-in oscillator type of circuit seems destined to influence the design of frequency-modulation receivers.

(18) G. L. Beers, "A frequency-dividing locked-in oscillator frequency-modulation receiver," Proc. I.R.E., vol. 32, pp. 730–737; December, 1944.

One of the serious problems in the design and operation of frequency-modulation broadcast receivers has been the difficulty in accurately stabilizing the frequency to which the receiver is tuned. A relatively inexpensive design of a crystal-controlled frequency-modulation receiver has been developed. The use of this receiver essentially eliminates this problem.

(19) William Maron, "Crystal-tuned F-M receivers," *Electronics*, vol. 18, pp. 138–141; October, 1945.

The planning and construction of a new 50-kilowatt frequency-modulation transmitter has been reported in considerable detail. This report presents a convenient reference for the many individuals about to plan for new frequency-modulation stations. The frequency shift to the new allocations introduces a variation in the problems, but fundamentally the problems are similar.

(20) P. B. Laeser, "Planning an F-M station," *Electronics*, vol. 18, pp. 92–97; February, 1945.
(21) P. B. Laeser, "A 50-kw F-M transmitter," *Electronics*, vol. 18, pp. 100–105; April, 1945.

With the design of frequency-modulation antennas for use by broadcasters who are already operating transmitters in the standard broadcast range, a special square-loop antenna together with an insulated antenna coupler has been developed which allows the standard insulated tower to be used as the support for the frequency-modulation antenna. Using the new design, the reduced wind resistance allowed in one case the saving of 150 feet in antenna height, as compared with the flag pole which would have been required with a corresponding six-layer turnstile antenna. The resultant antenna gain was even better than that obtainable from the turnstile.

(22) J. P. Taylor, "A square-loop F-M antenna," *Electronics*, vol. 18, pp. 96–100; March, 1945.
(23) J. P. Taylor, "F-M antenna coupler," *Electronics*, vol. 18, pp. 107–109; August, 1945.

The development of a radio-relay system for television using frequency-modulation has been announced. Frequency-modulation has the distinct advantage, in this work, of allowing limiting action at each station, and of reducing the noise level per station below that encountered when amplitude modulation is used. Since signal-to-noise ratio is the primary limiting factor in determining the maximum distance between stations, a distinct advantage is gained by the use of frequency-modulation in this application.

(24) C. W. Hansell, "Radio-relay-systems development by the Radio Corporation of America," Proc. I.R.E., vol. 33, pp. 156–168; March, 1945.

A proposal has been made to develop a duplex communication system involving frequency-modulation and using the transmitter oscillator at one terminal as the local oscillator of a superheterodyne at that same terminal. Thus the transmission in one direction is carried at a frequency differing from the frequency of transmission in the opposite direction by the intermediate frequency of the receivers.

(25) E. E. Suckling, "A stabilized narrow-band frequency-modulation system for duplex working," Proc. I.R.E., vol. 33, pp. 33–35; January, 1945.

The work has continued on investigation of the transmission of frequency-modulation signals through tuned circuits and on the degree of interference between two frequency-modulation signals having the same carrier frequency. It is found experimentally that, for negligible distortion to a 15,000-cycle signal, the ratio of the peak frequency swing to the bandwidth at the half-power point should be equal to one quarter.

(26) David Lawrence Jaffe, "A theoretical and experimental investigation of tuned-circuit distortion in frequency-modulation systems," Proc. I.R.E., vol. 33, pp. 318–333; May, 1945. (Corrections, pp. 482; July, 1945.)
(27) R. N. Johnson, "Interference in F-M receivers," *Electronics*, vol. 18, pp. 129–131; September, 1945.

In general, 1945 has been a year of preparation for a most rapid future advance in the field of frequency modulation.

Radio Receivers

The ending of the war in August, 1945, brought an immediate and widespread change in both engineering and production from receivers for military and naval applications to receivers for civilian use.

Despite the fact that War Production Board limitation orders were rapidly withdrawn following the war's end, by the end of the year the total production volume in the United States, in the four months during which civilian production was permitted, amounted to only about 300,000 receivers, or less than 2 per cent of conservative estimates for production expected in the first entire postwar year. This low rate of production was due primarily to a shortage of component parts, which shortage was, in turn, caused principally by parts-manufacturers' belief that the prices originally permitted for their products were too low to permit economic manufacture, and secondarily, towards the close of the year, by labor unrest.

The end of the war also brought a lifting of restrictions on publication of technical information on wartime uses of radio, and papers describing those uses began to appear in the technical literature. Many of those uses involved complete systems of transmission so that the papers dealt only in part with the receiver portion of the systems. Among such papers were descriptions of radar equipment; the long-range navigation system known as "loran"; the proximity fuze; and other specialized military applications of radio techniques.

(28) "The SCR-268 radar," *Electronics*, vol. 18, pp. 100–109; September 1945.
(29) "The SCR-584 radar," *Electronics*, vol. 18, pp. 104–109; November, 1945; pp. 104–109; December, 1945.
(30) "Radar specifications," *Electronics*, vol. 18, pp. 116–119; November, 1945.
(31) "The loran system," *Electronics*, vol. 18, pp. 94–99; November, 1945.
(32) "Proximity fuze," *Electronics*, vol. 18, pp. 110–111; November, 1945.
(33) Daniel E. Noble, "Details of the SCR-300 F-M walkie-talkie," *Electronics*, vol. 18, pp. 204, 209, 212, 216; June, 1945.
(34) Harry Stockman, "UHF converter analysis", *Electronics*, vol. 18, pp. 140–143; February, 1945.

The widespread use of piezoelectric crystals during wartime led to their more general consideration than heretofore as components in peacetime receivers. In general, a quartz crystal was used to control the frequency of the heterodyne oscillator, and such use may become important in applications where the added cost of such crystals is not a deterrent, such as in high-quality frequency-modulation, television, and communication receivers. A compact two-channel diversity receiver was described, in which the heterodyne-oscillator frequency is determined by the combination of the outputs of a crystal-controlled and a variable-frequency oscillator. Improvement in oscillator stability by design improvements in components also received attention.

(35) William Maron, "Crystal-tuned F-M receivers," *Electronics*, vol. 18, pp. 138–141; October, 1945.
(36) Sidney X. Shore, "Crystal oscillators in F-M and television," *Communications*, vol. 25, pp. 50, 52, 54, 83–86; August, 1945. (Part one of a series.)
(37) J. G. Nordahl, "Tank radio set," *Bell Labs. Rec.*, vol. 23; pp. 1–5; January, 1945.
(38) H. A. Ross and L. K. Curran, "Some developments in crystal-controlled diversity receivers," *A.W.A. Tech. Rev.*, vol. 6, pp. 337–349; March, 1945.
(39) John B. Moore, "Design of stable heterodyne oscillators," *Electronics*, vol. 18, pp. 116–118; October, 1945.

Rectifying crystals also received attention due to their use as frequency converters in ultra-high-frequency superheterodyne receivers. The design and performance have been covered with applications to radar noted. In addition, the theory of rectification was given in terms of the work function of conductors and semiconductors.

(40) Arthur C. Gardner, "Rectifying crystals," *Radio*, vol. 29, pp. 48–50, 68, 69; August, 1945.
(41) Harry Stockman, "UHF converter analysis," *Electronics*, vol. 18, pp. 140–143; February, 1945.

Frequency-modulation reception techniques were given increasing attention. The design of the intermediate-frequency amplifier was discussed as was the problem of distortion introduced by both single- and double-tuned circuits.

(42) William H. Parker, Jr., "The design of an intermediate-frequency system for frequency-modulated receivers," Proc. I.R.E., vol. 32, pp. 751–753; December, 1944.
(43) David Lawrence Jaffe, "A theoretical and experimental investigation of tuned-circuit distortion in frequency-modulation systems," Proc. I.R.E., vol. 33, pp. 318–333; May, 1945. (Corrections, p. 482; July, 1945.)

A new detector for frequency-modulated waves with inherent limiting qualities within the detection process was described.

(44) S. W. Seeley, "Ratio detectors for frequency-modulation receivers," presented, New York Section, October 3, 1945, New York, N. Y.

A receiving system and the various parts of the receiver were described, in which harmonic distortion produced by fading of the carrier with respect to the sidebands is eliminated. Results of observations of reception on an exalted-carrier diversity receiving system were given.

(45) Murray G. Crosby, "Exalted-carrier amplitude- and phase-modulation reception," Proc. I.R.E., vol. 33; pp. 581–591; September, 1945.

The problem of receiver noise received further attention from the standpoint of the input circuit and with regard to the effects of automatic gain control.

(46) R. E. Burgess, "Signal-to-noise characteristics of triode input circuits," *Wireless Eng.*, vol. 22, pp. 56–61; February, 1945.
(47) John B. Moore, "AGC-noise considerations in receiver design," *Electronics*, vol. 18, pp. 116–118; May, 1945.

Several novel types of superheterodyne receivers were described during the year. One type in which tuning to any broadcast channel is accomplished solely by push-buttons was described and demonstrated at the I.R.E. 1945 Winter Technical Meeting. Interest in the design of superheterodyne receivers with an intermediate-frequency higher than the received frequency was revived. A novel method of obtaining some new capabilities from the superheterodyne receiver has recently been described. It employs a triple-detection receiver, each of the fixed-tune amplification channels being given an infinite-rejection characteristic on one side. Thus, by varying the frequency of the second beating oscillator, the admittance band is varied from very wide down to zero. New noise-rejection possibilities are obtained in continuous-wave reception when the bandwidth is made zero and the desired signal swept periodically into an acceptance band by frequency modulation of the second beating oscillator at audio frequency.

(48) John D. Reid, "I.R.E. Winter Technical Meeting," *Electronics*, vol. 18, pp. 318, 320; March, 1945.
(49) Harvey Kees, "Receiver with 2 Mc. I.F.," *Electronics*, vol. 18, pp. 129–131; April, 1945.
(50) Dana A. Griffin, "Griffin triple detection superhet," *CQ*, vol. 1, pp. 11–14, 38–39; May, 1945.

A radiation method for sensitivity calibration of receivers at frequencies above 30 megacycles employed calculations of the field at the receiving antenna due to current in the transmitting antenna.

(51) J. S. McPetrie, W. E. Perry, and L. H. Ford, "Sensitivity calibration of receivers," *Wireless Eng.*, vol. 22, pp. 6–13; January, 1945.

The requirements and design of a receiver for use in multiplex radiotelephony, which employed many interesting principles, were discussed. The receiver is a triple-detection type designed to work in the radio-frequency spectrum between 150 and 160 megacycles.

(52) D. M. Black, G. Rodwin, and W. T. Wintringham, "Ultra-short-wave receiver for the Cape Charles-Norfolk multiplex radiotelephone circuit," Proc. I.R.E., vol. 33, pp. 95–100; February, 1945.

Electron Tubes

Large High-Vacuum Tubes

Relatively very few papers dealing directly with development of power-output electron tubes were published in the technical literature in the United States during the period from December, 1944, to November, 1945. Still less could be found in the fragments of literature published in other countries which reached the United States during this period. However, the termination of the war has permitted disclosure of several developments which during the war were classified as "secret" or "confidential." Up to the time of writing this report, not many papers have been published on the subject of power-output vacuum tubes specially designed for war applications. Nevertheless, in a number of public lectures some interesting features of such special tubes have been revealed directly or by implication, as subjects were being taken off the classified list.

Most important and interesting from the engineering viewpoint is the development of electron tubes for radar. Specific features of their designs resulted from the character of radar operation. The most important demand was to deliver the generated radio-frequency energy to the antenna in extremely short but powerful pulses spaced by relatively large time intervals. Therefore, the operating voltages used even on small tubes for this operation are up to 15,000 or 20,000 volts. Then, in order further to increase the peak power, the cathode emission was to be as high as could be made. Hence, attempts were made to use generously dimensioned thoriated-tungsten filamentary cathodes or indirectly heated oxide-coated cathodes even with the specified high operating voltages. This was contrary to the designers' common prejudice against the use of activated cathodes at voltages above 4000 volts. However, the vast experience fully justified use of activated cathodes under the condition of pulse operation.

Instantaneous power output in radar tubes exceeds many times the normal maximum power output from tubes of the same size in ordinary continuous-wave amplitude- or frequency-modulation operation. The average power naturally depends on pulse width (from 10 microseconds to a fraction of a microsecond) and frequency of pulsing (from 200 to several thousands per second). It is limited not only by the permitted anode and grid dissipation, but also by cathode dissipation, as the cathodes are in some types of tubes subject to severe electron bombardment.

General design and structural details of the radar tubes comply with the frequency to be generated. For frequencies from 100 to 300 and even 600 megacycles used in the long-range radar installations, specially designed triodes proved to be satisfactory.

A series of special radar triodes was developed shortly before and during the war, known as 15E, 127A, VT-158, 227A, 327A, 527, 434A, 530, etc. Also British types were manufactured in this country, designated VT-31, VT-90, VT-98, VT-99, and VT-114. Many of these tubes have thoriated-tungsten cathodes; the VT-99 and 527 have oxide-coated cathodes. The possible peak power output depending on emission and duty cycle ranges from 5 kilowatts per tube to more than one megawatt.

(53) Roger B. Colton, "Radar in the United States Army," Proc. I.R.E., vol. 33, pp. 740–753; November, 1945.
(54) "The SCR-268 radar," *Electronics*, vol. 18, pp. 100–109; September, 1945.
(55) "Radar specifications," *Electronics*, vol. 18, pp. 116–119; November, 1945.
(56) I. E. Mouromtseff, "Electronics and development of electronic tubes," *Jour. Frank. Inst.*, pp. 171–192; September, 1945.

An outstanding war development in the line of power tubes was the resonant or multicavity magnetron. It received early attention in Great Britain, and in general its features somewhat resemble the Russian magnetron mentioned in last year's report. Enormous contribution to the final design and manufacturing methods of the resonant magnetron has been made by various organizations in the United States. These magnetrons were designed for operation in the ship, plane, and gun-fire-control radar systems on frequencies from 600 megacycles up to above 10,000 megacycles (from 50-centimeter to less than 3-centimeter wave length). These tubes are made of a block of solid copper with a central cylindrical chamber (interaction space) with an axially mounted oxide-coated cathode and with several resonance cavities arranged in a circle around and opening into the central chamber. Usually these tubes are cooled by air blast.

With dimensions approximately $1\frac{1}{2}$ inches long and 2 inches in diameter, these tubes are capable of producing peak power output of several hundred or even a thousand kilowatts. Hundreds of thousands of such magnetrons were manufactured during the war in this country. Undoubtedly, various aspects of this marvelous development will be discussed in the technical literature during the next year.

(57) "Radar specifications," *Electronics*, vol. 18, pp. 116–119; November, 1945.

Another war development was that of "jamming" tubes for making the enemy's radar ineffective. One of these tubes was the "resnatron," developed in the United States under the auspices of Office of Scientific Research and Development. The resnatron is a water-cooled tetrode with built-in oscillating circuits in the form of cavity resonators. In continuous-wave operation it is capable of developing more than 50 kilowatts output power at 600 megacycles. Another development in the same field was a series of split-plate magnetrons for continuous-wave operation, covering a wide range of frequencies.

An important factor in all types of "microwave tubes," used in radar and also in other ultra-high-frequency applications, is the elimination of discontinuity between the tube electrodes and the oscillating circuit.

A thorough application of this idea to the triode permitted extension of the usefulness of this type of tube up to 600 megacycles with most unexpectedly high outputs. Representative of this type of tube is one capable of supplying 75-kilowatt peak power described in a paper by Major Zahl and Dr. Gorham at the 1945 Winter Technical Meeting; also the Sloan tube, the "resnatron," previously mentioned, with more than 50 kilowatts in continuous-wave operation at the specified frequency. A third tube of similar type is one delivering a peak power of 500 kilowatts at 400 megacycles. This tube is a combination of two triodes in a push-pull arrangement with cylindrical cavity resonators between them. The characteristic feature of all these tubes is making the tube elements part of the oscillating circuits inherently attached to the tube and placing them in the same vacuum enclosure. Useful power is then taken outside by a suitable transmission line coupled to one of the internal oscillating circuits.

It is interesting to note that in a paper in foreign literature, a split-plate magnetron is described having a grid by means of which the output can be modulated.

(58) C. J. Brawde and A. M. Ivanenko, "Magnetron with grid control and some of its applications in the band of medium u-h-f and decimeter waves," *Jour. Tech. Phys.*, vol. 14, pp. 611–622; September–October, 1944.

Among other radar developments, tubes of the "lighthouse" type also have been described.

(59) E. D. McArthur, "Disc seal tubes," *Electronics*, vol. 18, pp. 98–102; February, 1945.

In connection with the development of radar systems, a "pulse-modulator" tube type came into use. Its function is the abrupt opening and stopping of the flow of the direct-current power to the radio-frequency oscillator tube during each cycle and withholding this power from reaching the oscillator during the intervals between the successive pulses. The necessary characteristics of the pulse-modulator tubes are (1) ability to pass very high currents during time intervals of several microseconds or a fraction of a microsecond; (2) low internal voltage drop even at the maximum pulse current; (3) ability to bar direct-current power supply at approximately 10 to 15 kilovolts from finding its way to the oscillator; (4) convenience of triggering the direct-current power to give the desired pulse shape. Both triodes and tetrodes were developed for this purpose, tetrodes having the advantage of greater "power gain."

In the frequency band from 500 to 1000 megacycles, new small triodes capable of delivering powers up to 500 watts at 600 megacycles, and reduced power up to 1000 megacycles, have been developed by one of the electron-tube manufacturers. These tubes can be cooled either by forced-air or by water. Several other newly designed tetrodes have also been announced by various manufacturers in connection with the pending development of television and frequency modulation. For frequencies up to 120 megacycles, radiation-cooled tetrodes are available with approximately 350 watts and up to 70 megacycles with 750 watts output. At the November, 1945, I.R.E.-R.M.A. meeting at Rochester, an outstanding development of a 5-kilowatt push-pull tetrode which is satisfactory to at least 300 megacycles was described. This tube uses water-cooling of all supporting members and the anodes, resulting in a structure with very low capacitances.

The development of power-output tubes for industrial application continued mainly in the frequency range below 30 megacycles for dielectric heating. Frequencies of 13.6 and 27.66 were specially allocated by the Federal Communications Commission for such use. Some of these tubes with reduced output, or specially designed triodes of various makes intended for frequencies up to 100 megacycles, are gradually appearing on the market. They are preponderantly of the forced-air-cooled type with plate ratings up to 2500 watts. The same tubes may perhaps be employed in frequency-modulation sets in the 88- to 108-megacycle band newly assigned for this purpose. In this latter case, the tubes may be operated in grounded-grid circuits.

(60) Clayton E. Murdock, "VHF tetrode for medium output power," *FM and Television*, vol. 5, pp. 20–21; February, 1945.

In the field of power-output tubes for intercontinental broadcasting, some transmitters have employed new tubes capable of delivering 100 kilowatts each at 22 megacycles.

(61) Hugo Romander, "Engineering details of OWI 200-kw units," *Electronic Indus.*, vol. 4, pp. 100–103, 158, 162; October, 1945.

Among other developments for broadcast service, it is worth mentioning that favorable experience with high-output radar tubes having thoriated filaments and operated at 15 kilovolts on the plate, accelerated the development of several more or less successful experimental tubes with similar cathodes. There is an indication, but no full assurance, that these tubes will immediately be able to compete with the standard water-cooled tubes with pure-tungsten cathodes.

It is also worth mentioning that, as an outcome of war development, intensive study of secondary-emission cathodes in power tubes, mainly of the magnetron type, has been carried out.

Another improvement in power-output tubes, which steadily finds its way into tube design, is replacing the standard cathode presses by glass dishes supporting inner-tube structure as the technique of making dishes improves. This permits shortening the tube structural parts, thus extending the tube frequency limit upwards.

Continuation of work on materials for grids of high-power tubes has resulted in another nonemitting grid material.

(62) Harold E. Sorg and George A. Becker, "Grid emission in vacuum tubes," *Electronics*, vol. 18, pp. 104–109; July, 1945.

From the reviews published in other countries, which became available in the United States during 1945, one cannot draw much information regarding the power-output tube development progress in Europe. However, this interesting remark can be made. Several years ago (up to 1942) a large European firm was strongly advocating demountable types of high-vacuum tube with continuous exhaust in operation in preference to the sealed-off type even for smaller sizes, with 5- or 19-kilowatt output ratings. A suggestion has even been made for application of demountable high-vacuum tubes as "mutators" (in our terminology, "invertors") instead of mercury-pool tubes in high-voltage direct-current power-transmission installations. In a few available issues of one publication for 1945, the same firm now promotes sealed-off tubes even for the 50-kilowatt size.

(63) A. Gaudenzi, "High-power demountable transmitting tubes," *Brown Boveri Rev.*, vol. 28, pp. 389–393; December, 1941.
(64) A. Gaudenzi, "High-vacuum mutators for direct-current transmission," *Brown Boveri Rev.*, vol. 28, pp. 319–322; October, 1941.
(65) F. Jenny, "Sealed-off transmitting tubes and their production," *Brown Boveri Rev.*, vol. 33, pp. 309–312; September, 1944.

Small High-Vacuum Tubes

The expanded production in the United States, required primarily for military purposes, is indicated by the following comparative figures. The large increase in dollar values on electron tubes as compared with the number of units is a reflection of an increasing proportion of closer spaced and more complex tubes as well as of increased production costs.

TABLE II

	1939 Average Monthly Production	June, 1945, Deliveries
Receiving tubes	9,127,000 units	13,117,000 units
Receiving tubes	$2,747,000	$6,380,000
Transmitting tubes	27,000 units	2,412,000 units
Transmitting tubes	$189,000	$15,860,000
Transformers	$706,000	$12,090,000
Capacitors	$2,298,000	$12,023,000
Resistors	$710,000	$4,429,000

Radio and Radar Information Letter, issued by United States Government War Production Board, September, 1945, p. 1.

An interesting summary of the developmental history of all classes of vacuum tubes was made available.

(66) I. E. Mouromtseff, "Development of electronic tubes," PROC. I.R.E., vol. 33, pp. 223–233; April, 1945.

Possibly the best available picture of the progress of tube development and production during the war is shown by the listing of certain types of tubes on the United States Government's Joint Army-Navy Preferred List together with typical characteristics given in the accompanying table. These are the types used for new designs for service equipment unless other types were especially authorized. Hundreds of other tube types were still being procured at the end of the war.

(67) Army-Navy Preferred List of Radio Electron Tubes, September 15, 1944.

One of the wartime requirements was for tubes of increased resistance to shock and extreme vibration due to gunfire, engine vibration, etc. Specifications for the first of such tubes became available for public reference.

(68) Joint Army-Navy Specifications JAN-1A, pp. JAN-6AC7W (January 15, 1945) and JAN-6SN7W (June 30, 1945).

Still another outstanding development was miniature electron tubes for proximity fuzes (which replaced time fuzes in the head of shrapnel-like projectiles). These tubes are the smallest in existence. Their over-all length, including the base, is slightly over one inch and their rectangular cross section approximately $\frac{3}{8}'' \times \frac{1}{4}''$. Within such a space, triode, tetrode, or pentode structures are located. Each proximity fuze employs several miniature tubes some of which perform the duty of real "power-output" tubes although their output is measured in only a few milliwatts (up to 25). The outstanding feature of these tubes, besides being the smallest power-output tubes ever built, is the mechanical design which

TABLE III
JOINT ARMY-NAVY PREFERRED TUBES
(United States Government)

Triodes	*Ef*	*Eb*	*Ec*	*If*	*Ib*	*Mu*	*Gm*
1LE3	1.4	90	−3	0.050	1.4	14.5	760
2C22	6.3	300	−10.5	0.3	11	20	3000
2C40*	6.3	250	−3.3	0.75	16.5	36	4800 ("light-house")
6AQ6*	6.3	250	−3	0.15	1.0	70	1200 (two diodes)
6C4*	6.3	250	−8.50	0.15	10.5	17	2200
6F4*	6.3	80	−20	0.225	13	17	5800
6J4*	6.3	150		0.4	15	55	12000
6J5, 6J5GT	6.3	250	−8	0.3	9.0	20	2600
6SQ7, 6SQ7GT	6.3	250	−2	0.3	0.9	100	1100 (two diodes)
6SR7, 6SR7GT	6.3	250	−9	0.3	9.5	16	1900 (two diodes)
Twin Triodes (each section)							
3A5*	1.4	90	−2.5	0.22	3.7	15	1800
6J6*	6.3	100	−.85	0.45	8.5	32	5300
6SL7GT	6.3	250	−2	0.3	2.3	70	1600
6SN7GT	6.3	250	−8	0.6	9	20	2600
7F8*	6.3	250	−2.5	0.3	10	52	5000

Pentodes	*Ef*	*Eb*	*Ec2*	*Ec1*	*If*	*Ib*	*Gn*	*Rp*
1L4	1.4	90	67.5	0	0.05	2.9	925	0.6
1LN5	1.4	90	90	0	0.050	1.6	800	1.1
1S5	1.4	90	90	0	0.050	2.7	720	0.5 (one diode)
6AB7	6.3	300	200	−3	0.45	12.5	5000	0.7
6AC7	6.3	300	150	−2	0.45	10	9000	1.0
6AG7	6.3	300	150	3.0	0.65	30	11000	0.13
6AJ5*	6.3	28	28		0.175	3.0	2750	0.09
6AK5*	6.3	180	120	−2	0.175	7.7	5100	0.69
6AS6*	6.3	120	120	−2	0.175	5.8	3500	—
6SG7*	6.3	250	150	−2.5	0.3	9.2	4000	over/1.0
6SJ7, 6SJ7GT	6.3	250	100	−3	0.3	3.0	1650	over/1.0
6SK7, 6SK7GT	6.3	250	100	−3	0.3	9.2	2000	0.8
7W7	6.3	300	150		0.45	10	5800	0.3
9001	6.3	250	100	−3	0.15	2.0	1400	over/1.0
9003	6.3	250	100	−3	0.15	6.7	1800	0.7

Converters	*Ef*	*Eb*	*Esg*	*If*	*Ik*	*Ib*	*Gc*
1LC6	1.4	90	35	0.050	2.9	0.75	275 (pentagrid)
1R5	1.4	90	67.5	0.05	5	1.7	300 (pentagrid)
6SA7, 6SA7GT	6.3	250	100	0.3	12.5	3.5	450 (pentagrid)
14J7	12.6	250	100	0.15	10.0	1.3	300 (triode-hexode)

Output Tube	*Ef*	*If*	*Eb*	*Ec2*	*Ec1*	*Ib*	*Ic2*	*Gm*	*P.O. Watts*
1LB4	1.4	0.5	90	90	−9	5.0	1.0	925	0.2
3A4*	1.4	0.2	150	90	−8.4	13.3	2.2	1900	0.7
3S4	1.4	0.1	90	67.5	−7	7.4	1.4	1575	0.27
6B4G	6.3	1.0	250		−45	60		6250	3.2 (one triode)
6G6G	6.3	0.15	180	180	−9.0	15.0	2.5	2300	1.1
6L6GA	6.3	0.9	350	250	−18	54	2.5	5200	10.8
6N7GT	6.3	0.8	294		−6	7		3200	10.0
6V6GT	6.3	0.45	315	225	−13	34	2.2	3750	5.5
6Y6G	6.3	1.25	200	135	−14	61	2.2	7100	6.0
12A6	12.6	0.15	250	250	−12.5	30	3.5	3000	3.4
25L6GT	25.0	0.3	200	110	−8	50	2.0	9500	4.3
28D7*	28.0	0.4	28	28	−3.5	12.5	1.0	3000	0.1 (each section)

Diodes and Rectifiers (Vacuum Types)	*Ef*	*If*	*Maximum Ib*	*Maximum Peak Inverse Eb*	
1A3*	1.4	0.15	0.5	330 volts	Cathode
5U4G	5.0	3.0	225	1550	Full wave
5Y3GT	5.0	2.0	125	1400	Full wave
6AL5*	6.3	0.3	9	420	Twin diode
6H6, 6H6GT	6.3	0.3	8	420	Twin diode
6X5GT	6.3	0.6	70	1250	Full wave
25Z6GT	25.0	0.3	75	700	Full wave
559	6.3	0.75	30	100	"Light-house" diode

Cathode-Ray Indicator Tubes			
6AF6G	6.3	0.15	Dual indicator
6E5	6.3	0.3	Single indicator with triode

* Type not available prior to the war.

must withstand, without losing parts alignment, a shock equivalent to from 15,000 to 20,000 g, and a centrifugal force generated by rotation at the rate of 475 revolutions per minute.

(69) "Proximity fuze," *Electronics*, vol. 18, pp. 110–111; November, 1945.

An analysis of electron paths and current densities for beam-power tubes with parallel-plane configurations, including mathematical computation and a description of the physical picture, was published. A new study of emission from oxide-coated cathodes and a new analysis of transit-time effects in high-frequency tubes appeared.

(70) G. B. Walker, "Space charge effects between a positive grid and anode of a beam tetrode," *Wireless Eng.*, vol. 23, pp. 157–169; April, 1945; pp. 212–222; May, 1945; pp. 276–281; June, 1945.
(71) S. Rodda, "Space charge and electron deflections in beam tetrode theory," *Electronic Eng.*, vol. 17, pp. 541–545; June, 1945; pp. 589–592; July, 1945; pp. 649–652; August, 1945.
(72) Robert L. Sproull, "An investigation of short-time emission from oxide-coated cathodes," *Phys. Rev.*, vol. 67, pp. 167–178; March, 1945.
(73) Arthur B. Bronwell, "Electron transit time in varying fields," PROC. I.R.E., vol. 33, pp. 712–716; October, 1945.

There appeared descriptions of several new types of tubes.

(74) G. T. Ford, "Midget tubes for high frequencies," *Bell Lab. Rec.*, vol. 22, pp. 605–608; November, 1944.
(75) R. M. Smith, "Orbital beam UHF tubes," *Electronics*, vol. 18, pp. 103–105; May, 1945.

There were several interesting papers giving analyses of tube and circuit performance.

(76) John W. Miles, "Junction analysis in vacuum-tube circuits," PROC. I.R.E., vol. 32, pp. 617–620; October, 1944.
(77) J. R. Pierce, "Reflex oscillators," PROC. I.R.E., vol. 33, pp. 112–118; February, 1945. (Discussion, E. U. Condon, A. E. Harrison, W. W. Hansen, J. R. Woodyard, J. R. Pierce, PROC. I.R.E., vol. 33, pp. 483–485; July, 1945.)
(78) L. C. Peterson and F. B. Llewellyn, "The performance and measurement of mixers in terms of linear-network theory," PROC. I.R.E., vol. 33, pp. 458–476; July, 1945.
(79) W. W. Hansen, "On maximum gain-band width product in amplifiers," *Jour. Appl. Phys.*, vol. 16, pp. 528–534; September, 1945.
(80) E. W. Herold, R. R. Bush, and W. R. Ferris, "Conversion loss of diode mixers having image-frequency impedance," PROC. I.R.E., vol. 33, pp. 603–609; September, 1945.
(81) Robert J. Meyer, "Open-grid tubes in low-level amplifiers," *Electronics*, vol. 17, pp. 126–128, 234; October, 1944.

Phototubes

Little material on phototubes has appeared in the published literature during the year 1945 which would indicate progress of a fundamental research nature. However, during the war two large-scale military applications of phototubes were developed. The first required the development of a very rugged tube for use in a photoelectric version of the proximity fuze. Although a large quantity of such fuzes was built the radio-operated proximity fuze was deemed superior from a tactical standpoint. The photoelectron multiplier found itself in a novel spot. Because of the extraordinary gains available, the random-shot noise in the photocathode current could be amplified to a usable level for modulation of radar countermeasure or "jamming" signals. Effective combination of electronic jamming with other methods reduced bomber losses to a considerable degree.

The photoelectron multiplier continued to receive attention as a competitor of the photographic plate for rapid spectrochemical analysis.

(82) G. H. Dieke and H. M. Crosswhite, "Direct intensity measurements of spectrum lines with photo multiplier tubes," *Jour. Opt. Soc. Amer.*, vol. 35, pp. 471–480; July, 1945.
(83) George A. Nahstoll and Ford R. Bryan, "Application of multiplier photo-tubes to the spectro-chemical analysis of magnesium alloy," *Jour. Opt. Soc. Amer.*, vol. 35, pp. 646–650; October, 1945.
(84) J. L. Saunderson, V. J. Caldecourt, and E. W. Peterson, "Photoelectric instrument for direct spectro-chemical analysis,"

Jour. Opt. Soc. Amer., vol. 35, pp. 681–697; November, 1945.

Gas Tubes

Studies of the wave-forms of load currents obtained from one- and two-tube gas-tube rectifier circuits were published in one series of papers.

(85) P. T. Chin, "Gaseous rectifier circuits," *Electronics*, vol. 18, pp. 138–143; April, 1945; pp. 132–137; May, 1945.
(86) P. T. Chin and G. E. Walter, "Transient response of controlled rectifier circuits," *Trans. A.I.E.E.* (*Elec. Eng.*, April, 1945), vol. 64, pp. 208–214; April, 1945.

Further uses for sealed metal ignitron tubes were described.

(87) M. M. Morack, "Design of sealed ignitron rectifiers for three-wire service," *Trans. A.I.E.E.* (*Elec. Eng.*, March, 1945), vol. 64, pp. 103–107; March, 1945.

Theoretical determinations were made and experimental data were obtained with respect to the magnitude of currents obtained on arc back of power rectifiers.

(88) R. D. Evans and A. J. Maslin, "Arc-backs in rectifier circuits—artificial arc-back tests," *Trans. A.I.E.E.* (*Elec. Eng.*, June, 1945), vol. 64, pp. 303–311; June, 1945.
(89) C. C. Herskind and H. L. Kellogg, "Rectifier fault currents," *Trans. A.I.E.E.* (*Elec. Eng.*, March, 1945), vol. 64, pp. 145–150; March, 1945.

A description of latest ignitron design for high-voltage (15 kilovolts) operation was published.

(90) H. C. Steiner, J. L. Zehner, and H. E. Zuvers, "Pentode ignitrons for electronic power converters," *Trans. A.I.E.E.* (*Elec. Eng.*, October, 1944), vol. 63, pp. 693–697; October, 1944.

One paper discussed the interference caused by rectifier circuits.

(91) D. J. McDonald, "Rectifiers and inductive co-ordination," *Elec. Eng.*, vol. 64, pp. 60–64; February, 1945.

A description was given of a mass spectrometer tube and associated circuits.

(92) John A. Hipple, Don J. Grove, and W. M. Hickam, "Electronics of the mass spectrometer," *Elec. Eng.*, vol. 64, pp. 141–145; April, 1945.

A discussion of the economics involved in power-inversion circuits was given in one paper.

(93) S. B. Crary and R. M. Easley, "Frequency changers—characteristics, applications, and economics," *Trans. A.I.E.E.* (*Elec. Eng.*, June, 1945), vol. 64, pp. 351–358; June, 1945.

Cathode-Ray Tubes and Television Tubes

During the early part of 1945, cathode-ray and pickup tube development was continued for the war program. A few new cathode-ray tube types were introduced; one with nonglare coating, higher light output, and improved deflection sensitivity to be used in airborne equipment in high ambient light; one high-voltage, high-frequency type for the study of fast transient and high-frequency phenomena in the range of 10 to 100 megacycles.

(94) P. S. Christaldi, "Cathode-ray tubes and their applications," Proc. I.R.E., vol. 33, pp. 373–381; June, 1945.

Other types of cathode-ray tubes were developed with minor changes for special applications. A new pickup tube known as the image orthicon with high infrared sensitivity having an operating sensitivity of the order of 100 times that of the iconoscope, was made in production for the armed forces.

(95) "Sensitive television camera tubes," *Electronics*, vol. 18, p. 330; December, 1945.

The work on improved performance of the JAN preferred types of cathode-ray tubes was continued with the production of the so-called "zero first-anode current gun," having improved focus and decreased deflection defocusing, in practically all of the electrostatic-deflection types.

(96) L. E. Swedlund, "Improved electron gun for cathode-ray tubes," *Electronics*, vol. 18, pp. 122–124; March, 1945.

The resolution performance of the JAN magnetic-deflection types was greatly improved by the use of the so-called "limiting-aperture magnetic-focus gun."

In the United States the Joint Electron Tube Engineering Council (JETEC) Cathode-Ray Tube Committee was formed by combining the activities of The Radio Manufacturers Association (RMA) and The National Electrical Manufacturers Association (NEMA) for continuing activity in industry co-ordination of standardization of test methods and recommendation for cathode-ray-tube specifications.

Among the developments in cathode-ray tubes during the past four to five years for the war program, which can now be described, are the P7 and P14 double-layer long-persistence fluorescent screens, and the radio-deflection-type cathode-ray tube. The P7 and P14 are similar double-layer long-persistence screens. The P7 screen was developed early in the war program and was used in a number of radar cathode-ray-tube types manufactured in large quantities and used extensively in many types of radar equipment. The radial deflection type cathode-ray tube was developed to provide a longer base line and thereby improve the accuracy of small cathode-ray tubes which were used to a considerable extent in altimeter and gun-fire control equipment. The detailed performance characteristics of these tubes and the part they played in many equipments used during the war will undoubtedly appear in papers in the near future.

A number of important papers appeared on electron optics and beam focusing.

(97) G. Liebmann, "The image formation in cathode-ray tubes and the relation of fluorescent spot size and final anode voltage," Proc. I.R.E., vol. 33, pp. 381–389; June, 1945.
(98) J. R. Pierce, "A figure of merit for electron-concentrating systems," Proc. I.R.E., vol. 33, pp. 476–478; July, 1945.
(99) D. Gabor, "Dynamics of electron beams, application of Hamiltonian dynamics to electronic problems," Proc. I.R.E., vol. 33, pp. 792–805; November, 1945.
(100) C. J. Calbick, "Historical background of electron optics," *Jour. Appl. Phys.*, vol. 15, pp. 685–690; October, 1944.
(101) H. Gunther Rudenberg, "Deflection sensitivity of parallel-wire lines in cathode-ray oscillographs," *Jour. Appl. Phys.*, vol. 16, pp. 279–285; May, 1945.
(102) R. G. E. Hutter, "The class of electron lenses which satisfy Newton's image relations," *Jour. Appl. Phys.*, vol. 16, pp. 670–678; November, 1945.
(103) R. G. E. Hutter, "Rigorous treatment of the electrostatic immersion lens whose axial potential distribution is given by: $\phi(z)=\phi_0 e^{k \arctan z}$," *Jour. Appl. Phys.*, vol. 16, pp. 678–699; November, 1945.

(104) L. S. Goddard, "The computation of electron trajectories in axially symmetric fields," *Proc. Phys. Soc.* (London), vol. 56, pp. 372–378; November, 1944.
(105) L. S. Goddard and O. Klemperer, "Electron ray tracing through magnetic lenses," *Proc. Phys. Soc.* (London), vol. 56, pp. 378–396; November, 1944.
(106) A. L. Samuel, "Some notes on the design of electron guns," PROC. I.R.E., vol. 33, pp. 233–240; April, 1945.
(107) Otto Ackerman and Edward Beck, "Electronic oscillograph-time microscope," *Westinghouse Eng.*, vol. 4, pp. 169–173; November, 1944.

The field of electron microscopy continued to expand at a rapid rate with the development of new instruments and extension of applications to microchemical analysis and electron-diffraction studies of surface structure.

(108) Eileen I. Alessandrini, "The use of the electron diffraction camera to detect insulating films," *Jour. Appl. Phys.*, vol. 16, pp. 94–96; February, 1945.
(109) R. D. Heidenreich and L. Sturkey, "Crystal interference phenomena in electron microscope images," *Jour. Appl. Phys.*, vol. 16, pp. 97–105; February, 1945.
(110) D. G. Brubaker and M. L. Fuller, "The electrical charging of electron diffraction specimens," *Jour. Appl. Phys.*, vol. 16, pp. 128–130; March, 1945.
(111) L. Marton, "A 100-kv electron microscope," *Jour. Appl. Phys.*, vol. 16, pp. 131–138; March, 1945.
(112) "Abstracts of proceedings of the Electron Microscope Society of America meeting, November 16, 17, and 18, 1944, in Chicago, Illinois," *Jour. Appl. Phys.*, vol. 16, pp. 263–266; April, 1945.
(113) H. C. O'Brien, Jr., "Pigment dispersion methods for electron microscopy," *Jour. Appl. Phys.*, vol. 16, pp. 370–372; June, 1945.
(114) C. Marton, "A bibliography of electron microscopy III," *Jour. Appl. Phys.*, vol. 16, pp. 373–378; July, 1945.
(115) James Hillier and R. F. Baker, "A discussion of the illuminating system of the electron microscope," *Jour. Appl. Phys.*, vol. 16, pp. 469–483, August, 1945.
(116) E. A. Gulbransen, "An electron diffraction camera for the study of high temperature surface reactions," *Jour. Appl. Phys.*, vol. 16, pp. 718–724; November, 1945.
(117) R. B. Barnes, C. J. Burton, and R. G. Scott, "Electron microscopical replica techniques for the study of organic surfaces," *Jour. Phys.*, vol. 16, pp. 730–739; November, 1945.

During the latter half of the year, development work on cathode-ray and pickup tubes was largely directed toward the provision of improved tubes for postwar television. An effort was being made to utilize knowledge and experience gained during the war. The new cathode-ray tubes are expected to feature wide-angle deflection, shorter over-all length, essentially flat screen, higher picture brightness, and better resolution. The new pickup tubes are expected to have much higher sensitivity, smaller photocathode, making possible their use with a wider variety of lenses and with greater depth of focus. Detailed publications will doubtless appear in 1946 covering the new features of these new tubes.

Television

There was a very great increase in television activity in 1945 coincident with the end of the war. American industry proceeded with developments and plans aimed at the widespread use of television in the very near future. Most of the technical advances achieved in the course of this activity, however, have not yet been made public, so that there is little to report in this annual review.

During the year the basic technical standards for the transmission of television signals in 6-megacycle channels were finally developed by Panel 6 of the Radio Technical Planning Board in the United States and were adopted with slight changes for commercial broadcasting by the Federal Communications Commission.

(118) For reference to the work of the Radio Technical Planning Board, see PROC. I.R.E., vol. 33, p. 143; March, 1945.

In addition, some type tests and performance standards for transmitters were approved and work is continuing in this field. The Commission allocated thirteen 6-megacycle channels for use for commercial broadcasting between 44 megacycles and 216 megacycles, and a master geographical allocation plan providing for stations in practically all metropolitan areas was released. The Federal Communications Commission also allocated the band from 480 to 920 megacycles for experimental television operation, and the band from 1245 to 1325 megacycles for television-relay use.

During the year, most of the television stations already in operation increased their program time on the air but were still operating a limited program service. At the close of the year, however, every indication pointed to a large increase in the number of active stations during the coming year, and to an expanded broadcast program by all stations.

A new television radio-relay link from Washington to Philadelphia was completed during the year, and other previously built cable and radio-relay links between Philadelphia and New York, and between New York and Schenectady continued in operation. It is also worthy of note that a 2000-megacycle radio-relay link between studio and transmitter was in operation. This used a transmitting tube of the disk-seal type.

A new television camera tube, the "image orthicon," was announced and demonstrated. This tube gives an increase in sensitivity of up to 100 times over previously available tubes and therefore greatly widens the scope of television program operation.

The year also saw a marked increase in research and development in color television. While this fact has appeared in the public press, the results of these investigations have not yet appeared in technical publications.

A new discriminator circuit for the sound channel, which uses a frequency-modulated signal according to present standards, has been described. This is called a "ratio-detector." It does not require preceding limiter stages to obtain the interference- and noise-reduction properties which are characteristic of frequency-modulation reception.

During the year, a high-impedance (about 300 ohms) flexible transmission line of the solid-dielectric type was developed for use between a television receiving antenna and the receiver. This is a low-loss line for wide-band reception with a dipole or similar antenna. The line consists of a flat strip of low-loss dielectric, with conductors imbedded near the edges of the strip.

There has also been some work reported on the development of television amplifiers and other equipment having television applications as indicated by some of the following references.

(119) H. E. Kallmann, R. E. Spencer, and C. P. Singer, "Transient response," Proc. I.R.E., vol. 33, pp. 169–195; March, 1945.
(120) G. Liebmann, "The image formation in cathode-ray tubes and the relation of fluorescent spot size and final anode voltage," Proc. I.R.E., vol. 33, pp. 381–389; June, 1945.
(121) M. J. Larsen, "Low-frequency compensation of video-frequency amplifiers," Proc. I.R.E., vol. 33, pp. 666–670; October, 1945.
(122) G. C. Sziklai and A. C. Schroeder, "Cathode-coupled wide-band amplifiers," Proc. I.R.E., vol. 33, pp. 701–709; October, 1945.
(123) G. C. Sziklai and A. C. Schroeder, "Band-pass bridged-T network for television intermediate-frequency amplifiers," Proc. I.R.E., vol. 33, pp. 709–711; October, 1945.
(124) W. R. Piggott, "Producing rectangular R-F pulses of known amplitude," *Wireless Eng.*, vol. 22, pp. 119–125; March, 1945.
(125) C. C. Eaglesfield, "A square-wave analyser," *Wireless Eng.*, vol. 22, pp. 223–232; May, 1945.
(126) H. Moss, "Time-base converter and frequency divider," *Wireless Eng.*, vol. 22, pp. 368–372; August, 1945.
(127) P. Nagy and M. J. Goddard, "Oscillograph for the direct measurement of frequency employing a signal converter," *Wireless Eng.*, vol. 22, pp. 429–441; September, 1945; pp. 489–496; October, 1945.
(128) R. G. Mitchell, "Cascade H. T. generator," *Wireless Eng.*, vol. 22, pp. 474–483; October, 1945.
(129) L. C. Jesty, "Scanning systems for colour television," *Electronic Eng.*, vol. 17, pp. 456–460; April, 1945.
(130) V. M. Bradley, "Engineering aspects of television programming," *Electronics*, vol. 18, pp. 107–109; March, 1945.
(131) J. H. Jupe, "Large screen television," abstract, *Electronics*, vol. 18, pp. 270, 274, 278; April, 1945.
(132) Emanuel Last, "Restorer-circuit operation," *Electronics*, vol. 18, pp. 132–133; September, 1945.
(133) F. J. Bingley, "VHF multiple-relay television network," *Electronics*, vol. 18, pp. 102–108; October, 1945.
(134) R. B. Austrian, "Some economic aspects of theater television," *Jour. Soc. Mot. Pic. Eng.*, vol. 44, pp. 377–385; May, 1945.
(134) H. S. Osborne, "Coaxial cables and television transmission," *Jour. Soc. Mot. Pic. Eng.*, vol. 44, pp. 403–418; June, 1945.
(135) D. W. Epstein and I. G. Maloff, "Projection television," *Jour. Soc. Mot. Pic. Eng.*, vol. 44, pp. 443–455; June, 1945.
(136) A. H. Rosenthal, "Problems of theater television projection equipment," *Jour. Soc. Mot. Pic. Eng.*, vol. 45, pp. 218–240; September, 1945. Abstract, *Electronics*, vol. 18, pp. 218, 222, 226, 230; May, 1945.
(137) C. H. Bachman, "Image contrast in television," *Gen. Elec. Rev.*, vol. 48, pp. 13–19; September, 1945.
(138) E. A. Henry, "Practical design of video amplifiers," *QST*, vol. 29, pp. 11–16; April, 1945; *QST*, vol. 29, pp. 32–38; May, 1945.
(139) H. N. Kozanowski, "DC picture transfer," *Broadcast News*, pp. 32–34, 40; August, 1944, *Electronic Industries*, vol. 4, pp. 106–107, 140, 142, 144; April, 1945.
(140) K. Pestrecov, "Television optics," *Electronic Indus.*, vol. 4, pp. 80–82, 146, 150; August, 1945.
(141) S. W. Seeley, "Ratio detectors for frequency-modulation receivers," presented, New York Section, October 3, 1945, New York, N. Y.

Facsimile

During the year there have been technical developments both in the design of terminal equipment and in methods of facsimile transmission over radio circuits and wire lines. Terminal equipment for long-distance radio circuits has continued to run at approximately 100 revolutions per minute drum speed, and wire-line-message transmitting equipment at maximum speeds between 200 and 300 revolutions per minute. In the laboratories scanners and recorders for very much higher speeds have been built, some running at 1200 revolutions per minute or 80 square inches per minute. These developments represent progress in mechanisms, signal-frequency amplifiers, and synchronizing devices. Scanners and recorders with large drums are being regularly used for the transmission of weather maps. Special transceivers have been developed for high definition which scan at either 200 or 300 lines per inch. In signal amplifiers for fine detail and high speed, there has been an increasing use of electron-multiplier phototubes. Facsimile recording techniques and recording papers have found many war uses in apparatus quite outside the field of facsimile.

For long radio circuits, frequency-shift modulation, with one radio frequency for black and a slightly different one for white, has become well established and has brought considerable improvement in the quality of recorded pictures. Better operation is also observed over wire lines where simplification of scanners, recorders, and associated switching equipment have made the services function more smoothly and more reliably. Most wire-line transmissions continue to use an amplitude-modulated subcarrier, although subcarrier frequency modulation is under consideration. Experimental transmissions have also been made over microwave relay circuits and an early extension of these facilities is anticipated.

An ever-increasing volume of wire-line telegraph traffic is being sent by facsimile. In the United States over a million and a half messages were handled in 1945 by this method, and with the increased construction of equipment permitted by the relaxation of priority restrictions, this message volume should further increase. Visitors to this country show marked interest in facsimile as a practical method of record communication for the rehabilitation of communications services in some other countries. Its value in direct transmission of languages unsuited to teleprinter keyboards is now widely recognized.

With war production finished, active attention is being directed to other facsimile applications. There has been experimental operation in the field of railroad dispatching. Police departments have recommended its use as a part of their communication system. Studies and developments on broadcast facsimile have begun in several laboratories with the objective of designing apparatus suitable for receiving facsimile news in the home or office.

During the war years, over 1000 facsimile sets have been manufactured for the Army, Navy, and Office of War Information of the United States. These have provided the equipment for a world-wide development of picture transmission by these services. Secrecy restrictions have prevented a report on this activity until now, and it therefore seems worthwhile to include here the following paragraphs taken from an historical report of the United States Signal Corps. They describe the most extensive application of facsimile communication so far made.

"In December, 1941, the necessity of providing telephoto service for wartime operations was realized by the Signal Corps and direct responsibility for it was assigned to Army Communications Service. Newspicture equipment was adapted and tests were successfully conducted. In June, 1942, the first installation of the telephoto network for the exclusive transmission of military material to the various Defense Commands was made.

"Initially, telephoto equipment was installed at New Orleans and at New York City. The net control station was located in Washington. For more than a year the traffic, entirely continental, consisted of a daily submarine-situation map, transmitted to coastal points for G-2 to utilize in combatting the German underwater menace, and of semiweekly weather charts for the Army Air Forces. . . .

"Introduction of new and improved equipment and practices stimulated by the effective application of telephoto to military purposes resulted in an expansion of the network to include transmitting and receiving stations at San Antonio, Seattle, Pasadena, Memphis, and other domestic points. These provided the War Department with a contact at each of the Defense Commands, and with the headquarters of the Alaska Communications System. The service during its first year proved a great success.

"In January, 1943, at the request of the Air Corps, a station was installed at the California Institute of Technology, where the Meteorological Research Division of the Air Forces was then located. From this station weather charts and maps were transmitted for delivery to the Directorate of Weather. . . .

"At the beginning of 1943, the equipment necessary to adapt the wire telephoto to radio operation had been designed and manufactured. This resulted in an expansion of the War Department facsimile network overseas with the installation of a radiophoto station in Algiers in February, 1943. A specially selected team flew to Africa to get test equipment set up and to experiment with the types of photograph developing and printing best suited to transmission by radio. . . . The first Signal Corps radiophoto newspicture transmitted for release was taken on 18 March, 1943. It pictured a gun crew on the alert in North Africa. . . .

"In keeping with the War Department policy of informing the public as quickly as possible on the progress of the war, news combat photographs were radioed to Washington for immediate release to the press. The radiophoto network expanded rapidly. Stations were fast established at such cities as Caserta (Italy), London, Paris, Honolulu, Brisbane, Manila, and Berlin. Thousands of pictures have been transmitted from all theaters of operation and have been released in this country at approximately the same time their corresponding news stories hit front pages. Shots of the invasion of France, for example, were received in Washington within two hours after General Eisenhower's first communique was released.

"The radiophoto headquarters in the War Department's Signal Center was not always on the receiving end of pictures from the combat fronts. Throughout the war many transmissions were made from there for reproduction overseas in publications such as 'Stars and Stripes' and 'Yank.' The material transmitted consisted mostly of photographs of sporting events, happenings of national import, and items involving troops. . . .

"Vast improvements in the quality of photographs transmitted by radio have been accomplished by ACS. At first the single-sideband (voice) radio system was used exclusively for the transmission of pictures. Later, ACS co-ordinated the development of the carrier shift method of transmission by which photographs could be sent over continuous-wave circuits used normally for radioteletypewriter. By this method the radio carrier is radiated continuously at constant amplitude and its frequency is varied in direct proportion with the change in picture tone. The highest carrier frequency corresponds to picture black and the lowest to picture white. . . . The carrier shift method reduced the effects of fading and made possible an expansion of radiophoto activities to installations where voice facilities were unavailable. Through the constant experimentation of ACS, facsimile transmission has been so improved that it is often difficult to distinguish between radiophotos and originals. . . .

"The first news color picture ever transmitted by radio was released for publication on 3 August, 1945, though test for color separation prints began on 22 July. The photograph pictured the 'Big Three' at the Potsdam Conference. It was radioed from Berlin, where a radiophoto station was specially activated, to Washington where it was released to the news services. The time required for its transmission was approximately 21 minutes, the normal transmitting time being seven minutes per negative.

"Details for making and transmitting color photographs by radio were perfected jointly by ACS and APS. The historic first picture was taken with a one-shot camera which exposed three negatives simultaneously. From these exposures, three prints were made and each placed on a cylinder representing one of the three basic colors—red, yellow, and blue. The three prints were transmitted separately and combined into a color picture at the receiving terminal in Washington. Work is being continued by the Signal Corps to perfect radio color transmission and make it a regularly available service."

The following digest from the Signal Corps report lists the stations in operation and gives the number of pictures sent or received by each one during the year July 1, 1944 to June 30, 1945:

Stations	*Total Sent or Received*
Anchorage	775
Berlin	
Fairbanks	318
France (Mobile)	138
France (7th Army)	38
Honolulu	1100
India	142
Italy	1458
Leyte	36
London	5843
Manila	475
New York	9
Paris	2080
Saipan	185
San Francisco	230
France (6th Army Group)	6
S. W. Pacific Area (New Guinea)	336
Brisbane	457
Algiers	2
Total Year Ended June 30, 1945	13,608

(142) R. C. Davies and P. Lesser, "Facsimile equipment communication units," *Electronic Indus.*, vol. 4, pp. 96–99, 170; February, 1945.

(143) "Facsimile transmitter and receiver," *Radio News*, vol. 33, pp. 43, 110, 112; March, 1945.

Antennas

In spite of the war, the published record for the year discloses valuable material in the antenna field, though naturally many new aspects of the art are scarcely represented. For the purpose of this review, the following illustrations are given of literature in this field.

That the designer of radio equipment is well aware of problems involved in airplane design is evident in such papers as

(144) F. D. Bennett, P. D. Coleman, and A. S. Meier, "The design of broad-band aircraft-antenna systems," Proc. I.R.E., vol. 33, pp. 671–700; October, 1945.

(145) Charles B. Bovill, "Aerials for use on aircraft: A comparison between fixed and trailing types on the 900-meter waveband," *Jour. I.E.E.* (London), vol. 92, part III, pp. 105–119; June, 1945.

The first of these gives, in considerable detail, some of the techniques used at Aircraft Radio Laboratories, Wright Field. Measurement of antenna impedance, design of impedance-matching circuits, and the development of one type of broadband antenna for use on aircraft, are covered. The second analyzes antennas used in the medium-frequency range and compares the trailing and fixed types.

An analysis and defense of that system of direction finding which, in addition to a loop, employs a horizontal antenna to provide a voltage with which to neutralize the undesired pickup from the horizontal members of the loop, will be found in

(146) Frederick Emmons Terman and Joseph M. Pettit, "The compensated-loop direction finder," Proc. I.R.E., vol. 33, pp. 307–318; May, 1945.

Another paper proposed a system of automatic direction finding based on the use of a goniometer in which the radio pickups from cross-loops are in effect, converted into proportional direct currents which reverse in sense when a directional change causes the loop pickup to pass through a null, thus imparting an unambiguous direction to a magnetic needle.

(147) C. C. Pine, "A new type of automatic radio direction finder," Proc. I.R.E., vol. 33, pp. 522–527; August, 1945.

A paper on the radio-instrument landing system adopted by the Civil Aeronautics Administration for use in this country by civil aviation gave technical details of the runway localizer which operates between 108 and 111 megacycles. The installation program, though already started, was not expected to attain full volume until after the war.

(148) Peter Caporale, "The CAA instrument landing system," *Electronics*, vol. 18, pp. 116–124; February, 1945; pp. 128–135; March, 1945.

A receiving antenna for use with the localizer was described.

(149) Bruce E. Montgomery, "A very-high-frequency aircraft antenna for the reception of 109-megacycle localizer signals," Proc. I.R.E., vol. 33, pp. 767–772; November, 1945.

The disclosure of new forms of antenna for frequency-modulation broadcasting and discussions of the relative advantage of different types have appeared, as illustrated by the following papers:

(150) M. W. Scheldorf, "Circular antennas for FM broadcasting," *FM Television*, vol. 5, pp. 30–34; May, 1945; pp. 39–42, 83; June, 1945.
(151) J. P. Taylor, "A square-loop FM antenna," *Electronics*, vol. 18, pp. 96–100; March, 1945.
(152) G. H. Brown and J. Epstein, "A pretuned turnstile antenna," *Electronics*, vol. 18, pp. 102–107; June, 1945.

The experimental and the theoretical approaches to a problem are illustrated by the following papers which, though not directly connected, will be found of special interest from this point of view:

(153) S. A. Schelkunoff, "Concerning Hallen's integral equation for cylindrical antennas," Proc. I.R.E., vol. 33, pp. 872–878; December, 1945.
(154) George H. Brown and O. M. Woodward, Jr., "Experimentally determined impedance characteristics of cylindrical antennas," Proc. I.R.E., vol. 33, pp. 257–262; April, 1945.

The performance of directional arrays has been studied experimentally and compared with theory.

(155) H. Page, "The measured performance of horizontal dipole transmitting arrays," *Jour. I.E.E.* (London), vol. 92, part III, pp. 68–70; June, 1945.

The directional properties of two intersecting planes as a "reflector" for an exciter located on the bisector are analyzed by

(156) E. B. Moullin, "Theory and performance of corner reflectors for aerials," *Jour. I.E.E.* (London), vol. 92, part III, pp. 58–67; June, 1945.

In the following:

(157) J. Cooper and E. Green, "The design of directional aerial arrays," *Marconi Rev.*, vol. 8, pp. 12–23; January-March, 1945.

is given an example of the design of arrays to give a predetermined directional characteristic.

Among other titles indicative of the range of antenna interest during 1945 are the following:

(158) M. W. Scheldorf, "A new studio-to-transmitter antenna," Proc. I.R.E., vol. 33, pp. 106–112; February, 1945.
(159) C. W. Hansell, "Radio-relay-systems development by the Radio Corporation of America," Proc. I.R.E., vol. 33, pp. 156–168; March, 1945
(160) Chandler Stewart, Jr., "A proposed standard dummy antenna for testing aircraft-radio transmitters," Proc. I.R.E., vol. 33, pp. 772–777; November, 1945.

Radio Wave Propagation

During the final year of the war, investigations of wave propagation were carried on extensively in the United States and other countries in connection with communication, radar, and navigation systems employed in military operations. Much of the information accumulated in the course of these studies will doubtless prove of great interest when it is eventually released for publication. Fortunately, the rapid rate at which declassification of military material is proceeding leads one to hope that the major part of it will be generally available before the end of another year.

Books

There was published in 1945 a somewhat larger number of volumes containing sections on wave propagation than appeared during the two preceding years.

(161) A. de Quervain, "Cavity Resonators and Their Application in Ultra-Short-Wave Amplifier Engineering," A. G. Gebr. Leeman and Co., Zurich, Switzerland, 1944.
(162) W. L. Emery, "Ultra-High-Frequency Radio Engineering," Macmillan Co., New York, N. Y., 1944.
(163) W. Jackson, "High Frequency Transmission Lines," Methuen and Co., London, England, 1945.
(164) R. W. P. King, "Electromagnetic Engineering," McGraw-Hill Book Co., Inc., New York, N. Y., 1945.
(165) R. W. P. King, H. R. Mimno, and A. H. Wing, "Transmission Lines, Antennas, and Wave Guides," McGraw-Hill Book Co., Inc., New York, N. Y., 1945.
(166) M. S. Kiver, "UHF Radio Simplified," D. Van Nostrand Co., Inc., New York, N. Y., 1945.
(167) S. Ramo, "Introduction to Microwaves," McGraw-Hill Book Co., Inc., New York, N. Y., 1945.
(168) Standards on Radio Wave Propagation: "Definition of Terms Relating to Guided Waves," The Institute of Radio Engineers, New York, N. Y., 1942.

Ionosphere

Even fewer papers dealing with the ionosphere have been published in 1945 than in 1944. In 1945 the USSR and the United States have each contributed about a fourth of the year's papers, while England and India each provided an eighth. The remaining quarter have come from France, Sweden, and China. The theory of reflection and cosmic relations has received continued attention, as has the constitution of the upper atmosphere, diffusion, and absorption. Work has been reported on each of the D, E, and F layers and on fade-outs and solar-eclipse observations. There have been few contributions to the communication problems, presumably because of military regulations.

(169) J. Alpert and V. Ginsburg, "Absorption of radio waves in the ionosphere," *Bull. de l'Acad. des Sci. de l'URSS* (*Izvestiya*), *Série Physique*, vol. 8, pp. 42–67; 1944. (In Russian.) *Jour. Phys.* (U.S.S.R.) vol. 8, p. 383; 1944. (Summary in English.)
(170) J. Alpert and B. Gorozhankin, "Solar eclipses and radio investigations of the ionosphere," *Bull. de l'Acad. des Sci. de*

l'URSS (Izvestiya), Série Physique, vol. 8, pp. 85–108; 1944. (In Russian.) Jour. Phys. (U.S.S.R.), vol. 8, p. 382; 1944. (Summary, in English.)
(171) S. S. Baral and S. N. Mitra, "Effect of solar eclipse on the ionosphere," *Science and Culture* (Calcutta), vol. 10, pp. 175–176; October, 1944.
(172) A. C. Clarke, "V2 for ionosphere research," *Wireless World*, vol. 51, p. 58; February, 1945.
(173) T. G. Cowling, "The electrical conductivity of an ionized gas in a magnetic field, with applications to the solar atmosphere and the ionosphere," *Proc. Roy. Soc.*, ser. A, vol. 183, pp. 453–479; June, 1945.
(174) J. H. DeWitt, Jr. and A. D. Ring, "Significant radiation from directional antennas of broadcast stations for determining sky-wave interference at short distances," PROC. I.R.E., vol. 32, pp. 668–673; November, 1944.
(175) V. C. A. Ferraro, "Diffusion of ions in the ionosphere," *Terr. Mag. and Atmos. Elec.*, vol. 50, pp. 215–222; September, 1945.
(176) V. C. A. Ferraro, "On the electrical state of the upper atmosphere," *Terr. Mag. and Atmos. Elec.*, vol. 50, pp. 223–229; September, 1945.
(177) O. P. Ferrell, "Radio investigation of air movement in the upper atmosphere," *Science and Culture* (Calcutta), vol. 9, p. 555; June, 1944.
(178) Perry Fennell, Jr., "Winds in the ionosphere indicated by radio 'Clouds'," *Bull. Amer. Met. Soc.*, vol. 25, p. 371; November, 1944.
(179) J. A. Fleming, "Summary of the year's work to June 30, 1944, Department of Terrestrial Magnetism, Carnegie Institution of Washington," *Terr. Mag. and Atmos. Elec.*, vol. 49, pp. 245–250; December, 1944.
(180) V. Ginsburg, "The reflection of radio impulses from the ionosphere," *Bull. de l'Acad. des Sci. de l'URSS* (*Izvestiya*), *Série Physique*, vol. 7, pp. 114–133; 1943. (In Russian.)
(181) V. Ginsburg, "The refraction index of an ionized gas (ionosphere)," *Bull. de l'Acad. des Sci. de l'URSS* (*Izvestiya*), *Série Physique*, 1944. *Jour. Phys.* (U.S.S.R.), vol. 8, p. 383, 1944. (Summary in English.)
(182) M. N. Gnevyshev, "On certain problems in the physics of the ionosphere and geomagnetic disturbances, and on the equivalent problems in astrophysics," *Bull. de l'Acad. des Sci. de l'URSS* (*Izvestiya*), *Série Physique*, vol. 7, pp. 134–144; 1943. (In Russian.)
(183) M. M. Sengupta and S. K. Dutt, "On the experimental investigation of night-time ion-densities and their determination by the application of Chapman's formula," *Indian Jour. Phys.*, vol. 18, pp. 88–96; April, 1944.
(184) H. E. Hallborg, "Sun, earth, and short-wave propagation: effects of the solar system upon long-distance short-wave communication," *Proc. Radio Club Amer.*, vol. 21, pp. 1–6; December, 1944.
(185) C. K. Jen, K. T. Chow, Y. T. Co, and C. C. Kuan, "An observation on the ionosphere during the solar eclipse of July 20, 1944," *Phys. Rev.*, vol. 66, p. 226; October, 1944.
(186) R. Jouaust, "The mechanism of fade-outs of radio electric waves," *Comptes Rendus* (Paris), vol. 216, pp. 294–295; March, 1943.
(187) V. N. Kessenikh, "An estimation of the integral absorption in the ionosphere according to measurements of the strength of vertical field," *Bull. de l'Acad. des Sci. de l'URSS* (*Izvestiya*), *Série Physique*, vol. 8, pp. 68–75; 1944.
(188) V. N. Kessenikh and H. D. Bulatov, "The continental effect in the geographic distribution of the electron concentration in the F_2 layer," *Comptes Rendus* (Doklady), *de l'Acad. des Sci. de l'URSS*, vol. 45, pp. 234–237; November, 1944. On December 28, 1945, the Slavonic Division of the New York Public Library reported that this volume was in the bindery.
(189) M. A. R. Khán, "Hissing sounds heard during the flight of fireballs," *Nature*, vol. 155, p. 53; January 13, 1945.
(190) D. F. Martyn, "Anamolous behavior of the F_2 region of the ionosphere," *Nature*, vol. 155, pp. 363–364; March 24, 1945.
(191) J. B. Moore, "Fading effects at high frequencies," *Electronics*, vol. 17, pp. 100–106; October, 1944.
(192) E. R. Mustel, "Connection between faculae and geomagnetic activity," *Comptes Rendus* (Doklady) *de l'Acad. des Sci. de l'URSS*, vol. 42, pp. 112–115; January, 1944.
(193) R. Rawer, "The formation of the abnormal E-layer of the ionosphere," *Naturwiss.*, vol. 28, p. 577; September, 1940.
(194) R. Rivault, "Study of the D region of the ionosphere," *Comptes Rendus* (Paris), vol. 216, pp. 494–496; April, 1943.
(195) O. E. H. Rydbeck, "On the Propagation of Radio Waves," Göteborg, Chalmers Tekniska Högskolas Handlingar, 168 pages, 1944.
(196) O. E. H. Rydbeck, "A Theoretical Survey of the Possibilities of Determining the Distribution of the Free Electrons in the Upper Atmosphere," Göteborg, Chalmers Tekniska Högskolas Handlingar, 74 pages, 1942.
(197) I. Tamm, "On currents in the ionosphere which cause the variations of the terrestrial magnetic field," *Jour. Phys.* (U.S.S.R.), vol. 8, p. 383; 1944. (Summary, in English.) Published in full, in Russian, in *Bull. de l'Acad. des Sci. de l'URSS* (*Izvestiya*), *Série Physique*, vol. 8, pp. 30–41; 1944.
(198) A. Vassy and E. Vassy, "The temperature of the upper atmosphere," *Jour. de Phys. et le Radium*, vol. 3, p. 8; January, 1942.
(199) W. Waldmeier, "Ionospheric determination of the ultra violet intensities of the solar radiation in the region 700–900 A.U., *Helv. Phys. Acta*, vol. 17, pp. 168–180; 1944.
(200) "Solar eclipse observations: Effects on the ionization of the E and F layers," *Wireless World*, vol. 51, p. 240; August, 1945.
(201) Ta-You Wu, "Recombination processes in the E-layer of the ionosphere," *Terr. Mag. and Atmos. Elec.*, vol. 50, pp. 57–62; March, 1945.

Effect of the Troposphere and Earth on Propagation

A very large portion of the work on radio wave propagation done during the war under the restrictions of military security was related to propagation in a non-homogeneous atmosphere. These investigations will contribute greatly to a qualitative understanding of the effect of the troposphere on propagation but the practical utility of numerical calculations has been severely limited by the lack of necessary meteorological data. Relatively few papers on the subject of any great significance appeared in journals available to the general public. On the other hand, papers dealing with discontinuities or irregularities in the earth's surface are being published in increasing numbers. Two papers dealing with the effect of various soils on propagation are reported.

(202) J. Alpert and B. Gorozhankin, "Experimental investigation of the structure of an electromagnetic field over the inhomogeneous earth's surface," *Jour. Phys.* (U.S.S.R.), vol. 9, pp. 115–122; 1945.
(203) S. S. Banerjee, "Effect of water vapor in the atmosphere on the propagation of ultra-short radio waves," *Science and Culture* (Calcutta), vol. 10, pp. 453–454; April, 1945.
(204) P. Caporale, "The CAA instrument landing system," *Electronics*, vol. 18, pp. 128–135; March, 1945.
(205) L. DeBroglie, "On the propagation of luminous energy in anistropic media," *Comptes Rendus*, Paris, vol. 215, p. 153; August, 1942.
(206) E. Feinberg, "On the propagation of radio waves along an imperfect surface," *Jour. Phys.* (U.S.S.R.), vol. 8, pp. 317–330; 1944. (In English.)
(207) E. Feinberg, "The effective path of radio waves," *Jour. Phys.* (U.S.S.R.), vol. 8, p. 382; 1944. (In English, summary only.) In full, in Russian, in *Bull. de l'Acad. des Sci. de l'URSS* (*Izvestiya*), *Série Physique*; 1944.
(208) E. Feinberg, "On the propagation of radio waves along the real surface of the earth," *Jour. Phys.* (U.S.S.R.), vol. 8, p. 382. (In English, summary only.) In full, in Russian, in *Bull. de l'Acad. des Sci. de l'URSS* (*Izvestiya*), *Série Physique*; 1944.
(209) E. Feinberg, "On the propagation of radio waves along an imperfect surface," *Jour. Phys.* (U.S.S.R.), vol. 9, pp. 1–6; 1945.
(210) V. A. Fock, "The electrical field near a depression in a conducting plane," *Comptes Rendus* (Doklady) *de l'Acad des Sci. de l'URSS*, vol. 40, pp. 343–345; September, 1943. (In English.)
(211) Albert W. Friend, "A summary and interpretation of ultra-short-wave-propagation collected by the late Ross A. Hull," PROC. I.R.E., vol. 33, pp. 358–373; June, 1945.
(212) W. Geffcken, "Reflexion of electromagnetic waves at an inhomogeneous layer," (in German), Ann. der Phys., vol. 40, pp. 385–492; 1941.
(213) V. L. Ginsburg, "On the paramagnetic effects influencing the radio wave propagation in the atmosphere," *Comptes Rendus* (Doklady) *de l'Acad. des Sci. de l'URSS*, vol. 35, pp. 270–273; June, 1942. (In English.)
(214) V. L. Ginsburg, "On the effect of polar and paramagnetic molecules on the absorption and refraction of radio waves in the atmosphere," *Bull. de l'Acad. des Sci. de l'URSS, Série Physique* (*Izvestiya*), vol. 7, pp. 96–98; 1943. (In Russian.)
(215) R. Guelke, "A geophysical prospecting instrument using

alternating currents of audio frequency," *Jour. Sci. Instr.*, vol. 22, pp. 141–145; August, 1945.
(216) G. A. Grünberg, "On the propagation of radio waves over the surface of the earth, taking into account the non-uniformity of the atmosphere and the shape of the earth," *Bull. de l'Acad. des Sci. de l'URSS (Izvestiya), Série Physique*, vol. 7, pp. 99–113; 1943. (In Russian.)
(217) G. W. O. Howe, "The radiation resistance of a half-wave dipole aerial," *Wireless Eng.*, vol. 22, pp. 153–156; April, 1945.
(218) N. N. Kalitin, "On scattering of radiation by clouds," *Comptes Rendus* (Doklady) *de l'Acad. des Sci. de l'URSS*, vol. 43, pp. 289–291; June, 1944. (In English.)
(219) D. I. Lawson, "Multipath interference in television transmission," *Jour. I.E.E.* (London), vol. 92, part III, pp. 125–144; September, 1945.
(220) M. Leontovich, "Concerning a certain method for solving problems of propagation of electromagnetic waves along the earth's surface," *Bull. de l'Acad. des Sci. de l'URSS (Izvestiya), Série Physique*, vol. 8, pp. 16–22; 1944. *Jour. Phys.* (U.S.S.R.), vol. 8, p. 382; 1944. (In English, summary only.)
(221) C. Mihul, "Reflection of electromagnetic waves by media whose optical constants vary in a continuous fashion," *Phys. Berichte*, vol. 24, p. 1323; 1943. Summary of a paper which appears in a publication from Jassy University. Translation of part of summary in *Wireless Eng.*, vol. 22, pp. 444–445; September, 1945.
(222) F. Odone, "Propagation, according to geometrical optics, of a monochromatic luminous wave in an isotropic heterogeneous medium," *Nuovo Cimento* (Turin), vol. 19, p. 157; May/July, 1942. Abstract, *Wireless Eng.*, vol. 22, p. 444; September, 1945.
(223) Ralph G. Peters, "45.5 and 91-mc field intensity tests," *Communications*, vol. 25, pp. 68, 70, 72; April, 1945.
(224) L. Pincherle, "The polarizing angle for reflection at the boundary between two absorbing media," *Proc. Phys. Soc.*, vol. 57, part 1, pp. 56–60; January 1, 1945.
(225) B. Polic, "The investigation of the propagation of electromagnetic waves in mountain and river valleys, fiords, etc., by means of models," *Telegraphen-Fernsprech- und Funk-Technik*, vol. 33, pp. 63–78; April, 1944.
(226) S. N. F. Rahman and F. Muhi, "Electrical properties of Indian soils at medium broadcast frequencies," *Indian Jour. Phys.*, vol. 18, pp. 31–37; February, 1944.
(227) T. W. Wigton, "Railroad radio communication on the V.H.F.'s," *Radio*, vol. 29, pp. 35–39; August, 1945.

Propagation Along Lines and in Guides

By far the most important advances in this domain made during the war have to do with wave guides. A vast amount of progress has been made in the development of techniques and engineering data for their use. This information is now largely declassified and shortly should be available to all. Published material during 1945 represents, on the whole, rather modest contributions to the art, with a preponderance of papers containing design data and charts.

Parallel-Wire Transmission Lines

There were no important theoretical contributions to general line theory in 1945. Some expository papers were published, and some suggestions for approximate or graphical methods of determining line constants. There was also more detailed discussion of the design of single- and double-stub matching sections.

(228) A. Bloch, "Fresnel's reflection formulae and parallel transmission lines," *Wireless Eng.*, vol. 21, pp. 560–562; December, 1944.
(229) B. C. Dees, "Graphical methods of solving transmission-line problems," *Radio News, Radio-Electronic Dept.*, vol. 5, pp. 16–18, 41–44; August, 1945; pp. 18–20, 24–26; September, 1945.
(230) Edward N. Dingley, Jr., "The theory of transmission lines," Proc. I.R.E., vol. 33, pp. 118–125; February, 1945; discussion, pp. 810–812; November, 1945.
(231) A. C. Gardner, "Parallel wire transmission lines," *Radio*, vol. 29, pp. 25–28, 60; April, 1945.
(232) T. A. Garretson, "Transmission lines at 200 mc.," *Radio News*, vol. 33, pp. 28–31, 90, 92–94; February, 1945.
(233) G. W. O. Howe, "Resonance in quarter-wave lines," *Wireless Eng.*, vol. 21, pp. 509–511; November, 1944.
(234) R. G. Middleton, "Graphical treatment of high frequency lines," *Radio News, Radio-Electronic Dept.*, vol. 3, pp. 20–22, 38–39; December, 1944.
(235) H. E. Newell, Jr., "Transmission lines as tuning elements," *Electronics*, vol. 18, pp. 150, 152; October, 1945.
(236) Robert C. Paine, "Graphical solution of voltage and current distribution and impedance of transmission lines," Proc. I.R.E., vol. 32, pp. 686–695; November, 1944.
(237) R. C. Paine, "Transmission-line impedance matching chart," *Radio*, vol. 29, pp. 34–36, 62, 64; February, 1945.
(238) R. C. Paine, "Transmission-line calculator," *Electronics*, vol. 18, pp. 140–141; March, 1945.
(239) R. C. Paine, "Graphical method for computing transmission-line impedance," *Radio News, Radio-Electronic Dept.*, vol. 4, pp. 10–12, 41–42; June, 1945.
(240) R. C. Paine, "Computing double-stub lengths for lines," *Electronic Indus.*, vol. 4, pp. 94–96, 194; July, 1945.
(241) R. C. Paine, "Solving transmission-line problems," *Communications*, vol. 25, pp. 66–67, 89; October, 1945.
(242) R. H. Paul, "Rigorous methods of solving long transmission-line problems," *Jour. I.E.E.* (London), vol. 92, part 2, pp. 20–22; February, 1945.
(243) D. H. Ray, "High-frequency transmission," *Jour. I.E.E.* (London), vol. 92, part 1, pp. 133–134; March, 1945.
(244) A. C. Schwager and P. Y. Wang, "New transmission-line diagrams," *Trans. A.I.E.E.* (*Elec. Eng.*, September, 1945), vol. 64, pp. 610–615; September, 1945.
(245) R. Sibson, "Loss-free transmission lines," *Wireless Eng.*, vol. 22, pp. 420–428; September, 1945.
(246) T. F. Wall, "Alternating current transmission," *Engineering* (London), vol. 160, pp. 1–3; July 6, 1945; pp. 61–62; July 27, 1945; pp. 101–102; August 10, 1945; pp. 201–202, September 14, 1945.

Coaxial Transmission Lines

Emphasis in this field was chiefly in the technique of measurements at increasingly high frequencies. One paper on discontinuities in coaxial lines appeared, and the use of solid-dielectric cables in the ultra-high-frequency range was being carefully studied. The elimination of reflection in a line terminated by a thin film was discussed theoretically.

(247) P. R. Bray, "Approximate formulae for the calculation of attenuation from open and closed impedances," *Post Office Elec. Eng. Jour.*, vol. 38, pp. 52–55; July, 1945.
(248) G. W. O. Howe, "Resonance in quarter-wave lines," *Wireless Eng.*, vol. 21, pp. 509–511; November, 1944.
(249) F. Jones and R. Sear, "Testing high-frequency cables," *Wireless Eng.*, vol. 21, pp. 512–520; November, 1944; pp. 571–583; December, 1944.
(250) A. G. Kandoian, "Special transmission problems in solid dielectric high frequency cable," *Elec. Commun.*, vol. 22, pp. 198–202; 1945.
(251) N. D. Kenney, "Coaxial cable design," *Electronics*, vol. 18, pp. 124–128; May, 1945.
(252) N. Marchand, "Special aspects of high frequency flexible balanced cables," *Elec. Commun.*, vol. 22, pp. 193–197; 1945.
(253) N. Marchand and R. Chapman, "U-H-F impedance measurements," *Electronics*, vol. 18, pp. 97–101; June, 1945.
(254) D. H. Smith, "The non-reflecting termination of a transmission line," *Proc. Phys. Soc.* (London), vol. 57, pp. 90–96; March 1, 1945.
(255) Chandler Stewart, Jr., "A method of measuring attenuation of short lengths of coaxial cable," Proc. I.R.E., vol. 33, pp. 46–48; January, 1945.
(256) Chandler Stewart, Jr., "Electrical testing of coaxial radio-frequency cable connectors," Proc. I.R.E., vol. 33, pp. 609–619; September, 1945.
(257) Chandler Stewart, Jr., "The S-function method of measuring attenuation of coaxial radio-frequency cable," *Trans. A.I.E.E.* (*Elec. Eng.*, September, 1945), vol. 64, pp. 616–619; September, 1945.
(258) P. H. Ware, "Coaxial cable tests," *Electronics*, vol. 18, pp. 130–134; October, 1945.
(259) A. J. Warner, "Dielectrics in U-H-F flexible coaxial cables," *Communications*, vol. 24, pp. 33–35, 54, 90–91; December, 1944.
(260) J. R. Whinnery, H. W. Jamieson, and Theo Eloise Robbins, "Coaxial-line discontinuities," Proc. I.R.E., vol. 32, pp. 695–709; November, 1944.

(261) W. H. Wood, "Approximate losses for various sizes of concentric transmission lines at 46 mc.," *Communications*, vol. 25, p. 64; March, 1945.

Cylindrical Wave Guides

The field of a rectangular wave guide due to a transverse current filament was given careful theoretical treatment. The application of the Lorentz transformation to the field in a rectangular wave guide, and a study of the field in the vicinity of a gap in a cylindrical conductor should also be noted.

(262) G. R. Cooper, "Circular wave guide fields," *Electronics*, vol. 18, pp. 106–109; February, 1945.
(263) W. D. Hershberger, "Waves guides and the special theory of relativity," *Jour. Appl. Phys.*, vol. 16, pp. 465–468; August, 1945.
(264) "Discussion on 'Wave guides in electrical communication,'" *Jour. I.E.E.* (London) vol. 91, part III, pp. 145–155; September, 1944.
(265) S. S. Mackeown and John W. Miles, "The plane-wave resolution of guided waves," Proc. I.R.E., vol. 33, pp. 805–808; November, 1945.
(266) E. B. Moullin, "The propagation of electric waves in a rectangular wave guide," *Jour. I.E.E.* (London), vol. 92, part III, pp. 8–17; March, 1945.
(267) S. A. Schelkunoff, "On waves in bent pipes," *Quart. Appl. Math.*, vol. 2, pp. 171–172; July, 1944.
(268) J. McG. Sowerby, "Radio data charts: attenuation in wave guides," *Wireless World*, vol. 50, pp. 328–331; November, 1944.
(269) E. M. Studenkov, "Propagation of electromagnetic waves in branched hollow-pipe lines," *Jour. Phys.* (U.S.S.R.), vol. 7, pp. 308–309; 1943.
(270) C. C. Wang, "Electromagnetic field inside a cylinder with a gap," *Jour. Appl. Phys.*, vol. 16, pp. 351–366; June, 1945.

Tapered Transmission Lines

One paper on tapered lines considered two kinds of taper, exponential and "lumped," for which fairly simple solutions of the transmission equations could be obtained.

(271) J. W. Milnor, "The tapered transmission line," *Trans. A.I.E.E.* (*Elec. Eng.*, June, 1945), vol. 64, pp. 345–346; June, 1945.
(272) D. H. Smith, "The non-reflecting termination of a transmission line," *Proc. Phys. Soc.* (London), vol. 57, pp. 90–96; March 1, 1945.

General Theory and Experiments

The number of papers published during the past year on more general aspects of wave propagation was relatively small, but several were of considerable interest. The paper by Bethe on diffraction is representative of a rather large amount of theoretical work done during the war in this country and in England on the coupling of wave guides and cavity resonators. The theory of scattering and noise from stellar space continue to be of interest.

(273) H. Alfvén, "On the existence of electromagnetic-hydrodynamic waves (in conducting liquids in a uniform magnetic field: importance in the formation of sunspots)," *Phys. Berichte*, vol. 25, p. 92; 1944.
(274) H. A. Bethe, "Theory of diffraction by small holes," *Phys. Rev.*, vol. 66, pp. 163–182; October, 1944.
(275) N. E. Dorsey, "The velocity of light," *Trans. Amer. Phil. Soc.*, vol. 34, pp. 1–110; October, 1944.
(276) H. Feshbach, "On the perturbation of boundary conditions," *Phys. Rev.*, vol. 65, pp. 307–318; June, 1944.
(277) L. L. Foldy, "The multiple scattering of waves: I. General theory of isotropic scattering by randomly distributed scatterers," *Phys. Rev.*, vol. 67, pp. 107–119; February 1 and 15, 1945.
(278) H. Fröhlich, "Theory of dielectric constant and energy loss in solids and liquids," *Jour. I.E.E.* (London), vol. 91, part I, pp. 456–463; December, 1944.
(279) H. Gutton and J. Ortusi, "A study of guided Hertzian waves: Application to the filtering of decimetric waves," *Bull. de la Soc. Franc. des Elec.*; February, 1944.
(280) H. Gutton and J. Ortusi, "On the theorem of reciprocity for Hertzian waves," *Comptes Rendus* (Paris), vol. 217, pp. 677–679; December, 1943.
(281) M. G. Scroggie, "Waves guides: how to visualise their action and characteristics: modes in circular guides: launching and collecting devices," *Wireless World*, vol. 50, pp. 258–261; September, 1944; pp. 303–307; October, 1944.
(282) G. C. Southworth, "Microwave radiation from the sun," *Jour. Frank. Inst.*, vol. 239, pp. 285–297; April, 1945.
(283) V. Vladimirsky, "Propagation of electromagnetic waves along a single wire," *Jour. Phys.* (U.S.S.R.), vol. 8, p. 382; 1944. (In English, summary only.) In full in *Bull. de l'Acad. des Sci. de l'URSS* (*Izvestiya*), vol. 8, 1944.
(284) "Measurement of V-H-F bursts," *Electronics*, vol. 18, p. 105; January, 1945.

Cavity Resonators

The number of papers dealing with cavity resonators continues to increase. This subject is one which borders also on circuit theory.

(285) J. Bernier, "Principle of equivalence between an electromagnetic cavity and a circuit with localized constants," *Comptes Rendus* (Paris), vol. 217, pp. 424–426; November, 1943.
(286) J. Bernier, "Principles for the calculation of electromagnetic cavities," *Comptes Rendus* (Paris), vol. 217, pp. 530–532; November, 1943.
(287) J. Bernier, "A reference method for the calculation of electromagnetic cavities," *Comptes Rendus* (Paris), vol. 218, pp. 186–188; January, 1944.
(288) F. Borgnis, "Resonance of electromagnetically excited cavities," *Zeit. für Phys.*, vol. 122, pp. 407–412; May, 1944.
(289) H. A. Brown, "Frequency of capacitance tuned lines and resonant line oscillators," *Communications*, vol. 25, pp. 51–52, 54, 56, 90–93; May, 1945.
(290) C. F. Davidson and J. C. Simmonds, "Cylindrical cavity resonators," *Wireless Eng.*, vol. 21, pp. 420–424; September, 1944.
(291) L. S. Goddard, "A method for computing the resonant wave length of a type of cavity resonator," *Cambridge Phil. Soc. Proc.*, vol. 41, pp. 160–175; August, 1945.
(292) M. S. Kiver, "Theory and application of U-H-F, part 9: Covering the principles and operation of commonly employed methods used to obtain energy from cavity resonators," *Radio News*, vol. 33, pp. 58–59, 150, 151; February, 1945.
(293) W. R. MacLean, "The reactance theorem for a resonator," Proc. I.R.E., vol. 33, pp. 539–541; August, 1945.
(294) D. Middleton and R. King, "Transmission-line theory applied to wave guides and cavity resonators," *Jour. Appl. Phys.*, vol. 15, pp. 524–535; July, 1944.
(295) D. Middleton, "Transmission-line theory applied to wave guides and cavity resonators," *Jour. Appl. Phys.*, vol. 15, pp. 535–544; July, 1944.
(296) R. Warnecke and J. Bernier, "Electronic generation of electromagnetic waves in a cavity resonator," *Comptes Rendus* (Paris), vol. 218, pp. 73–75; January, 1944.
(297) R. A. Whiteman, "Cavity resonators," *Radio News, Radio-Electronic Dept.*, vol. 5, pp. 11–13, 41–44; September, 1945.
(298) C. N. Works, T. W. Dakin, and F. W. Boggs, "A resonant-cavity method for measuring dielectric properties at ultra-high frequencies," Proc. I.R.E., vol. 33, pp. 245–254; April, 1945.

Piezoelectric Crystals

Among the references in this section are a few published prior to 1945, which were not yet at hand when the 1944 report was prepared.

Recent advances in piezoelectricity have had to do mainly with the study of certain artificially grown crystals and with the technique and performance of quartz plates for thickness vibrations.

The activities of the Zurich investigators, mentioned in the report for 1944, were continued. Although nothing particularly exciting came to light, considerable progress was made in the study of the dielectric, piezoelectric, optical, and thermal properties of the primary phosphates and arsenates of potassium, ammonium, and deuterium. Some tests were also made of rubidium phosphate and of ammonium-phosphate crystals in which the ammonium was partly replaced with thallium. In particular, it was found that the face-shear vibrational modes of Z-cut plates cut from KH_2PO_4 and $NH_4H_2PO_4$ crystals have a zero temperature coefficient of frequency in the neighborhood of 0 degrees centrigrade, while for KD_2PO_4 the zero coefficient comes at 20 degrees centigrade. Observations on the converse piezoelectric effect in KH_2PO_4 led to the conclusion that in this crystal, as in Rochelle salt, the physical anomalies could be attributed to anomalies in the dielectric constant.

The piezoelectric constant d_{36} was measured for KH_2PO_4 and $NH_4H_2PO_4$ over a wide range of temperatures, by a dynamic method.

(299) A. von Arx and W. Bantle, "The converse piezo effect of the Seignette-electric crystal KH_2PO_4," *Helv. Phys. Acta*, vol. 17, pp. 298–318; 1944.
(300) W. Bantle, "An artificially grown crystal with a zero temperature-coefficient of resonant frequency at room temperature," *Helv. Phys. Acta*, vol. 18, pp. 245–247; 1945.
(301) W. Bantle and B. Matthias, "A purely electrical method for the measurement of piezoelectric constants," *Helv. Phys. Acta*, vol. 18, pp. 242–245; 1945.
(302) W. Bantle, B. Matthias, and P. Scherrer, "Dynamic measurements with KH_2PO_4 and $NH_4H_2PO_4$ crystals," *Helv. Phys. Acta*, vol. 18, pp. 389–404; 1945.
(303) P. Bärtschi, B. Matthias, W. Merz, and P. Scherrer, "Displacement of the transition point of the NH_4-rotation transformation," *Helv. Phys. Acta*, vol. 18, pp. 238–240; 1945.
(304) P. Bärtschi, B. Matthias, W. Merz, and P. Scherrer, "A new Seignette-electric modification of rubidium phosphate," *Helv. Phys. Acta*, vol. 18, pp. 240–242; 1945.
(305) B. Zwicker and P. Scherrer, "Electro-optical properties of the Seignette-electric crystals KH_2PO_4 and KD_2PO_4," *Helv. Phys. Acta*, vol. 17, pp. 346–373; 1944.

For all four primary phosphates and arsenates the piezoelectric constants d_{14} and d_{36}, as well as dielectric and elastic constants, were measured at 27 degrees centigrade by the converse piezoelectric effect at 60 cycles per second. So far as these results overlapped those of the foregoing references, there was satisfactory agreement.

(306) H. Jaffe, "Piezoelectric studies of primary phosphates and arsenates," *Bull. Amer. Phys. Soc.*, vol. 20, p. 5; January 19, 1945.

On the theoretical side, a calculation of e_{14} for zinc blende from atomic data alone was made for the first time. The result was reasonably close to the observed value. Problems on the vibrations of crystal plates were attacked by several investigators.

(307) R. Bechmann, "Natural vibrations of a rectangular quartz parallelepiped," *Zeit. für Phys.*, vol. 122, pp. 510–526; May, 1944.
(308) H. Ekstein, "High frequency vibrations of thin crystal plates," *Phys. Rev.*, vol. 68, pp. 11–23; July, 1945.
(309) H. Jaffe, "Calculation of the piezoelectric effect in ionic lattices of the zinc blende type," *Phys. Rev.*, vol. 66, pp. 357–358, 1944.
(310) H. Mähly, "Natural vibrations of thin square crystal plates," *Helv. Phys. Acta*, vol. 18, pp. 248–251; 1945.

A number of authors discussed the axes of quartz, the indexing of quartz faces, and the etch patterns on quartz crystals. Mention may be made of the following:

(311) Choong Shin-Piaw, "New etching pattern of quartz and its uses for the determination of electric axes and the detection of crystalline defects," *Jour. Opt. Soc. Amer.*, vol. 35, pp. 552–558; August, 1945.
(312) Austin F. Rogers, "Physical axes of reference and geometrical axes of reference for quartz," *Amer. Jour. Sci.*, vol. 243, pp. 384–392; July, 1945.

The year marked the closing down of the phenomenal production of quartz crystal units for military uses which attained a rate of 30,000,000 crystal units per year and a total wartime production of approximately 75,000,000. These figures are to be compared with a production of 50 to 75 thousand crystal units per year prior to the war.

The latter part of the production period witnessed several symposiums and technical sessions devoted to piezoelectric crystals. In addition to those held under military auspices in connection with the production program, a symposium on quartz crystals formed a part of the program of the American Association for the Advancement of Science at Cleveland, September 12, 1944. Papers at this session were presented by a number of physicists, geologists, and radio engineers who were actively concerned in the wartime production problem. Abstracts were printed in the program of the meeting. A technical session of the 1945 Winter Technical Meeting of the I.R.E., January 24 to 27, 1945 (see January, 1945, issue of PROCEEDINGS of the I.R.E. for titles and abstracts) was devoted to quartz-crystal progress. Although most of the papers presented at the two sessions referred to have not appeared in print, some of the material appeared in papers by the same authors in the May–June issue of the *American Mineralogist* for 1945. This issue contained an extensive series of papers which were reprinted under the title, "Symposium on Quartz Oscillator-Plates." This symposium reviewed the wartime production of quartz crystals, their radio-circuit application, the geology of principal quartz deposits, the selection of the grade of quartz for radio uses, techniques in fabrication, and the development of production tools. Of special interest from its fundamental physical implications is the effect of X-ray irradiation on the frequency of quartz-crystal plates.

(313) Clifford Frondel, "History of the quartz oscillator-plate industry, 1941–1944," *Amer. Mineralogist*, vol. 30, pp. 205–213. May–June, 1945.
(314) Karl S. Van Dyke, "The piezoelectric quartz resonator," *Amer. Mineralogist*, vol. 30, pp. 214–244; May–June, 1945.
(315) Richard E. Stoiber, Carl Tolman, and Robert D. Butler, "Geology of quartz crystal deposits," *Amer. Mineralogist*, vol. 30, pp. 245–268; May–June, 1945.
(316) Samuel G. Gordon, "The inspection and grading of quartz," *Amer. Mineralogist*, vol. 30, pp. 269–290; May–June, 1945.
(317) Joseph S. Lukesh, "The effect of imperfections on the usability of quartz for oscillator-plates," *Amer. Mineralogist*, vol. 30, pp. 291–295; May–June, 1945.
(318) William Parrish and Samuel G. Gordon, "Orientation techniques for the manufacture of quartz oscillator-plates," *Amer. Mineralogist*, vol. 30, pp. 296–325; May–June, 1945.
(319) William Parrish and Samuel G. Gordon, "Precise angular control of quartz-cutting by X-rays," *Amer. Mineralogist*, vol. 30, pp. 326–346; May–June, 1945.
(320) Samuel G. Gordon and William Parrish, "Cutting schemes for quartz crystals," *Amer. Mineralogist*, vol. 30, pp. 347–370; May–June, 1945.
(321) William Parrish, "Methods and equipment for sawing quartz crystals," *Amer. Mineralogist*, vol. 30, pp. 371–388; May–June, 1945.
(322) William Parrish, "Machine lapping of quartz oscillator-plates," *Amer. Mineralogist*, vol. 30, pp. 389–415; May–June, 1945.
(323) Clifford Frondel, "Final frequency adjustment of quartz

oscillator-plates," *Amer. Mineralogist*, vol. 30, pp. 416–431; May–June, 1945.
(324) Clifford Frondel, "Effect of radiation on the elasticity of quartz," *Amer. Mineralogist*, vol. 30, pp. 432–446; May–June, 1945.
(325) Clifford Frondel, "Secondary Dauphiné twinning in quartz," *Amer. Mineralogist*, vol. 30, pp. 447–461; May–June, 1945.
(326) There is appended to these papers a "Glossary of terms used in the quartz oscillator-plate industry," *Amer. Mineralogist*, vol. 30, pp. 461–468; May–June, 1945.

A session of the Metropolitan Section of the American Physical Society, November 9, 1945, was devoted to a series of seven papers on piezoelectric crystals, emphasizing synthetic substitutes for quartz and Rochelle salt, as well as the problem of detwinning low-grade quartz. (Abstracts printed in program of meeting.)

Prominent in manufacturing and specification considerations and in the use of quartz-crystal units has been the problem of the aging of crystal plates, particularly the deterioration of crystal surfaces which have been produced by abrasive action, the method of etching crystal plates to frequency as a means of preventing aging, and the predimensioning of plates in order to avoid critical internal elastic coupling. Papers on the aging phenomenon (not yet in print) were read at a number of the technical sessions on crystals. One such treatment was given wide circulation as a Signal Corps document.

(327) V. E. Bottom, "Aging of quartz crystal units," Engineering Memorandum No. 4 of Camp Coles Signal Laboratory; June 29 1944.

Miss E. J. Armstrong presented at the Cleveland Symposium an important review of X-ray studies of surface layers of crystals with special reference to quartz and to the aging of its surfaces, but this has so far appeared in print only as a brief abstract in the program of the meeting. A review of predimensioning as practiced by one manufacturer was published as follows:

(328) B. P. Haines, C. D. O'Neal, and S. A. Robinson, "Predimensioning quartz crystal plates," *Electronics*, vol. 18, pp. 112–119; June, 1945.

A sound motion picture in color, "Crystals Go to War," prepared by Reeves Sound Laboratories, New York City, in 1943, and in a new edition in 1945, illustrated production techniques in one crystal-manufacturing plant and was shown widely. Photography was by André LaVarre.

Papers on the measurement of the intrinsic properties of crystal units and on instrumentation for crystal measurement indicated that progress was being made in the direction of replacing arbitrary oscillation tests of crystal units for frequency control by the specification of their intrinsic properties in terms of conventional electric circuit quantities. The formalization of United States Government Joint Army-Navy specifications for certain large production units and the interest in the intrinsic properties of crystal units as circuit elements indicated considerable progress in the direction of standardization of high-frequency crystals.

(329) I. E. Fair, "Piezoelectric crystals in oscillator circuits," *Bell Sys. Tech. Jour.*, vol. 24, pp. 161–216; April, 1945.
(330) C. W. Harrison, "The measurement of the performance index of quartz plates," *Bell Sys. Tech. Jour.*, vol. 24, pp. 17–252; April, 1945.
(331) K. S. Van Dyke, "The standardization of quartz-crystal units, Proc. I.R.E., vol. 33, pp. 15–20; January, 1945.

Electroacoustics

During 1945, a number of advances were made in the field of electroacoustics, both for military and for nonmilitary applications.

Some new microphones, sound-reproducing systems. and combinations thereof were announced for general use. These include improved standard instruments, announcing systems, circuit arrangements, particularly for higher fidelity or other special characteristics, special devices to aid in making acoustic calibrations, and devices using electroacoustic means for making various industrial tests. In this general field were the following papers:

(332) W. W. Brockway and D. C. Brockway, "Air terminal sound system," *Electronics*, vol. 18, pp. 138–141; June, 1945.
(333) Theodore E. Campbell, "Microphone input circuit," *Radio News*, vol. 33, pp. 49, 134; January, 1945.
(334) F. Earle Clark, "Quartz crystals—today and tomorrow," *Radio News*, vol. 34, pp. 45, 145–146; September, 1945.
(335) Nicholas B. Cook, "Phasing of loud speakers," *Radio News*, vol. 33, pp. 30–31, 126; April, 1945.
(336) R. W. Crane, "Audio mixer design," *Electronics*, vol. 18, pp. 120–121; June, 1945.
(337) R. W. Crane, "Suggestions for design of volume expanders," *Electronics*, vol. 18, pp. 236, 240, 244, 248, 252; May, 1945.
(338) R. W. Ehrlich, "Volume expander design," *Electronics*, vol. 18 pp. 124–127; December, 1945.
(339) G. Grammer, "Bass boost," *QST*, vol. 29, pp. 35–38; July, 1945.
(340) Erwin Griebe, "Supersonic echo depth indicators," *Radio News, Radio-Electronic Eng. Dept.*, vol. 5, pp. 5–7, 41–43; July, 1945.
(341) R. V. L. Hartley, "Production of inharmonic subfrequencies by a loud speaker," *Jour. Acous. Soc. Amer.*, vol. 16, pp. 203–205; January, 1945.
(342) E. H. Hartnell, "A home-made intercommunicating system," *QST*, vol. 29, pp. 46–47; January, 1945.
(343) R. K. Hellmann, "Curve-tracer for acoustic devices," *Electronics*, vol. 18, pp. 130–133; December, 1945.
(344) J. C. Hoadley, "Audio oscillators and their applications," *Radio News*, vol. 34, pp. 29, 138–142; September, 1945.
(345) Paul K. Hudson, "Calibration of decibel meters," *Communications*, vol. 25, pp. 58–59, 86; July, 1945.
(346) R. S. Jerrett, "The acoustic strain gage," *Jour. Sci. Instr.*, vol. 22, pp. 29–34; February, 1945.
(347) L. W. Labaw, "Curved quartz crystals as supersonic generators," *Jour. Acous. Soc. Amer.*, vol. 16, pp. 237–245; April, 1945.
(348) C. J. Leipert, "An extended-range audio oscillator," *QST*, vol. 29, pp. 24–26, 84; February, 1945.
(349) A. Liebscher, "The audio chanalyst," *Radio News*, vol. 34, pp. 32–34, 92, 94, 96, 98, 100; December, 1945.
(350) W. J. Lloyd, and D. E. L. Shorter, "A war correspondent's recorder at BBC: Disc-recording unit," *Communications*, vol. 25. pp. 33–35, 68–69; February, 1945.
(351) H. Mark, "Some applications of ultrasonics in high-polymer research," *Jour. Acous. Soc. Amer.*, vol. 16, pp. 183–187; January, 1945.
(352) F. Massa, "A working standard for sound pressure measurements," *Jour. Acous. Soc. Amer.*, vol. 17, pp. 29–34; July, 1945.
(353) W. F. Meeker and F. H. Slaymaker, "A wide range adjustable acoustic impedance," *Jour. Acous. Soc. Amer.*, vol. 16, pp. 178–182; January, 1945.
(354) B. M. H. Michel, "The design of loudspeaker systems," *Radio News, Radio-Electronic Eng. Dept.*, vol. 4, pp. 3–6, 38–41; June, 1945.
(355) Willard Moody, "Servicing public address equipment," *Radio News*, vol. 33, pp. 46–48, 110, 112, 114; January, 1945.
(356) B. Olney, F. H. Slaymaker, and W. F. Meeker, "The dipole microphone," *Jour. Acous. Soc. Amer.*, vol. 16, pp. 172–177; January, 1945.
(357) G. N. Patchett, "A new versatile tone control circuit," *Wireless World*, vol. 51, pp. 71–74; March, 1945; pp. 106–109; April, 1945.
(358) P. S. Rand, "A high-gain A.C.-D.C. audio amplifier," *QST*, vol. 29, pp. 32–33, 84; January, 1945.

(359) Rogelio P. McLoughlin, translated by Neil E. Handel, "Frequency standard for use at high and low frequencies," *Jour. Acous. Soc. Amer.*, vol. 17, pp. 46–70; July, 1945.
(360) Robert G. Rowe, "Ultrasonic communications," *Radio News*, vol. 34, pp. 48–49, 118, 120, 122; October, 1945.
(361) Arthur J. Sanial, "Acoustic feedback reduction by increased directivity in electric megaphones," *Communications*, vol. 25, pp. 62–64; September, 1945.
(362) Arthur J. Sanial, "Electric megaphones," *Communications*, vol. 25, pp. 33–35, 64–65, 68–69, 76–80; July, 1945.
(363) W. Saraga, "An electronic musical instrument," *Electronic Eng.*, vol. 17, pp. 601–603; July, 1945.
(364) P. D. Saw, "Electronic sound effects," *Electronic Eng.*, vol. 17, pp. 580–584; July, 1945.
(365) H. H. Scott, "Audible audio distortion," *Electronics*, vol. 18, pp. 126–131; January, 1945.
(366) R. F. Scott, "Speech amplifiers," *Radio Craft*, vol. 6, p. 218; January; p. 289; February; pp. 354, 378; March; pp. 423, 441; April; pp. 491, 523; May, 1945.
(367) H. B. Shaper, "Frequency-response curve tracer," *Electronics*, vol. 18, pp. 118–121; March, 1945.
(368) Frederick W. Smith, Jr., "Resonant loudspeaker enclosure design," *Communications*, vol. 25, pp. 35–37; 77–78, August, 1945.
(369) C. Stevens, "Unique volume expander and compressor," *Radio News*, vol. 34, pp. 50–51, 94; July, 1945.
(370) K. R. Sturley, "Low-frequency amplification," *Electronic Eng.*, vol. 17, pp. 236–238, 247; November, 1944; pp. 290–293; December, 1944; pp. 335–338; January, 1945; pp. 378–381; February, 1945; pp. 429–431; March, 1945; pp. 470–472; April, 1945; pp. 510–513; May, 1945.
(371) G. J. Thiessen, "R-C filter circuits," *Jour. Acous. Soc. Amer.*, vol. 16, pp. 275–279; April, 1945.
(372) J. A. Weller, "A volume limiter for leased-line service," *Bell Lab. Rec.*, vol. 23, pp. 72–75; March, 1945.

Many electroacoustic devices were developed for the armed forces. Information regarding a large number of these is still unpublished for military reasons and during 1946 it is expected that there will develop a large list of such devices. Some that were described during 1945 are listed as follows:

(373) L. B. Cooke, "The voice of ship command," *Bell Lab. Rec.*, vol. 23, pp. 241–245; July, 1945.
(374) H. W. Duffield, "A 9-speaker battle announcing system," *Communications*, vol. 25, pp. 48–50; October, 1945.
(375) J. C. Hoadley, "Wartime speaker enclosures," *Radio News*, vol. 34, pp. 48–49, 150; July, 1945.
(376) B. E. Phelps, "Motor noise unit for aircraft trainer," *Electronics*, vol. 18, pp. 96–99; August, 1945.

One device of particular significance for industrial application was the supersonic reflectoscope.

(377) F. A. Firestone, "The supersonic reflectoscope for interior inspection," *Metal Progress*, p. 505; September, 1945.

New equipment and techniques were announced for disk, wire, and film recordings.

(378) W. S. Backman, "Phonograph dynamics," *Electronic Indus.*, vol. 4, pp. 86–89, 124, 128, 190; July, 1945.
(379) B. B. Bauer, "Notes on distortion in phonograph reproduction caused by needle wear," *Jour. Acous. Soc. Amer.*, vol. 16, pp. 246–253; April, 1945.
(380) B. B. Bauer, "Tracking angle in phonograph pickups," *Electronics*, vol. 18, pp. 110–115; March, 1945.
(381) N. L. Chalfin, "Phono head balance," *Electronic Indus.*, vol. 4, pp. 102–103, 138, 142; September, 1945.
(382) R. H. Cricks, "Sound reproduction amplifiers," *International Projectionist*, vol. 20, pp. 10, 12; June, 1945.
(383) R. N. Farr, "Sound on the record," *Sci. News Letter*, vol. 47, pp. 362–364, 366; June 9, 1945.
(384) L. C. Holmes and D. L. Clark, "Supersonic bias for magnetic recording," *Electronics*, vol. 18, pp. 126–136; July, 1945.
(385) E. W. Kellogg, "The ABC of photographic sound recording," *Jour. Soc. Mot. Pic. Eng.*, vol. 44, pp. 151–194; March, 1945.
(386) T. Lindenberg, Jr., "Moving-coil pickup design," *Electronics*, vol. 18, pp. 108–110; June, 1945.
(387) W. C. Miller, "The PH-346A recording equipment," *Jour. Soc. Mot. Pic. Eng.*, vol. 44, pp. 75–96; February, 1945.
(388) W. A. Mueller and M. Rettinger, "Anecdotal history of sound recording technique," *Jour. Soc. Mot. Pic. Eng.*, vol. 44, pp. 48–53; July, 1945.
(389) "Multi-channel sound recording on film," *Electronic Indus.*, vol. 4, pp. 92–93, 158, 160; April, 1945.
(390) P. Peters, "New portable disc recorder," *Radio News*, vol. 33, pp. 35, 142, 144–145; April, 1945.
(391) N. C. Pickering, "Improving recordings," *Electronic Indus.*, vol. 4, pp. 82–84, 206, 210, 214; October, 1945.
(392) I. Queen, "Noiseless recording," *Radio-Craft*, vol. 16, pp. 274, 320–321; February, 1945.
(393) H E. Roys, "Experience with an FM calibrator for disk recording units," *Jour. Soc. Mot. Pic. Eng.*, vol. 44, pp. 461–471; June, 1945.
(394) Robert Stone, "Business recording equipment," *Radio News*, vol. 34, pp. 32–34, 100, 102–104, 106; November, 1945.
(395) Carl E. Winter, "Magnetic tape recording," *Radio News*, vol. 33, pp. 32–34, 138, 140–141; June, 1945.

Among the developments in hearing aids, audiometry, and miscellaneous medical applications are those described in the following papers:

(396) H. A. Carter, "The consideration of hearing aids and audiometers by the Council on Physical Medicine," *Jour. Acous. Soc. Amer.*, vol. 16, pp. 203–205; January, 1945.
(397) V. E. Eitzen, "Hearing-aid microphone design," *Radio News*, Radio-Electronic Eng. Dept., vol. 4, pp. 13–15, 30, 32; May, 1945.
(398) J. D. Harris, "Group audiometry," *Jour. Acous. Soc. Amer.*, vol. 17, pp. 73–76; July, 1945.
(399) C. J. LeBel, "Hearing aid technic," *Electronic Indus.*, vol. 4, pp. 104–106, 198, 200–202, 204–205; January, 1945.
(400) K. Lowy, "Some experimental evidence for peripheral auditory masking," *Jour Acous. Soc. Amer.*, vol. 16, pp. 197–202; January, 1945.
(401) F. E. Planer and E. A. Marland, "Negative feedback in hearing aid amplifiers," *Electronic Eng.*, vol. 17, pp. 450–453, 455; April, 1945.
(402) Maurice B. Rappaport, "Development of cardiac diagnostic instruments," *Radio News*, vol. 34, pp. 25–28, 106, 108, 110, 112; September, 1945.
(403) M. B. A. Schier, "Clinical phenomena in conductive media: the individual earpiece," *Jour. Acous. Soc. Amer.*, vol. 17, pp. 77–82; July, 1945.
(404) "Tentative code for measurement of performance of hearing aids," *Jour. Acous. Soc. Amer.*, vol. 17, pp. 144–150; October, 1945.
(405) N. A. Watson, "Air- and bone-conduction audio testing assembly," *Jour. Acous. Soc. Amer.*, vol. 16, pp. 194–196; January, 1945.

A number of purely analytical studies was made extending the theory of operation of various acoustic radiating elements, as well as studies of various field problems including conduction through ducts. One significant feature was the increased emphasis given to reciprocity methods of calibrating instruments. Among the studies presented were:

(406) Piero Giorgio Bordoni, "The conical sound source," *Jour. Acous. Soc. Amer.*, vol. 17, pp. 123–126; October, 1945.
(407) E. Fisher, "Attenuation of sound in circular ducts," *Jour. Acous. Soc. Amer.*, vol. 17, pp. 121–122; October, 1945.
(408) Leslie L. Foldy and Henry Primakoff, "A general theory of passive linear electroacoustic transducers and the electroacoustic reciprocity theorems," *Jour. Acous. Soc. Amer.*, vol. 17, pp. 109–120; October, 1945.
(409) Charles E. Harrison, "Electrical-acoustical equivalents," *Communications*, vol. 25, pp. 44–45; June, 1945.
(410) R. Clark Jones, "On the theory of the directional patterns of continuous source distributions on a plane surface," *Jour. Acous. Soc. Amer.*, vol. 16, pp. 147–171; January, 1945.
(411) A. Kahn, "How microphones work," *QST*, vol. 29, pp. 34–37; September, 1945.
(412) P. W. Klipsch, "A note on acoustic horns," PROC. I.R.E., vol. 33, pp. 447–449; July, 1945.
(413) L. W. Labaw, "Wave-front determination in a unidirectional supersonic beam," *Jour. Acous. Soc. Amer.*, vol. 17, pp. 19–23; July, 1945.
(414) C. T. Molloy and E. Honigman, "Attenuation of sound in lined circular ducts," *Jour. Acous. Soc. Amer.*, vol. 16, pp. 267–272; April, 1945.
(415) George M. Nixon, "'Higher fidelity' in sound transmission and reproduction," *Jour. Acous. Soc. Amer.*, vol. 17, pp. 132–135; October, 1945.

(416) R. A. Scott, "An investigation of the performance of the Raleigh disc," *Proc. Roy. Soc.*, ser. A, vol. 183, pp. 296–316; February 22, 1945.
(417) Eugene Tsung-Yueh Hsu, "Measurement of supersonic absorption in water by the balance method with mechanical integration," *Jour. Acous. Soc. Amer.*, vol. 17, pp. 127–131; October, 1945.
(418) A. O. Williams, Jr., and L. W. Labaw, "Acoustic intensity distribution from a 'piston' source," *Jour. Acous. Soc. Amer.*, vol. 16, pp. 231–236; April, 1945.

Several significant papers were published on matters which had been previously classified. Included in these were:

(419) C. J. Burbank, "Acoustic reflections from triplanes, spheres, and disks," announced for presentation to the American Physical Society in January, 1946.
(420) W. L. Bond, "Methods of orienting and cutting synthetic crystals," presented to Metropolitan Section, American Physical Society, Columbia University, November 9, 1945.
(421) Hans Jaffe, "The order of magnitude of piezoelectric effects," presented to Metropolitan Section, American Physical Society, Columbia University, November 9, 1945.
(422) G. W. Willard, "Ultrasonic interference at angular reflection," presented to Metropolitan Section, American Physical Society, Columbia University, November 10, 1945.

Circuits

Network Analysis and Synthesis

A number of papers, significant because of their value in contributing to the advancement of fundamental theoretical knowledge in connection with the general problems of analysis and synthesis appeared during 1945. In a few appropriate instances, attention is drawn, in the following summary, to papers appearing in 1944.

On the subject of transient response of networks the most significant contribution of recent years is contained in the paper

(423) H. E. Kallmann, R. E. Spencer, and C. P. Singer, "Transient response," Proc. I.R.E., vol. 33, pp. 169–195; March, 1945.

An analysis is given here of the step-function response of a variety of actual and ideal networks suitable as coupling networks in television amplifiers. A principal feature of the investigation is the determination of an ideal characteristic yielding a transient response exhibiting uniform stretch properties when identical stages are cascaded. This result readily permits the evaluation of a design for stated over-all tolerances.

A second paper concerned with the basic principles of transient response appeared late in 1944.

(424) W. W. Hansen, "Transient response of wide-band amplifiers," *Electronic Indus.*, vol. 3, pp. 80–82, 218, 220; November, 1944.

The paper suggests that the quality of the transient response of low-pass and band-pass networks be expressed in terms of a quantity (called "transient bandwidth") which is essentially the reciprocal of the mean squared error between the impulse response and the impulse itself. This index is compared with the commonly employed bandwidth (of the steady-state response function) for singlestage and multistage wide-band amplifiers employing the more commonly considered types of coupling networks.

Of theoretical interest in the field of network synthesis is a paper concerned with the problem of showing that a transfer function having an amplitude given by the probability function, although theoretically not realizable, may nevertheless be approximated asymptotically by cascading an unlimited number of simple constant-resistance networks; the joker, however, being that the resulting time delay approaches infinity. The authors point out that one may ordinarily content oneself with a moderately good degree of approximation and thus obtain for certain applications a desired form of response for pulses which themselves have the form of the probability function.

(425) F. F. Roberts and J. C. Simmonds, "The physical realizability of electrical networks having prescribed characteristics, with particular reference to those of the probability function type," *Phil. Mag.*, vol. 35, pp. 778–783; November, 1944.

It has long been known that the real and imaginary parts of an impedance or propagation function are so-called conjugate potential functions and that an electrolytic tank may be used to study the properties of such functions. That this technique may effectively be employed in the evaluation of impedances as functions of frequency when their zeros and poles are specified is shown in the following paper:

(426) W. W. Hansen and O. C. Lundstrom, "Experimental determination of impedance functions by the use of an electrolytic tank," Proc. I.R.E., vol. 33, pp. 528–534; August, 1945.

In the design of coupling networks for wide-band amplifiers, the maximum gain-bandwidth product obtainable is limited by the parasitic shunt capacitances of the associated tubes. H. A. Wheeler has, in the past, made notable contributions toward evaluating the ultimate limit obtainable, and H. W. Bode (see comments on his recent book below) by applying synthesis procedures, succeeded in obtaining the correct theoretical upper limit as well as developing a method of design whereby one may practically find networks which yield any desired approximation to this limit. In the paper

(427) W. W. Hansen, "On maximum gain-bandwidth product in amplifiers," *Jour. Appl. Phys.*, vol. 16, pp. 528–534; September, 1945,

the author shows how these results may be obtained more simply through reasoning in terms of potential theory, although his conclusions in the case of a four-terminal interstage network were not obtained by this method alone but are a substantiation of results given by Bode. He carries his analysis further than has heretofore been done in considering the additional advantage gained through the use of stagger-tuned stages.

Much heretofore unpublished material relating to network analysis and synthesis has appeared in the book

(428) H. W. Bode, "Network Analysis and Feedback Amplifier Design," D. Van Nostrand Company, Inc., New York, N. Y., 1945.

The discussion relating to passive network synthesis is restricted to that portion having a more immediate bearing upon the problem of feedback-amplifier design, this being the primary topic. A very complete discussion is given of the relations between the real and imaginary parts of an impedance or propagation function. While a significant application of these results is that dealing with the design of interstage coupling networks and the maximum gain-bandwidth limitation mentioned above, their use is exhaustively discussed in connection with the stability problem arising in the design of feedback amplifiers.

A topic of interest to those concerned with developing synthesis procedures applicable to problems dealing with ultra-high frequencies is that of determining whether properties of lumped-circuit impedances apply also to impedances of wave-guide sections and cavities. A contribution showing that this is the case for lossless cavities is given in the paper

(429) W. R. MacLean, "The reactance theorem for a resonator," Proc. I.R.E., vol. 33, pp. 539–541; August, 1945.

In the design of servomechanisms, the techniques of network synthesis are gradually being more fully applied. A discussion from this point of view, using a very strong mathematic approach and making full use of the methods developed by Bode, is given in the book

(430) L. A. MacColl, "Fundamental theory of servomechanisms," D. Van Nostrand Company, Inc., New York, N. Y., 1945.

An additional contribution in this field in which the servo problem is analyzed in terms of the methods of conventional transmission theory is given in the paper

(431) Enoch B. Ferrell, "The servo problem as a transmission problem," Proc. I.R.E., vol. 33, pp. 763–767; November, 1945.

In addition to the above contributions which deal with topics having a more direct bearing upon the advancement and application of knowledge in circuit theory generally, the following additional papers on miscellaneous specialized subjects may also be mentioned.

An adaptation of the twin-T circuit in a feedback amplifier is shown to yield a method of designing satisfactory filter circuits with resistance and capacitance elements alone in the paper

(432) G. J. Thiessen, "R-C filter circuits," *Jour. Acous. Soc. Amer.*, vol. 16, pp. 275–279; April, 1945.

A practical method of obtaining stable negative circuit elements is discussed in the following:

(433) E. L. Ginzton, "Stabilized negative impedances," *Electronics*, vol. 18, pp. 140–144, 146, 148, 150; July, 1945; pp. 138–144, 146, 148; August, 1945.

A discussion of the properties and possible uses of the "butterfly" circuit as a resonator for frequencies in the range 100 to 1000 megacycles is given by

(434) Edward Karplus, "Wide-range tuned circuits and oscillators for high frequencies," Proc. I.R.E., vol. 33, pp. 426–441; July, 1945.

The familiar image-parameter methods of linear-network analysis are applied to the problem of mixers to determine conditions for optimum performance in the paper

(435) L. C. Peterson and F. B. Llewellyn, "The performance and measurement of mixers in terms of linear-network theory," Proc. I.R.E., vol. 33, pp. 458-476; July, 1945.

A study of the distortion introduced by the tuned circuits of a frequency-modulation system is given by

(436) David Lawrence Jaffe, "A theoretical and experimental investigation of tuned-circuit distortion in frequency-modulation systems," Proc. I.R.E., vol. 33, pp. 318–333; May, 1945.

Standards

During the closing months of the war and for the remainder of the year 1945, progress was made in reactivating the I.R.E. standardization program, which, during the war years, had reflected the preoccupation with the war effort. Through joint efforts and interest, the Institute's standardization organization will cooperate much more closely than ever before with other organizations having a community of interest in common fields of activity. In the closing months of the year these plans were being placed into effect, particularly with respect to the Radio Manufacturers Association and the American Institute of Electrical Engineers. The I.R.E. standardization program will be accelerated through the addition of a full-time Technical Secretary, an office which was created by the Board of Directors during this year.

Acknowledgment

As in previous years, this summary for 1945 covers generally, for the subjects dealt with, developments described in publications issued up to about the first of November. It is subject, as recent reviews have been, to the fact that publication and the distribution of publications have been limited by the circumstances of war. The material has been prepared by members of the 1945 Annual Review Committee of the Institute, edited and co-ordinated by Laurens E. Whittemore, Chairman,and Keith Henney, H. A. Wheeler, I. S. Coggeshall, and J. Warren Horton, Members-at-Large.

The other members of the Annual Review Committee for 1945 and the committees of the Institute of which they are chairmen are as follows:

R. S. Burnap	Electron Tubes
W. G. Cady	Piezoelectric Crystals
P. S. Carter	Antennas
C. C. Chambers	Frequency Modulation
W. T. Cooke	Railroad and Vehicular Communications
D. E. Foster	Radio Receivers
E. A. Guillemin	Circuits
R. F. Guy	Standards
I. J. Kaar	Television
A. C. Keller	Electroacoustics
J. F. Morrison	Radio Transmitters
E. W. Schafer	Symbols
J. A. Stratton	Radio Wave Propagation and Utilization
C. J. Young	Facsimile
P. Zottu	Industrial Electronics

The chairmen of the above committees wish to acknowledge the assistance given them in many cases by individual members of the committees.

Those New Frontiers*

PAUL A. PORTER†

IN THE PAST 25 years, the American radio engineer has built the largest broadcasting system and the largest international radio-communications system in the world.

The major role that the radio engineer has played in our life in recent years, and especially in wartime, has made his profession one of the more glamorous of our times. A grateful and admiring population, awed by the miracles already produced and excited by the promise of other miracles still shrouded in secrecy, is in a mood to unhook the horses from your carriages and haul your electronic heroes through the streets. The rise of the radio engineer in the esteem of the whole fraternity of learned professions has been equally marked.

But this review of past successes does not by any means indicate that your profession has now completed its life cycle and that you must convert to some other occupation if you are to continue to serve society as well as earn your daily bread. On the contrary, this 1946 Meeting of The Institute of Radio Engineers finds radio moving rapidly towards revolutionary developments. All your achievements of the past have been merely a prologue to a dynamic, ever-expanding future. In the next quarter of a century, I confidently expect to see your accomplishments tripled or quadrupled.

The house of radio has, of course, been drastically expanded during the war. The usable spectrum space has been extended from 300 megacycles to more than 30,000 megacycles. Instead of the ivy-covered cottage of the simple prewar days, the radio engineer now has a skyscraper. We haven't found the keys to all the rooms yet and there is some difference of opinion among the prospective tenants over the desirability of the upstairs floors versus the lower floors for their special needs; but nevertheless, no landlord has a longer waiting list of applicants than the Federal Communications Commission.

As soon as it became apparent that the unprecedented technical advances during the war were going to provide more operating space in the radio spectrum, the Federal Communications Commission, in conjunction with industry, with special co-operation from this organization, began laying plans for a reallocation of frequencies that would provide channels for a number of new radio services and for the expansion of existing ones.

That work has now been largely completed and while many policy questions still remain to be decided, such great new fields of activity have been opened up that the radio industry is now enjoying a phenomenal boom, with the radio engineer riding the crest of the wave.

Let's look at some of the many fields in which radio is expanding: In standard broadcasting, there are 940 stations on the air, and 64 construction permits for new stations have been issued. We have 525 applications on file for new amplitude-modulation stations, 250 applications for changes in existing stations, and more continue to come in daily.

Frequency modulation, whose qualities of life-like high-fidelity reception will provide a superior broadcasting service, has attracted the support of both the present standard broadcasters and newcomers. More than 750 applications for new frequency-modulation stations have been received. Conditional grants have been issued to nearly 300 of them. I anticipate that in a few years' time several thousand such stations will be constructed. It is now apparent that, eventually, frequency-modulation broadcasting will largely supplant the present system of standard broadcasting especially for regional and local service. Radio engineers can contribute much to the solid growth of frequency modulation by insisting on receiver design that will give the listener the fullest benefit of frequency-modulation's superior qualities.

The immediate development of television was given the green light by the Commission with the allocation of 13 channels below 300 megacycles, the allotment of channels over the nation, and the issuance of standards of good engineering practice. More than 150 applicants have filed for television stations in these channels. In addition, the Commission is encouraging the fullest experimentation with wide-channel color television in the higher frequencies.

Experimentation is also going forward in facsimile broadcasting.

All these new and expanded types of broadcasting will demand the expenditure of hundreds of millions of dollars for transmitting and receiving equipment, not to mention the expenditures for program services and other operational expenses.

This new era in communications is witnessing the introduction of beam radio into domestic telegraph and telephone operation. The revolutionary modernization program which Western Union has embarked upon calls for the construction of beam radio between the larger cities to replace its overhead pole-and-wire plant. The use of short-wave radio in telephone operations should extend service to thousands of rural residents, who now do not have telephone service because wire lines are not accessible. Four other companies are experimenting with radio-relay systems.

Westinghouse has been granted a license to experiment with its stratovision relay and broadcasting system using airplanes circling aloft as transmitter sites.

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† At the time of this address Mr. Porter was Chairman of the Federal Communications Commission, Washington, D. C. He later became Chairman of the Office of Price Administration.

And, of course, the coaxial-cable system being rapidly pushed forward by the American Telephone and Telegraph Company will speed the growth of television network service.

Short-wave radio will be used in the General Mobile Service which will provide two-way telephone communication for various types of mobile units. A limited number of experimental licenses is being issued by the Commission to determine the best operating plan for this service. Bell System companies have already filed applications for experimental urban mobile stations in 27 cities and have under consideration applications for additional experimental stations in 42 other cities.

The American Telephone and Telegraph Company has advised the Commission that it expects at least 10,000 doctors' cars, ambulances, buses, taxicabs, and commercial vehicles to be equipped with two-way radio within the next two years, in New York alone.

Regular two-way radio service was authorized for the use of the nation's railroads by the Commission last December 31st, after considerable experimentation and after public hearings had been held. The good old days of brakemen crawling over the tops of trains or stumbling through the darkness and the blizzards to protect their trains seem on their way out, as the short wave comes in. The Commission has been advised that 52 railroads plan to install radio equipment as soon as possible, to promote safety and efficiency. We anticipate that every class I railroad in the country will be equipped within the next five years. Many of them will have more than 100 two-way stations each.

The walkie-talkie will soon be putting on civilian clothes when the Commission authorizes the establishment of the Citizens Radiocommunication Service. This will permit anyone to be licensed to use this two-way type of radio for his personal convenience or to aid in running his business. We expect wide use by farmers, doctors, hunters, fishermen, dairies, express companies, laundries, and other individuals or concerns who do not require an exclusive frequency.

The radio "ham" who was silenced all during the war has been restored his historic privilege of chinning with other like-minded enthusiasts over the minutiae of their hobby. At present, about 60,000 amateurs hold licenses but we expect that number to go up to 100,000 because of the huge number of men who learned radio while in the service.

The expansion of the Aviation Radio Services will, of course, be tremendous. Whereas there are at present only 3000 United States aircraft stations, we expect at least 26,000 by a year from now. Some experts predict that all itinerant aircraft using established airways will be required to carry radio in a few years because of the increasing congestion of traffic. There will also be a rapid increase in ground stations.

The wartime mushrooming of the nation's shipbuilding program and the allocation of additional very-high-frequency channels for maritime use insures a sharp rise in the number of ship-radio installations, especially in the coastal-harbor service.

Also, radio is destined to become a bigger police weapon than ever before. While the value of radio in fighting crime is universally conceded, the wartime shortages of equipment have not permitted the fullest utilization of this powerful aid. I think you will be surprised to learn, as I was recently, that the police of only 1300 of the 16,500 incorporated cities of the nation are equipped with police radio—an indication of the possibilities of future development. Fire departments were given their own frequencies in our allocation plan, and we anticipate that 5000 of them eventually will have their own systems.

The Commission reached a reconversion milestone on December 13th when it issued its first license—an experimental license—for the civilian use of radar. It also recently granted its first license for the use of radio for irrigation control. What nonmilitary use will be made of such inventions as loran, shoran, the huff-duff, and so on, we cannot now estimate.

Radio will be used in many industrial processes, especially in heat treating. The latest flash from this radio front brings tidings of a slot machine which will cook hot dogs by radio waves and will deliver them in a sandwich complete with mustard for one dime.

A vast new field for radio engineering lies in the refinement of international radio-communications equipment. The scarcity of frequencies makes such refinements absolutely necessary. I have in mind such wartime developments as multichannel transmission, the carrier shift system and improvements in directional antennas.

New wonders, still unsuspected by most of us laymen, are no doubt locked in many a bosom in this distinguished assembly of radio engineers. And these, of course, do not include the inventions already perfected but which are still kept a military secret. But this much I can tell you: because of military demands and also because of the availability of federal funds for these wartime research projects, the number of experimental stations authorized by the Commission last year jumped 100 per cent. The study of technical inventions or improvements as they are declassified by the military will be a continuing responsibility of the Commission.

This bold program of experimentation, carried out under the pressure of wartime demands and financed by the federal government, has produced technical advances which we would not otherwise have had for years or for generations. That program has made it possible for you and me to enjoy in our lifetime technological improvements for a better and richer life which otherwise might not have come until we had departed these earthly shores—might not even have come in time for our children or our grandchildren to enjoy. And of course, I need not enlarge here on the new horizons that have been opened up, particularly for the radio-engineering profession, by these great wartime co-operative technical projects.

In view of the giant strides made through this concentrated wartime effort, I am naturally highly enthusiastic over the steps now being taken to formulate a federal research program which will blaze the trail for further practical applications to improve our way of life. To me, such a program seems such a logical move toward the fuller utilization of our intellectual resources that I regret that it was not undertaken years ago. It is indeed so logical that, while there has been some disagreement as to details, the testimony of scientists, educators, industrialists, civic leaders, farm leaders, government administrators, military officials, and others before the Congress has been overwhelmingly in favor of a federally supported research program.

The keen interest displayed by the scientists is in line with the growing concern which so many of them are evincing over the social results of their discoveries. The most notable instance, of course, is the organization of the Federation of American Scientists by the men who worked on the atomic bomb—a group dedicated to political action. I was deeply impressed by the testimony of Dr. Isaiah Bowman, president of Johns Hopkins University: "The scientist cannot afford to neglect politics and the Congressman cannot afford to neglect the scientist. We are in this boat together. Each of us must use language that the other can understand; all must participate in a final judgment upon wise action."

This interest, too, is in recognition by some leaders of the profession that the members of the profession have not been as concerned as they might have been in the past with the social consequences of their endeavors. I am thinking of Morris Cooke's warning: "Notwithstanding the fact that science and engineering steadily acquire a larger place in our civilization, they all but unknowingly practice a form of isolationism which retards social progress and keeps us in many ways from realizing on the American dream of Thomas Jefferson, 'a people living in comfort on the fruits of their industry'."

The Subcommittee on War Mobilization of the Senate Military Affairs Committee, headed by Senator Kilgore, has been studying this need for more adequate research for three years, and called attention more than a year ago to the need for a continued high level of research in the postwar period with the federal government contributing such support as may be required to supplement the work of private organizations and institutions.

As a spur to research, Dr. Vannevar Bush, Director of the Office of Scientific Research and Development, in a report to President Truman last July 5th, proposed the creation of a permanent over-all federal agency for the support of science. The President, in his message to Congress on September 6th urged early legislation for this program.

Among the organizations favoring a federal research program is the Engineers Joint Council which includes the American Institute of Electrical Engineers. Their endorsement includes this statement: "The engineering profession stands undivided back of the words of the President, that 'Progress in scientific research and development is an indispensable condition to the future welfare of and security of the Nation'." The statement adds: "It is self-evident that the size and the urgency of the problem are such that scientific research in this country no longer can be allowed to depend on the course of natural development that prevailed in the past, and to rely upon the diminishing funds of private philanthropy. A systematic and generous yearly appropriation of Government funds becomes a necessity."

No one knows better than you radio engineers the frontiers that still remain to be conquered in your particular field. These are tasks of such magnitude and of such general benefit to the entire field that no one company can or should be expected to undertake them. They are proper concerns of the federal government. It is now plain that we will have no alternative in this matter. Either research into "pure" science is to be aided by the federal government, or much of it will simply be left undone. Few people realize how great a debt we owe to the "pure" science researches of Europe for our great strides here in applied science.

I have been gratified by the general broad-gauge view taken by the nation's leaders on this matter. It has been almost unanimously conceded that, while there may be no immediate practical benefit from the proposed basic research, the long-range results will pay rich dividends, and that, in fact, such fundamental spade work is indispensable to practical application.

Having shifted from low gear to high gear in radio progress during the war, we can only maintain that speed by intensive research in a wide range of problems. For instance, we have really only begun to explore the higher reaches of the radio spectrum. If we had a public domain of comparable extent in the form of land, we would need no urging to devise ways and means of exploiting its natural resources. Yet this ethereal area of public-domain promises is susceptible to perhaps equal or greater yields. Our present knowledge of one of the most important elements in radio transmission, the ionosphere, is limited. The study of this element will afford a challenge to the best research brains in America.

One of the foremost beneficiaries, from an occupational standpoint, of the current trend toward a closer international relationship, is the radio engineer. For without fuller communications facilities such relationship cannot flourish.

The development of the United Nations Organization will demand a continuing expansion of communications facilities. In due time, there will be a World Telecommunications Conference to pave the way further for a freer flow of communications on a world-wide basis. I have every reason to expect that the trend to co-operation, to a lowering of barriers which featured the Third Inter-American Radio Conference at Rio de Janeiro last September and the British-American conference at Bermuda last December, will also prevail at the forthcoming world conference. America and the other nations of the world must have ample, rapid, cheap communication with each other if we are to achieve the ideal of common understanding and co-operation to which we are committed. In this connection, I trust that this nation will not fail as it did after the last world war to put its house in order by a unification of its international communications facilities.

The demands of world trade and the development of an international information program by the Department of State will aid and be aided by an expansion of our international communications systems.

You now have the following immediate assignments:

1. The construction of an entirely new system of aural broadcasting, frequency modulation, complete with thousands of transmitters, millions of receivers, and nationwide networks.

2. The construction of a nationwide system of television.

3. The construction of scores of radio systems for a wide variety of uses to promote safety and efficiency.

Frequency Service Allocations*

PAUL D. MILES†, SENIOR MEMBER, I.R.E.

THE SCIENCE of frequency allocations, which was at one time very simple, has become exceedingly complex within the past few years. The first international radio conference, at Berlin in 1906, dealt with only two frequencies, namely 500 and 1000 kilocycles, and was concerned with ship-shore telegraphy exclusively. The London Conference of 1912 dealt with a slightly expanded spectrum between approximately 150 and 1000 kilocycles, but again was confined almost entirely to ship-shore communications. The development of high-frequency communications expanded the spectrum so materially that the Washington Conference of 1927 effected service allocations from 10 to 23,000 kilocycles. By the time of Madrid, 1932, this had been increased to 30,000 kilocycles, while the Cairo Conference, in 1938, extended the allocation table on a regional basis to 200,000 kilocycles.

Frequency allocations had an equally simple beginning in the United States, being first specifically treated by the Radio Communications Act of 1912, which granted limited administrative power for its enforcement to the Secretary of Commerce. The rapid growth of broadcasting in the 1920's resulted in a crisis which was resolved by the creation of the Federal Radio Commission under the Radio Act of 1927, in turn superseded by the Federal Communications Commission under the Communications Act of 1934.

The developments of the recent war lent impetus to a very rapid expansion of the radio spectrum above 200 megacycles, and gave rise to new techniques which vastly complicated frequency service allocations. Because of this situation, it became apparent by 1943 that the Government should begin preparatory studies immediately for the next world telecommunications conference. Accordingly, the Interdepartment Radio Advisory Committee[1] in August of that year appointed a subcommittee to deal exclusively with that subject and simultaneously the Federal Communications Commission designated an engineering committee to undertake parallel studies. By June of 1944, the Interdepartment Radio Advisory Committee had completed its study of the subject, had prepared a tentative international service-allocation table, and had transmitted it to the Department of State. Following a suggestion by the Chairman of the Commission in November, 1942, the Radio Technical Planning Board was established in September, 1943, to organize technical facts which would assist in the development of the radio industry in accordance with the public interest, and to advise Government, industry, and the public of its determination. In August, 1944, the Commission scheduled a general allocation hearing, to commence on September 28 of that year, to determine the present and future needs of the various nongovernment services for frequencies in the radio spectrum between 10 and 30,000,000 kilocycles. In May, 1945, the Commission, in co-operation with the Interdepartment Radio Advisory Committee, promulgated the final United States allocation plan above 25 megacycles and a tentative plan below 25 megacycles.

This unique departure in the mode of technical preparation for an international telecommunications conference was necessitated largely because the work was begun in the midst of a war when military security restrictions made it impossible to proceed in a different manner. Because of this departure it may be helpful to outline some of the principles underlying our work. In beginning our postwar planning we had the choice of disturbing the Cairo table as little as possible, or of making a fresh start in the light of modern needs. Upon considering the needs of services such as aviation, recent developments making use of techniques unknown at the

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† Federal Communications Commission, Washington, D. C.

[1] E. M. Webster, "The interdepartment radio advisory committee," Proc. I.R.E., vol. 33, pp. 495–499; August, 1945.

time of Cairo, together with the fact that this probably would be the last opportunity for many years to make drastic changes in the allocation table, it seemed to us the better course to adopt the second alternative.

After we had determined upon the course to follow, we took up the question of shared bands in the high-frequency spectrum (3 to 30 megacycles), and decided that they should be eliminated as far as possible. It was also decided that the aeronautical mobile service should have its exclusive bands of frequencies and similarly that the maritime mobile service should have its exclusive bands. In addition, it seemed to us equally desirable to do everything possible to encourage the transfer of radio services now using medium and high frequencies to that portion of the spectrum now known as the very-high (30 to 300 megacycles), the ultra-high (300 to 3000 megacycles), or super-high (3000 to 30,000 megacycles), wherever the local nature of the service would permit, thereby materially relieving congestion in the lower part of the spectrum in order that more effective use might be made thereof for the long-distance services.

In our detailed consideration of the table below 30 megacycles, we first took up the specific frequencies to be employed by the maritime mobile service for distress and calling purposes. We made a careful study of the frequency of 500 kilocycles, to determine whether that was the optimum frequency for the purpose. The decision was reached that this frequency must be retained, but it was felt that it might be desirable to provide a second distress frequency, intended primarily for intercommunication over the seas between aircraft and ships in cases of distress. While the solution to that problem has not been finally determined, the tentative plan does provide, in addition to 500 kilocycles, a frequency in the 2-megacycle band. It also seemed desirable to us to strengthen the intent of both the Madrid and Cairo regulations to provide high frequencies for maritime calling, by specifically designating a harmonically related series for the purpose.

Turning then to the amateur problem, we replaced in the table the Cairo bands, with the single exception of the band 1750 to 2050 kilocycles which, of course, had to be eliminated because of the establishment therein during the war of loran, a high-power, long-range navigation system employing pulse emission. In addition, a new band was laid down for the amateur service in the vicinity of 21 megacycles, in partial harmonic relationship with the 7-megacycle band.

As we proceeded in building our table, we next turned to the high-frequency maritime mobile bands. It will be recalled that Cairo provides such bands in the vicinity of 4, 5, 6, 8, 11, 12, 16, and 22 megacycles. Because of the essential requirements of other services, it seemed desirable to effect a reduction, resulting in the provision of such bands in harmonic relationship as far as possible in the vicinity of 4, 6, 8, 12, 16, and 20 megacycles.

In our further work we proceeded to the consideration of high-frequency broadcasting and in that connection had the benefit of a study prepared by a special interdepartmental government committee. This study indicated that approximately 118 countries and territories were making use of the frequency range between 4 and 20 megacycles for some form of broadcasting. It indicated further that, in addition to the 105 broadcast channels available under the Cairo table, broadcast stations have been monitored from time to time on 495 other frequencies between 4 and 20 megacycles. In other words, for every useful frequency within the bands now allocated, more than 4 others have been found outside of these bands. It therefore appeared to us that to provide sufficient frequencies to permit all of the nations to operate an unlimited high-frequency broadcast service, from one third to one half of the entire high-frequency portion of the spectrum might be required. In the light of the current United States policy to maintain a high-frequency broadcast service, and one which is not inferior to that of any other nation, the only feasible solution appeared to be the continuance of the Cairo bands, recognizing that the only hope for interference-free operation of this service would be a detailed agreement among the nations concerned which would stipulate precisely which frequency or frequencies each could use and when by making full use of geographical and time-sharing factors, as well as a rigid limitation in the number of stations that each nation would operate. It is of interest to note that the Third Inter-American Radio Conference, held at Rio de Janeiro in September, 1945, unanimously adopted a resolution introduced by Brazil which recommended that a special world broadcasting conference be held, immediately following the next world telecommunications conference, to reach international agreement on the use of the frequencies available for that service.

Because of the expansion of the standard broadcast service, augmented by the growth of that service in Cuba and Mexico, a serious attempt was made to procure more spectrum space for it. While the continued need of the maritime mobile service for medium frequencies provided the limiting factor, it was found possible to extend the lower limit of the standard broadcast band to 535 kilocycles, thus providing one additional assignable frequency.

Before we leave broadcasting, I will note tropical broadcasting, an innovation introduced at Cairo in an attempt to satisfy the broadcasting needs of certain tropical areas which cannot make effective use of the standard band. Because such operations to the South of us have resulted in severe interference to our fixed and mobile communications, we intend to do everything possible to discourage this service, simultaneously urging the development of frequency-modulation broadcasting as the ultimate solution to this problem. A beginning was made by our delegation at the Rio Conference, which introduced a resolution urging immediate frequency-modulation broadcast experimentation in the tropical areas of this continent to determine to what extent this might provide a solution for the tropical broadcast problem. This resolution was adopted unanimously by the Conference. Anything which can be done by the industry to further this objective will be of material benefit to us all.

Turning now to the aeronautical service, whose importance had been spectacularly demonstrated by the war, we had the benefit of the recommendations of another special interdepartmental committee. Adopting the recommendations of that committee as far as possible, aeronautical mobile bands have been proposed which we believe should be sufficient to provide the necessary air-ground communications for the postwar international air routes. I think it is well recognized that it was most unfortunate that the Cairo Conference did not provide route aeronautical frequencies below 6 megacycles, a deficiency that has been remedied in our current allocation proposal.

That portion of the table between 3 and 30 megacycles was then completed by allocating the remaining space to the fixed service. While it is impossible to make a direct comparison between the current proposals for the fixed service and the fixed allocations contained in the Cairo table, since there are so many shared bands in the latter, it is quite apparent that the fixed service will probably suffer a loss in spectrum space in the order of 15 per cent below 10 megacycles, and 5 per cent above that point. It is obvious that when we are faced with the problem of providing spectrum space for new and rapidly expanding services such as, for example, aviation, others must suffer in proportion. In the present United States proposal, while certain other services have suffered somewhat, the fixed service has suffered the most. It is fortunate, however, that the fixed service is in the best position of all the services to take full advantage of the latest techniques in directive antennas for both transmission and reception, selective receivers, strict frequency tolerances, and the use of single sideband and multichannel methods of operation wherever the traffic load justifies. World-wide fixed-service operations cannot possibly operate effectively in this reduced spectrum space unless full advantage is taken of all such modern techniques. This, however, does not lessen the responsibility of each of the other services to utilize modern techniques to the maximum extent practicable.

The preparation of our proposals above 30 megacycles had to be approached on an entirely different basis. Whereas it has never been possible to segregate government from nongovernment operations in the lower spectrum, the principle of such segregation was established above 30 megacycles in the middle 1930's by the provision of exclusive bands for government and nongovernment services. Since this has proven very successful, it was decided to continue its application throughout the upper spectrum.

The spectrum above 100 megacycles was developed and used almost exclusively for military purposes during the war, and for reasons of security classification it was necessary to rely heavily upon the War and Navy Departments for guidance at this stage of our work. As is now well known, radar was one of the most spectacular applications of electronics during the war. This technique had become so useful and was expanded so rapidly that by mid-1942 it became apparent that without some kind of a check, radar equipments in large numbers would soon be in widespread use throughout the upper spectrum to the possible detriment of communications developments. The military services, therefore, found it useful to allocate this spectrum in bands by equipment function, such that certain bands were made available exclusively for radar, certain others for pulse communications, others for conventional communication systems, etc. This proved so successful that it was decided to apply this principle to the postwar allocation problem. It then became necessary to examine all of the radar equipments in existence or in the process of development and decide which should prove most suitable for postwar civil application. This was a difficult task since many assumptions had to be made, but the utter impossibility of providing more than a very limited part of the spectrum for radar use made it imperative. Accordingly, bands were blocked out for radar application at 420 to 460 megacycles, 960 to 1215 megacycles, 1600 to 1700 megacycles, 2700 to 3700 megacycles, 4000 to 4200 megacycles, and 8500 to 10,000 megacycles.

With this done, the amateur bands were placed in the table at various points throughout the upper spectrum, following which certain aeronautical needs were provided for from 108 to 132 megacycles, 328.6 to 335.4 megacycles, and 5000 to 5250 megacycles.

I am sure there is no need to tell what was done to provide for the various forms of broadcasting above 30 megacycles since this has been widely publicized and discussed throughout the industry. In order to complete the record, however, I will state briefly that 13 six-megacycle channels have been provided for television broadcasting between 44 and 216 megacycles, together with an experimental allocation for this service between 480 and 920 megacycles; frequency-modulation broadcasting was provided for between 88 and 108 megacycles, while facsimile broadcasting finds as its spectrum space 470 to 480 megacycles and 106 to 108 megacycles, which latter band is shared with frequency-modulation broadcasting in area 1.

The remaining spectrum between 30 and 30,000 megacycles was divided between government and nongovernment services and labeled "fixed and mobile," or "fixed and mobile except aeronautical mobile," in order to provide the greatest possible flexibility in effecting future frequency assignments.

In making its detailed breakdown of the nongovernment allocations, the Commission has introduced a unique innovation by providing for a new service between 460 and 470 megacycles known as the citizens radio communications service. Herein there is included a portable mobile service for use by the public in the cities, on the highways and in rural areas, the possibilities of which are as broad as the imagination of the public and the ingenuity of equipment manufacturers can devise. It can be used, for example, to establish a physician's calling service; department stores, dairies, laundries, and other business organizations can use it in communicating to and from their delivery vehicles; it can be used on farms and ranches for communicating to men in the fields, on board harbor and river craft, in mountain and swamp areas, and during emergencies when wire facilities are disrupted. It follows, of course, that common carriers will not be permitted in this band and, therefore, that no charge can be made for the transmission of messages or the use of the licensed facilities in this service.

As we have proceeded with the preparation of our proposals for the next service-allocation table, we have been deeply interested in the progress of similar work by other nations. During the course of the Third Inter-American Radio Conference at Rio de Janeiro, an opportunity was afforded to exchange views with the other American nations. The United Kingdom has made available to us informally certain of their views with respect to this problem, and I am glad to be able to report that there seems to be no insurmountable problems in reconciling such differences as now exist. It is hoped that a limited agenda conference can be held in the near future to exchange views further on frequency allocations and related matters, and possibly to provide a temporary solution to the problem of effecting international frequency registrations.

Many problems, however, remain to be solved before our work has been completed. For example, there have been developed during the war several systems for long-range air and surface navigation, the principal ones being standard loran, low-frequency loran, Decca, consol, P.O.P.I., and gee. The two systems first mentioned, which were developed by the United States, use pulse technique; the others were developed or perfected by the United Kingdom and of these only gee is a pulse system. The Third Commonwealth and Empire Conference on Radio for Civil Aviation, held in London in August, 1945, devoted considerable attention to this subject and attempted to determine which of these should be proposed as a world-wide system for long-range air navigation. While standard loran was so designated by this Conference and later by the Communications Subcommittee of the Air Navigation Committee of the Provisional International Civil Aviation Organization, its very limited usefulness over land indicates that it does not provide a final solution to this problem. Certain elements in the United Kingdom, particularly those concerned with surface navigation, are inclined toward Decca, consol, or P.O.P.I., principally because such systems do not require special receivers and are more economical to operate. The problem is further complicated because there seems to be no hope of a world-wide allocation for low-frequency loran without a serious dislocation of the European broadcast system. A solution to this problem must be found on or before the time of the next conference, since the congestion of the spectrum will not permit a world-wide allocation for more than one such system.

Another point concerning which doubt exists is the proper treatment of the spectrum above 10,500 megacycles. One school of thought indicates that we know too little about it now to attempt service allocations therein and therefore believes that it should be labeled "experimental." Another school of thought argues that even though it is too early to effect precise service allocations, from the research standpoint there should be some general indication of those bands in which pulse techniques should be permitted and those in which they should be excluded.

Pulse-communication techniques are attracting the attention of many engineers at the present time. Assuming that pulse and conventional modulating systems cannot operate effectively in the same band, we must determine in which bands they are to be permitted, and those from which they are to be excluded. Furthermore, before pulse-communication systems are placed in operational use it should be determined whether such systems make sufficiently efficient use of the spectrum, as compared to systems employing conventional modulation, to permit their general use.

Additional points to be determined prior to the conference are the desirability of segregating aeronautical fixed communications in exclusive bands, and the feasibility of attempting an international peak-power limitation in certain parts of the spectrum which are allocated on a regional basis.

It is obvious that if an allocation table similar to the one we have been discussing were adopted by the next world conference, it would be necessary for stations all over the world to be shifted into other service bands, thereby losing the international priorities they have now established. I think it is equally obvious that no nation would be willing to give up the priorities it has established unless all other nations agreed to do likewise. The present International List of Frequencies has become practically useless; it contains many stations which do not now exist, and does not contain many stations established since 1939 which were not registered because of the war.

Looking toward a solution to this problem, the United States now proposes that the next conference should effect the establishment of a permanent International Frequency Registration Board, composed of five members and three alternates to be elected by the conference as custodians of an international public trust, to undertake the task of effecting the international registration of frequencies.

Thereafter, any nation which has begun or proposes to begin the use of a frequency would submit to this Board a notice giving the necessary technical information required. The Board would first determine if the notice were in conformity with the table and rules for the allocation of frequencies; second, decide if it were in conformity with the other provisions of the convention and regulations; and finally, determine if harmful interference would result to the use of any other frequency previously registered with the Board.

The proposal is predicated upon the principle that the new International List of Frequencies, based upon the official International Frequency List as maintained by the Secretary of the Union, would contain two date columns, one called the registration date and the other the notification date. Each frequency listing, however, would be given a date in only one of the two columns, depending upon the findings of the Board for the case in question.

Generally speaking, a listing would be given a date in the registration column only if it was found to be satisfactory in all three of the particulars named above. The notice would be returned to the notifying government if it was found not to be in conformity with the provisions of the Convention and Regulations (other than the allocation table). In the other cases it would be given a listing with the date in the notification column, with suitable provision for later transfer to the registration column under certain circumstances.

It is obvious that with such an International Frequency List, the existence of a date in its registration column would be taken as prima facie evidence in any negotiations between contracting governments or in any proceedings before the International Court or Board of Arbitrations that the Board had made a finding that the operation in question could take place without causing harmful interference with services rendered by stations for which assignments had previously been registered. No such prima facie evidence would follow from the appearance of a date in the notification column of the list.

In addition to the duties outlined above, the Board would be given certain advisory functions in connection with the selection of substitute frequencies more technically suitable than those notified; the issuance of reports containing its technical findings and recommendations in cases of alleged improper operation or harmful interference; or the making of recommendations to facilitate the more effective use of a particular portion of the spectrum by the accommodation of additional channels or services. It is further proposed that, under certain circumstances, such changes in registrations could be effected, with the consent of the parties concerned, without loss of priority on the part of the existing registrations so affected.

In the earlier stages of our work on this problem we were tempted to give the Board much more power, but after careful consideration it was decided that the nations of the world had not yet advanced to that state where we could, in effect, transfer their sovereign rights to an International Board of this character.

It is quite apparent that this Board could not begin its work with the present International Frequency List in the condition in which we now find it. While we are still considering this aspect of the problem, it is our present belief that it will be necessary for the next conference to appoint a special engineering committee which would have as its only objective the re-examination of the present International Frequency List, in order to remove therefrom all stations which are inactive and to readjust the assignments of the remaining stations in accordance with the service allocation table adopted by that conference and with engineering principles, so as to avoid harmful interference.

One thing demonstrated by the war is the desirability of close liaison between research and development on the one hand, and frequency service allocations on the other. Each is dependent upon the other; the former, to avoid the expenditure of large sums in the development of systems which cannot be accommodated in the spectrum; and the latter, to insure that the allocation table reflects, to the fullest extent possible, the latest advances in the radio art. As a step toward that end, the Commission, in the recent reorganization of its Engineering Department, has placed the Laboratory Division, the Field and Monitoring Division, the Technical Information Division, and the Frequency Service-Allocation Division within the same Branch. It is to be hoped that equally close liaison will develop within the industry, and between industry and government.

Naval Wartime Communication Problems*

J. O. KINERT†

I AM addressing you as a communication officer who had to use the equipment which you and other engineers developed. I would prefer to claim more technical knowledge in addressing this group, and must beg your indulgence as a user rather than as a designer of electronic equipment.

After considerable communication experience in the fleet, I served as communication officer on the staff of the Commander, Third Amphibious Force, from August, 1943, until May, 1945. Since June, 1945, I have been in the plans and operations section of the office of the Chief of Naval Communications.

My purpose is to present a frank appraisal of some of the problems involved in wartime communications and to recommend design principles based on the lessons learned during the recent war. In justice to the splendid support we had from the electronic industry and the many scientific groups in the country, I wish to make clear that our equipment was generally excellent. The amazing quantities of equipment produced, all of which met or exceeded the requirements of the specifications under which it was procured, stand as a record of achievement which is well known to all of you.

Due to the broad scope of my subject and the necessary briefness of its treatment, I will have to resort to the use of statements which are generalities. Such statements indicate conditions which, while to a large degree true, are subject to many exceptions that I have no desire to deny simply because I do not cite them. For example, I may say that our personnel, because of necessity, were not always sufficiently trained without explaining that we did, very fortunately, obtain the services of many excellent engineers, technicians and operators from both amateur and professional sources in civil life.

Communications are so vital in modern war that any failure may result in consequences ranging from inconvenience to the loss of whole campaigns. The potential power of large and complex forces cannot be developed and used against the enemy unless the efforts of all components are co-ordinated. Such co-ordination depends entirely upon reliable, secure, and rapid communications. It was our success in approaching this ideal of co-ordination that made possible our successful amphibious campaigns. We have made much progress since a Persian king tattooed his message on the scalp of his slave, but our very existence, at some future time, may depend to a large extent upon what progress we make in electronic developments.

From the first days after Pearl Harbor, communication traffic increased much faster than our organization and installations could be expended to handle it. We still needed more and better operators, equipment, and frequencies when VJ-Day arrived, but by this time lack of clear frequencies was a more restrictive factor than lack of personnel or equipment.

Normal naval communications which had been the object of much training and planning in peacetime were generally satisfactory. Amphibious communications, on the other hand, presented new problems for which we were, to a great degree, unprepared. In point-to-point work the use of teletype methods and semiautomatic tape relay permitted sufficient expansion of system capacity so that we could handle all traffic offered. This system was extended to key overseas points by use of radio-teletype links, including the adoption of multiplex operation.

When we commenced our amphibious offensive in the Pacific, this type of operation was new to the experience of most of the participants. The marines and a few naval personnel had engaged in amphibious exercises in peacetime, but all had much to learn before they could claim proficiency in this type of operation.

In communications, particularly, the problems of amphibious assault were staggering. Control of naval gunfire, supporting aircraft, and all types of landing craft had to be centralized in a flagship which also acted as an "afloat command post" for the commanding general of the assault troops. This could be accomplished only by improvising additional facilities in whatever type of ships were available. We used battleships, destroyers, and transports until we could design, build, and equip sufficient command-communication ships to do the job properly.

The magnitude of the larger amphibious operations, such as Leyte, Lingayen, and Okinawa, is hard to portray in a few words. Whole series of landings, varying from regimental to two-divisional in force, were carried out simultaneously on a front twenty miles or more long. Hundreds of transports and landing ships and thousands of landing craft were supported by tens of battleships, cruisers, and small carriers, and scores of destroyers, destroyer escorts, submarine chasers, and minesweepers.

After the troops were ashore, gunfire and air support was continued for weeks. In close support of troop operations we were often called upon to deliver shells, bombs, rockets, or machine-gun strafing within a few hundred feet of our front lines. The ordnance or air officer controlling those attacks had to have continuous communication direct to front-line positions, and the attacking ships or planes, in order to insure that the enemy and not our own troops would feel the effects of our attack.

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Analysis of early actions showed the majority of communication difficulties to be caused by one or another of the following:

(a) Inexperienced Personnel

This was our outstanding limitation. We met it by constant training, simplification of duties, and specialization. In many cases an excellent piece of equipment failed to render the performance for which it was built simply because it was manned by an inadequately trained operator. It might seem that the solution should be more careful selection and better training of personnel, but I am convinced that this is only part of the answer. I believe that any future war will find this country placing inadequately trained personnel in the field because we can neither afford the luxury of a sufficiently large professional force to meet all contingencies, nor in an emergency can we insure adequate training and still place the required forces in the field on time. The fact that we were able to maintain effective communications, under conditions where often whole groups arrived in battle for the first time with only a few per cent of their numbers having even peacetime experience in either naval or civilian communications, is a tribute to the intelligence and resourcefulness of the average American. They made some mistakes but they also established an outstanding record of accomplishment. Most American boys have developed mechanical ability through maintaining bicycles, jaloppies, and old alarm clocks, that was a godsend when they were called upon to learn quickly how to operate the complicated mechanisms and devices of modern war.

(b) Equipment Failures

Many of these were also incident to inadequately trained personnel. But if we accept the experience of this war, we must accept as a design principle the fact that equipment must be operated and maintained by personnel after the minimum training possible. Exceptions to this principle should be certain delicate and complicated equipment which must produce maximum performance regardless of the difficulty of insuring trained operators and technicians.

(c) Planning Failures

Most of these occurred in the early days, but we continued to the last to learn ways to better our plans. We often learned by bitter experience. In addition to our own inexperience and lack of ability to foresee possible developments, certain physical limitations complicated our problems. In the beginning, the most important were shortages of personnel and equipment. Later, the most difficult problem was to crowd all the necessary communications into frequency bands limited both by propagation characteristics and by equipment coverages.

(d) Enemy Action

Fortunately, outside of occasional destruction by bombs and other missiles, the Japanese were not in a position to interfere seriously with our communications. They were so short of electronic matériel that they could ill afford to divert much equipment to interfere with our operations. Next time we may have a less impoverished opponent. An example of enemy action occurred at Vella la Vella when air raids destroyed a great deal of our communication and radar equipment on the beaches. Incidentally, the same raids made a foxhole a far safer place for personnel than the top of a hill which was to be the location of the new radio station. In spite of this, Lieutenant Mervin Fickas, who in civilian life was a radio engineer from the West Coast, managed to establish and maintain communications with our Guadalcanal headquarters on a 9-watt portable set over a distance of about 180 miles. This feat enabled us to expedite replacement of ammunition and other stores destroyed by the enemy. In all cases, reverses due to enemy action were met with courage and resourcefulness. The same was not true of the Japanese, who frequently became completely ineffective and disorganized when something interfered with their plans. I suspect that communication failures played a large part in their difficulties under adversity.

Other lessons were:

(a) Co-ordination of Equipment Design Within and Between All of the Armed Services is Essential.

This had been foreseen in the last period of peace, but on the principle that the various services would benefit by working primarily on different frequency bands. Most portable equipment was designed to cover a relatively narrow band of frequencies common to all services and a wider band that was not normally covered by equipment of other services. This policy resulted in great overcrowding of the common coverage bands in order to provide the interservice channels of communication required.

(b) Reliability of Equipment is often Preferable to the Ultimate in Performance.

In my experience, most of our equipment had adequate performance characteristics to meet operational requirements, provided it operated at all. Some of us were a bit jealous of the Japanese when we found that their equipment, while inefficient and obsolete, was simple to maintain and strongly constructed. However, our equipment was far superior in performance, and usually in reliability, to anything the Japanese had. I am only indicating a willingness to sacrifice performance, in some cases, to reliability. Reliability depends largely on operating conditions and adequate maintenance. Design should reflect the possibility of abuse and unavailability of repair facilities in combat.

(*c*) *More Efficient Use Must Be Made of Existing Radio-Frequency Channels.*

This problem is particularly acute in the case of frequencies suitable for long-range communication. There are no possibilities of finding new frequencies in these bands; all of them are in use now. It does seem possible to develop new techniques which will permit more intelligence to be transmitted in a given time on a specified frequency band.

To those of you who may, in the future, be engaged in design or development of military equipment, I wish to recommend:

(1) the greatest simplification of operation and maintenance consistent with performance specifications;

(2) reduction of weight and size to the practicable maximum consistent with required resistance to immersion, vibration, etc.;

(3) standardization of parts and components to simplify the supply and use of spare parts in the field;

(4) maximum use of automatic or other design features which may reduce the number or qualification of operating personnel required.

In the first war using modern electronic devices, I attribute a large measure of the credit for our successes to the contributions of our electronic engineers. The armed services have learned many lessons and are now engaged in plans so to strengthen our defenses that we may not become engaged in another war. To implement these plans we must rely on you to provide the skills and inventive genius which will keep us ahead of any other country of the world in the use of electronics.

Address of Retiring President*

WILLIAM L. EVERITT†, FELLOW, I.R.E.

THE YEAR 1945 was a momentous year in the affairs of the world. Those who lived through it will never forget it and future generations will study its historical effects on their own lives. The significance of its events will be determined primarily not by what happened, but by what was started. The United Nations Organization is a plan for the future; the capitulation of our enemies makes that plan an actuality; the atomic bomb marks the beginning of an era whose potentialities are unknown.

In The Institute of Radio Engineers, we may also observe significant beginnings in 1945. The importance of these steps forward lies not in their own completion but in their significance as part of a plan which will lead to a greater and more active Institute. The future will determine whether 1945 provided our organization with the means and the impetus to meet the challenge.

The Institute is a co-operative effort for the advancement of the science and technology of communication, electronics, and the allied arts. It now has over 16,000 members. Co-operation of such a large group can be accomplished only with effective leadership. Your Board of Directors has been active and progressive and it has been a real pleasure to serve as their chairman. But the Directors cannot supply the day-to-day co-ordination necessary in an active organization. They have long realized the necessity of an adequate headquarters staff. I feel that the outstanding advancement of the year has been the development of this staff, and the provision for their adequate housing and support.

Early in the year, George W. Bailey was secured as our executive secretary and the members of the Board have been exceedingly happy about that choice as they have seen him take hold. William H. Crew has joined us as Mr. Bailey's able assistant. The editorial department has been reorganized with the addition of R. D. Rettenmeyer as Technical Editor; Miss Helen M. Stote has advanced to the position of Publications Manager and Miss Winifred Carrière has taken the position of Assistant Editor. Miss Elizabeth Lehmann and her staff have accomplished the unbelievable in the handling of a mountain of correspondence and performing the other office functions. Miss Alice Connolly has reorganized our bookkeeping department. I wish there were time to mention all of our loyal staff and what they have contributed.

Robert Jacques has accepted the position of Technical Secretary, and, at long last, we will have a full-time coordinator of our technical committees and other technical activities.

Such a staff deserves the best in accommodations. In 1945, we made that possible. With the energetic leadership of our Building Fund Committee headed by B. E. Shackelford, Ivan S. Coggeshall, and Raymond F. Guy, $625,000 was raised. Not only will this provide an adequate building, but also it will be endowed so that the burden of maintaining it will not exceed the rental of our present inadequate quarters. These funds have been translated into an actual building at Fifth Avenue at 79th Street, in a location where it will be pleasant to work and pleasant for our membership to visit and do business. The selection and purchase of a building seems simple, but let me assure you that the Building Committee, led by Raymond A. Heising and with the able assistance of our attorney, Harold R. Zeamans, overcame

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difficulties which at times we feared were insurmountable. I do not see how we could possibly have come out better than we did.

The raising of this building fund has also established close ties with industry under the direction of W. R. G. Baker's subcommittee and with the sections themselves under the leadership of Austin Bailey. It also brought out criticisms of the Institute which have been most helpful. We feel that the value of the Building Fund Campaign in these intangible results was of importance comparable with that of the money raised.

The development of an adequate headquarters staff would have been a precarious and useless undertaking if we had not provided for adequate financing to pay their salaries and engage in the activities they will lead. The membership recognized this and voted to raise their dues by the adoption of the Westman Amendment. It is a unique accomplishment when 83 per cent of the voting membership of any society agree to raise their own dues. It indicates the faith of our membership in the organization and places a great responsibility on our Board to be sure that the money is spent wisely, for the benefit of all.

The most important single activity of the Institute since its inception has been its publications. The PROCEEDINGS, under the editorship of Alfred N. Goldsmith, have been unequalled in their field and unexcelled as examples of high quality in technical society journals. We rejoice that Dr. Goldsmith has been restored in health in order to continue his service to the Institute. The editorial staff, under his leadership, has developed further plans during the year which are now coming to fruition. A new publication, WAVES AND ELECTRONS, appeared in January. It begins as a section of the PROCEEDINGS but we expect that ultimately it will be issued as a separate publication to give greater service to our entire membership.

The YEARBOOK is nearly ready for publication. Dr. Goldsmith and Mr. Copp, our Advertising Manager, are planning a greatly expanded edition, and the work of preparing it has been enormous, in view of our recent growth and the frequent moves of our members. You will be surprised when you see the improvements which have been made. The editorial staff also deserves special commendation for the speed with which it expanded the PROCEEDINGS immediately after V-J Day, when more paper became available.

Next to the publications, the most important contact of the society with its membership is the work of the Sections. I have been fortunate in being able to meet with every Section in the United States and Canada since my election. I can assure you that they are an active group and have the interests of the Institute at heart.

To help the Sections, a speakers' bureau has been organized under the direction of Dr. Crew, to assist in the planning of programs. He is ready to serve you but will need your co-operation and suggestions to develop this program adequately. He is planning a traveling lecture series for the near future.

In order to increase Section activities, provisions for greater financial support were made this year and the continental United States was redistricted so that every member in that area belongs to some section, as shown on the map in the January, 1946, PROCEEDINGS. We hope that the new Section members who are geographically remote from the cities will find some opportunities each year to visit their section and get acquainted with its activities. In turn, the sections must look after the interests of these new men to the same extent as they do their older members. We are awaiting the recommendations of the Canadian Council on the districting of Canadian Sections.

It has not been the policy of the Board to found new Sections by Headquarters action. The initiative must come from local groups so that there may be assurance of interest and leadership. This policy has been proven to be a wise one. I would recommend to members with initiative, who live in urban areas either far removed from present sections, or where there has developed increased interest in our field, that they contact Headquarters and get lists of members in their locality who could serve as a nucleus for a Section. They will find that Headquarters is now organized to give them aid. They can do the Institute and themselves a real service by organizing. It has been a common experience that when a Section is once initiated, the local membership grows manyfold. Several Subsections were developed during the year and the Sections Committee has made recommendations.

Our membership in countries outside the United States and Canada has now grown so that, with the coming of peace, a number of other groups throughout the world are following the lead of our members in Argentina and are planning Sections. It is to be hoped that this evidence of healthy growth will be accelerated.

With the development of an adequate headquarters staff, the Board of Directors should and will function less in guiding operations and more in determining policy. This determination of policy should be guided by the entire membership. To make this effective we need:

1. A larger proportion of our membership in the voting-professional grades.
2. Regional representation on the Board of Directors.

Steps to fulfill both these needs were taken this year but they require further action by the membership.

The individual Sections were asked to set up personnel committees to accelerate transfers of qualified personnel into the Member and Senior Member grades. A simplified procedure for providing reference information was developed and transmitted to the Sections. As a result, 722 members were transferred to higher grades in 1945, compared with 324 in 1944, and 525 were admitted to higher grades, compared with 157 in 1944. The admissions to the Associate grade were about 1800 each year. This represented an enormous task for the Admissions Committee led by G. T. Royden. They have worked long and hard, are frequently scolded by the members, but seldom appreciated. I want to express publicly the appreciation of the Board for their work. To clarify their method of operation to the members, they have prepared a detailed Manual of Operations which has been sent to each Section for their guidance.

There are still many professional radio engineers in the Associate grade and it is important that those who can qualify, advance, obtain voting privileges, and participate in directing the affairs of the Institute.

A special committee under the chairmanship of Harold Wheeler has prepared a plan for the election of regional representatives to the Board of Directors and for the maintenance of regional committees to handle problems of local interest. This plan was referred to the Sections for advice and many helpful suggestions were received. The Constitution and Laws Committee has drafted a constitutional amendment to activate the plan. You will get full details and a ballot shortly. I strongly urge the adoption of this amendment as a forward step in Institute management.

The technical committees of the Institute have not been very active during the war, largely due to factors beyond their control. As a result there is an enormous backlog of work to be done. This work can be accomplished only by our individual members. We confidently anticipate that the selection of a Technical Secretary will provide the necessary co-ordination that only full-time leadership can give. The standing of our Institute with industry and with other societies will depend largely on the accomplishments of these groups. We need to initiate a number of technical conferences for groups of special interest. The time for action in this field is here. Let's get going.

Engineering, like religion, is broken up into many groups. As a result, the voice of the engineer frequently cannot be heard in the councils of state and of industry because it is a babble instead of a voice. The ultimate solution for this must lie in an over-all engineering organization uniting all engineering societies on matters of common interest, but allowing them autonomy in their special fields. The immediate action to be taken is to initiate closer co-ordination with other societies in the solution of mutual problems. Several steps along this line were taken during the year. Among them were the following:

1. Co-operation through the Radio Technical Planning Board was continued with other societies. Haraden Pratt was elected Chairman and William H. Crew, Secretary of this Board.
2. A co-ordination committee has worked out mutual plans for co-operation with the Radio Manufacturers Association.
3. Joint committees on electronic standards have been set up with the American Institute of Electrical Engineers.
4. A joint plan of co-operation with the British Institution of Electrical Engineers has been developed.
5. A committee on a code of ethics has been co-ordinating with the Engineers Council on Professional Development.
6. A plan for the development of joint student branches with the AIEE has been initiated.
7. A conference of presidents of leading engineering societies was called at the invitation of your president to consider the problem of the resumption of the training of engineers in the universities. A program and resolution were prepared, subsequently adopted by the great majority of societies represented, and are now being presented to the Congress and the President.
8. All co-ordinated activities with groups such as the American Standards Association, the American Association for Advancement of Science, and others, have been continued.

Only the highlights of a busy year have been presented. When the servant of Andrew Jackson was asked after Jackson's death if he thought Old Hickory had gone to Heaven, he replied, "I don't know, suh, but if he wanted to get there, he'll get there."

The year 1945 was a year of preparation—1946 should be a year of accomplishment. If you set your goal high and want to get there, you'll get there, and soon. You have selected an energetic and able new leader. It gave me great pleasure to serve you. It gives me even greater pleasure to turn over the reins of office to Frederick B. Llewellyn.

Final Report of the National Patent Planning Commission*†

THE National Patent Planning Commission consisting of Charles F. Kettering, Chester C. Davis, Francis P. Gaines, Edward F. McGrady, Owen D. Young, Andrey A. Potter, and Conway P. Coe made a final report on their activities. The Commission left unfinished the study of various problems but presumably these will be considered by an equivalent commission appointed by President Truman on April 20.

In the final report the Commission emphatically reemphasized that the suggestions offered by the Commission in the first report did not include any changes which departed from the basic principles of the patent system. The Commission again pointed out that the principles of the patent system are sound and therefore the Commission has rejected any proposals for revision of the patent system involving a departure from the principles upon which it was founded and by the effectuation of which it has furthered the nation's industrial and social improvement.

The principal suggestions for improving the patent system without departing from its principles included:

(1) a single court of patent appeals;

(2) Congressional establishment of a reasonably understandable test of patentability;

(3) reference back to the Patent Office of technical questions raised in infringement suits for advisory opinion as to the validity of the patents involved;

(4) recording of all contracts relating to patents;

(5) a twenty-year term for patents beginning with the filing date;

(6) simplification of appellate procedure;

(7) challenge of validity of a patent within six months of the date on which it is granted;

(8) limiting the recovery of the patent owner to reasonable compensation without prohibiting the continued use of the patented invention in the fields of National Defense, public health, and public safety;

(9) creation of a public register for owners of patents willing to license others at a reasonable royalty;

(10) rejection of all proposals for general compulsory licensing of patents.

With respect to the last recommendation the final report again emphasizes that compulsory licensing would not only nullify the patent owner's proprietorship, but would also discourage inventiveness and lessen the initiative of investors by exposing them to greater uncertainty and larger risks in the investment of capital requisite to the development and commercialization of new mechanisms and compositions. The report also emphasizes that the property represented in the patent is unique and that the invention safeguarded thereby has been brought from the realm of ideality to the sphere of actuality and utility. Except for the inventor's success in converting mere potentiality to materiality, the world would have been deprived of a benefit whether great or small; whether a telephone, an airplane, a radio, or a useful but simple latchet for a shoe.

* Decimal classification: 347.7. Original manuscript received by the Institute, October 18, 1945.

† This summarized account was prepared for The Institute of Radio Engineers by Alois W. Graf, (Senior Member, I.R.E.) former Secretary of the Chicago Section.

Proposed Standards of the Radio Manufacturers Association*

Introduction

IN furtherance of the joint program of The Institute of Radio Engineers and the Radio Manufacturers Association for closer collaboration in standardization activities, and to keep I.R.E. members informed on such matters, the Institute will from time to time publish RMA Standards and Standards Proposals of general interest.

RMA Standards Proposals are submitted to members of the RMA after they have been approved by the Executive Committee of the originating section. Although they do not become RMA Standards until they have been approved by the RMA membership, and in some cases require modification before acceptance, it is considered that a useful purpose is served in publishing them in advance of formal adoption. A group of such RMA Standards Proposals follows:

No. 163—Very-High-Frequency Broadcast Receivers; Intermediate Frequency

The intermediate frequency for very-high-frequency broadcast receivers shall be 10.7 megacycles.

No. 164—Television Broadcast Receivers; Antenna-to-Set Transmission Line

The antenna-to-set transmission line for television broadcast receivers shall be an unshielded, parallel line of 300 ohms impedance.

* Decimal classification: R020. Original manuscript received by the Institute, January 11, 1946.

No. 165—Television Broadcast Receivers; Intermediate Frequency for Sound Channel

The sound-channel intermediate frequency of television broadcast receivers shall be located in the region 21.25 to 21.9 megacycles, and the oscillator frequency shall be higher than the signal frequency, thus placing the corresponding upper-frequency limits of the video channel between 26.5 and 27.15 megacycles.

No. 166—Export Receivers

166-1—Stating the Number of Tubes in Radio Receivers.

It shall be standard in stating the number of tubes in a radio receiver to state the total number of evacuated envelopes, exclusive of such of these as provide enclosure solely for illuminants.

166-2—Specifying the Frequency Coverage of Broadcast Receivers.

It shall be standard to state the assured upper- and lower-frequency limits of all continuous frequency bands in terms of:

(a) Kilocycles, where the lower limit of frequency is less than two megacycles.

(b) Megacycles, where the lower limit of frequency is between one megacycle and one kilomegacycle.

(c) Kilomegacycles, where the lower limit of frequency is between one kilomegacycle and one megamegacycle.

166-3—Specifying the Power-Supply Voltage and Power-Supply Frequency of Broadcast Receivers.

It shall be standard to specify the values or range(s) of voltage and the value or range of frequency of the power supply on which satisfactory operation of the receiver is assured. (For example: 90 to 130 volts; 180 to 260 volts; 50/60 cycles.)

No. 167—Chassis Pickup in Vehicular Receivers

It is proposed that vehicular receivers shall be considered as complying with the principles of good engineering practice if, when installed according to the manufacturers' instructions and using materials supplied by the manufacturer, there is no *perceptible chassis pickup* with any setting of the user controls.

"Chassis pickup" is defined as the interference arriving in the vehicular receiver other than through the antenna.

"Perceptible" is defined as the difference in the noise output of the receiver with the engine running and with it stopped.

Testing for chassis pickup shall be done by replacing the antenna of the installed receiver by an antenna equivalent, adequately shielded and grounded; the antenna trimmer of the receiver shall be tuned for resonance at the normal aligning frequencies; and observation made of any perceptible noise output.

No. 168—Type Designations for Electron Tubes

It is proposed to rescind the type-designation system for transmitting and special-purpose tube types here shown and identified by number SP 168-1, and simultaneously to standardize the proposed numerical system of type designation for other than receiving-tube types and cathode-ray-tube types here shown and identified by number SP 168-2.

SP 168-1—It is Proposed that the Following Scheme of Type Designation be Rescinded

For transmitting and special purpose tubes: the type designation shall comprise three distinctive symbols. These will be, in their regular order, a number symbol, a letter symbol, and a number symbol, the significances of which are given below:

1. *The first number symbol* will indicate the cathode power required for normal operation in accordance with Table I.

TABLE I

Designation	Range of Filament or Heater Power	Watts
1		0
2	In excess of zero watts and up to and including	10
3	In excess of 10 watts and up to and including	20
4	In excess of 20 watts and up to and including	50
5	In excess of 50 watts and up to and including	100
6	In excess of 100 watts and up to and including	200
7	In excess of 200 watts and up to and including	500
8	In excess of 500 watts and up to and including	1000
9	In excess of 1000 watts	

2. *The letter symbol* will indicate the structure in accordance with Table II.

TABLE II

A. Monodes—Such as ballast tubes and vacuum-sealed resistors.
B. Diodes—Including full-wave as well as half-wave rectifiers, protective tubes, spark gaps, voltage regulators, etc.
C. Triodes—Including thyratrons, cold-cathode three-electrode control tubes, etc.
D. Tetrodes—Including thyratrons, cold-cathode four-electrode control tubes, etc.
E. Pentodes
F. Hexodes
G. Heptodes
H. Octodes
L. Vacuum-sealed types of capacitors
N. Crystal detectors and crystal rectifiers
P. Photo-emissive, vacuum-sealed devices; phototubes, photomultipliers, pickup tubes, etc.
R. Mercury-pool types, inclusive
S. Vacuum-sealed contactor-type switches

3. *The second number symbol* will be a serial designation and in no case shall be less than 21.

Use of Suffix Letter for Type Designations

(Standards Proposal No. 144)

It shall be standard to use the same type designation for both the prototype and the improved version where complete interchangeability exists between the two types, and to assign different type designations in accordance with the appropriate standard to tube types that are not completely interchangeable, except that it shall be standard to permit the assignment of a suffix letter in alphabetical order, beginning with *A*, to the type designation of a prototype to identify the improved version where both

A. unilateral interchangeability exists between the improved version and the prototype; i.e., where the improved version may serve to replace the prototype in all known, important applications but not vice-versa, and,

B. the improved version is intended to displace completely the prototype.

Typical Type Designations

1C23	3C44
1N35	6D25
2C53	1P39

SP 168-2—It is Proposed that the Following Scheme of Type Designation be Adopted

I. It shall be standard to use the following system of type designations for tubes and devices exclusive of receiving and cathode-ray tubes.

II. The type designation shall consist of a pure numeric starting with 5500 and shall be assigned consecutively and chronologically in the order of type-number request.

(The request shall be accompanied with sufficient data to define the tube adequately.)

III. A new type designation shall be assigned to a new version of a prototype whenever the new version is not completely interchangeable with the prototype.

(Whenever a new designation is assigned to a type which is unilaterally interchangeable with a former type, such interchangeability may be indicated by marking the new type with its assigned designation followed, at the option of the manufacturer, by the designation of the former type.)

This system shall not be retroactive.

Typical Type Designations

5501	5923
5712	6234
6545	

No. 169—Proposed Dimensional Characteristics of Phonograph Records for Home Use.

	10 inch Records	*12 inch Records*
169.1—Diameter	$9\frac{7}{8}''$ $\pm\frac{1}{32}''$	$11\frac{7}{8}''$ $\pm\frac{1}{32}''$
169.2—Thickness Measured at 4 points, 1 inch from outer edge, 90 degrees apart	$0.080'' \pm 0.010''$	$0.090'' \pm 0.010''$
169.3—Diameter of outermost groove of recording pitch	$9\frac{1}{2}''$ $\pm 0.02''$	$11\frac{1}{2}''$ $\pm 0.02''$

169.4—Center-hole diameter $0.286'' {+0.001'' \atop -0.002''}$

169.5—Minimum inside diameter of recording $3\frac{3}{4}''$

169.6—Eccentric stopping groove
- (a) Diameter $3\frac{3}{8}''$
- (b) Run-out relative center hole $0.250'' \pm 0.015''$
- (c) Groove shape
  - (1) Minimum depth $0.003''$
  - (2) Contour approximately as music grooves.

169.7—Concentricity of music grooves
Indicated run-out relative center hole $0.020''$ (maximum)

169.8—Lead-in spiral
At least one complete turn between outer edge of record and recording pitch.

169.9—Lead-out spiral
Nominal pitch $\frac{1}{8}''$ (minimum)
Contour: approximately as music groove.
Depth: may vary to blend from music groove to eccentric stopping groove.

169.10—Shape of outer edge.
- (a) Semicircular, or
- (b) "V"

Where "V" edge is used, it is recommended that it have
- (1) Included angle of 80 degrees $\pm$ 10 degrees
- (2) Edge radius of $\frac{1}{64}$inch (approximate)
- (3) Apex of the "V" depart from the midplane between record faces by not more than 0.010 inch.

Contributors to Waves and Electrons Section

William L. Everitt

William L. Everitt (A'25–M'29–F'38) received the E.E. degree from Cornell University in 1922, the M.S. degree from the University of Michigan in 1926, and the Ph.D. degree from Ohio State University in 1933. He has taught electrical engineering at Cornell, Michigan, Ohio State, and the University of Illinois. Since 1942, Dr. Everitt has been Director of Operational Research Staff with the Signal Corps of the United States Army and is now head of the electrical engineering department of the University of Illinois. Dr. Everitt initiated and directed the annual Broadcast Engineering Conference at Ohio State. He is a Fellow of the American Institute of Electrical Engineers and a member of Tau Beta Pi, Sigma Xi, Eta Kappa Nu, the Acoustical Society of America, and the American Association for Advancement of Science.

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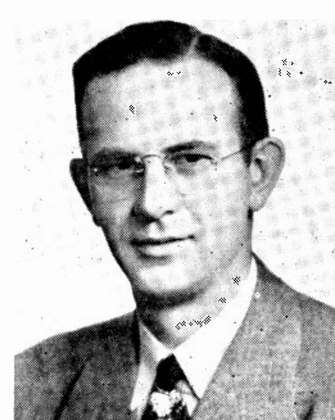


Alois W. Graf

J. O. Kinert

J. O. Kinert was born on July 25, 1907, at Colfax, Indiana. He graduated from the United States Naval Academy in 1930, commissioned as Ensign. From 1930 to 1936 he served on cruisers and destroyers on the West Coast, and from 1936 to 1938 he attended the postgraduate school of Applied Communications.

After serving in the Asiatic fleet from 1938 to 1941, and on the U.S.S. *Maryland* from 1941 to 1942, he joined the staff of Battle Division Four in 1942, serving in that division until 1943, when he was transferred to the staff of Carrier Division Twenty-two, and later to the Third Amphibious force during the Solomons and Philippine campaigns from 1943 to 1945. He is at present stationed in Washington, D. C., with the rank of Captain, as assistant chief of Naval Communications for Plans and Operations, with the United States Navy Department.

Paul D. Miles

Paul D. Miles was graduated from the United States Naval Academy in 1927. He resigned his commission in 1929, and became a member of the Naval Reserve. From 1929 to 1936, he was associated with the Mackay Radio and Telegraph Company, and was appointed superintendent of communications, western division, for the Hearst Radio, Inc., in 1936.

In 1939, Commander Miles accepted an appointment as civilian radio engineer in the radio liaison division, Office of Naval Operations, and was ordered to active duty in June, 1941. In 1942, he was transferred to the Office of Naval Communications to handle frequency procurement and assignment activities, and became chief of the frequency section.

Returning to inactive duty in November, 1945, he was chief of the frequency service-allocation division. He became a member of the Interdepartmental Radio Advisory Committee in 1942, serving as vice-chairman in 1943 and chairman in 1944. He is now the Federal Communications Commission member of that committee.

Commander Miles acted as an observer at the Third Commonwealth and Empire Conference on Radio for Civil Aviation, held in London in July, 1945; and served as a delegate to the Third Inter-American Radio Conference at Rio de Janeiro in September, 1945, and to the United States and British Commonwealth Communications Conference, held in Bermuda in November, 1945.

Alois W. Graf (A'26–M'44–SM'45) was born at Mankato, Minnesota, in 1901. He received the B.S. degree in electrical engineering from the University of Minnesota in 1926, and the LL.B. degree from National Law University in 1931.

In 1926, he entered the United States Patent Office as an examiner of radio, carrier current, and multiplex communication systems, and radio controlled devices. In 1930, he was engaged in patent work in radio and audio systems. From 1930 to 1938, he was a member of the Patent Department of General Electric Company where he handled transmitting, receiving, aeronautic and marine radio applications, and power applications of vacuum tubes.

During 1939 and 1940 he was the patent lawyer for Productive Inventions, Incorporated, and The Anderson Company, both of Gary, Indiana. In 1940, he opened his own patent law practice, and since 1943 he has been associated with Moore, Olson & Trexler, Patent Lawyers, of Chicago, Illinois, specializing in radio, electronic, and electrical patent matters.

He became a member of the bars of District of Columbia in 1931, Indiana in 1940, and Illinois in 1942. He is also a member of the American Bar Association, Chicago Patent Law Association, Chicago Law Institute, Illinois Society of Engineers, National Society of Professional Engineers, and American Arbitration Association.

Mr. Graf's Institute activities include Chicago Section Membership Committee, chairman 1943–1944; Membership Committee, 1944, 1945; Education Committee 1945; Board of Editors 1945; secretary, Chicago Section, 1944–1945; and vice-chairman 1945–1946.

Paul A. Porter

Paul A. Porter was born at Joplin, Missouri, on October 6, 1904. He was graduated from the University of Kentucky Law School in 1928, and practiced law until 1929 in Kentucky. From 1929 through 1932, he was editor of the Mangum, Oklahoma, *Daily News*, and the LaGrange, Georgia, *News*.

In 1933 Mr. Porter became executive assistant to the Administrator of the Agricultural Adjustment Administration, and from 1937 to 1942, he was Washington counsel for the Columbia Broadcasting System. He was appointed deputy administrator of the Office of Price Administration in charge of organizing the rent-control program in 1942, becoming associate administrator of the War Food Administration in 1943, and in the same year was appointed assistant to the director of the Office of Economic Stabilization.

Mr. Porter served as director of publicity for the Democratic National Committee in 1944, and was appointed chairman of the Federal Communications Commission in December, 1944. Early in 1946 he became chairman of the Office of Price Administration.

Institute News and Radio Notes

Board of Directors

February 6 Meeting: At the regular meeting of the Board of Directors, which was held on February 6, 1946, the following were present: F. B. Llewellyn, president; G. W. Bailey, executive secretary; S. L. Bailey, W. H. Crew, assistant secretary; Alfred N. Goldsmith, editor; V. M. Graham, R. F. Guy, Keith Henney, L. C. F. Horle, F. R. Lack, G. T. Royden, D. B. Sinclair, H. M. Turner, W. L. Webb, and W. C. White. Guests: P. Dunsheath, president, British Institute of Electrical Engineers; W. K. Brasher, secretary, British Institute of Electrical Engineers; and F. S. Barton, British Air Commission.

President Llewellyn officially welcomed President Dunsheath and Secretary Brasher of the Institution of Electrical Engineers of London, England, and Dr. F. S. Barton of the British Air Commission. He stated that arrangements had been made by the Secretaries of the two societies to learn the names of members of the I.E.E. who plan to visit New York, so that The Institute of Radio Engineers could make arrangements for them to visit Section and technical meetings wherever possible and that the same procedure was being followed with reference to I.R.E. members going to England.

At the request of President Llewellyn, Executive Secretary Bailey outlined the arrangements which had been made with the I.E.E. for each society to handle membership dues and magazine subscriptions for the other society, payment to be made in currency of the country where the subscription was placed and a credit balance to be paid by one society to the other at intervals.

President Llewellyn then called upon Secretary Brasher who stated that he would be happy to put any American member of I.R.E. in contact with the I.E.E. Section representative in London and that he would be pleased to refer such a member to any Section representative of the I.E.E. in other parts of Great Britain where meetings might be held or even for business introductions.

President Llewellyn introduced President Dunsheath who thanked the Directors for welcoming him and Secretary Brasher and Dr. Barton so cordially and for giving them the opportunity to meet the Board of Directors. He stated that correspondence had already taken place between Mr. Bailey and Mr. Brasher with reference to a representative of the I.R.E. participating in their meeting in London in March. He emphasized the wish of the British Council that the British meeting should have a representative of the Institute to enter into the discussions at the London meeting and he stressed the welcome that the representative of the Institute would receive if the I.R.E. would accept the invitation to send a representative to the London meeting.

Secretary Brasher then stated that he hoped the I.R.E. would be able to name at once a representative to come to England as Secretary Brasher would like to secure an adequate place on the program for him. This representative would take part in the opening meeting, which will be under the chairmanship of President Dunsheath, and attended by leading people from all the Services of His Majesty. The First Sea Lord of the British Navy will attend the opening meeting and the equivalent in rank from the Army and the Scientific Government Branches also will attend. The work of the engineer in the development of science and the efforts and co-operation of American scientists in the successful prosecution of the war will be stressed. British engineers and scientists made many scientific and technical developments and many have been developed here in America and it is fitting that the representative of the Institute describe them in Britain. Secretary Brasher also stated that if it was desired he would arrange again to set up the transatlantic telephone link and hold a meeting at a time when it would be convenient and possible for the I.R.E. to have a meeting in New York simultaneously and discuss one of the papers.

Secretary Brasher assured the I.R.E. that the Finance Committee of the I.E.E. would gladly accept the privilege of offering hospitality to any guest from the I.R.E. at the London meeting. He also called attention to the fact that the work of the Liaison Committees of the two societies would be improved if there could be a representative of the I.R.E. who lived in London. When matters are under discussion on either side of the Atlantic it would be helpful to have an I.R.E. representative in England to discuss them, with full power to act under the authority of the Executive Committee and the Council. They would like to have a representative who would be familiar with the reasons for making certain suggestions and with a knowledge of exactly what was under discussion and in reporting back to America.

President Llewellyn then requested President Dunsheath upon his return to extend the greetings of our Board of Directors to the Institution of Electrical Engineers and express our appreciation of their co-operation. In reply President Dunsheath stated he would be delighted to take such a message back to the Council and said that he was sure they would be glad to know the extent to which I.R.E. encourage co-operation between the Institutes.

I.R.E. Representative: President Llewellyn was selected to represent the Institute at the Meeting of the British Institution of Electrical Engineers to be held March 26, 27, and 28, 1946, in London, England.

Approval of Executive Committee Actions: The actions of the Executive Committee taken at its January 9, 1946 meeting were unanimously approved.

Heising Resolution: The Board of Directors expressed their appreciation of the work of Raymond A. Heising in the following resolution:

> "On the occasion of the relinquishment by Raymond A. Heising of the Office of Treasurer of the Institute, the Board of Directors expresses to him
>
> —its deep gratitude and that of the membership of the Institute for his devoted and capable services during his long term of office;
>
> —its appreciation of his combination of keen analysis, thorough and consistent accomplishment, and unfailing good nature in his official activities and in his contacts with his associates; and
>
> —its warm wishes for his continued success and health, as well as his future close association in the activities of the Institute."

Constitution and Laws

Regional-Representation Plan: The Board adopted the proposed Constitutional changes, a necessary part of the Regional-Representation Plan, and the proposed Constitutional Amendments will be submitted to the membership for voting.

Article VI, Section 4, Paragraph 1: The Board adopted the proposed modification of Article VI, Section 4, Paragraph 1 which will be submitted to the membership for voting as follows:

> "Section 4—The Secretary shall be responsible for the preparation for all meetings of the Board of Directors and all principal meetings of the Institute and the recording of the Minutes of such meetings. He shall be responsible for the correspondence of the Institute and the keeping of full records thereof and shall be responsible for the provision of such information from them as is requested by the Board of Directors."

Article VI, Section 5: Article VI, Section 5, was modified for submission to the membership for voting as follows:

> "Section 5—The Treasurer, under the control of the Board of Directors, shall have general supervision of the fiscal affairs of the Institute and shall be responsible for the keeping of the books of account."

Readmission of Former Members: The board adopted the following resolution:

> "Resolved, that the Board of Directors readmit to the grade of membership previously held (or the Associate grade if formerly a Junior) those former members (a) whose memberships terminated before or during 1945 and who pay either current dues or all dues in arrears, or (b) whose memberships terminate on April 30, 1946, and who pay dues for 1946 at a later date during 1946. The payment of a new entrance fee, if such would normally be required, is waived. Associates, who formerly had the privilege of voting, will be readmitted as nonvoting Associates."

Committees

Education: The Education Committee was authorized to proceed with the preparation of a plan for joint Student participation in I.R.E.-A.I.E.E. Student Branches.

Liaison: The Board adopted the recommendation of the Executive Committee that E. M. Deloraine be appointed a member of the Liaison Committee; that an American member of the Institute now residing in England be added as a member to the Committee; and that the name of the Committee be changed to "International Liaison Committee."

Proceedings

Board of Editors: The Board of Editors has held two meetings since the close of the war. Editor Goldsmith solicited comments and criticisms from the Board members relative to the journals of the Institute with the assurance that any comments will receive close attention.

An Editorial Executive Committee of five men has been appointed and its functions shall include advising the Editor and the Editorial Department and, when required, interpreting policy and procedures to the Editorial Department. The members of the Editorial Executive Committee will be alphabetically listed and, in the event of the unavailability of the Editor, and when the Editorial Department requires guidance, it will consecutively call the members of the Editorial Executive Committee to obtain guidance. The Editorial Executive Committee will meet more frequently than the Board of Editors and will submit recommendations and reports to the Board of Editors from time to time. A number of new members have been added to the Board of Editors for the purpose of reducing the amount of work to be done by each. The Papers Review Committee and the Papers Procurement Committee have become subcommittees of the Board of Editors.

Postwar Publication Fund: The Board adopted the recommendation of the Executive Committee that $10,000 of the Postwar Publication Fund be released for use during the year of 1946, in accordance with the plan by which the Fund was set up.

Houston and Milwaukee Sections: The Board adopted the recommendation of the Executive Committee that the petitions for the establishment of a Houston Section and a Milwaukee Section be approved.

Veteran Wireless Operators Association: It was unanimously approved that the Board express appreciation to the Veteran Wireless Operators Association for the plaque to be presented to the I.R.E. in recognition of the services of engineers in the war.

Executive Committee

February 5 Meeting: The Executive Committee meeting, held on February 5, 1946, was attended by F. B. Llewellyn, president; G. W. Bailey, executive secretary; S. L. Bailey, W. H. Crew, assistant secretary; Alfred N. Goldsmith, editor; R. F. Guy, Keith Henney, and W. C. White.

A.A.A.S. Bulletin: Dr. Goldsmith called the attention of the Committee to an article, written by Dr. W. H. Crew, regarding the Institute, which had appeared in the January issue of the *A.A.A.S. Bulletin*, and complimented Dr. Crew on the manner in which he had covered concisely the history, purpose, membership details, and aims of the Institute. Mr. Henney moved that appreciation be expressed to Dr. Crew on the preparation of this article.

Electron-Tube Committee: A preliminary report of the Electron-Tube Committee, received from Chairman Guy of the Standards Committee, will be published in Waves and Electrons Section of the PROCEEDINGS OF THE I.R.E. AND WAVES AND ELECTRONS.

Membership: Approval was given to the 358 applications for membership in The Institute listed on page 40 A of the March, 1946, issue of the PROCEEDINGS OF THE I.R.E. AND WAVES AND ELECTRONS. These applications are as follows:

For Transfer to Senior Member Grade	15
For Admission to Senior Member Grade	9
For Transfer to Member Grade	24
For Admission to Member Grade	47
For Admission to Associate Grade	189
For Admission to Student Grade	74
	358

1947 Winter Technical Meeting: President Llewellyn reported that he had authorized the 1946 Winter Technical Meeting Committee to make tentative arrangements at three different locations in New York, and for two separate weeks for the 1947 meeting.

1946 Electronics Conference: Mr. S. L. Bailey reported that it was the sense of the Electronics Committee meeting held during the Winter Technical Meeting that the Electronics Conference should be held in 1946.

Thompson Memorial: It was unanimously approved that the first Browder J. Thompson Memorial Award be made at the proposed Electronic Conference to be held this summer, subject to approval by Dr. R. R. Law.

During the 1946 Winter Technical Meeting of the Institute of Radio Engineers, the President of the National Academy of Sciences addressed the annual I.R.E. Banquet, held on Thursday night, January 24, 1946. His subject, Industrial Research, is outlined briefly below.—*The Editor*

Industrial Research—Past and Prospective Future

F. B. JEWETT

A brief recital was presented of the status of scientific and technical development activities at the end of the nineteenth century, and of the factors which initiated the beginnings of industrial research in the form with which we are now familiar.

There were then discussed some of the early problems encountered in selling the basic idea, the difficulties encountered in fitting it effectively into the existing industrial structures, problems encountered in finding qualified men, and steps taken in influencing the form of education and in interesting young men to take advanced training in basic science with a view to entering industry.

The early problems of effective organization and those of indoctrinating men with the idea of teamwork were then treated. This was followed by a summary of the influence of industrial research on the organization and operation of other parts of industry.

Tribute was paid to the rapid growth of industrial-research organizations in a wide and expanding sector of industry following World War I and to the powerful position in which the Nation was placed thereby to cope with the problems of World War II.

Looking to the future, there were discussed some prospects for enlargement and change in industrial research resulting from the war experience, the further development of electronics, chemistry, metallurgy, and applied biology.

Some observations were presented on the reaction of these factors on scientific and technical education and on the whole matter of proper Governmental support and control of scientific development.

Fellow Awards

At the I.R.E. Banquet, held Thursday night, January 24, the annual Fellow Awards were presented. Dr. Julius A. Stratton of the Research Laboratory of Electronics, Massachusetts Institute of Technology, accepted the Awards in behalf of the recipients. His speech of acceptance is as follows:

"Mr. President, Members of the Institute of Radio Engineers, and our guests:

"I am extremely proud to respond in behalf of the new Fellows and to express our appreciation of the honor that has been conferred through this award by The Institute of Radio Engineers. In return, I am sure that for their part it will be the constant endeavor of the Fellows to continue to merit such an honor through unremitting service to the field of radio engineering."

Journal I.E.E.

The ordinary subscription rate of Part III of the Journal of The Institution of Electrical Engineers will be increased from £1 1s. 0d. to £1 11s. 6d., less 50 per cent, which amounts to a change from 10s. 6d. to 15s. 9d. To subscribers taking all three Parts, the rate of £1, 11s. 6d. will remain unchanged.

I.R.E.—U.R.S.I. Meeting

The annual joint meeting of the American Section, International Scientific Radio Union, and the Washington Section, Institute of Radio Engineers, which before the war was held in Washington each spring, is being renewed this year. The meeting will be held in Washington in the Auditorium of the New Interior Department Building, C Street between 18 and 19 Streets, beginning on Thursday, May 2, and will be either a two- or three-day meeting. The program will, as usual, be devoted to the more fundamental and scientific aspects of radio and electronics. It is expected that much material hitherto classified will be released for presentation, and therefore this meeting should be of particular interest. The program of titles and abstracts will be available in booklet form for distribution before the meeting. Correspondence should be addressed to the Institute office, or to Dr. J. H. Dellinger, National Bureau of Standards, Washington 25, D. C.

I.R.E. Electron-Tube Conference

An Electron-Tube Conference is being planned for June, 1946, by the Electron-Tube-Conference Committee which functions as a subcommittee of the Technical Committee on Electron Tubes. These meetings are limited in scope to the more-fundamental problems connected with the physics of electron tubes and provide a forum for the exchange of ideas between electron-tube specialists with the minimum amount of formality. The subject matter of this conference (the fourth of the series which was interrupted by the war) will be limited to problems of electron dynamics with particular emphasis on these problems as they are encountered in microwave tubes. The Committee is currently distributing a questionnaire regarding the conference to individuals known to be interested in this field soliciting material for presentation and discussion.

Because of the specialized nature of the conference and the size of available facilities, the attendance necessarily must be limited to those actively engaged in work in the field covered by the conference. The Committee, is, of course, extremely anxious that no one be excluded who has a good reason for wishing to attend. Electron-tube specialists who feel that they can contribute to the success of the conference and who failed to receive the Committee's questionnaire are urged to write the chairman at their earliest convenience. Please give your company or institution affiliation, your field of specialization, and a list of subjects on which you can present material or on which you can contribute to the discussion. Further information as to the exact time and place of the conference and the subjects finally chosen for discussion, together with a registration form will be mailed directly to those individuals who have indicated their desire to attend.

Meetings of Standing Committees I.R.E.

Education

Date.............November 1, 1945
Place............McGraw-Hill Building, New York City
Chairman.........A. B. Bronwell
Acting Secretary...W. H. Crew

Present

A. B. Bronwell, *Chairman*

H. A. Chinn	W. J. Seeley
Alan Hazeltine	R. F. Stansel
G. B. Hoadley	J. A. Stratton
F. H. Kirkpatrick	G. R. Town
H. J. Reich	E. Weber

I. Wolff

Guests

W. H. Crew, *Acting Secretary*

G. W. Bailey	Alfred N. Goldsmith

F. B. Llewellyn

The purpose of this meeting was to discuss plans for the establishment of a Speaker's Bureau, Traveling-Lecture Series, the procurement of symposium papers, and Joint A.I.E.E.-I.R.E. Student activities. There were also considered the shortage of highly qualified young electrical engineers, and the urgency of encouraging veterans to continue their professional education.

Meetings of Technical Committees I.R.E.

Antennas

Date........October 19, 1945
Place........Editorial Department, I.R.E., New York City
Chairman....P. S. Carter

Present

P. S. Carter, *Chairman*

W. S. Duttera	D. C. Ports
D. W. Epstein	S. A. Schelkunoff
Sidney Frankel	J. C. Schelleng
R. F. Guy	George Sinclair
E. C. Jordan	P. H. Smith

L. C. Van Atta

The purpose of this meeting was to organize the work of the committee, form subcommittees, and make assignments to them. The following subcommittees were formed to prepare reports on the divisions of the work indicated:

- Antenna Theory (S. A. Schelkunoff)
- Testing Methods (George Sinclair)
- Microwave Antennas (L. C. Van Atta)
- Broadcasting and Other Types of Communications (W. S. Duttera)
- Air Navigation Systems (Harry Diamond)
- Television Antennas (G. H. Brown)
- Testing Television Transmission Lines and Antennas (D. B. Sinclair)
- Annual Review (J. C. Schelleng)

Antennas

Date............January 23, 1946
Place............Hotel Astor, New York City
Acting Chairman...W. S. Duttera

Present

W. S. Duttera, *Acting Chairman*

Cledo Brunetti	S. A. Schelkunoff
D. W. Epstein	J. C. Schelleng
Sidney Frankel	D. B. Sinclair
E. C. Jordan	George Sinclair
D. C. Ports	Carl E. Smith (*guest*)

P. H. Smith

The subcommittees reported on the work being done in the following fields: Testing Methods; Broadcasting and Other Types of Communication; and Testing Television Transmission Lines and Antennas.

Electron Tubes

Date........October 24, 1945
Place........Editorial Department, I.R.E., New York City
Chairman....R. S. Burnap
Secretary....R. L. Freeman

Present

R. S. Burnap, *Chairman*
R. L. Freeman, *Secretary*

W. G. Dow	J. A. Morton
T. T. Goldsmith, Jr.	L. S. Nergaard
R. F. Guy (*guest*)	G. D. O'Neill
L. B. Headrick	H. J. Reich
D. E. Marshall	A. L. Samuel
I. E. Mouromtseff	J. R. Steen

C. M. Wheeler

The Committee expressed dissatisfaction with the name "Technical Committee on Vacuum Tubes" and recommended the name "Technical Committee on Electron Tubes."

The subcommittee on Advanced Developments recommended that the prepared "Proposed Standards on Ultra-High-Frequency Electronics" be published at an early date.

Definitions and methods of testing submitted by the Cathode-Ray-Tube subcommittee and the Small-High-Vacuum-Tube subcommittee were considered.

Facsimile

Date........November 20 and December 4, 1945
Place........Editorial Department I.R.E., New York City
Chairman....C. J. Young

The committee reported that good progress has been made in bringing up to date Definitions of Terms. Two subcommittees were set up: Terminal Equipment, E. F. Watson, *chairman;* and Transmission, H. G. Ressler, *chairman.*

Frequency Modulation

Date.........January 23, 1946
Place.........Hotel Astor, New York City
Chairman.....C. C. Chambers

Present

C. C. Chambers, *Chairman*

R. A. Biggar	D. L. Jaffe
M. G. Crosby	F. J. Kelley (observer)
W. F. Goetter	V. D. Landon
A. C. Goodnow	C. T. McCoy (representing D. B. Smith)

The definitions in the report were discussed, and recommendations were made to change some of the terminology.

The personnel of the subcommittees is as follows:

Receivers

J. E. Brown V. D. Landon
C. T. McCoy (representing D. B. Smith)

Transmitters

W. F. Goetter M. H. Jennings
A. C. Goodnow J. E. Young

Pulse Modulation

M. G. Crosby, *Chairman*
E. M. Deloraine (or alternate) C. T. McCoy
R. D. Kell Bertram Trevor

RADIO RECEIVERS

Date............October 16, 1945
Place............Editorial Department
I.R.E., New York City
Chairman.........D. E. Foster
Secretary, *pro tem*..H. P. Westman

Present

D. E. Foster, *Chairman*
H. P. Westman, Secretary, *pro tem*
G. L. Beers Garrard Mountjoy
C. J. Franks H. O. Peterson
R. M. Wilmotte

The committee discussed the report on "Methods of Testing Frequency-Modulation Broadcast Receivers." As it was required to prepare an annual review on radio receivers, various members of the committee were assigned to search specific publications for some of the material needed.

RADIO RECEIVERS

Date.........January 23, 1946
Place.........Hotel Astor, New York City
Chairman.....D. E. Foster

Present

D. E. Foster, *Chairman*
G. L. Beers J. K. Johnson
L. F. Curtis Garrard Mountjoy
C. J. Franks E. D. Passow (representing J. E. Brown)

The committee discussed the draft proposal on "Methods of Measurement of Frequency-Modulation Receivers" which had been received from committee members and from the Radio Manufacturers Association.

The chairman reported on a meeting he had had with the chairman of the Radio Manufacturers Committee on Very-High-Frequency Receivers relative to the RMA data sheet for reporting measurements on such receivers. At that meeting, the RMA decided on a data sheet and to use the I.R.E. test methods as drawn up by the Committee on Radio Receivers.

NAB COMMITTEES

The following membership list, made available through the courtesy of Mr. Howard Frazier, on behalf of the National Association of Broadcasters Engineering Committee, will be of interest to our readers.

EXECUTIVE ENGINEERING COMMITTEE

(The personnel of the N.A.B. District Engineering Committee is identical to that of the N.A.B. Executive Engineering Committee)

G. PORTER HOUSTON, *Chairman*
Radio Station WCBM
3000 Manhattan Avenue
Baltimore, Maryland

J. B. Fuqua
Radio Station WGAC
Augusta, Georgia

William B. Lodge
Engineering Department
Columbia Broadcasting System
485 Madison Avenue
New York, New York

Karl B. Hoffman
Radio Station WGR
Buffalo, New York

O. B. Hanson
National Broadcasting Company
30 Rockefeller Plaza
New York, New York

Howard S. Frazier, *ex-officio*
National Association of Broadcasters
1730 Eye St., N.W.
Washington 6, D. C.

District 1—Richard Blackburn
Radio Station WTHT
983 Main Street
Hartford 1, Connecticut

District 2—Frank V. Bremer
Technical Director
Radio Station WAAT
11 Hill Street
Newark 1, New Jersey

District 3—Louis E. Littlejohn
Chief Engineer
Radio Station WFIL
Philadelphia, Pa.

District 4—

District 5—W. Walter Tison
Radio Station WBRC
Birmingham, Alabama
Mailing Address:
901 S. Newport
Tampa, Florida

District 6—J. D. Bloom, Jr.
Chief Engineer
Radio Station WWL
New Orleans, Louisiana

District 7—Lester H. Nafzger
Chief Engineer
Radio Station WBNS
33 North High Street
Columbus, Ohio

District 8—

District 9—Oscar C. Hirsch, Owner
Radio Station WKRO
Cairo, Illinois
Mailing Address:
Radio Station KFVS
Cape Girardeau, Missouri

District 10—Mark Bullock
Chief Engineer
Radio Station KFAB
Sharp Building
Lincoln, Nebraska

District 11—

District 12—K. W. Pyle
Radio Station KFBI
Wichita, Kansas

District 13—Frank Jones
Chief Engineer
Radio Station KGKL
San Angelo, Texas

District 14—Robert Owen
Radio Station KOA
Denver, Colorado

District 15—George Greaves
Chief Engineer
Radio Station KPO
San Francisco, Calif.

District 16—Ralph G. Denechaud
Radio Station KECA
1440 N. Highland Avenue
Los Angeles 28, California

District 17—Louis S. Bookwalter
Radio Station KOIN
Portland, Oregon

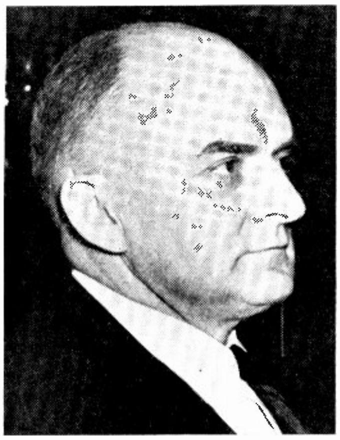
FRANK M. DAVIS

FRANK M. DAVIS

Frank M. Davis (M'44), general manager of the Collins Radio Company's research and engineering division, Cedar Rapids, Iowa, died on February 4, 1946. Mr. Davis, an early amateur radio operator, was born in Monett, Missouri, on February 13, 1912. He received the B.S. degree in electrical engineering from the University of Arkansas in 1934 and later joined the Collins staff, subsequently becoming a member of its Board of Directors. He became widely known for his research and development work in the radio communications field and was recognized by members of the War and Navy departments for his leadership in important war projects.

Mr. Davis was a member of the American Institute of Electrical Engineers and the Acoustical Society of America. A charter member of the Cedar Rapids Section of the I.R.E., he became chairman during the first year of its formation.

I.R.E. People



James G. Black

Philips' Appointments

O. S. Duffendack (SM'44), president of Philips Laboratories, Inc., Irvington, New York, has announced the appointment of James G. Black (A'45) as chief of the miscellaneous projects and analytical laboratories division, and George A. Esperson (A'34) as associate physicist of the microwave section.

Dr. Black, who received his Ph.D. degree from the University of Michigan in 1929, recently completed work on an important secret project for the National Defense Research Committee. Mr. Espersen has been transferred from Philips' plant at Dobbs Ferry, New York, where he was tube division engineer.

John Altmayer

John Altmayer (A'45), for many years associated with the production of radio and electronic precision parts, has become president of the newly formed Asco Corporation of Cleveland, Ohio. The company has been established for the manufacture of radio, television, electronic, mechanical, and electrical components.

George A. Espersen

RMA Engineering Department Committees

The Radio Manufacturers Association Engineering Department is engaged in numerous projects of importance, and of interest to the membership of the I.R.E. There are accordingly presented below lists of the various engineering groups within the RMA Engineering Department and their respective chairmen.

Transmitter Section

Committee	Chairman
Executive	J. J. Farrell
Amplitude-Modulation Broadcast Transmitters	M. R. Briggs
International Broadcasting	H. Romander
Satellite Transmitters	H. S. Frazier
Frequency Modulation Broadcast Transmitters	R. H. Williamson
Antennas	T. M. Bloomer
Studio-to-Transmitter Links	J. F. Wilcox
Television Transmitters	C. A. Gunther
Program Transmitters	J. E. Keister
Antennas	H. E. Gihring
Relays	C. A. Gunther
Studio Facilities	J. C. Ferguson
Co-ordination Panel	H. B. Fancher
Audio Facilities	R. A. Miller
Communication and Marine Aids	E. Ports
Point to Point	H. R. Dyson
Marine Communication	L. H. Lynn
Fixed Stations	F. A. Polkinghorn
Mobile Stations	F. A. Polkinghorn
Navigational Aids	G. H. Phelps
Direction Finding	P. A. D'Orio
Obstacle Detection	J. Rankin
Loran	R. C. Ferrar
Aeronautical Radio	H. B. Fischer
Instrument Landing	H. Busignies
Navigation	R. R. Welsh
Private Flying	S. Nesbitt
Communication	H. B. Fischer
Emergency Services	D. E. Noble
Transmitters	F. D. Budelman
Receivers	G. M. Brown
Point-to-Point Relay	H. R. Dyson
Facsimile and Radio Type	*
Selective Calling	W. E. Reichbe
Noise (Ignition)	*
Bandwidth	*
New Applications	*
Systems Standards of Good Engineering Practice	W. R. Young
Transmitter Components	D. G. Little
Crystals	C. F. Baldwin
Dynamotors	*
Vibrators	*
Transformers	Reuben Lee
Batteries	*
Resistors	H. A. Cooke
Capacitors	R. W. Orr
Tube Sockets	H. R. Terhune
Connectors	S. J. Holland
Instruments	O. S. Meixell
Solid Dielectric Radio-Frequency Cables	A. J. Warner
Facsimile	J. N. Whittaker

* Chairman not yet appointed.

Sound Equipment Section

Committee	Chairman
Executive	H. S. Knowles
Sound Systems	O. L. Angevine, Jr.
Distribution	S. B. Hughes
Mixers and Terminal Impedances	J. R. McCraigh
Panels, Racks, and Associated Equipment	R. F. Shea
Amplifiers	A. N. Curtiss
Speakers	W. A. Ellmore
Microphones	F. F. Romanow

Special Electronic-Equipment Section

Committee	Chairman
Executive	P. K. McElroy
Frequency-Modulation Receiver Testing	J. Minter
Frequency-Modulation and Television Test Equipment	D. B. Sinclair

Receiver Section

Committee	Chairman
Executive	D. D. Israel
Executive, Components Group	H. C. Forbes
Fixed Capacitors	J. I. Cornell
Electrolytic Capacitors	J. Hood
Mica Capacitors	A. DiGiacomo
Paper Capacitors	L. Kahn
Variable Air Capacitors	H. D. Sarkis
Sockets	S. DelCamp
Dry Batteries	H. J. Mason
High-Frequency Cores	H. A. Williams
Characteristics	H. Benner
Ceramic Dielectric Capacitors	J. D. Heibel
Acoustic Devices	W. A. Ellmore
Vibrating Interrupters and Rectifiers	K. M. Scafer
Switches	C. Rainwater
Variable Control Resistors	H. W. Rubinstein
Fixed Composition Resistors	D. S. W. Kelly
Wire-Wound Resistors	J. Marsden
Power Transformers	A. Helgason
Standardization of Laminations and MountingDimensions	R. J. Horstmann
Audio Transformer Standards	A. E. Chettle
Vibrator Transformer Standards	P. J. Koppe
Plug-in Resistors	G. Mucher
Radio-Frequency and Intermediate-Frequency Transformers	F. G. Webber
Broadcast and International Short-Wave Receivers	P. Craig
Executive, Television Receivers	I. J. Kaar
Television Receivers	I. J. Kaar
Standards of Good Engineering Practice	D. W. Pugsley
Optics	I. G. Maloff
Antennas and Transmission Lines	H. Selvidge
Special Components	S. C. Spielman
Vehicular Receivers	*
Very-High-Frequency Receivers	G. E. Gustafson
Executive, Phonograph Combinations and Home Recording	F. C. Young
Phonograph Combinations and Home Recording	F. C. Young
Phonograph Records	H. I. Reiskind
Record Changers, Etc.	H. Davis
Disk Home Recorders	L. V. Wells
Magnetic Recorders	W. A. Ellmore
Minimum Standards for Export Receivers	L. M. Clement
Vehicle Radio Interference	K. A. Chittick
Receiver Susceptibility	M. Levy
Measurements and Instrumentation	J. Minter
Vehicle Radio Interference (Society of Automotive Engineers)	P. J. Kent
Safety	W. Vassar
Transformer Isolated Receivers	A. C. Miller
Direct Connected Receivers	K. E. Hassell
Phono Combinations and Recorders	H. E. Kranz
Television Receivers	A. Wright

* Chairman not yet appointed.

Joint Electron-Tube Engineering Council

Committee	Chairman
Council	O. W. Pike
Staff	K. C. DeWalt (C. of S.)
High-Vacuum Power Tubes	K. C. DeWalt
Glass Standardization	H. S. Lovatt
Mechanical Inspection	H. L. Thorson
Magnetrons	J. H. Findlay
Gas Tubes	V. L. Ronci
Vacuum-Sealed Devices	H. W. Parker
Crystal Rectifiers	H. Heins
Phototubes	A. M. Glover
Receiving Tubes	A. K. Wright
Cathode-Ray Tubes	I. E. Lempert
Characteristics	A. J. Harcher
Line Width and Modulation Characteristics	L. B. Headrick
Glass Characteristics	J. R. Beers
Phosphor-Screen Characteristics	L. B. Headrick
Type Designations	R. S. Burnap
Mechanical Standardization	E. F. Peterson
Shock and Vibration	V. L. Ronci
Water-Cooled Types, Anodes and Gaskets	M. Youdin
Pool Types	D. E. Marshall
Electron-Tube Packaging	R. S. Bolan
Marking	Harvey Fay
Sampling Procedure	S. W. Horrocks

I.R.E. People

Edward L. Bowles

Edward L. Bowles

Edward L. Bowles (A'22–M'28–SM'43) was awarded the Distinguished Service Medal on November 14, 1945, for exceptionally meritorious service to the United States Government.

Dr. Bowles received the B.S. degree from Washington University in 1920 and the M.S. degree in electrical engineering from the Massachusetts Institute of Technology in 1922. The degree of Doctor of Science was awarded him by Norwich University in 1945. He was professor and head of electrical communications at M.I.T. and secretary of the microwave committee of the National Defense Research Committee.

In 1942, Dr. Bowles was appointed expert consultant to the Secretary of War to advise on radar policy. He was responsible for establishing experimental and operational Army Air Force units to combat the submarine menace off the Atlantic seaboard, and for the plans carried to President Roosevelt. As a result of the comprehensive antisubmarine proposal, General Arnold requested that Dr. Bowles assume over-all supervisory responsibility for A.A.F.'s communications comprising all forms of radar, countermeasures, radar aids to fire control

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David B. Smith

I.R.E. People

Maxwell H. A. Lindsay

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and bombing, radio and radar aids to navigation, and electronics. In 1944, he became special consultant to the Commanding General, A.A.F. General Marshall then called upon Dr. Bowles for assistance in the British "buzz-bomb" assaults. He formulated a plan leading to the dispatch of special antiaircraft equipment which functioned under conditions of complete invisibility when fighter planes were helpless against the missiles.

Included in Dr. Bowles' activities were the planning for the radar bombing by the 8th, 15th, and 20th Air Forces, and the 315th Air Wing was the result of plans originated by him for General Arnold. During the war, Dr. Bowles had representatives on General Eisenhower's and General MacArthur's staffs and on those of the major Air Force commanders in the European, Pacific, and China-Burma theaters to assist in the introduction and development of radar. In January, 1945, upon nomination of the Secretary of War, Dr. Bowles was appointed an Army member of the National Academy of Sciences and National Research Council Board for National Security.

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David B. Smith

David B. Smith (A'35–SM'44) has recently been appointed vice-president in charge of engineering of Philco Corporation.

In 1933, Mr. Smith was graduated from the Massachusetts Institute of Technology with the degrees of S.B. and S.M. in electrical engineering. The following year, he joined Philco as patent engineer after which he was placed in charge of an advanced-studies group in the research and engineering department. Appointed technical consultant to the vice-president in charge of engineering in 1938, he became director of research in 1941. In this capacity, he directed the microwave and ultra-high-frequency research that led to the production of many types of airborne radar used by the United States Army and Navy.

Visiting Engineers

It has been suggested that visitors from engineering societies abroad get in touch with The Institute of Radio Engineers, the Societe Francaise, the Institution of Electrical Engineers, and other similar engineering organizations with the thought that these visitors be invited to present papers before meetings of these scientific bodies. In case visitors are not prepared to present formal papers, it has been suggested that they be invited to address the meetings informally.

Mr. Smith was a member of the Radio Manufacturers Association's Television Committee, and chairman of Panel 9 of the National Television System Committee. Elected to the Radio Technical Planning Board, he served as chairman of its Television Panel, and in 1945, he was named chairman of RMA's Television System Committee. Mr. Smith is also a member of Tau Beta Pi. Presently chairman of the Philadelphia Section of the I.R.E., Mr. Smith is credited with many patents and patent applications covering inventions in radio, radar, and television.

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Maxwell H. A. Lindsay and Finley W. Tatum

Maxwell H. A. Lindsay (A'30) has been appointed assistant chief engineer, and Finley W. Tatum (A'43) has been named engineering supervisor of American District Telegraph Company, New York City.

Born in St. John's, Newfoundland, Mr. Lindsay received the B.S. degree from Mt. Allison University, New Brunswick, Canada, in 1925, and the M.S. degree in mathematical physics from Columbia University in 1930. While an undergraduate at Mt. Allison, he was physics instructor and assistant in descriptive geometry. From 1925 to 1926, he was instructor in the physics department of the Massachusetts Institute of Technology, after which he became a member of the technical staff in the physical laboratory and radio department of Bell Telephone Laboratories, Inc. In 1932, he joined the engineering department of the American District Telegraph Company, and he became engineering supervisor on intrusion detection systems and electronic equipment in 1935. Mr. Lindsay's work has involved the development and application of photoelectric, sound, and capacitance principles to the electrical protection of establishments and property, and he holds many patents in the field of protective signaling. He is a member of the Acoustical Society of America and the International Municipal Signal Association.

Mr. Tatum was born in Kent, Texas, and was graduated from Columbia University with a B.S. degree in electrical engineering in 1935. Later that year, he joined the plant department of the American District Telegraph Company and, in 1936, entered the engineering department to handle the development of various protective signaling systems. He has been in charge of electronic training courses for the company's personnel since 1944. Mr. Tatum is a member of the American Institute of Electrical Engineers and is a licensed professional engineer.

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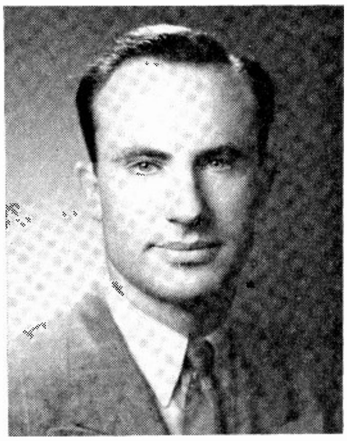
Finley W. Tatum



Leon Trice

Paul M. Reyling

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Paul M. Reyling

Paul M. Reyling (M'44) has been named production and engineering manager of Freeland and Olschner Products, Inc., of New Orleans, Louisiana, where he will manage the tube plant and supervise tube-development projects.

Mr. Reyling, who received his B.S. degree in electrical engineering from Brooklyn Polytechnic Institute, was affiliated with the Radio Corporation of America Manufacturing Company at Harrison, New Jersey, and Lancaster, Pennsylvania. He then became vacuum-tube engineer with Federal Telephone and Radio Corporation at Clifton,

I.R.E. People

New Jersey, where he directed the development and production of large vacuum tubes. Before joining Freeland and Olschner, he was on the staff of the Tennessee Eastman Corporation as senior engineer in charge of the vacuum-tube program for the Oak Ridge atomic-bomb project.

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RCA Promotions

David Sarnoff (A'12–M'14–F'17), president of the Radio Corporation of America, recently announced the appointment of E. W. Engstrom (A'25–M'38–F'40) as vice-president in charge of research of RCA Laboratories; C. B. Jolliffe (M'25–F'30), executive vice-president in charge of RCA Laboratories; Meade Brunet (M'26–SM'43), vice-president in charge of RCA Victor engineering products; J. W. Murray (A'45), vice-president in charge of RCA Victor records; and T. H. Mitchell (SM'45), executive vice-president of RCA Communications, Inc.

A graduate of the University of Minnesota, Mr. Engstrom served for thirteen years in research positions at RCA. He became research director of RCA Laboratories and supervised research and engineering which resulted in wartime advances in radar, television, radio, and other electronic developments.

Dr. Jolliffe received the B.Sc., M.S., and LL.D. degrees from West Virginia University, and the Ph.D. degree from Cornell University. He was physicist in the Bureau of Standards' radio section and later became chief engineer of the Federal Radio Commission. He first joined RCA as engineer-in-charge of its frequency bureau, and, subsequently, he was named chief engineer of RCA Laboratories and assistant to the president of RCA Victor. In 1942, Dr. Jolliffe became chief engineer of RCA Victor at Camden, New Jersey.

Mr. Brunet, a graduate of Union College, joined RCA in 1921 and had charge of production and distribution of RCA Radiotrons and Radiolas. He was appointed manager of the Radiola division, advanced to sales manager, and later became general manager of engineering products.

A Columbia University graduate, Mr. Murray first joined RCA Victor as general manager of the phonograph-record commercial division and later was promoted to general manager of RCA Victor records. From 1932 to 1939, he was engaged in the sales and manufacture of phonograph records in the Far East, which activities he continued upon his return to the United States.

Mr. Mitchell served as vice-president and general manager of RCA Communications, Inc., before his new appointment as executive vice-president.

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Frank H. R. Pounsett

The appointment of Frank H. R. Pounsett (A'26–SM'44) as chief engineer of the Stromberg-Carlson Company, Ltd., Toronto, Canada, has recently been announced by Ralph A. Hackbusch (A'26–M'30–F'37), vice-president and managing director.

Mr. Pounsett, a graduate in electrical engineering of the University of Toronto, was engineer for the De Forest Crosley Radio Company. He served as chief engineer in the radio division of the Stewart-Warner-Alemite Corporation, and later held the same position on the staff of Research Enterprises, Ltd. Mr. Pounsett is a registered professional engineer and holds the chairmanship of the Toronto Section of the I.R.E.

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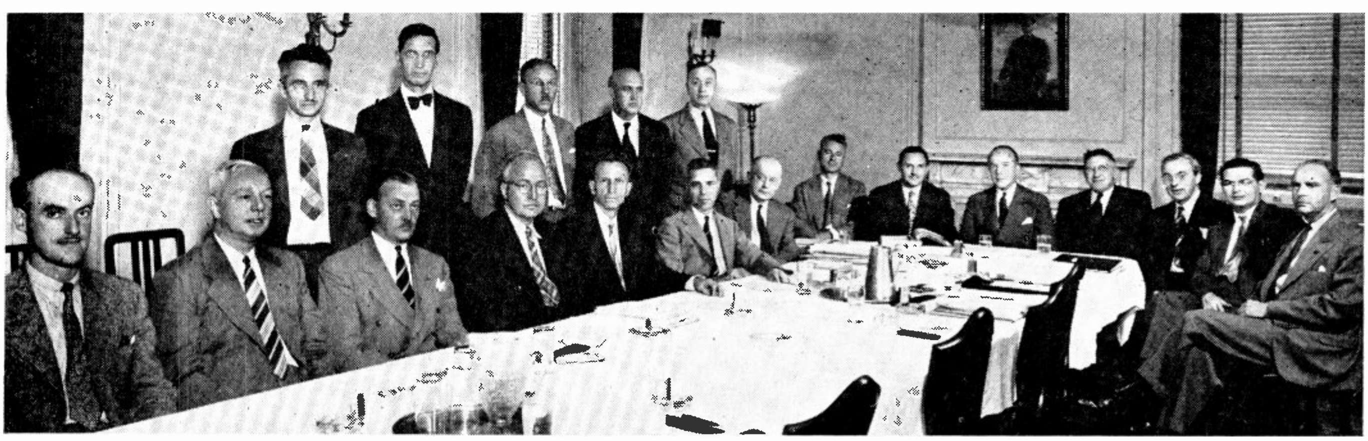
G. Emerson Pray

G. Emerson Pray (M'41–SM'43) has purchased the Tuck Electronic Corporation of New York and New Jersey engaged in the development of electronic and electromechanical devices and equipment.

Mr. Pray received the E.E. degree from Rensselaer Polytechnic Institute and performed graduate work at Rutgers University. He joined RCA Laboratories, Rocky Point, New York, in 1928 where he engaged in the development of frequency modulation, high-speed transmitter keying, very-high-frequency wave propagation, and resonant line oscillators. From 1931 to 1935, while with the Signal Corps Laboratories, Fort Monmouth, New Jersey, he developed the first superheterodyne receiver adopted for use by the United States Army.

As assistant chief of the radio research section of the Naval Research Laboratory, Anacostia, D. C., Mr. Pray completed the first successful Navy radar receiver. He became chief engineer and assistant to the vice-president of Airplane and Marine Instruments, Inc., Clearfield, Pennsylvania, in 1941, where he developed the Sono-Radio Buoy, the static direction finder, and the automatic cathode-ray direction finder.



Some Members of Canadian Radio Technical Planning Board at Meeting in Montreal

Seated, left to right—W. G. Southam and A. Reid, American Radio Relay League, Canadian Section; B. C. Fairfield and A. S. Runciman, Canadian Electrical Association; H. W. Haberl, Quebec H.E.P.C.; R. V. MacAulay, Telephone Association of Canada; L. S. Payne (M'16–SM'43), chairman, Panel A; G. M. Olive (M'43), Canadian Broadcasting Corporation; W. W. Richardson, secretary-treasurer; R. M. Brophy, president; R. A. Hackbusch (A'26–M'30–F'37), vice-president, Radio Manufacturers Association of Canada; A. B. Oxley (A'25–M'33), general co-ordinator; G. J. Irwin (A'35–M'37–SM'43), co-ordinator; and A. B. Hunt, Canadian Electrical Manufacturers' Association.

Standing, left to right—S. Sillitoe (A'35) chairman, Panel C; J. F. Neild, Canadian Transit Association; D. G. Geiger (A'31–M'45–SM'45), Telephone Association of Canada; F. S. Howes (A'37–M'43–SM'43), Institute of Radio Engineers; and J. A. Brass, Railway Association of Canada.

Books

A.S.T.M. Standards on Electrical Insulating Materials (With Related Information). Prepared by A.S.T.M. Committee D-9 on Electrical Insulating Materials

Published (1945) by the American Society for Testing Materials, 260 S. Broad St., Philadelphia 2, Pennsylvania. 528 pages+17-page index+xii pages. 147 illustrations. $5\frac{7}{8}\times 9$ inches. Price, $3.25.

This book contains a wealth of data covering the latest forms of specifications and test methods for electrical insulating materials and related products. A similar volume is published annually.

The contents comprise eighty-two separate sections, each of which consists of a separate report. Twenty-eight standard methods of test, eighteen tentative methods of test, and twelve specifications are described for insulating materials. In addition the book contains twenty specifications and methods of test for various paper, textile, and rubber products, plastics, shellac, and related materials of interest.

Several sections are devoted to the general significance of tests of electrical insulating materials. The scope of the material presented includes lacquers, paints, and insulating varnishes, mineral oils, and ceramic products such as Steatite, porcelain and glass. Methods are described for testing liquids to determine the pour point, viscosity, moisture content, insoluble matter, iodine number, wax content, density, flash point, time of drying, gas content, heat endurance, sludge, color, flammability, and others.

For solids, methods of test are described to determine the tensile strength, resistance to impact, dielectric, strength, resistivity, power factor, specific gravity, volume resistance-temperature characteristics, coefficient of expansion, softening point, arc resistance, dielectric constant, water absorption, flexural strength, effect of heat, Rockwell hardness, compressive strength, etc.

This book contains all of the essential data which normally would be of interest to engineers engaged in the design or testing of electrical insulating materials and is presented in clear and easily readable form.

Raymond F. Guy
National Broadcasting Company, Inc.
New York 20, N. Y.

Elementary Engineering Electronics, by Andrew W. Kramer

Published (1945) by The Instruments Publishing Co., Inc., 1117 Wolfendale St., Pittsburgh 12, Pennsylvania. 334 pages+6-page index+iv pages. 259 illustrations. $4\frac{1}{2}\times 8$ inches. Price, 2.00.

This little book which can easily be carried in one's pocket, was written for the individual with a limited background in physics and mathematics. Most such books

SECTIONS

Chairman		Secretary
	Atlanta April 19	M. S. Alexander 2289 Memorial Dr., S.E. Atlanta, Ga.
R. N. Harmon 1920 South Rd. Mt. Washington Baltimore 9, Md.	Baltimore	F. W. Fischer 714 S. Beechfield Ave. Baltimore, Md.
C. C. Harris Tropical Radio Telegraph Co. Box 584 Hingham, Mass.	Boston April 26	A. G. Bousquet General Radio Co. 275 Massachusetts Ave. Cambridge 39, Mass.
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J. M. Van Baalen 282 Orchard Dr. Buffalo 17, N. Y.	Buffalo-Niagara May 15	H. W. Staderman 264 Loring Ave. Buffalo, N. Y.
T. A. Hunter Collins Radio Co. 855—35 St., N.E. Cedar Rapids, Iowa	Cedar Rapids	R. S. Conrad Collins Radio Co. 855—35 St., N.E. Cedar Rapids, Iowa
Cullen Moore 327 Potomac Ave. Lombard, Ill.	Chicago April 19	D. G. Haines 4000 W. North Ave. Chicago 39, Ill.
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R. C. Higgy 2032 Indianaola Ave. Columbus, Ohio	Columbus May 10	Warren Bauer 376 Crestview Rd. Columbus 2, Ohio
H. W. Sundius Southern New England Telephone Co. New Haven, Conn.	Connecticut Valley April 18	L. A. Reilly 989 Roosevelt Ave. Springfield, Mass.
R. M. Flynn KRLD Dallas 1, Texas	Dallas-Ft. Worth	J. G. Rountree 4333 Southwestern Blvd. Dallas 5, Texas
L. B. Hallman 3 Crescent Blvd. Southern Hills Dayton, Ohio	Dayton April 25	Joseph General 411 E. Bruce Ave. Dayton 5, Ohio
H. E. Kranz International Detrola Corp 1501 Beard Ave. Detroit 9, Mich.	Detroit April 19	A. Friedenthal WJR Fisher Building Detroit 2, Mich.
N. L. Kiser Sylvania Electric Products, Inc. Emporium, Pa.	Emporium	D. J. Knowles Sylvania Electric Products, Inc. Emporium, Pa.
E. M. Dupree Star Electric and Engineering Co. 613 Fannin St. Houston, Texas	Houston	L. G. Cowles Box 425 Bellaire, Texas
H. I. Metz Civil Aeronautics Authority Experimental Station Indianapolis, Ind.	Indianapolis	V. A. Bernier 5211 E. 10 Indianapolis, Ind.
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L. A. W. East Canadian Pacific Railway 204 Hospital St. Montreal, Que., Canada	Montreal, Quebec April 24	R. R. Desaulniers Canadian Marconi Co. Box 1690 (Place D'Armes) Montreal 1, Que., Canada
G. B. Hoadley 85 Livingston St. Brooklyn, N. Y.	New York May 1	J. T. Cimorelli RCA Victor Division 415 S. Fifth St. Harrison, N. J.
W. A. Steel 298 Sherwood Dr. Ottawa, Ont., Canada	Ottawa, Ontario April 18	L. F. Millett 33 Regent St. Ottawa, Ont., Canada
D. B. Smith Philco Corporation Philadelphia 34, Pa.	Philadelphia May 2	P. M. Craig Philco Corporation Philadelphia 34, Pa.
J. A. Hutcheson 852 N. Meadowcroft Ave. Pittsburgh 16, Pa.	Pittsburgh May 13 Mellon Institute Technical Radar Seminar	C. W. Gilbert 52 Hathaway Ct. Pittsburgh 21, Pa.
C. W. Lund Rt. 4, Box 858 Portland, Ore.	Portland	L. C. White 3236 N.E. 63 Ave. Portland 13, Ore.
G. R. Town Stromberg-Carlson Co. Rochester 3, N. Y.	Rochester April 18	A. E. Newlon Stromberg-Carlson Co. Rochester 3, N. Y.
B. B. Miller 2356A Lawrence St. St. Louis 10, Mo.	St. Louis April 25	N. J. Zehr 1538 Bradford Ave. St. Louis 14, Mo.
David Kalbfell 941 Rosecrans Blvd. San Diego, Calif.	San Diego May 7	Clyde Tirrell U. S. Navy Radio and Sound Laboratory San Diego 52, Calif.
R. V. Howard Mark Hopkins Hotel San Francisco, Calif.	San Francisco	Lester Reukema 2319 Oregon St. Berkeley, Calif.
E. H. Smith 823 E. 78 St. Seattle 5, Wash.	Seattle May 9	W. R. Hill University of Washington Seattle 5, Wash.
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H. E. Hartig University of Minnesota Minneapolis, Minn.	Twin Cities	M. R. Ludwig 315 E. 24 St. Minneapolis 4, Minn.
F. W. Albertson Room 1111, Munsey Bldg. Washington 4, D. C.	Washington May 13	G. P. Adair Federal Communications Commission Washington 4, D. C.
W. C. Freeman, Jr. 2018 Reed St. Williamsport 39, Pa.	Williamsport May 1	S. R. Bennett Sylvania Electric Products, Inc. Plant No. 1 Williamsport Pa.

SUBSECTIONS

N. F. Schlaack Bell Telephone Laboratories, Inc. 463 West St. New York 14, N. Y.	Monmouth (New York Subsection)	C. D. Samuelson 5 Russel Ave. Fort Monmouth, N. J.
W. C. Johnson Princeton University Princeton, N. J.	Princeton (Philadelphia Subsection)	J. G. Barry Princeton University Princeton, N. J.
H. E. Ellithorn 417 Parkovash Ave. South Bend 17, Ind.	South Bend (Chicago Subsection) April 18	J. E. Willson WHOT St. Joseph and Monroe Sts. South Bend, Ind.

Books

are either technically inadequate or are too difficult, but this one is written with a sympathetic understanding of the beginner's point of view, and the principles are explained in simple language. It provides a good introduction to the subject of electronics. The treatment is qualitative. There are less than a dozen simple equations in the book. For the most part the illustrations are effective. An exception is the mechanical analogy of the thyratron which probably adds little to the reader's understanding. Fig. 31 serves to illustrate the function of an amplifier or repeater, but the attenuation curve is not correctly drawn. On page 80 it is implied that reactance, which is a property of circuits in the steady state, may also be used under transient conditions, and on page 231 the equation for the average value of an alternating voltage appears to be in error. There are a few cases where the statements, although adequate for the purpose, are not strictly correct; however, considering the elementary nature of the book it is surprising that there are not more such cases.

There is inconsistency in the battery conventions in various circuit diagrams which is apt to confuse the reader; for example, in Fig. 70 it is correct and in Fig. 71 it is incorrect. Also, in Fig. 75 the inductances are drawn in the conventional manner while in Fig. 76 they are not so drawn. In chapter XXVII a discussion of the advantages and disadvantages of the various circuits shown would have been helpful.

In the conclusion the author states he is "conscious of so many things left out". He is to be congratulated, the value of the book has been increased by not trying to include everything.

The book is recommended to those who are interested in an elementary introduction to electronics as a basis for industrial and communication applications.

H. M. Turner
Yale University
New Haven
Connecticut

Fundamental Theory of Servomechanisms, by LeRoy A. MacColl

Published (1945) by D. Van Nostrand Co., Inc., 250 Fourth Avenue, New York, N. Y. 128 pages + 2-page index + xviii pages. 48 illustrations. $6\frac{1}{4} \times 9\frac{1}{4}$ inches. Price, $2.25.

The last ten years have witnessed a tremendous advance in the art of automatic control. Automatic control and remote control are old arts. A tremendous impetus has been given to the servo field by the demands of the war. As compared with a typical servomechanism of ten or more years ago, those developed during the war were capable of following a rapidly fluctuating signal with high dynamic accuracy and stability. In addition, many servomechanisms involve a very large amplification of power.

Many of the problems of designing or analyzing the modern servomechanism of

Books

good stability and high dynamic accuracy are somewhat involved. A good deal of the complication arises from the fact that the differential equations of servomechanisms are frequently of a high order so that a systematic study of the solutions following classical and orthodox methods is a tedious one at best. Although servomechanisms may be of mechanical, electrical, hydraulic, or pneumatic character, the underlying mathematical theory is essentially the same.

This book is written from the standpoint of the physicist. It presupposes a considerable knowledge of the fundamentals of feedback amplifiers and servomechanisms generally. It is, therefore, not for the casual reader. Unless the reader has had some little experience in reading scientific books, he cannot expect to read this book as he would a newspaper or novel. Even the physicist must read it carefully.

The book is exceedingly well written and appears to be free from obvious errors. It properly covers the subject matter the author intended, although in some spots more explanation would be helpful. In this reviewer's opinion, this book could well have been three or four times as long. It contains a short but excellent bibliography outlining much of the literature dealing with feedback amplifiers. The text is well illustrated, having some 48 illustrations and figures. The author's style is clear and logical, and the organization of the text appears to be excellent. Among other things, the author covers the elementary theory, the steady-state theory, the theory of servomechanisms and the theory of transients in linear systems. A chapter devoted to the stability of servomechanisms is particularly meritorious in its treatment of the subject. This text is particularly good if read in connection with some of the more practical treatises on the subject. It is believed that this book will be found a useful and worthwhile compilation for engineers interested in the mathematical theory of servomechanisms.

F. X. Rettenmeyer
Federal Telephone and Radio Corporation
Newark 4, New Jersey

Electron Optics and the Electron Microscope, by V. K. Zworykin, G. A. Morton, E. G. Ramberg, J. Hillier, and W. A. Vance

Published (1945) by John Wiley and Sons, Inc., 440 Fourth Avenue, New York 16, N. Y. 754 pages + 12-page index + xi pages. 549 illustrations. $5\frac{3}{4}\times8\frac{5}{8}$ inches. Price, $10.00.

The authors' preface states plainly the purpose of the book: "to aid the present or prospective electron microscopist in understanding his instrument and in using it to greatest advantage; to present systematically the practical and theoretical knowledge which must form the basis of further progress in electron-microscope design."

This reviewer believes that the book has adequately achieved that goal. It is divided into two parts. The first part starts by describing electron-optical applications in a general way. The various types of electron microscopes which have been developed are then touched upon briefly. The remainder and greater portion of Part I gives a rather thorough practical treatment of the electromagnetic-type microscope covering design features, electron-optical considerations, manipulation of the instrument, and its application to various fields of research.

If it is felt that at times the text has a tendency to elaborate unduly on the RCA Type B electron microscope, it should be remembered that this is the instrument which is in most widespread use in this country. However, already the same company has two other models available and this emphasis on one instrument type will prove a weakness in the book.

The treatment of electron diffraction is to some extent misleading. This well-established field is older than electron microscopy, but the text unfortunately gives the impression that such work was made possible by the development of adaptors for electron microscopes.

Part II of the book is made up nearly entirely of theoretical electron optics. The coverage is so complete that this portion of the book will undoubtedly serve as a reference work for many besides those whose interests lie in electron microscopy.

Although the contents of the second part are probably more enduring, their highly mathematical nature precludes popular appeal, whereas, Part I, which, will need constant revision to keep up to date, should prove to be of wide interest. It would seem that the two parts might better have been published as two separate volumes.

C. H. Bachman
General Electric Company
Schenectady, N. Y.

Dr. Waldman Talks on Atomic Power

On November 15, 1945, the South Bend Subsection held a meeting at which Dr. Bernard Waldman spoke. The attendance at this meeting was about one thousand, with forty members coming from Chicago.

Dr. Waldman, who is associate professor of physics of the University of Notre Dame, addressed the audience on the subject of atomic power at this meeting which was sponsored by the South Bend I.R.E. Subsection, the University of Notre Dame, and The Engineers' Club of St. Joseph Valley. Dr. Waldman was associated with the Manhattan (atomic-bomb) project and was present at the bomb test in New Mexico and was an observer of the bombing of Hiroshima.

He introduced his subject by stating that he would try to present thoughts which were representative of the group of scientists who worked on the Manhattan project. To introduce the subject logically to the audience, Dr. Waldman presented fundamental facts of nuclear physics together with a history of its development. This was illustrated by slides explaining the nuclear structure and the products obtained in atom splitting.

Dr. Waldman pointed out that the fundamental knowledge which made the atom bomb possible was developed over a considerable period of time beginning with the earliest work of splitting an atom back in 1890. This was carried on by various research projects which finally brought to light around 1940 the element known as plutonium. Up to that time any large-scale atomic changes, however, required a great amount of energy, and it was not until 1939 that Hahn and Strassmann produced proof of fission which is accompanied by a release of energy. This release of energy which exhibits itself in the form of heat was illustrated by the breaking down of uranium by bombardment with neutrons into krypton and barium which thereupon liberated more neutrons to start the chain of fission.

Dr. Waldman then discussed the questions as to what to do with the bomb and with atomic power. He stated that small power plants could be made to use uranium 235 or plutonium. He pointed out that in one form at the present time a twenty-foot cube is used in the chain reaction of atomic-energy change. The amount of heat generated by such cube is so great that the cooling water used at Hanford, Washington, when returned to the Columbia River increases the temperature of the river five degrees. This is indicative of the possibility of using the heat for the generation of power. At present, however, it is feasible to generate power in this manner. But it is not feasible to operate small plants with the concentrated uranium 235 or plutonium since it would be impracticable to attempt to control the material in such manner as to prevent enemies from withdrawing small amounts of uranium 235 or plutonium from various power plants whereby to obtain a supply of essential material with which to make bombs. In spite of this, however, it appears that within the next five or ten years, it will be possible to use piles of this material for power generation. The immediate future, however, within the next year or two offers a greater promise for the production of radioactive materials which will replace the more expensive radium.

Dr. Waldman pointed out that our greatest secret is our ability to carry on fundamental research and to apply the fundamental knowledge practically. He also showed that it is necessary to continue this fundamental research without restriction either by license from some government agency or by the necessity of submitting the research results and progress to a military research committee for their approval. Any such restrictions would so hamper and inhibit the necessary fundamental research that without doubt little progress would be made.

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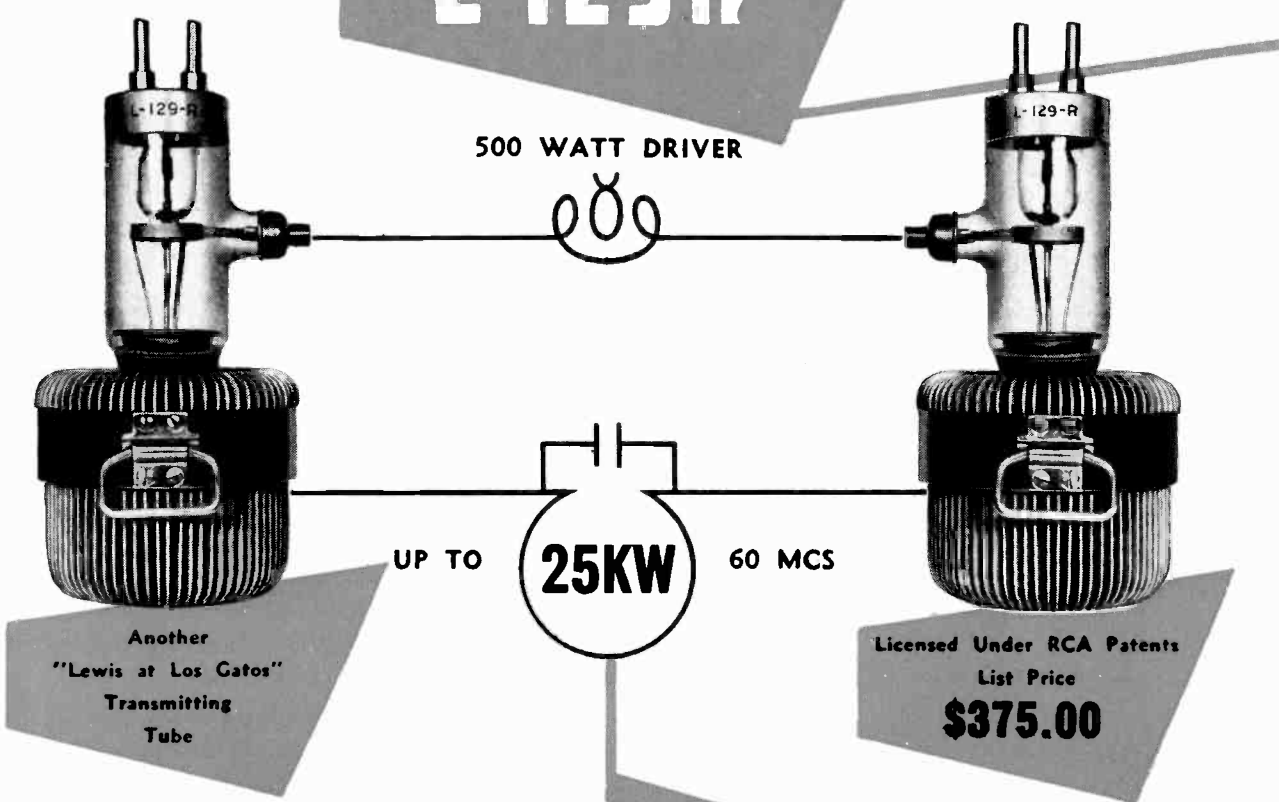

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SECTION MEETINGS

Atlanta

"General Properties of Cavity Resonators," by W. A. Edson, Georgia Institute of Technology; January 18, 1946.

Election of Officers; January 18, 1946.

"Reports on Frequency-Modulation Transmitters, Television, Studio Audio Equipment, Quartz Crystals," by G. A. Rosselot, M. A. Honnell, R. A. Holbrook, and Ben Akerman; February 15, 1946.

Boston

"Radar Indicators," by L. J. Haworth. Radiation Laboratory, Massachusetts Institute of Technology; February 8, 1946.

"Receivers for Microwave Radar," by S. N. Van Voorhis, Radiation Laboratory, Massachusetts Institute of Technology; February 15, 1946.

"The SCR-584, An Antiaircraft Radar Set," by I. A. Getting, Radiation Laboratory, Massachusetts Institute of Technology; March 1, 1946.

Cedar Rapids

"High Frequency As Applied to Industrial Processing," by B. E. Rector, Westinghouse Electric Corporation; January 17, 1946.

"The Electroacoustics of Audition," by S. N. Reger, State University of Iowa; February 20, 1946.

"The Microwave Spectrum Analyzer," by Arthur Wulfsberg, Collins Radio Company; February 20, 1946.

Chicago

Engineering Conference and Annual Banquet; February 9, 1946.

"Development of the Phasitron," by Robert Adler, Zenith Radio Corporation; February 15, 1946.

"Field Intensities Beyond Line of Sight at 45.5 and 91 Megacycles," by C. W. Carnahan, Zenith Radio Corporation; February 15, 1946.

Cincinnati

"Science Shapes the Future," by A. H. Compton, Washington University; March 1, 1946.

Cleveland

"Discussion, with slides, of various types of jet engines, and gas turbines," by A. Kindig, NACA, Cleveland Airport; February 20, 1946.

"Electronic Instruments and the Measurement of Radiation," by J. A. Victoreen, Victoreen Instrument Company; February 28, 1946.

(Continued on page 38A)

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The new Westinghouse WL 624 is capable of delivering 6.4 amperes average and 77 amperes peak current at 2500 volts peak inverse. The 12 to 1 ratio of peak to average anode current when considered with its averaging time of 15 seconds, is of great importance in motor-speed control applications. It is important also in welding applications where the thyratron conducts the actual current to the welder. The tube utilizes a shield grid which reduces the anode to control grid capacitance, enabling the designer to minimize the possibility of the tube losing control because of surges in the anode circuit. The shield grid also makes possible the use of very low control power.

The WL 624 employs a control-grid structure of very large area which radiates directly through the glass envelope rather than into the other metal parts—an important feature for a shield-grid tube.

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For further information, call your nearest Westinghouse Office or write Electronic Tube Sales Department, Lamp Division, Westinghouse Electric Corporation, Bloomfield, N. J.

General Characteristics

Air cooled tetrode

Heater voltage	5.0 volts
Heater current	10.0 amperes
Cathode heating time	5 minutes
Tube voltage drop	15 volts
Control characteristics	negative

Maximum Ratings Up to 150 Cycles

Anode voltage, peak forward	2500 volts
Anode voltage, peak inverse	2500 volts
Anode current, average	6.4 amps.
Anode current, peak	77 amps.
Anode current, surge, for design only	770 amps.
Averaging time, anode and grid currents	15 seconds
Temp. range, condensed mercury	+ 40°C to + 80°C

Westinghouse

Electronic Tubes at Work

SECTION MEETINGS

(Continued from page 36A)

Dallas-Ft. Worth

"Frequency Measuring Apparatus Used by the Federal Communications Commission and Its Predecessors," by N. A. Hallenstein, Federal Communications Commission; February 19, 1946.

Dayton

"Application of Radar to Aircraft," by J. E. Keto, F. L. Holloway, P. E. Koenig, I. Paganelli, L. B. Hallman, Jr., and R. D. Hultgren, Radar Laboratory, Wright Field; February 14, 1946.

Detroit

"Engine Analysis by Electronics," by J. W. Head, Industrial Electronics, Inc.; February 15, 1946.

Emporium

"Recording on Magnetic Wire," by L. C. Holmes, Stromberg-Carlson Company; February 7, 1946.

London

"Television," by F. S. Jackson, Radar and Communication School; January 18, 1946.

"The Electron Microscope," by E. F. Burton, University of Toronto; February 1, 1946.

Los Angeles

"Measurements in Frequency-Modulation Description of the New Phasitron," by Cameron Pierce, General Electric Company; January 18, 1946.

"Ground-Control-Approach Radar System," by William Lindsay, Gilfillan Brothers, Inc.; February 12, 1946.

Milwaukee

"VT Radio Proximity Fuse," by Cledo Brunetti, National Bureau of Standards, John M. Pearce, Johns Hopkins University, and A. S. Khouri, Globe Union Manufacturing Company; February 8, 1946.

Montreal

"Design Principles and History of Radar in Canada," by F. H. Sanders, National Research Council of Canada; January 16, 1946.

Philadelphia

"The Heritage of Radar," by L. N. Ridenour, Radiation Laboratory, Massachusetts Institute of Technology; February 6, 1946.

Portland

"Radar and Its Component Parts," by Howard Vollum, Physicist; January 23, 1946.

"Radar Counter Measures," by E. A Younker, Oregon State College; January 30, 1946.

(Continued on page 40A)

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SECTION MEETINGS

(Continued from 38A)

Rochester

"Railroad Radio," by W. D. Hailes, General Railway Signal Company; February 21, 1946.

St. Louis

"Coaxial Cable and Associated Carrier Equipment," by H. P. Lawther, Southwestern Bell Telephone Company; January 31, 1946.

San Diego

"Cathode-Follower Circuits," by D. C. Kalbfell, Physicist, University of California Division of War Research; February 5, 1946.

San Francisco

"The Butterfly Circuit," by M. P. Klein, Universal Research Laboratories; January 30, 1946.

Seattle

"Frequency-Modulation Equipment," by W. U. Dent, Westinghouse Electric Corporation; January 16, 1946.

Toronto

"Electronic Heating in Industry," by T. J. Thwaites, Canadian Westinghouse Electric Corporation; December 10, 1945.

"Radar, History and Fundamental Design Cosiderations," by F. Sanders.] National Research Council Ottawa; January 14, 1946.

"Radar-Antenna Developments," by C. J. Bridgland, Research Enterprises, Ltd.; January 14, 1946.

"Circuits for the Measurements of Range," by J. D. Bain, Research Enterprises, Ltd.; January 14, 1946.

"German Radio-and-Communications Developments," by C. G. Lloyd, Canadian General Electric Company; February 4, 1946.

Twin Cities

"The Radio Proximity Fuse," by Cledo Brunetti, National Bureau of Standards; February 11, 1946.

Williamsport

"High-Quality Recording on Magnetic Wire," by L. C. Holmes, Stromberg-Carlson Company; February 6, 1946.

"Some Broad Aspects of Specialization," by E. F. Carter, Sylvania Electric Products, Inc.; March 6, 1946.

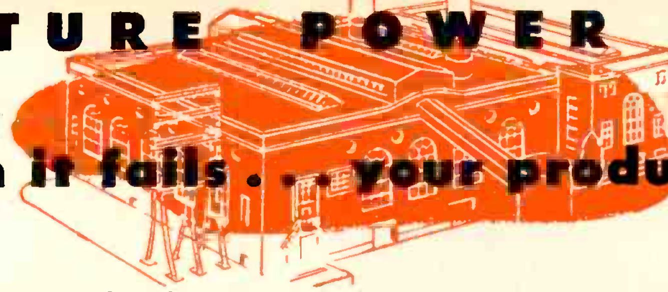
Election of Officers; March 6, 1946.

Subsections

Princeton

"The Heritage of Radar," by L. N. Ridenour, Radiation Laboratory, Massachusetts Institute of Technology; February 6, 1946.

MINIATURE POWER PLANT



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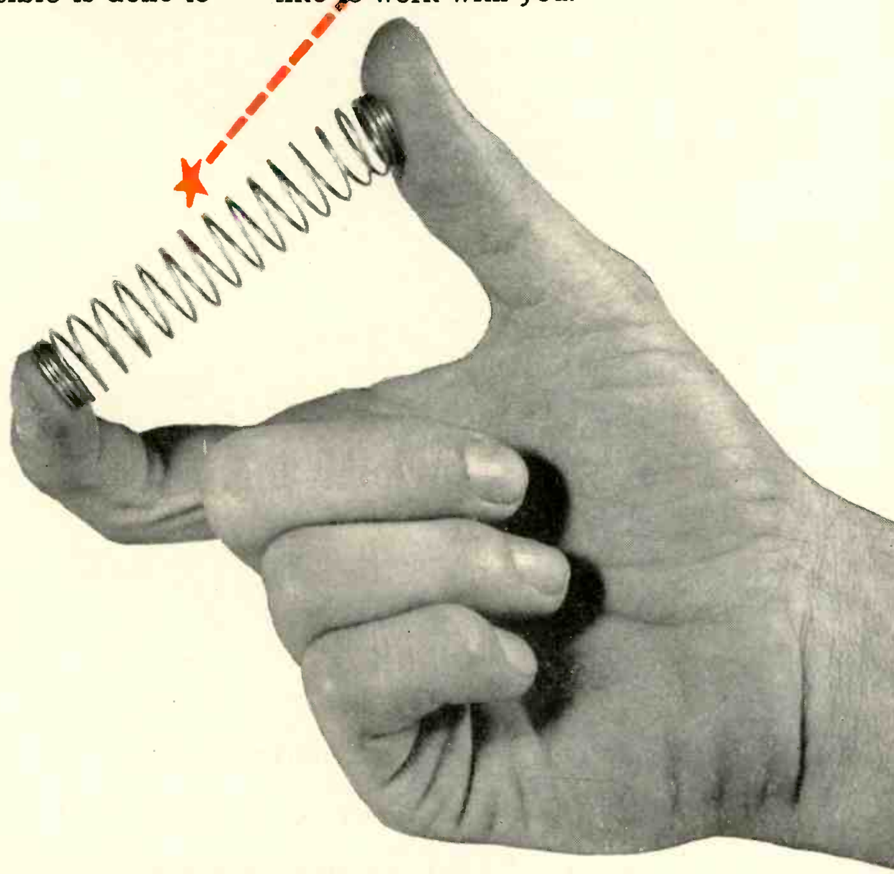
Insure your product's good reputation with springs from Accurate . . . where everything possible is done to give you springs you can depend upon. Our experienced spring engineers will help you be sure you have planned the right spring for the job... our skilled craftsmen and modern machinery assure you of fine workmanship . . . and, careful testing through critical stages of manufacture will give you springs that you can rely on to function well and long. Call us. We'd like to work with you.



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Goddard, D. R., Radio Corporation of America, Riverhead, L. I., N. Y.
Hok, C. G. M., 10 Forest St., Cambridge 40, Mass.
Isberg, R. A., 28 Curtis Pl., Lynbrook, L. I., N. Y.
Libby, L. L., 10 Summit St., East Orange, N. J.
Mackay, F. S., 788 Eglinton Ave. W., Toronto 10, Ont., Canada
Nicholas, E. A. Farnsworth Television and Radio Corp., Fort Wayne 1, Ind.
Pacholke, F., 10611 S. Bell Ave., Chicago 43, Ill.
Pan, W. Y., 5 Clinton Ave., Merchantville, N. J.
Peterson, A. P. G., General Radio Co., 275 Massachusetts Ave., Cambridge 39, Mass.
Sharp, J. W., 6001 Dickens Ave., Chicago 39, Ill.
Stuhrman, A. P., Wilcox Electric Co., 1400 Chestnut St., Kansas City 1, Mo.
Tellman, H. A., 4641—30 Rd., Fairlington, Va.
Wahlgren, W. W., 6021 College Ave., Oakland 11, Calif.
Wickizer, G. S., 131 Brook St., Riverhead, L. I., N. Y.

Admission to Senior Member

Begun, S. J., 3405 Perkins Ave., Cleveland 14, Ohio
Blasi, E. A., 154 Park Dr., Dayton 10, Ohio
Clark, A. B., Bell Telephone Laboratories, 463 West St., New York 14, N. Y.
Friedlaender, E. R., 52 Mauldeth Rd., Manchester 20, England
Leedy, H. A., Armour Research Foundation, 35 W. 33 St., Chicago 16, Ill.
Martin, W. H., Bell Telephone Laboratories, 463 West St., New York 14, N. Y.
Mason, W., 60 Broad St., New York 4, N. Y.
Rahmel, H. A., A. C. Nielsen Co., 2101 Howard St., Chicago 45, Ill.
Smith, F. B., 1527 Mars Ave., Lakewood, Ohio
Sollie, S. A., Graybar Bldg., New York, N. Y.
Van Deusen, G. L., 4000 Cathedral Ave., N. W., Washington 16, D. C.
White, W. T., 1640 Aladdin Ave., New Hyde Park, N. Y.

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MEMBERSHIP

(Continued from page 42A)

Transfer to Member

Adams, B. N., 215-10—111 Rd., Queens Village 9, L. I., N. Y.
Adams, K., General Radio Co., 920 S. Michigan Ave., Chicago 5, Ill.
Baerwald, H. G., 3405 Perkins Ave., Cleveland 14, Ohio
Beizer, H. H., 1955 La Mothe, Detroit 6, Mich.
Bonham, W. E., 31 Hubbard Ave., Red Bank, N. J.
Bullen, C. V., 415 N. First St., Rockford, Ill.
Cartier, W. O., 45 Moore Ave., Toronto, Ont., Canada
Chapman, S., Physics Dept., Stanford University, Calif.
Crump, E. E., 10 Summit Ave., East Orange, N. J.
Doersam, P. D., 835 Brunswick Rd., Essex, Baltimore 21, Md.
Ewing, E. G., BM/EGE, London W.C. 1, England
Freedman, M. M., 144-34—72 Dr., Kew Gardens Hills, L. I., N. Y.
Hansen, B. P., 738 W. Broadway, Council Bluffs, Iowa
Holliday, F. S., 411 Federal Annex, Atlanta, Ga.
Hopper, A. L., 85 Spring Valley Ave., River Edge., N. J.
Inglis, A. F., 623 Woodland Ave., Petoskey, Mich.
Killgore, H. S., Box 1120, Washington, D. C.
Maury, M. A., 232 Jackson St., Hempstead, L. I., N. Y.
McCann, D. J., 1306 Hinman Ave., Evanston, Ill.
Patterson, T. C., 22 Dryburn Rd., Durham Moor, N. Durham, England
Ronzheimer, S. P., 5025 N. Rockwell St., Chicago 10, Ill.
Sanders, E. W., Box 152, Andalusia, Pa.
Schonert, K. E., Knollwood Apts, Stamford, Conn.
Skipper, L. C., 98 Colony Dr., Baldwin, L. I., N. Y.
Soria, R. M., 3300 S. Federal St., Chicago 16, Ill.
Springer, P. W., 1115 Linden Ave., Dayton 10, Ohio
Stavis, G., 474 Third Ave., New York 16, N. Y.
Von Alven, W. H., 1012 Euclid Ave., Boise, Idaho
Walker, R. E., Civil Aeronautics Administration, Box 440, Reference 99, Anchorage, Alaska
Weber, J., Code 920, Bureau of Ships, Navy Dept., Washington 25, D. C.
Webster, G. E., Collins Radio Co., Cedar Rapids, Iowa
Weiss, E., 2901 S St., S.E., Washington 20, D. C.
Weiss, M. M., 2032 Creston Ave., New York 53, N. Y.
Yamins, H. G., Engineering Branch, Camp Evans Signal Laboratory, Belmar, N. J.

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WE'RE HAVING A WONDERFUL TIME

MEETING OLD FRIENDS

EVERY day old friends drop in to see us—familiar but long missed voices come over the phone—men back from strange lands, strange experiences.

Back home, back to the old job, the conversation swiftly turns to work. Pre-war dies and extrusion nozzles come out of the storage vault in perfect condition, ready for immediate production. Our men again produce pieces not made since before the war. Early designs, time tested and time proved, are being made in increasing quantities.

Most of our men are back too. Production is humming along at a pace even greater than the wartime speed which won American Lava Corporation employees five awards of the Army-Navy E. We're busy, but if you ever had tools at American Lava Corporation, they are still here, ready for your use, and somehow we'll take care of you.

Welcome home, it's great to see you back again.

Original Award July 27, 1942
Second Award February 13, 1943
Third Award September 25, 1943
Fourth Award May 27, 1944
Fifth Award December 2, 1944

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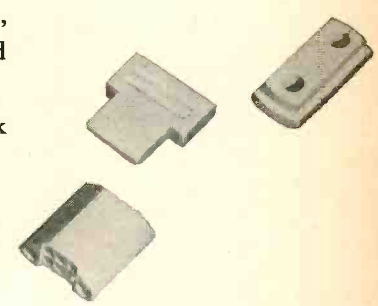

MEMBERSHIP

(Continued from page 44A)

Admission to Member

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Boatright, B. C., 6349 Homewood Ave., Hollywood 28, Calif.

Burchell, H. G., Naval Service Headquarters, Ottawa, Ont., Canada

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DeLoi, D. J., 196 S. First St., Brooklyn 11, N. Y.

Engle, V. M., 1435 Ogden Ave., New York 52, N. Y.

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Gabel, W., 5 Beech Spring Dr., Summit, N. J.

Garrett, G. A., 1922 W. Gray St., Houston, Tex.

Hall, J. A., 147 W. Pierrepont Ave., Rutherford, N. J.

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Hoff, H. B., 750 Huron Rd., Cleveland 15, Ohio

Hultgen, R. D., 542 Cedarhurst Ave., Dayton 7, Ohio

Johnson, S. F., 3050 Maiden Lane, Altadena, Calif.

Lader, L. J., 202 Wilmington Pl., S.E., Washington, D. C.

Leonard, E. V., 3202 H McMichael St., Philadelphia 29, Pa.

Lofton, J. H., 113 W. Clearfield Rd., Havertown, Pa.

Lucian, T. F., Box 133, 424 W. St. Louis St., Lebanon, Ill.

McGregor, J. C., Sperry Gyroscope Company, Inc., Garden City, L. I., N. Y.

Melnicoe, S. A., 924 Stanyan St., San Francisco 17, Calif.

Miller, G. H., 505 University Ave., Rochester 7, N. Y.

Miller, S. E., 37-21—80 St., Jackson Heights, L. I., N. Y.

Mondy, H. C., 741 Huffman Ave., Dayton 3, Ohio

Nesbitt, A. D., 818 Public Square Bldg., Cleveland 13, Ohio

Olson, J. H., Pacific Telephone and Telegraph Co., 601 Northern Life Tower, Seattle 1, Wash.

Piety, E. W., Laura Ave., Centerville, Ohio

Pullen, K. A., Jr., 8341—62 Ave., Rego Park, Brooklyn, N. Y.

Robertson, C. B., 722 N. Broadway, Milwaukee 2, Wis.

Russell, F. A., Newark College of Engineering, 367 High St., Newark 2, N. J.

Saroop, M., Technical Corp., Lall Bagh, Lucknow U.P., India

Veldhuis, A. C., Netherland Purchasing Commission, 41 E. 42 St., New York, N. Y.

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Sherron

AUDIO CONTROL DESK

Model SE-400

For Aural Monitoring

The Sherron Audio Control and Monitoring Console offers the aural technician or operator exclusive control in Television, FM or AM broadcasting.

All contacts are centrally located, so that the operator can meter and monitor the aural program with complete ease.

Among the many features of this unit are the following: seven (7) Audio Inputs; four (4) balanced ladder network for control of selector inputs; line equalizer; two (2) program amplifiers; inter-office communication; decibel indication for monitoring; two turntables, a complete aural control desk.

Another important feature of this unit is the fact that it is designed to permit expansion. The rack panels located in the center are readily removable; there are no wires to disconnect. All connections are made by means of plug-in jacks or sockets.

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Williams, E. E., General Electric Co., 1001 Wolf St., Syracuse 8, N. Y.
Zenner, R. E., 9409 Jefferson Ave., Brookfield, Ill.

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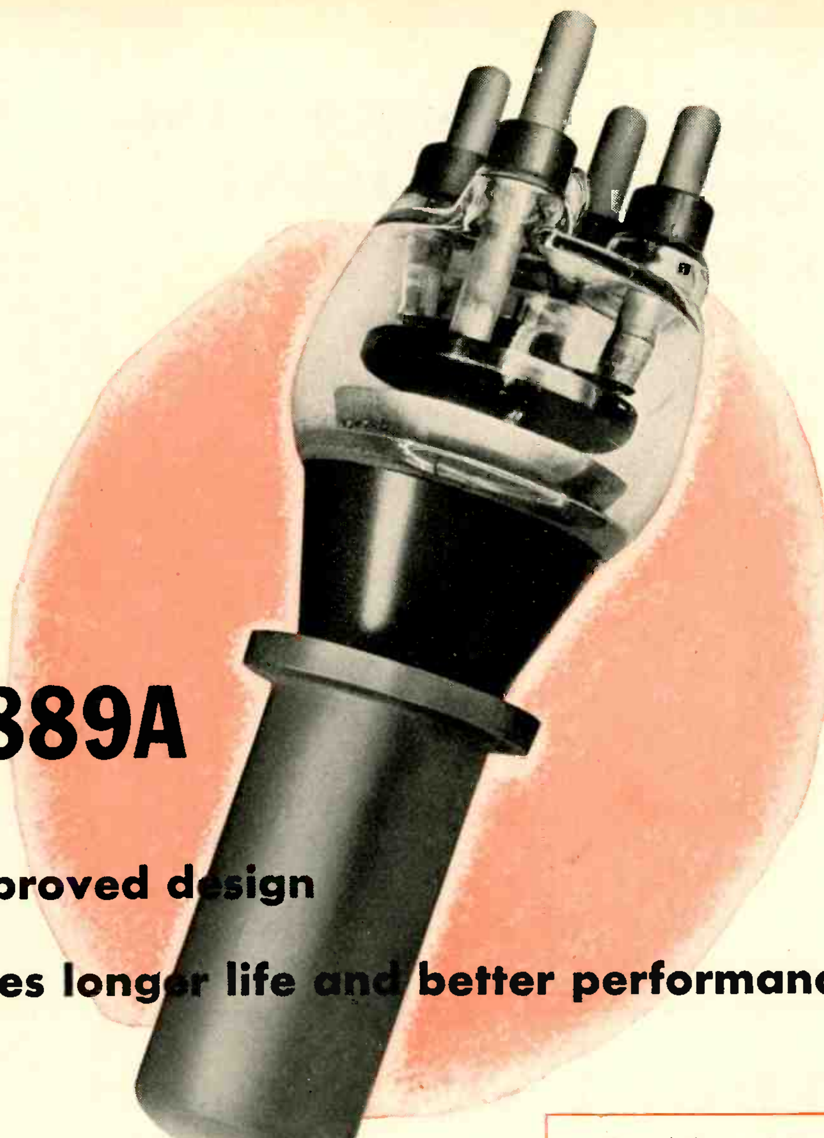
Adams, R. L., 8317 Garfield Ave., Bell Gardens, Calif.
Akin, R. H., 230 N. Fairview St., Burbank, Calif.
Albrough, C. E., Box 370, Ingersoll, Ont., Canada
Austin, J. B., Jr., 1424 W. Allegheny Ave., Philadelphia 32, Pa.
Balakrishnan, T. P., 7 Loge Bonheur, Off Station Rd., Mahim, Bombay, India
Baluta, R. E., 2700 Wisconsin Ave., N.W., Washington 7, D. C.
Bankson, H. D., Box 321, Main Office, Arlington, Va.
Bannett, D. R., 436 Fort Washington Ave., New York 33, N. Y.
Bansal, S. K., Marconi School of Wireless Communication, Arbour Lane, Chelmsford, Essex, England
Barna, W. W., Dept. of Physics, Tulane University of Louisiana, New Orleans 15, La.
Barnes, R., Hotel Victoria, Northumberland Ave., London W.C. 2, England
Barsky, H. S., 2420 Bigler Terrace, Philadelphia 45, Pa.
Bellew, R. W., 120 Church St., Newton 58, Mass.
Bessette, R. F., 104 Dunmoreland St., Springfield 9, Mass.
Birnie, A., 711 Churchill Ave., Westboro, Ont., Canada
Bristol, R. W., 155 Perry St., New York 14, N. Y.
Carl, J. E., 4701 E. Broad St., Columbus 9, Ohio
Buchter, T. W., 3408—150 Pl., Flushing, L. I., N. Y.
Cagle, H., c/o Fleet Post Office, New York, N. Y.
Carlson, B. V., 4822 Beech St., San Diego 2, Calif.
Carter, G. W., 5224—11 St. N., Arlington, Va.
Chu, C. C., Union Switch and Signal Co., Swissvale, Pa.
Conrad, E. G., 1759—14 St., Santa Monica, Calif.
Dance, D. W., 201C S. Oyster Bay Ave., Bremerton, Wash.
Das Gupta, S., c/o E. T. Dept., Indian Institute of Science, P.O. Malleswaram, Bangalore, India
Davies, R. J. C., 13, Glanmor Crescent, Swansea, England

(Continued on page 52A)



ML889A

Machlett improved design

provides longer life and better performance

General Characteristics — ML889A

Filament Voltage	11 volts
Filament Current	125 amperes
Amplification Factor	21
Maximum Frequency for Full Power	50 mc.
Capacity, Grid to Plate	17.8 uuf.
Capacity, Grid to Filament	19.5 uuf.
Capacity, Plate to Filament	2.5 uuf.
Cooling	Water
Water	3-6 gals/min.
Air (ML889RA)	15 cfm.

At reduced power, may be operated at frequencies as high as 150 megacycles.

The ML889A and ML889RA are outstanding examples of Machlett's ability to apply its time-tested and advanced techniques to tubes of standard design with resulting improvement in construction, performance and life. They incorporate the "know-how" that has made Machlett electron tubes demonstrably superior since 1897. Consider these advanced features that give you better tubes with longer and more uniform performance:

1. Heavy Kovar sections are used instead of the conventional and more fragile featheredge copper seals. Result—greatly increased mechanical strength, lessening danger of breakage in handling and installation.

2. Filament and grid terminals are solid, continuous and of high conductivity copper. Contact surfaces gold-plated to minimize contact resistance.

3. Special grid and filament assembly reduces lead inductance, permitting safer operation as high as 50 mc. with full input and output.

4. Internal structure greatly strengthened, assuring constant and more uniform grid-filament-plate spacing.

5. One piece copper anode and shield assure uniform internal surface, permit maximum accuracy of assembly, provide complete shielding of anode seal and reduce difficult-to-outgas inter-faces normally found in tubes of this type.

6. All internal parts completely processed by Machlett's special techniques which prevent contamination and assure complete and permanent out-gassing.

7. Tube "pumped" by unique Machlett straight line, high voltage exhaust process assuring same high standards as characterize the Machlett line of high-voltage X-ray tubes.

• • •

These perfected tubes for high frequency heating and communications purposes constitute a further contribution by Machlett of quality, durability and long life to the electron tube art. Now available for initial installation and renewal purposes. For further details, write Machlett Laboratories, Incorporated, Springdale, Connecticut.

ML889RA, Air-cooled version of the ML889A, may be operated at full output at frequencies up to 25 megacycles, at reduced power up to 100 mc.

MACHLETT

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The Institute reserves the right to refuse any announcement without giving a reason for the refusal.

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Primarily in the field of architectural acoustics, who is qualified to determine the acoustical properties of broadcasting and recording studios and to develop new methods and equipment for the measurement of these characteristics. A working knowledge of the acoustical problems associated with microphones and loudspeakers is also necessary.

Applications and requests for interviews should be made in writing to W. B.

(Continued on page 56A)

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(*Continued from page 48A*)

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Dee, H. E., 1931—16 St., N.W., Washington 9, D. C.
DeLany, R. H., 1311 Terminal Tower, Cleveland 13, Ohio
Dewar, H. D., 513 S. Tryon, c/o B. O. Vannort, Charlotte 2, N. C.
Dillow, J. C., 540 N. Ninth St., Corvallis, Ore.
Doolittle, K. H., 6732—35th Ave. S., Seattle 8, Wash.
Dowell, K. P., Western Electric Co., Radio Div., F.E.F., 120 Broadway, New York 5, N. Y.
Elnegaard, E., Baunegaardsvej 2 B, Gentofte, Copenhagen, Denmark
Ely, C. H., 1502 Schantz Ave., Dayton 9, Ohio
Emery, R. C., 166A Maple Ave., Red Bank, N. J.
Fligel, F. J., 1325 N.W. 16 St. Okahloma City 6, Okla.
Fockler, W. G., 91 Paulison Ave., Passaic, N. J.
Fox, B., 268 E. Durard Rd., Philadelphia 19, Pa.
Fredlund, F. A., 1024 E. Second St., National City, Calif.
Freed, R. D., 1140 Fifth Ave., New York 28, N. Y.
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Getting, H. W., Jr., 42 Birch Brook Rd., Bronxville, N. Y.
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Gleimer, B., 1349 Stratford Ave., New York 59, N. Y.
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Hansen, P., Petersborgvej 3B, Copenhagen, Denmark
Harr, F. L., WORD, Spartanburg, S. C.
Hengstler, J. J., 6222 Shadyside Ave., Capitol Heights, Md.
Holmes, D. B., 22 Rose Ave., Madison, N. J.
Hubbert, E. C., 1000 Chestnut St., Philadelphia 5, Pa.
Hutchinson, D. S., 827 Lovett St., London, Ont., Canada
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(*Continued on page 54A*)

"ZIRMET CUTS PUMPING TIME 30%"

Says Taylor Tubes, Inc.

Zirmet Benefits Both Tube Manufacturer and Tube User

Interested in reducing pumping time? Then you'll certainly want to look over these excerpts from a letter sent us by Taylor Tubes, Inc., commenting on their use of Zirmet (Foote Ductile Zirconium)...

"The application of the Zirconium Metal to the fins of the T-125 means that we are able to cut our pumping time by about thirty per cent, and the gettering action while the tube is actually in operation, is very good.

"The type T-125 tube is widely used in diathermy at frequencies up to 70 MC. and of course, in Amateur Radio opera-

Taylor Type 125 Tube for diathermy and radio applications.

tion at the present time, at 28 to 30 MC. We feel that the Metal is most effective in obtaining a higher order of vacuum in

Carbon Anode of Taylor Type 125 Tube. Four pieces of Zirmet 1/16" x 1 1/2" x .005" are welded to the molybdenum fins.

this particular application. It is well worth the small added expense."

Zirmet is literally "what the doctor ordered" and may prove equally effective for you.

Many Advantages for Tube Maker and User

If you are a tube manufacturer, the use of Zirmet as a continuous getter means less pumping time, better vacuum, less shrinkage, clean tubes, and, naturally, satisfied customers. If you are a tube user, you can count on better emission and longer life when you buy a tube containing Zirmet the *continuous getter*.

Investigate Zirmet now. Write or telephone our engineers today for details and prices.

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Kar, D. C., P60B, New Shambazar St., P.O. Shambazar, Calcutta, India

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Kirkman, D., Admiralty Hostel, Wormley, Godalming, Surrey, England

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Konig, V. A. Y., RFD 1, Edgewater Park, Grafton, Wis.

Langgaard, E., Duntzfelts 10, Hellerup, Denmark

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Lillie, C. E., 64 Pheasant Hill St., Westwood, Mass.

Lindstrom, E. B., Forskningsinstitutet for Fysik, Stockholm 50, Sweden

Lorentz, E. F., Commercial Radio Equipment Co., 1319 F St., N.W., Washington 4, D. C.

Lozowick, J. H., 176 Shepard Ave., Newark 8, N. J.

Mardock, R. W., 170 Jackson St., Mineola, N. Y.

Marlow, D. G., 16 Elm St., Garden City, L. I., N. Y.

McLaughland, W. S., c/o Patrick, 4, Mearns St., Greenock, Renfrewshire, Scotland

McManis, L. B., Watson Laboratories, WLMDA, Red Bank, N. J.

McNeese, S. J., 719 Fourth St., Coronado, Calif.

Mitchell, P. P., 1603 Wells Ave., Bakersfield, Calif.

Muhling, C. H., 104 Northwood St., Leederville, Perth, Western Australia

Nachtigall, A. J., 3521 Nichols Ave. S.E., Washington 20, D. C.

Natarajan, R., "Sunder Bavan," Krishnamachary Rd., Cathedral Post, Madras, India

Nixey, W. A., 74 Boullie St., London, Ont., Canada

Occhiogross, T., 84 Barker Ave., Eatontown, N. J.

Overton, B. H., Box 777, Leesburg, Fla.

Paley, W. D., 74 Post Ave., New York 34, N. Y.

Parsons, J. R., 741—51 St., S.E., Washington 19, D. C.

Pascual T., A., Chiloe 5399, Santiago de Chile

Pattee, H. H., 2022 N. Burling St., Chicago 14, Ill.

Pedersen, N. T., Skjoldagervej 24, Gentofte, Denmark

Quealy, O. H., 612 Bank St., Ottawa, Ont., Canada

Richards, T. K., 1700 S. Figueroa, Los Angeles 15, Calif.

Ricker, F. J., 46 Ashford St., Boston 34, Mass.

Rock, K. C., Jr., 215 E. Lake, Fort Collins, Colo.

Roy, K., Flora Cottage, Pabna, Bengal, India

Sadler, W. E., Broadway, Greenlawn, L. I., N. Y.

(*Continued on page 56A*)

Membership

(Continued from page 54A)

Samulon, H., Ottikerstrasse 25, Zurich, Switzerland
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Schwartz, T. F., 30 W. 90 St., New York 24, N. Y.
Seidel, H. W., 247 W. 31 St., Baltimore 11, Md.
Sills, M. M., 56 Featherbed Lane, New York 52, N. Y.
Smith, E. K., Jr., Engineering Dept., Mutual Broadcasting System, 1440 Broadway, New York 18, N. Y.
Spehr, C. J., RFD 1, Box 94, Diller, Nebr.
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Stillwaser, J. 419 S. Darling St., Angola, Ind.
Strouss, W. S., 1010 Oxford Rd. N.E., Atlanta, Ga.
Stultz, L. R., 111 N. 16 St., East Orange, N. J.
Swenson, W. J., 3713 Wheeler Rd., S.E., Washington 20, D. C.
Tang, K. C., Box 28, White Haven, Pa.
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Volger, W. A., 406 Prospect Ave., Hackensack, N. J.
Waller, W. E., 141 Joralemon St., Brooklyn 2, N. Y.
Weller, B. L., Remington Arms Co., Bridgeport, Conn.
Wiesner, L., 118-65 Metropolitan Ave., Kew Gardens 15, L. I., N. Y.
Williams, S. B., 4847 N. 41 St., Milwaukee 9, Wis.
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(Continued from page 50A)

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Chief Managing Engineer to take full charge of a division of a large manufacturing organization. Must have extensive experience in communications field, with substantial background in electronics and micro-wave research and product development. Salary $12,000 to $15,000.

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Can you use this finger-size 10 kw Triode?

Doubtless there are many electronic experimenters and designers working in the intermediate micro-wave range with need for just such a triode. Designed and built by National Union for advanced radar installations, this N. U. 3C37 should prove a "natural" for engineers concerned with instruments for aircraft, navigation, railroads, communication relay transmission and many related applications. Here is the only tube of its kind—a newcomer to electronics, yet an experienced veteran proved under the most rigorous service conditions. There are electronic jobs it can do better than they have ever before been done—problems it can solve for the first time. Why not write us about the N. U. 3C37? Or come to our laboratories and talk it over with a National Union engineer.

Qualifications of the N. U. 3C37

- Delivers 10 KW peak RF power output at frequencies as high as 1150 megacycles.
- Anode and grid dissipation capabilities are adequate to enable the tube to withstand large momentary overloads without damage or distortion of electrical characteristics.
- Internal and external surfaces are silver plated to minimize skin resistance and RF losses.
- Specially constructed radiator greatly reduces RF losses. Permits operation at duty cycles of 1% with air-blast cooling.
- Anode radiator of silver plated copper efficiently transfers heat to any resonator of which it becomes a part.
- Negligible frequency drift due to cylindrical construction and closely controlled mechanical tolerances.
- Maximum mechanical strength.

NATIONAL UNION
RADIO AND ELECTRON TUBES

NATIONAL UNION RADIO CORPORATION • NEWARK 2, N. J.

Why You Should Join The Institute of Radio Engineers

R. C. Poulter

In the October, 1945, issue of *Radio and Appliance Sales*, the following interesting aricle by an active member of the I.R.E. was published. R. C. Poulter, the author, has kindly consented to let us reprint it in its entirety.

The Editor

No engineering society has served the war effort of the United Nations to better advantage than The Institute of Radio Engineers, and none will serve the cause of peace more effectively.

During wartime the membership of I.R.E. rose rapidly as more and more engineers and technicians turned to it as a source of factual information and inspiration. And with the tremendous amount of technical data and knowledge concerning secret wartime developments soon to be released and for which important peacetime applications will be found, the Institute is bound to be the central point through which thousands upon thousands of engineers and technicians will turn for guidance.

Engineers and technicians have two responsibilities which they cannot—must not—shirk. One is to keep themselves fully posted on all important developments in the art of radio communications and electronics. The other is to pass along to others the knowledge which they themselves have gained over the years.

There is only one way in which they can be sure of meeting both of these responsibilities and that is through membership in the I.R.E. and by participating in its activities whenever the opportunity arises.

In the months and years ahead we engineers and technicians in Canada must take full advantage of every facility the Institute has to offer if we are to keep radio and electronics in the front rank of our country's industries.

We owe it to the general public, to our employers, our fellow workers and to ourselves to make sure that we are doing and shall continue to do everything in our power to push this great industry ahead.

Our responsibilities are much greater than most of us realize, and this is particularly true in the "reconstruction period" we are now in. To a very considerable extent, our efforts will influence employment trends. By keeping up public interest in radio and electronics, by developing new and improved products and services we can create a constantly growing demand for the industry's products and thus create more jobs for more men and women.

To accomplish this we must, therefore, keep ourselves fully informed as to what is going on in radio and electronics, and the I.R.E. offers by far the best way of achieving this aim.

The Institute of Radio Engineers is an international body with some 16,000 members scattered over the far corners of the earth. There are active sections throughout the United States, Canada, and the Argen-

(Continued on page 62A)

★ ★ ★

Positions Wanted By Armed Forces Veterans

In order to give a reasonably equal opportunity to all applicants, and to avoid overcrowding of the corresponding column, the following rules have been adopted:

The 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 within a period of one year. 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.

JUNIOR ENGINEER

B.S., age 22. Army experience: Development work on radio proximity fuze. Prefer Midwest or East. Available April. Box 8W.

POSITION WITH STATION

Age 25, single. Two years Signal Corps. First class license with 3½ years commercial indorsement. Experienced in studio and transmitter maintenance. Also audio and equipment design. Box 9W.

ELECTRICAL ENGINEER

B.S.E.E., University of California. Age 25, married. Four years executive experience in research, development, test, and maintenance of electronic and electmech devices. Now Naval Electronics Officer. Available May 1 for manufacturing or consulting firm. Box 10W.

INSTALLATION, TESTING OR CONSTRUCTION

NYU graduate, 1 year experience in Telephone Office, specification writing and DC machinery test, plus 3 years in field engineering and supervision of construction of Airways radio and navigation facilities. Box 11W.

ELECTRICAL ENGINEER

Electrical engineering plus electronics training as Army Officer at Harvard and MIT specializing in radar. Two years' experience on ground radar overseas. Supervised maintenance and repair of radar. I. Ginsberg, 20 Gilmer Street, Mattapan, Mass.

ENGINEER

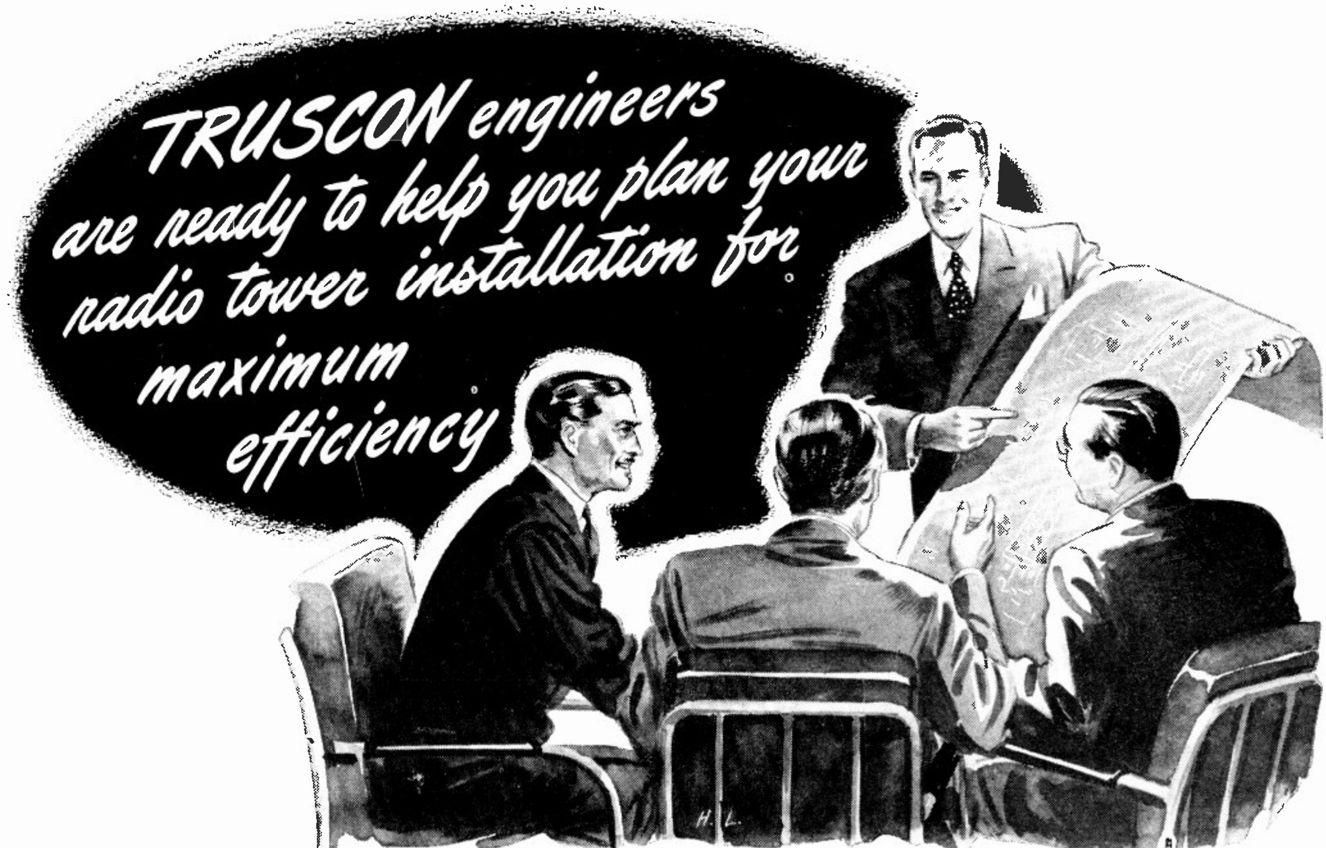
Caltech graduate, with development, test, installation, and administrative experience on instrument landing equipment, radio, and radar, consisting of 1 year industry, 2½ years Signal Corps Officer and 10 years practical radio. Box 2W.

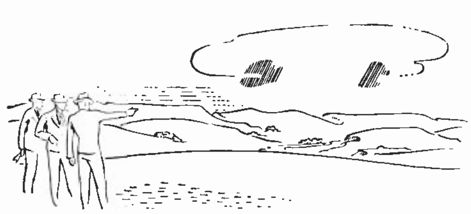
ENGINEER

Engineering graduate, age 38, desires permanent position, executive or administrative responsibilities. 11 years commercial engineering experience on radio and television receivers, signal generators, etc. 5 years' military experience on airborne radio and radar. Box 3W.

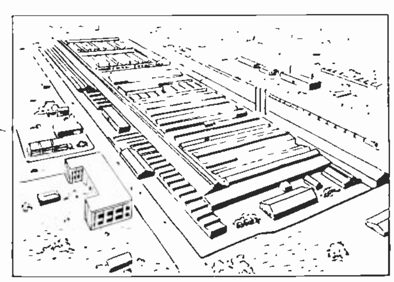
RADIO ENGINEER

Skilled radio engineer located in South Africa desires to join staff of radio factory planned for establishment in that country. Box 5W.

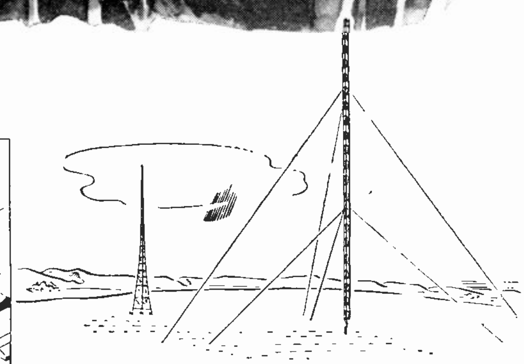




• Truscon engineers will help you select proper types and heights of towers for optimum efficiency.



• Truscon engineers have behind them over forty years of experience in the development and fabrication of steel products.



• Truscon engineers have designed towers to meet each advance in radio broadcast technique.

CALL IN TRUSCON ENGINEERS during the early stages of your plans for antenna installations. Their experience assures satisfactory, trouble free operation today — tomorrow — and during the years to come.

1946 is the year of decision and transition. Truscon can help toward the correct antenna decision — toward orderly and efficient transition to the newest in radio.

Truscon engineering consultation is yours without obligation. Write or phone our home office at Youngstown, Ohio, or any of our numerous and conveniently located district sales offices.

TRUSCON STEEL COMPANY

YOUNGSTOWN 1, OHIO • Subsidiary of Republic Steel Corporation

Manufacturers of a Complete Line of Self-Supporting Radio Towers . . . Uniform Cross-Section Guyed Radio Towers . . . Copper Mesh Ground Screen . . . Steel Building Products.

Why You Should Join The Institute of Radio Engineers

(Continued from page 58A)

tine, which hold regular meetings at which experts in all branches of the art deliver technical papers on the subjects in which they have specialized.

WHAT THE INSTITUTE DOES

1. Holds regular technical meetings.
2. Publishes the PROCEEDINGS OF THE IRE monthly.
3. Establishes standards on definition, test procedure, ratings, nomenclature, symbols, etc.
4. Recognizes outstanding achievements by award of honors.
5. Keeps its members up to date on developments in the radio-and-electronic art.
6. Increases the prestige of its members.

Every radio engineer and technician should be a member!

In Canada we have over 500 members, and there are four sections located in London, Montreal, Ottawa and Toronto. A Canadian I.R.E. Council, founded last year, will serve to co-ordinate the activities of the sections, to serve as a link between Canadian members and the Board of Directors.

The Institute of Radio Engineers was established long before broadcasting came into being. On May 13, 1912, the Institute was formed through the merger of two organizations active in the technical field. One of these was the Wireless Institute, the headquarters of which were in New York City, and the other, known as the Society of Wireless Telegraph Engineers, was located in Boston. It is the object of the Institute to advance the theory and practice of radio and electronics and allied branches of engineers. It includes among its members those who have played prominent parts in the development of radio throughout the world.

An important service which the Institute renders to its members is the publication of technical papers. In addition many papers are presented at Section meetings where discussions may be effective in increasing the knowledge of those present.

The PROCEEDINGS OF THE I.R.E.[1] is the official publication of the Institute and in it are published first-rate technical papers, discussions, communications and news of vital interest to everyone in radio. The PROCEEDINGS appears monthly and constitutes a most valuable reference.

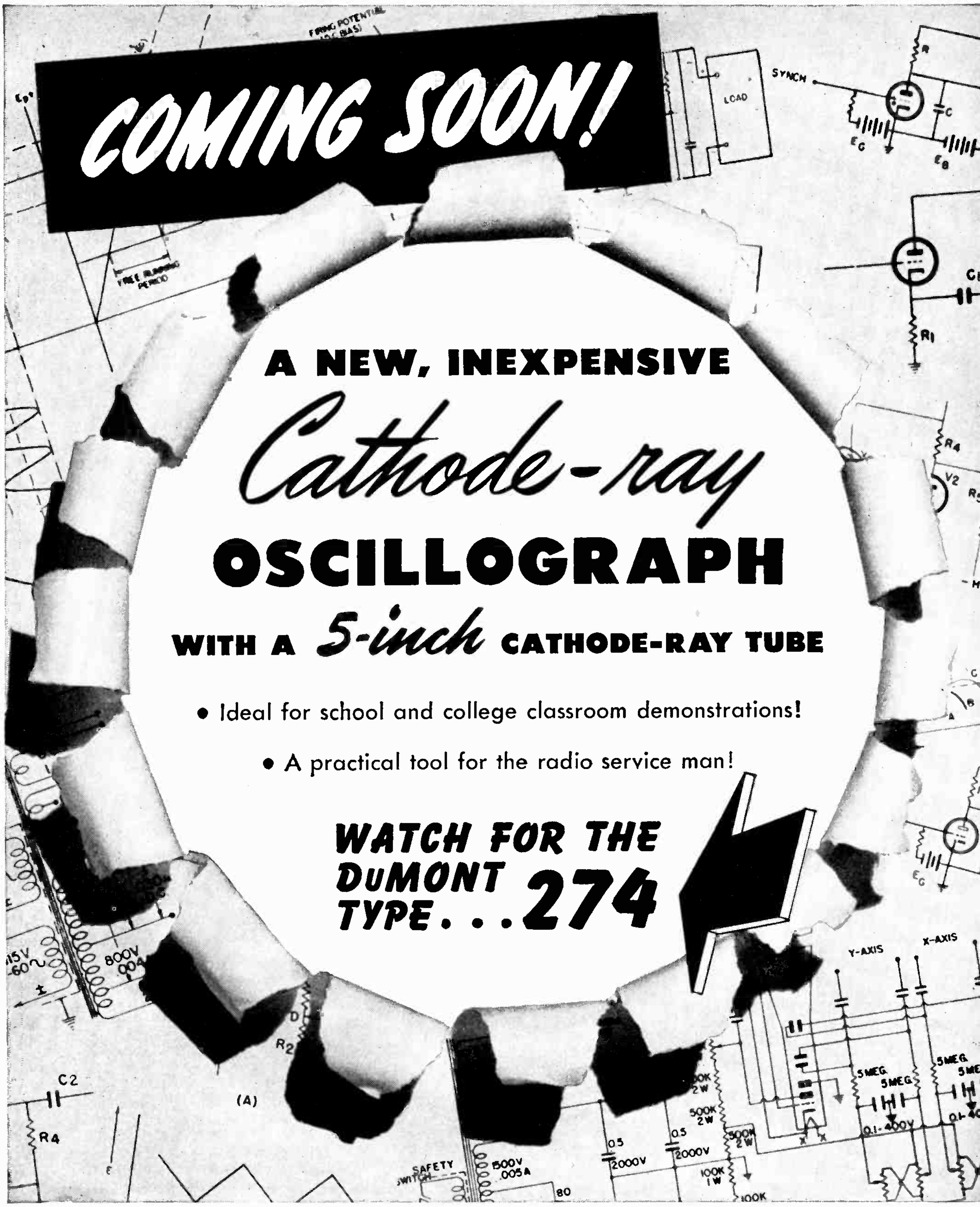
The Institute also publishes Standard reports, the work of its specialized Standards committees, and these establish definite standards for the industry in definitions, test procedure, ratings, nomenclature, symbols, etc.

Yearbooks are published at irregular intervals, eleven editions having appeared so far.

The Institute recognizes each year the outstanding achievements in the radio com-

(Continued on page 68A)

[1] Editor's Note: Since the publication of this article, the name of the official magazine of the Institute of Radio Engineers has been changed to PROCEEDINGS OF THE I.R.E. AND WAVES AND ELECTRONS.



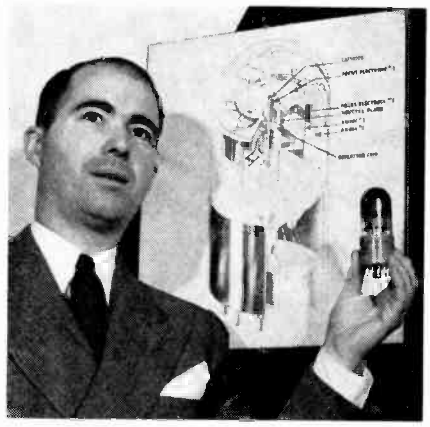
DuMONT Precision Electronics & Television

ALLEN B. DuMONT LABORATORIES, INC., PASSAIC, NEW JERSEY • CABLE ADDRESS: ALBEEDU, PASSAIC, N. J., U. S. A.

News and New Products

William G. Broughton (A'30) with new **General Electric** Phasitron modulator tube to be used in a new and revolutionary simplified circuit in all postwar FM transmitters built by the company. In the background is a sketch showing the internal parts of the tube.

The new circuit and Phasitron tube development are as fundamentally new and important to FM broadcasting as the introduction of crystal control was for AM broadcasting, G.E. engineers say.



"Broadcasters get an added 'bonus' when using the new circuit and tube," G.E. Engineers explain, "because it simplifies transmitter maintenance and operates with fewer tubes and simpler circuits than prewar FM transmitters. For the broadcasting technician" they claim, "it permits direct crystal control using a single crystal; modulation is independent of frequency control; it provides better frequency stability, has less distortion and lower noise level; and the circuit is extremely simple."

Sensitive R. F. Voltmeter announced by **Ballantine Laboratories, Boonton, N. J.** Model 304 is a version of the standard Ballantine Model 300 Electronic Voltmeter, bandwidth the high frequency limit extends to beyond 5 MEGACYCLES. The adoption of the probe type of input connec-

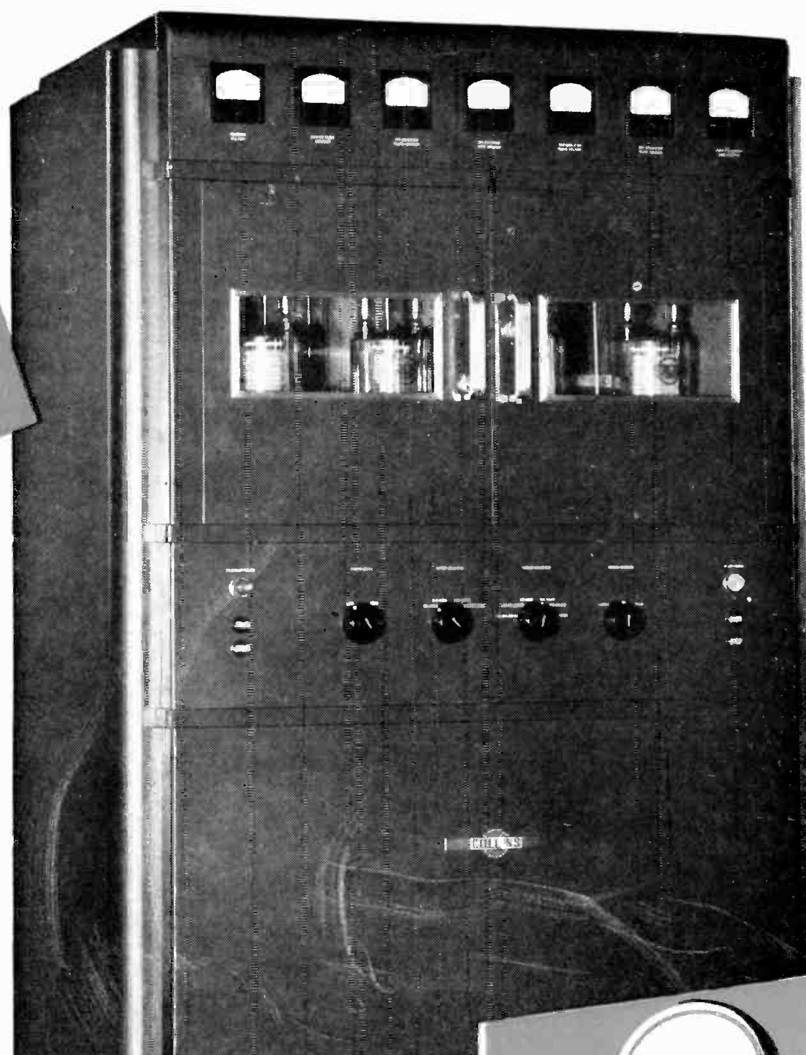
(*Continued on page 66A*)

More output per dollar input!

The highly efficient output network of the Collins 20K AM broadcast transmitter contributes materially to its high operating economy and reliability. Efficient transfer of power from final amplifier to antenna calls for less power input, and therefore less power dissipation in circuit elements. Lower operating cost, greater dependability, and longer component life are the results of ingenious coordination of circuit design, components, and tubes.

Audio frequency distortion, noise level, and audio frequency response are within FCC high fidelity requirements. Stabilized feedback constantly safeguards these excellent performance characteristics under widely varying operating conditions.

Complete metering and motor tuning provide control over all circuits. Power change-over from 1000 watts to 500 watts is instantaneous. Write for further information. Collins Radio Company, Cedar Rapids, Iowa; 11 West 42nd Street, New York 18, N. Y.



COLLINS One Kilowatt 20K Transmitter

FOR BROADCAST QUALITY, IT'S . . . . COLLINS

News and New Products

(Continued from page 64A)

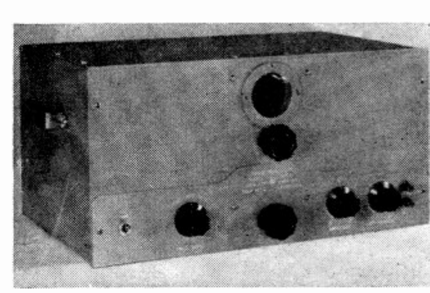
tion assures greatest accuracy of indication at radio frequencies.

The instrument to be described is not intended to replace the standard Model 300 Voltmeter. It fulfills the need for a voltmeter capable of indicating millivolts in television and F. M. intermediate frequency amplifier circuits, R.F. heating apparatus, carrier current systems, etc., wherever sensitivity and low shunting error are required. In such applications it provides reliable indications of the voltages to be measured. Due to component limitations, however, it does not possess the remarkable degree of accuracy of its prototype and where its greater frequency range is not required, should not be considered as equivalent.

The circuit bears a strong resemblance to the original Ballantine voltmeter. Once the applied signal has passed through the cathode follower input stage it is impressed across a resistance attenuator, followed by a 3-stage amplifier and diode rectifier which is characterized by the same feedback system as used in the standard Model 300 Voltmeter. The extension of the bandwidth has been accomplished by the use of higher gain tubes and rearrangement of circuit components to reduce high frequency losses.

The output of the amplifier is separately available through a coaxial type connector, hence permitting visual observation of the input wave on an oscilloscope as well as other applications for such a wide band amplifier. The full gain of this amplifier is approximately 500.

Since the design permits of only a 3-step attenuator, the extension of the voltage range above 1 volt requires the use of multipliers. Two such devices are supplied with each voltmeter so that the instrument then provides the same range as the standard Model 300 Voltmeter, namely .001 to 100 volts. The multipliers are compact units which fit snugly over the probe terminals and simply extend the length of the probe by 1¼ inches. Additional units will be made available in the future which will further raise the voltage limit. These will also provide progressive reduction of shunting loss as the input capacity becomes less for each upward extension of voltage range.



New-hp-Model 201B AF Oscillator is offered by **Hewlett-Packard, Inc., Palo Alto, California.** In FM and other fields where high fidelity is important, this new

(Continued on page 69A)

for any type of application

BLILEY has the crystals

Bliley CRYSTALS

To name all the engineers who "consult Bliley first" on frequency control problems would make a mighty impressive list.

They know from experience that Bliley engineers are always working in advance of the industry's requirements, and that the right crystal for their particular application will be available without undue delay.

That is why Bliley acid etched* crystals persistently show up wherever important developments are taking place in the communications field—and go with those developments to all parts of the globe.

Your products, too, will benefit if you make it a habit to "consult Bliley first" on frequency control problems. There's over 15 years of quartz crystal engineering experience at your beck and call.

* *Acid etching quartz crystals to frequency is a patented Bliley process.*

For complete listing of Bliley crystals now available see Bulletin P-27

BLILEY ELECTRIC COMPANY • UNION STATION BUILDING, ERIE, PENNSYLVANIA

Why You Should Join The Institute of Radio Engineers

(Continued from page 62A)

munications and electronic fields by the bestowal of its Medal of Honour and the Morris Liebmann Memorial Prize.

Membership in the Institute is open to engineers, technicians and executives. Membership is divided into several grades, each with its particular requirements, privileges, and dues. With the exception of Fellow grade, one may apply for admission to any grade for which he is qualified.

Fellow grade is awarded as an honor to those who have made outstanding contributions to the science or technology of radio and allied fields.

The grade of Senior Member is for the professional engineer of considerable achievement and is the highest grade for which application may be made.

The grade of Member is for the professional engineer who does not meet the high requirements of the Senior Member grade, either in years or professional achievement. Members have the same rights and privileges as Senior Members.

Those who are not qualified for Member grade may apply for Associate grade for which an interest in electrical communications and a good character are the only requirements. Associates receive the publications of the Institute and may attend its meetings.

The Student grade permits a college student studying for an engineering degree, to obtain the PROCEEDINGS and attend meetings at the lowest possible cost.

News and New Products

(Continued from page 66A)

-hp- Model 201B Audio Frequency Oscillator is designed to meet every requirement for speed, ease of operation, accuracy and purity of wave form.

The 201B has an accurate, convenient method of frequency control. The 6″ dial, with smooth-ball-bearing action, may be tuned by a directly controlled knob, or for still greater accuracy, may be set by the vernier which has a ratio of 6 to 1 to the main dial. The illuminated main dial is designed so that parallax is eliminated. It is calibrated over 300 degrees with approximately 95 calibration points and has an effective scale length of about 47 inches. Frequency range is 20 cps to 20 kc.

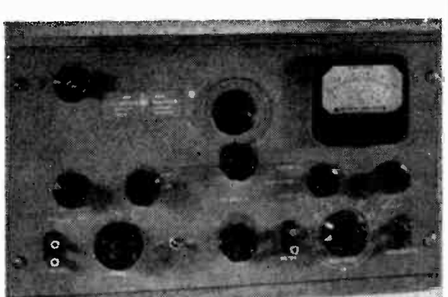
Increased Power Output: The amplifier delivers up to 3 watts of power into a 600 ohm resistance load, with distortion held to 1%. Thus there is sufficient power available for driving almost any kind of laboratory or production equipment. Harmonic distortion may be kept to less than ½ of 1%, if the output of the amplifier is limited to 1 watt.

Provision is made for standardizing each frequency range against a reliable standard.

Dual Control for Output Level: A volume control which is ahead of the amplifier controls the voltage at which the amplifier operates. An output attenuator is provided to attenuate the signal delivered by the amplifier. Attenuation is approximately linear from zero to 40 db. Both hum level and output voltage are thus attenutated together. As a result it is claimed that hum level may be kept 60 db. or more below the signal level, a special advantage in cases where small test signals are used.

The impedance looking back into the output circuit is about 50 ohms; thus the voltage regulation for varying loads is extremely good.

Improved chassis layout and placement of component parts minimizes thermal drift. The voltage on the oscillator is maintained constant with an electronic voltage regulator. The entire instrument is characterized by greater rigidity; the tuning assembly is mounted on a sturdy cast aluminum frame. The chassis itself is made of aluminum; the oscillator is light in weight and easy to handle.



New -hp- Model 330B Distortion Analyzer is announced by **Hewlett-Packard, Inc., Palo Alto, California.** This resistance-tuned circuit is used in conjunction with an

(Continued on page 70A)

News and New Products

(Continued from page 69A)

amplifier to provide many new advantages. The Model 330 B is claimed to be capable of measuring distortion at any frequency between 20 cps and 20,000 cps. It will make noise measurements of voltages as small as 100 microvolts. A linear r-f detector makes it possible to measure these characteristics directly from a modulated r-f carrier. The convenience of operation, high sensitivity, accuracy, stability, and light weight of the 330 B are its designed values for broadcast, laboratory, and production measurements.

In audio work the Model 330B measures distortion at any frequency between 20 cps and 20,000 cps! Thus an instrument which completely covers the audio spectrum is available for "total" distortion measurements.

The circuit of Model 330B consists of a linear r-f detector, a frequency-selective amplifier, a vacuum-tube voltmeter, and regulated power supply.

The voltmeter section of the instrument consists of a two-stage high-gain amplifier, a rectifier, and an indicating meter. A large amount of negative feedback is employed to insure stability and a uniform response from 10 cps to 100,000.

New Sound Pressure Measurement Standard

. . . . . is announced by **Massa Laboratories, Inc., 3686 Carnegie Ave., Cleveland 15, Ohio.** The Massa Model M 101 Sound Pressure Measurement Standard is claimed to be a precision acoustic instrument developed for making absolute sound pressure measurements throughout the audible frequency range without appreciably disturbing the sound field. The basic ideal requirements of high mechanical impedance, small physical size, wide dynamic range, and flatness of response are the objective of this unit. The vibrating system is stiffness-controlled to well beyond 30 kc, which results in a pressure sensitivity independent of frequency throughout the entire audible range. Its rugged design, and wide dynamic range, makes this standard also usable for the quantitative investigation of extremely high sound pressures, such as are encountered in the measurement of gun-blast waves.

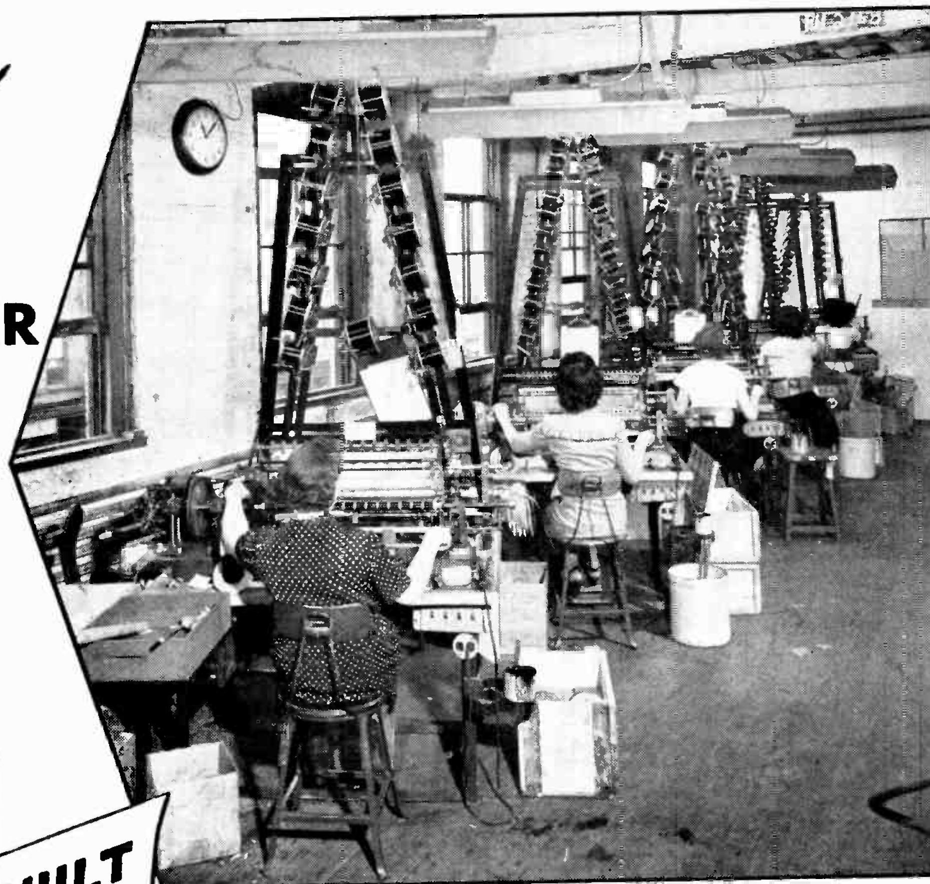
Applications:

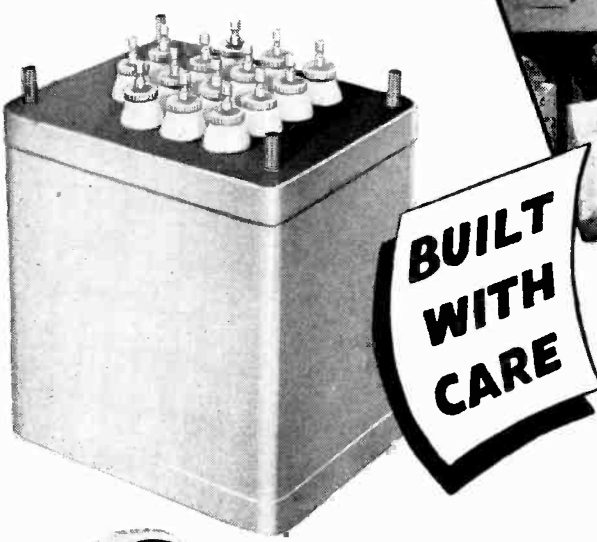
The Model M 101 Standard has been developed for all uses where accurate sound pressure measurements are to be made over a wide audio-frequency range. The mechanical system is linear to sound pressures of several million dynes/cm^2, permitting measurements over an extremely wide dynamic range. In addition to its conventional laboratory use in the calibration of sound fields, the unit is claimed to be ideal for many other types of acoustic measurements.

A technical bulletin is available upon request, giving a more complete description of the new standard.

(Continued on page 72A)

Every AMERTRAN TRANSFORMER *is* BUILT WITH CARE





Advantages of multiple coil winding

Coil winding is an important phase of AmerTran Transformer construction. Use is made of high speed multiple winding machines (some of AmerTran design) capable of producing many coils at a time with exceptional uniformity. Care enters the picture in the precise control with which such elements as number of turns, tightness of layers and wire tension are maintained. Tight coils have fewer and smaller air pockets, and greater heat-conducting capacity. AmerTran coil winding methods add up to close conformity to specifications, uniformly excellent characteristics, and usually a consumer saving for a specific type and quality of transformer.

Products:

Audio Transformers and Reactors. Modulation Transformers (to 500 KVA). Hermetically sealed Transformers. Plate and Filament Transformers. Filter Reactors. Wave Filters. High Voltage Rectifiers. Microphone and Interstage Transformers. Transtat A. C. Voltage Regulators. Other Electronic and Industrial Transformers.

AMERICAN TRANSFORMER COMPANY
178 EMMET STREET
NEWARK 5, N. J.

AMERTRAN
REG. U. S. PAT. OFF.
MANUFACTURING SINCE 1901 AT NEWARK, N. J.

Pioneer Manufacturers of Transformers, Reactors and Rectifiers for Electronics and Power Transmission

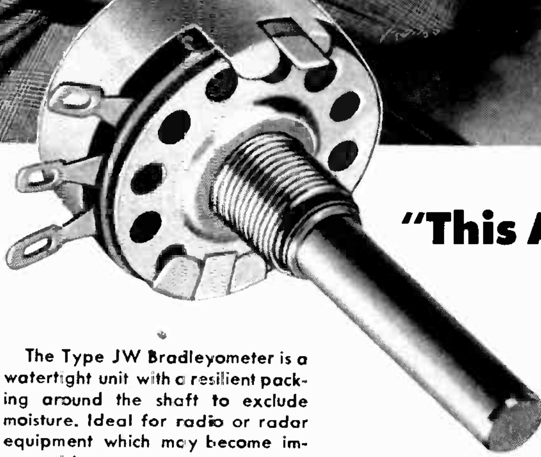
News and New Products

(Continued from page 70A)

Shown at the Sixth Annual Broadcast Engineering Conference

. . . . . by **Radio Engineering Laboratories, Inc.** REL Mo del 518A-DL 1 KW. FM Broadcast Transmitter, 88/108 mc. left picture is front view with doors and panels removed. Notethat all controlsandswitches are operated from the front of transmitter. Large scale meters are provided in an inclined position for easy reading by operator. The multiplier chassis shown in vertical position at left is the final panel of the Armstrong Dual Channel Direct Crystal Controlled Modulator. This is equipped with quick opening catches and quick opening hinges so that chassis may be swung open for inspection and servicing or entirely removed if necessary. All adjustable tuning controls are provided in the vertical panel at the right. The P.A. grid, P.A. plate, antenna, tuning controls, as well as crystal vernier are equipped with counters for assistance in proper tuning. The Crystal Vernier control enables the operator to adjust to center frequency by reference to a Frequency and Modulation Monitor which is also manufactured by REL. The wheel shown is a Variac controlling all filaments. In the center may be seen the P. A. chamber in which high power is fully isolated from other circuits. Between the P.A. lines, the antenna bazooka can be seen. In the lower right hand corner of the P.A. chamber is located the high frequency vacuum tube volt meter for antenna line RF indication. At the bottom of the cabinet, the blower with connection to plate lines is shown. The blower is claimed to be of more than sufficient size and capacity to provide cooling to all parts of the equipment.

Right side view with doors and panels removed showing large scale meters, front end controls, and switches. Also note that the power controls and power supply located in the right side are on vertical chassis which are hinged, providing complete accessibility of components and chassis wiring. This view also shows main transmitter wiring which runs entirely through vertical and horizontal ducts allowing ease of repair or replacement of connection in the equipment.



"This A-B Adjustable Resistor can provide any resistance-rotation curve"

The Type JW Bradleyometer is a watertight unit with a resilient packing around the shaft to exclude moisture. Ideal for radio or radar equipment which may become immersed in water.

The resistor of the Type J Bradleyometer is a solid molded ring. During manufacture, the resistor material is varied throughout the circumference of the molded ring to provide the desired resistance-rotation characteristic.

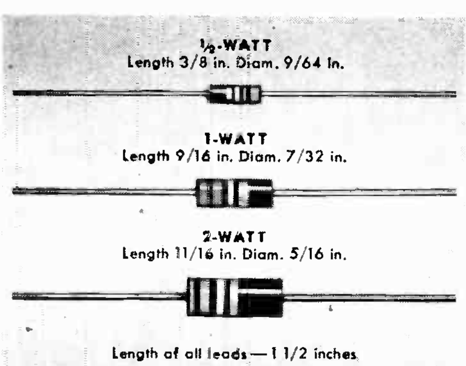
It is not a film or paint type resistor. Therefore, after molding, the resistance curve of the Bradleyometer is unaffected by heat, cold, moisture, or length of service.

The resistor unit is molded as a one-piece ring with terminals, face plate, and threaded bushing imbedded in the ring. The contact brush improves with age.

Type J Bradleyometers can be supplied in single, dual, triple unit construction for rheostat or potentiometer applications. A built-in line switch is optional. Complete specifications will be sent on application.

Allen-Bradley Company, 114 W. Greenfield Ave.,
Milwaukee 4, Wis.

ALLEN-BRADLEY FIXED RESISTORS



Bradleyunit Fixed Resistors are available in ½-watt, 1-watt, and 2-watt ratings in all RMA standard values from 10 ohms to 22.0 megohms.

A-B Quality

ALLEN-BRADLEY

FIXED & ADJUSTABLE RADIO RESISTORS

QUALITY

Professional Cards

ADVERTISER'S INDEX

FM radio receivers are more static-free and less costly—thanks to research at RCA Laboratories.

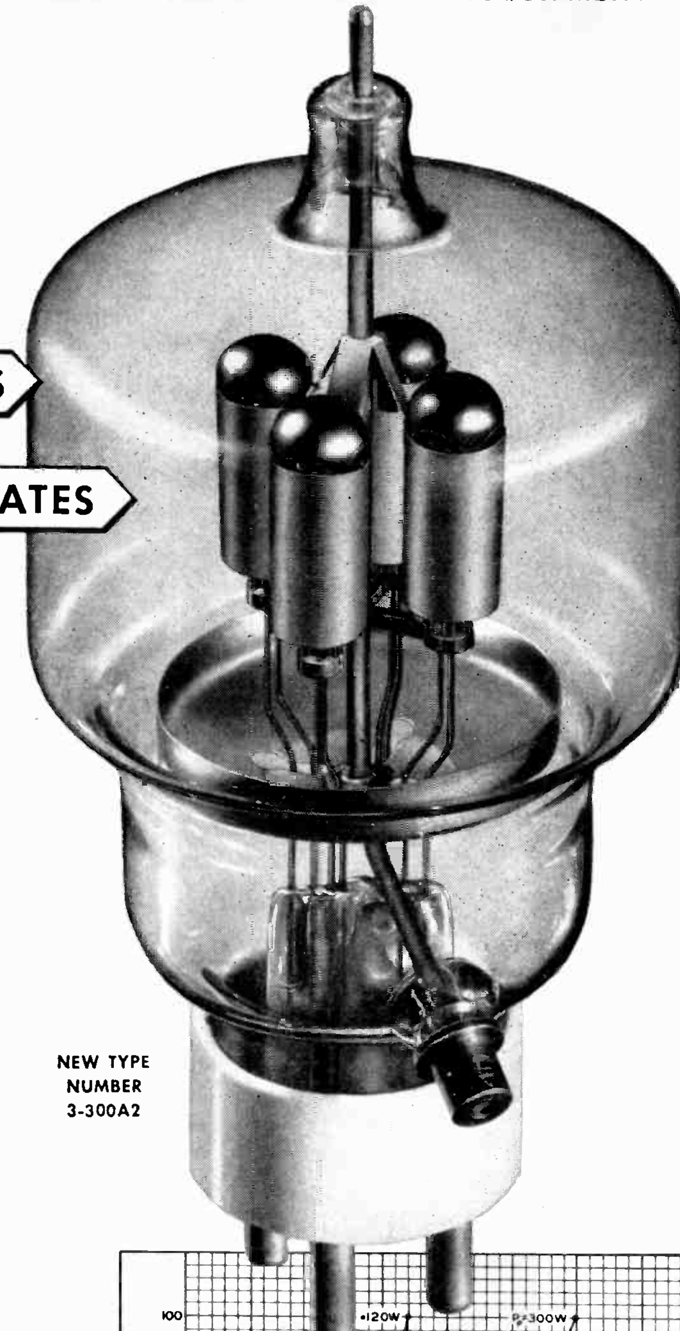
Stuart William Seeley, Manager of the Industry Service Laboratory, RCA Laboratories Division, perfected this new FM circuit. It not only operates equally effectively with strong or weak stations, but lowers the cost of receivers by eliminating additional tubes and parts that were formerly considered necessary in Frequency Modulation receivers.

Eimac TUBES — THE COUNTERSIGN OF DEPENDABILITY IN ANY ELECTRONIC EQUIPMENT

HERE IS A RADICALLY IMPROVED VERSION OF THE EIMAC MULTI-UNIT 304TL TRIODE

NEW NON-EMITTING GRIDS

NEW LOW-TEMPERATURE PLATES

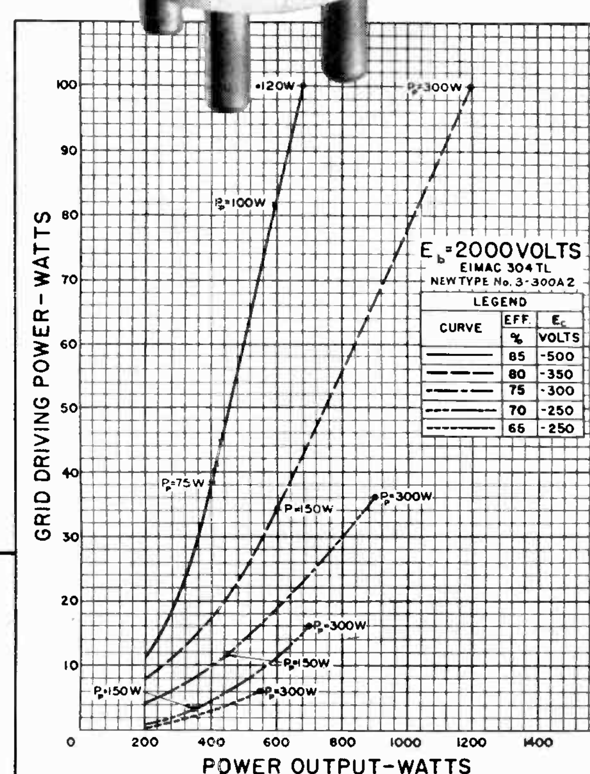


NEW TYPE NUMBER 3-300A2

The Eimac Multi-Unit triode 3-300A2 pictured above is a radically improved version of the original 304TL which has been establishing outstanding performance records for a number of years in both civilian and military equipment.

The use of Eimac developed, non-emitting grids, contributes greatly to its already high stability, efficiency and long life, and the new type plates enable it to operate at much lower temperatures.

One of its outstanding characteristics is its ability to handle high current at relatively low voltages. For example: as a class-C amplifier the Eimac 3-300A2 will handle 1200 watts plate input with only 2000 volts on the plate. Under these conditions, the tube will deliver a power output of 900 watts, with a driving power of only 36 watts. The chart at right shows driving power requirements vs. power output. The symbols P_p indicate plate dissipation. Further information will be promptly supplied without cost or obligation.



ELECTRICAL CHARACTERISTICS

Filament: Thoriated tungsten		
Voltage	5.0 or 10.0	volts
Current	25.0 or 12.5	amperes
Amplification Factor (Average)		12
Direct Interelectrode Capacitances (Average)		
Grid-Plate		9.1 uuf
Grid-Filament		8.5 uuf
Plate-Filament		0.6 uuf
Transconductance (I_b=1.0 amp., E_b=3000, e_c=−200)		16,700 umhos

FOLLOW THE LEADERS TO Eimac REG. U. S. PAT. OFF. TUBES

EITEL-McCULLOUGH, INC., 1176-J San Mateo Ave., San Bruno, Calif.

Plants located at: San Bruno, Calif., and Salt Lake City, Utah

Export Agents: Frazar and Hansen, 301 Clay St., San Francisco 11, Calif., U. S. A.

CALL IN AN EIMAC REPRESENTATIVE FOR INFORMATION

ROYAL J. HIGGINS (W9AIO)...600 S. Michigan Ave., Room 818, Chicago 5, Illinois. Phone: Harrison 5948.

V. O. JENSEN, General Sales Co., 2616 Second Ave., Seattle 1, Washington. Phone: Elliott 6871.

M. B. PATTERSON (W5CI)...1124 Irwin-Kessler Bldg., Dallas 1, Texas. Phone: Central 5764.

ADOLPH SCHWARTZ (W2CN)...220 Broadway, Room 2210, New York 7, N. Y. Phone: Cortland 7-0011.

HERB B. BECKER (W6QD)...1406 S. Grand Ave., Los Angeles 15, California. Phone: Richmond 6191.

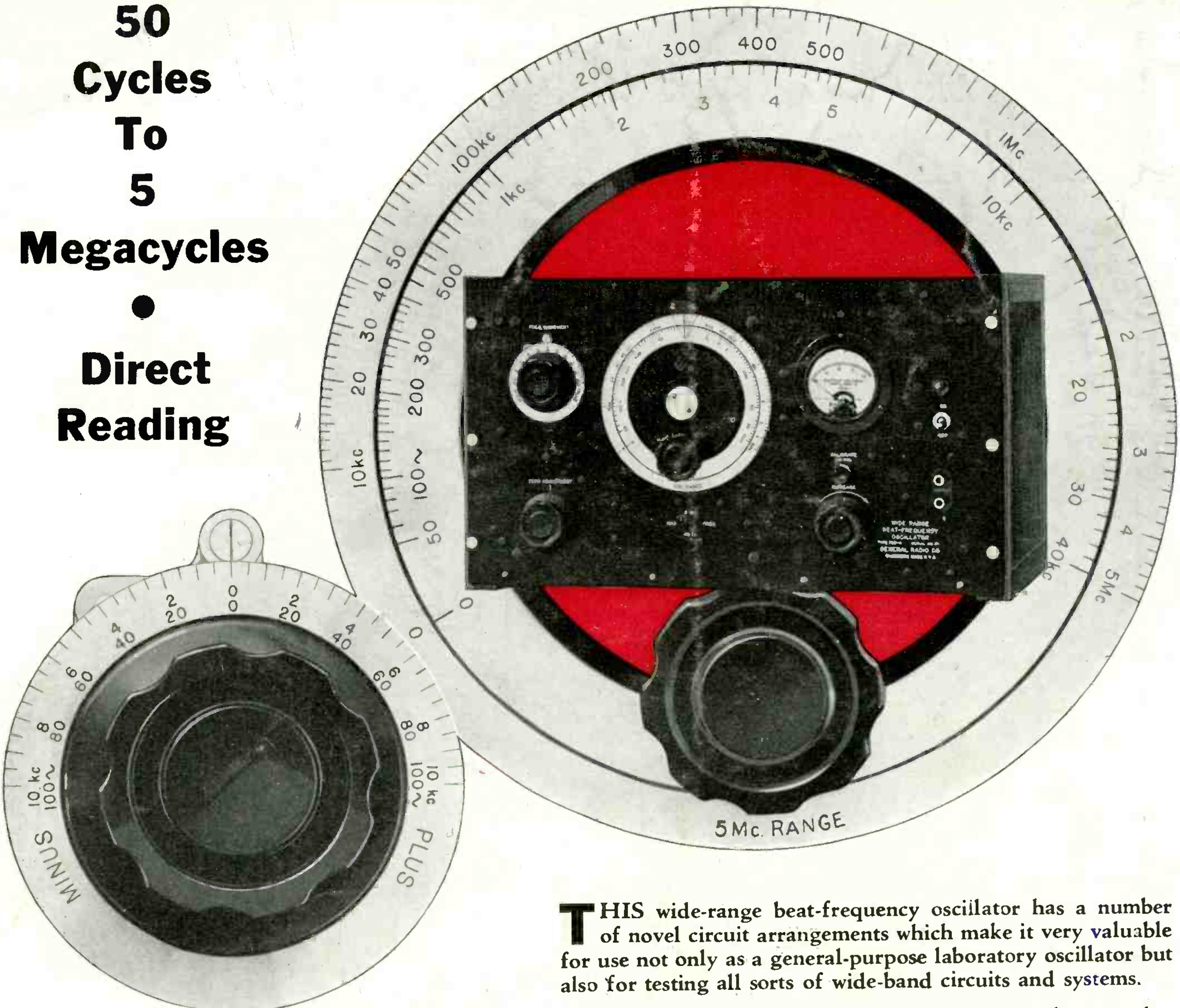
TIM COAKLEY (W1KKP)...11 Beacon St., Boston 8, Massachusetts. Phone: Capitol 0050.

CAUTION! Look for the latest serial numbers on Eimac Tubes. Be sure you get the newest types.

50 Cycles To 5 Megacycles

●

Direct Reading



FREQUENCY CONTROL AND CALIBRATION

The main dial is direct reading on two approximately logarithmic scales for 50 cycles to 40 kilocycles and 10 kilocycles to 5 megacycles. The incremental frequency control (above) is calibrated between —100 and +100 cycles and —10 and +10 kilocycles for the two respective ranges. Any frequency change made with this dial is added algebraically to the reading of the main dial.

The calibration may be standardized at any time, by setting the instrument to zero beat with the zero adjustment, to within 5 cycles on the low range and 500 cycles on the high range.

Write for Bulletin 989 for Complete Data

THIS wide-range beat-frequency oscillator has a number of novel circuit arrangements which make it very valuable for use not only as a general-purpose laboratory oscillator but also for testing all sorts of wide-band circuits and systems.

1 The wide ranges are obtained with a single control knob and a two-position range selector switch

2 The output voltage, by means of an a-v-c circuit, is held constant with ±1.5 decibels over the entire range

3 Frequency drift is held to a very small value through carefully designed thermal distribution and ventilation systems

4 Any small drift remaining may be eliminated by re-setting the oscillator to zero beat

5 A degenerative amplifier minimizes hum and distortion and also equalizes the frequency response

6 The output voltage is measured by a vacuum-tube voltmeter across the output terminals

7 One output terminal is grounded

For taking selectivity curves on tuned circuits over a wide range of frequencies this oscillator is especially useful in that these measurements may be made very rapidly and accurately through its use.

TYPE 700-A WIDE-RANGE BEAT-FREQUENCY OSCILLATOR $555.00

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