Proceedings of the I·R·E

A JOURNAL 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 •

JUNE, 1945

Volume 33 Number 6

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The Institute of Radio Engineers

Proceedings of the I·R·E

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THE INSTITUTE OF RADIO ENGINEERS

INCORPORATED

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ATLANTA	CHICAGO	CLEVELAND	DETROIT	LOS ANGELES
September 21	September 21	September 20	September 21	September 18
NEW YORK	**PHILADELPHIA**	**PITTSBURGH**	**PORTLAND**	**WASHINGTON**
September 5	September 6	September 10	September 10	September 10

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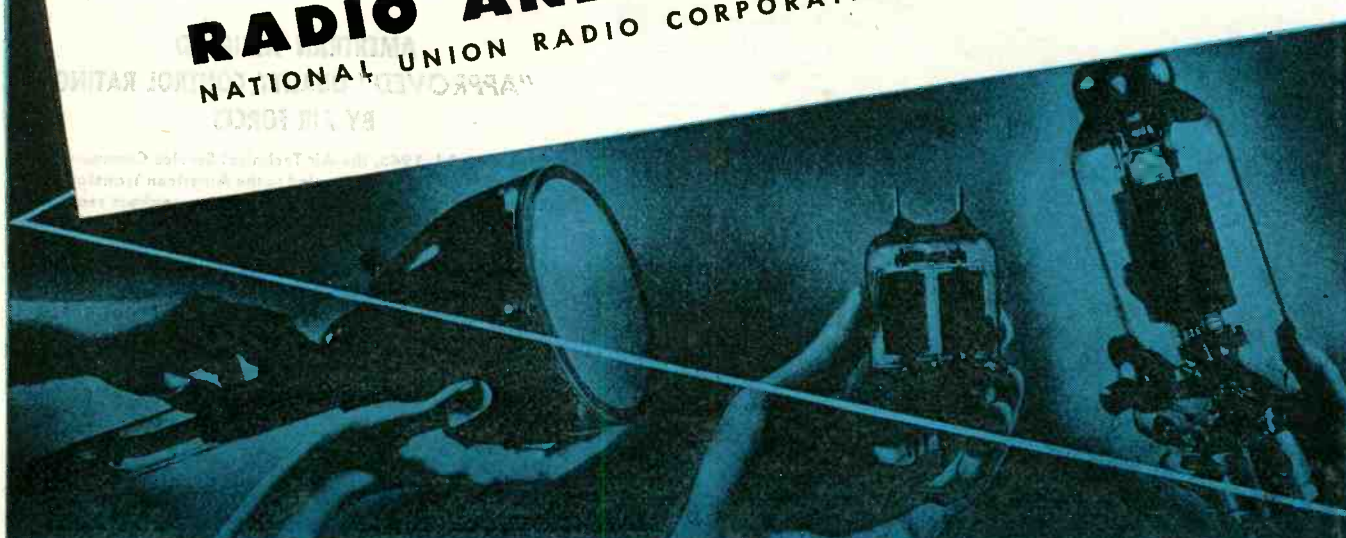
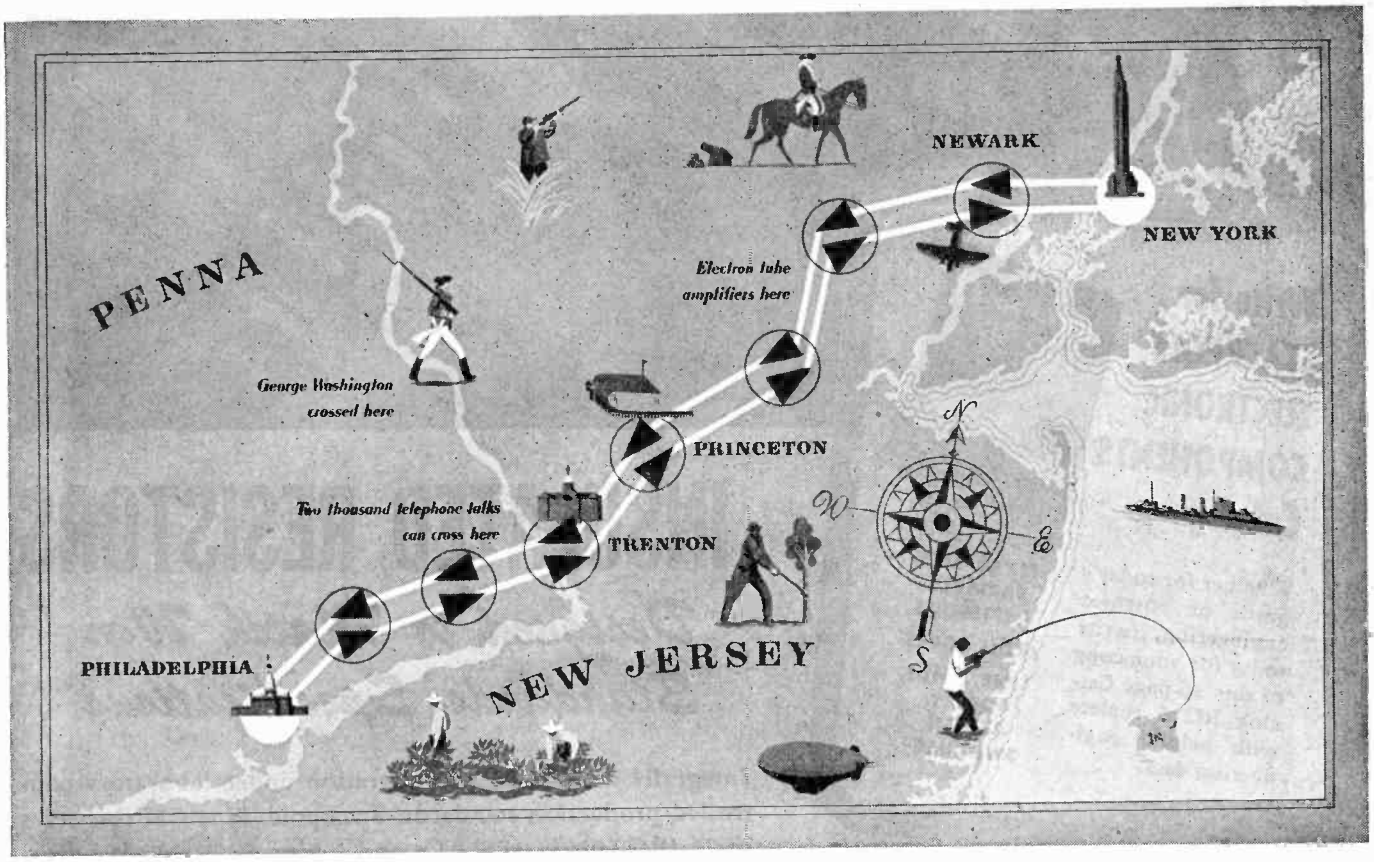


90-MILE LABORATORY

for Telephone and Television



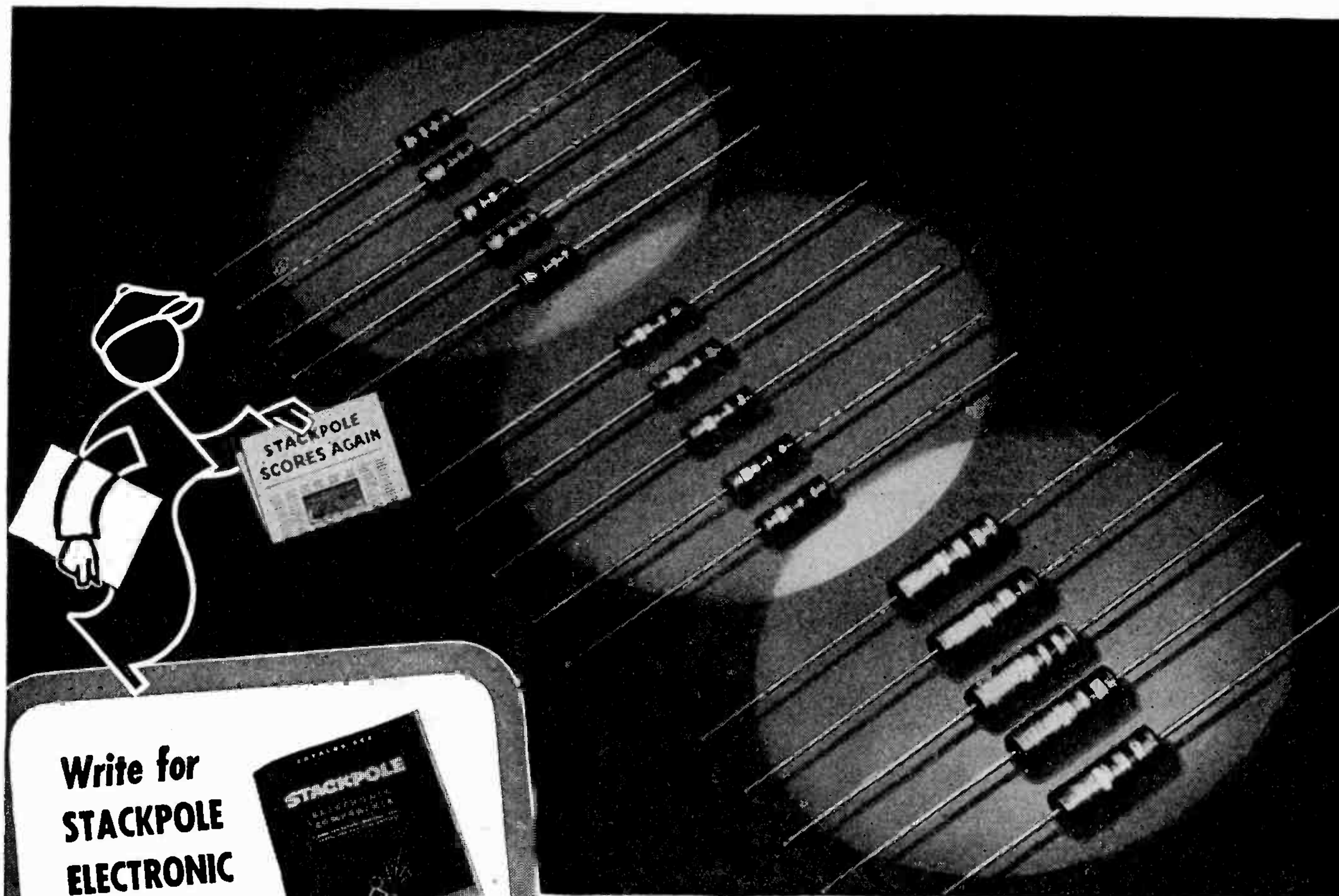
BETWEEN telephone offices in New York and Philadelphia once stretched a strange sort of laboratory. Most of the way it was underground; engineers made their measurements sometimes in manholes. It was a lead-sheathed cable containing two "coaxials" — each of them a wire supported in the center of a flexible copper tube the size of a lead pencil.

Theory had convinced engineers of Bell Laboratories that a coaxial could carry many more telephone talks than a full-sized voice frequency telephone cable; that it could carry adequately a television program. Experimental lengths were tested; terminal apparatus was designed and tried out. Finally, a full-sized trial was made with a system designed for 480 conversations. It was successful; in one demonstration people talked over a 3800-mile circuit looped back and forth. Now the cable is carrying some of the wartime flood of telephone calls between these two big cities.

This cable made television history also: through it in 1940 were brought spot news pictures of a political convention in Philadelphia to be broadcast from New York. Bell System contributions to television, which began with transmission from Washington to New York in 1927, have been laid aside for war work. When peace returns, a notable expansion of coaxial circuits is planned for both telephone and television in our Bell System work.

BELL TELEPHONE LABORATORIES

Exploring and inventing, devising and perfecting for our Armed Forces at war and for continued improvements and economies in telephone service.



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Designed to Match War Standards Specifications

Integrally molded in one operation under laboratory controlled production standards, Stackpole Type CM Resistors in ⅓-(RC-10): ½-(RC-21): and 1-watt (RC-30) sizes have been specifically designed to meet the newly issued Army-Navy specifications. The construction of these new resistors is such that they offer an exceptional degree of stability under load—the average change being less than 5% after 1000 hours under test at full load. In addition to having highly satisfactory humidity characteristics well within today's exacting requirements, Stackpole Type CM Insulated Resistors meet up-to-the-minute salt water immersion specifications.

Samples to any required tolerance on request.

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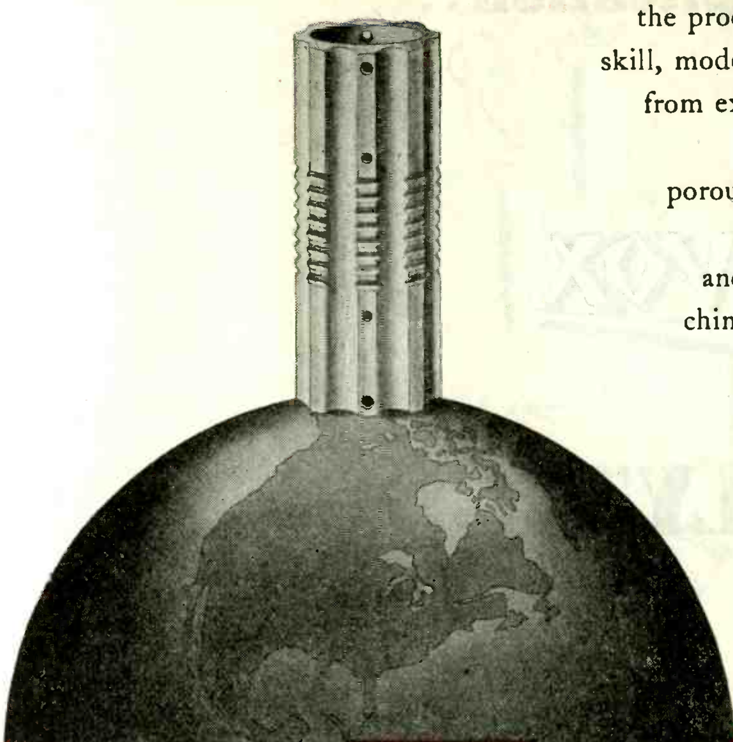
± OR + QUALITY

It's not wise to think that all Steatite Ceramic Insulators are equivalent in quality. From selection of materials through the processes of mixing, extrusion or stamping; on through the kiln to final inspection, the production of a high grade Steatite Insulator requires experience, skill, modern tools and machinery, plus the KNOWHOW that comes from extensive research and development.

Inferior Steatite Insulators may be produced. They may be porous or underkilned or overkilned.

Backed by 43 years of Ceramic Leadership, constant research and development, highly trained workers, the most modern machinery and production methods, AlSiMag has fully earned its reputation as "Tops Among the Steatites". Whatever you are planning in the electrical or electronic field, we believe our specialized knowledge will be helpful.

Let's work together.



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ARMY NAVY

TOPS IN STEATITE CERAMICS

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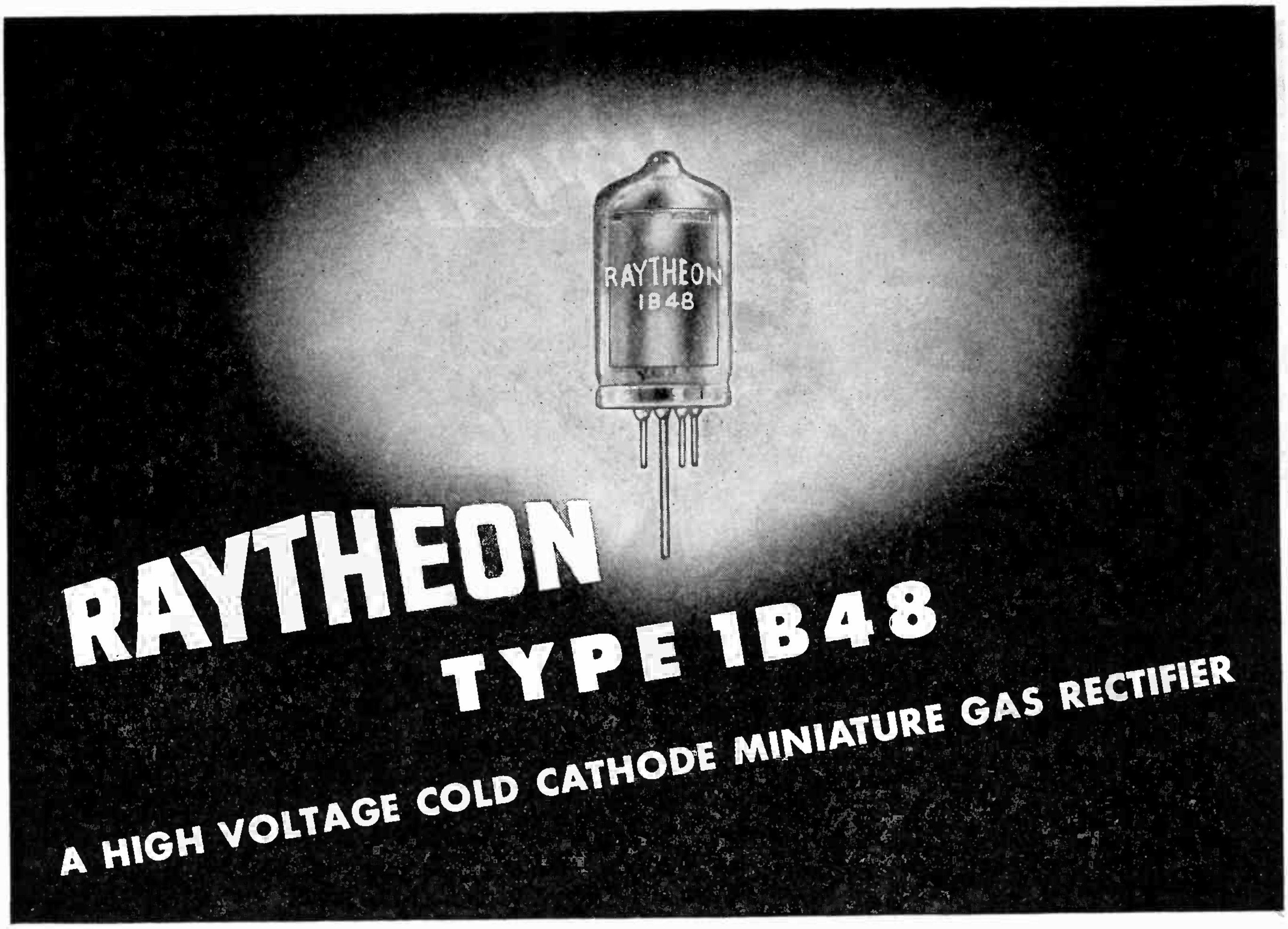


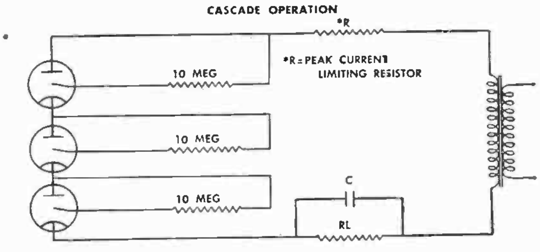
● There are many applications in which a high DC voltage, at a relatively low current, must be obtained in a minimum space and with maximum power efficiency.

If tubes necessitating a heater voltage supply are used, the space and weight requirements of a filament transformer insulated to withstand high potentials—and the additional power consumption—are often detrimental factors. Numerous oscilloscope applications are in this category.

Thus there is often a real need for a small modified miniature type cold cathode gas rectifier like the 1B48—which can easily deliver 1000 volts DC at 6 milliamperes average current. Furthermore, several tubes may be operated in series to obtain even higher voltages.

Shown below are the physical and electrical features of the 1B48. The schematic diagram indicates cascade operation in a half wave circuit. Full wave rectification may be accomplished in the conventional manner.

This Raytheon tube represents just one more entry in Raytheon's record of tube development . . . a continuing engineering program that is making possible still finer tubes for *your* postwar products.



SPECIFICATIONS OF 1B48

PHYSICAL:		
Maximum Over-all Length	2-1/4	inches
Maximum Seated Height	1-9/16	inches
Maximum Diameter	3/4	inches
ELECTRICAL:		
Maximum Peak Inverse Voltage	2700	volts
Maximum Peak Plate Current	50	ma
Average DC Voltage Drop at 6 ma	100	volts
Maximum DC Output Current	6	ma
Minimum Peak AC Starting Voltage	800	volts
Maximum Starter Anode Current	100	µa

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Newton, Massachusetts • Los Angeles • New York • Chicago • Atlanta

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Every Saturday Night
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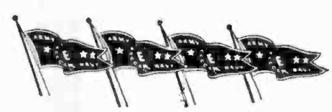


All Four Divisions Have Been Awarded Army-Navy "E" With Stars

DEVOTED TO RESEARCH AND THE MANUFACTURE OF TUBES AND EQUIPMENT FOR THE NEW ERA OF ELECTRONICS

Why Western Electric equipment leads the way!

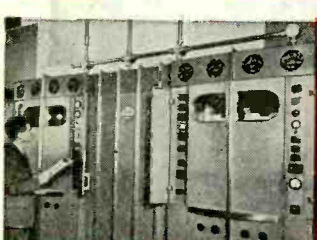
1. Western Electric products are designed by Bell Telephone Laboratories—world's largest organization devoted exclusively to research and development in all phases of electrical communication.

2. Since 1869, Western Electric has been the leading maker of communications apparatus. Today this company is the nation's largest producer of electronic and communications equipment.

3. The outstanding quality of Western Electric equipment is being proved daily on land, at sea, in the air, under every extreme of climate. No other company has supplied so much equipment of so many different kinds for military communications.

As you probably know, many of the electronic marvels of this war have been made possible by the successful harnessing of Super High Frequencies. The scientists at Bell Telephone Laboratories have taken a leading part in this work with MICROWAVES.

The devices they have designed have been built in vast quantities by Western Electric. In this work, Western Electric has added greatly to its fund of spe-



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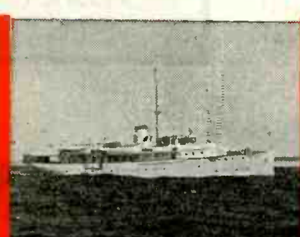
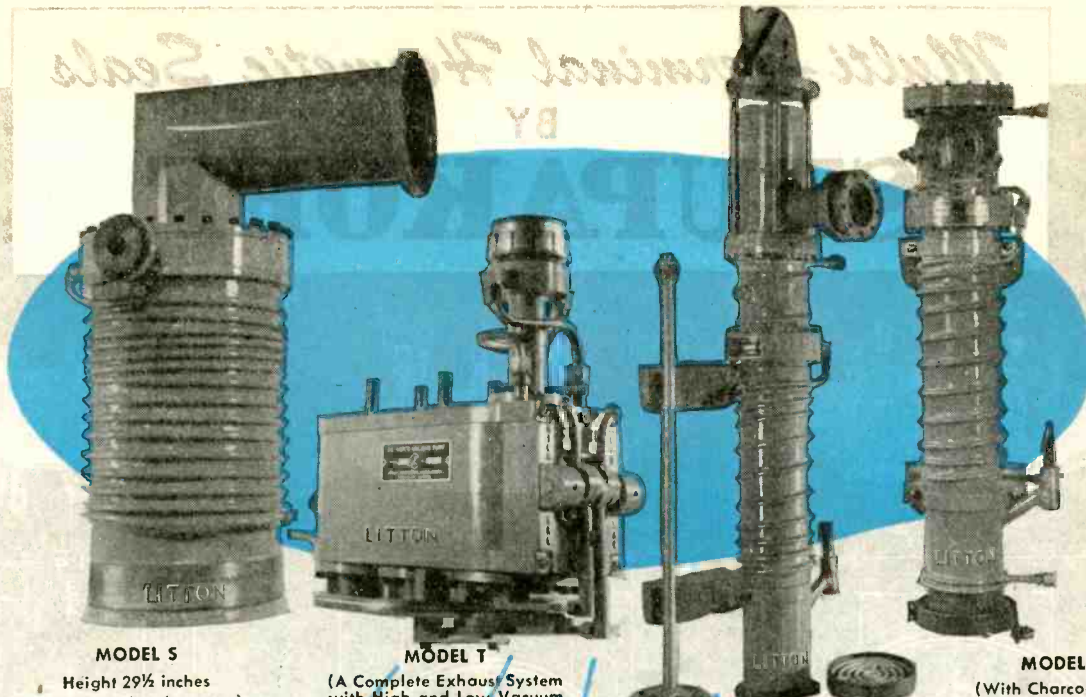


MARINE RADIO

AVIATION RADIO

MOBILE RADIO

Western Electric has specialized



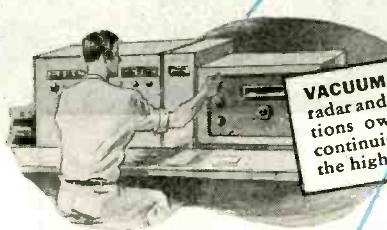
MODEL S
Height 29½ inches
Weight 100 lbs. (approx.)

MODEL T
(A Complete Exhaust System with High and Low Vacuum Valve and Charcoal Trap)
Height 11⅛ inches
Weight 12½ lbs.

MODEL R
(With Valve and Charcoal Trap)
Height 38¼ inches
Weight 40 lbs.

MODEL P
(With Charcoal Trap)
Height 24⅞ inches
Weight 31 lbs.

What you may expect from LITTON



VACUUM TUBES for radio, radar and other communications owe their existence, continuing improvement to the high vacuum pump.

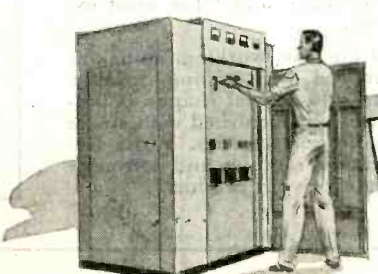
HIGH VACUUM has made possible the efficient processing of penicillin, foods, vitamins, etc.

LABORATORY RESEARCH in many fields to create new and useful products requires the use of high vacuum.

OIL VAPOR VACUUM PUMPS. Litton All Metal Vapor High Vacuum Pumps are specifically designed to serve a wide variety of high vacuum uses such as manufacturing all types of vacuum and gas filled tubes . . . heat treating and vacuum casting of metals . . . petroleum industrial applications . . . processing of pharmaceuticals and chemicals. Litton pumps serve scientists and technicians who today are creating tomorrow's world of induction heating, electronic controls and other wonders.

Designed by engineers experienced in high vacuum installation for many years, Litton pumps reach their maximum efficiency in a very short time. Their sturdy, compact structure insures lower installation costs, higher vacuum and longer life. The easily demountable boiler and charcoal baffle and the low cost, lasting Litton Molecular Lubricant provide greater economies in operation and maintenance.

Litton Engineering service is available for all high vacuum installations or problems. Catalogs will be furnished upon request.



Many metals and alloys used in warfare and modern industry are refined under high vacuum.

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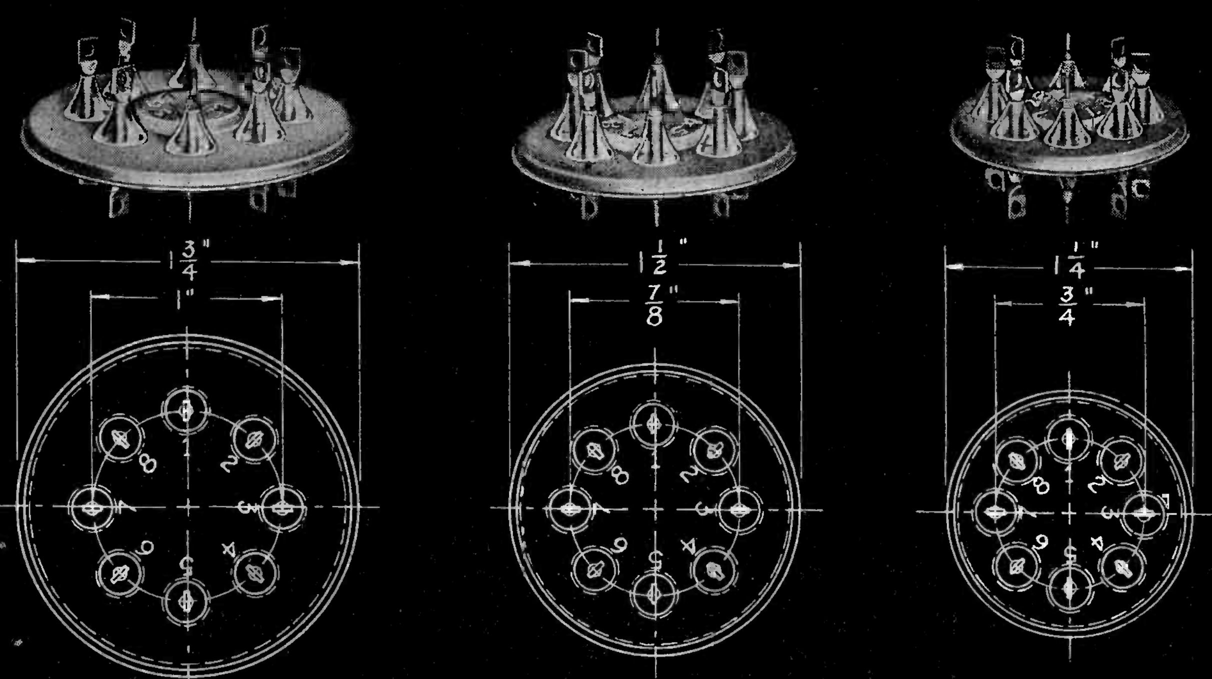
ENGINEERING LABORATORIES
REDWOOD CITY, CALIFORNIA, U. S. A.

Multi-Terminal Hermetic Seals

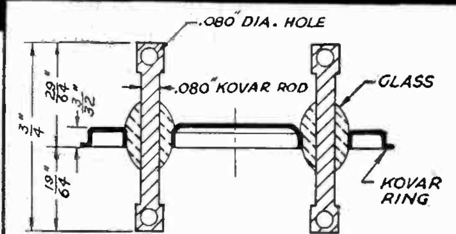
BY

STUPAKOFF



PART 9093-3A PART 9093-2A PART 9093-1A

ALSO AVAILABLE IN STYLE B WITH 4 INSTEAD OF 8 TERMINALS AS SHOWN.
4 OR 8 TERMINALS STANDARD—OTHERS ON SPECIAL ORDER



CONSTRUCTION DETAIL

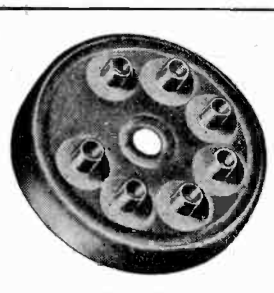
VERTICAL DIMENSIONS SHOWN COMMON TO ALL PARTS

THE Stupakoff Multi-Terminal Hermetic Seals illustrated were developed primarily for transformer application. They offer exceptional advantages to manufacturers concerned with the sealing of electrical components.

Each seal is individually tested to withstand a minimum pressure of 30 pounds—electrical breakdown of 3400 volts—insulation resistance of 500 megohms—thermal shock from 94° C to 4° C. Relatively low in initial cost, the one piece construction eliminates individual soldering of terminals, resulting in lower handling and assembly costs, fewer rejects in the finished product.

Stupakoff hermetic seals are made with the alloy, Kovar,* which matches the expansivity of certain hard glasses from −80° to +450° C (approximate annealing point of the glass). Through a heating process, the oxide of Kovar is dissolved into the glass to form a perfect bond—effective under the most extreme climatic conditions.

For users equipped for glass working, Stupakoff supplies Kovar as sheet, rod, wire, tubing, or fabricated into cups, eyelets, and special shapes. Completed seals in many styles are furnished with single or multiple, solid or hollow electrodes. Write Department K-56 for literature, samples, and deliveries on positive hermetic seals for your product.



ONE PIECE HEADER

Stupakoff pioneered in the construction of Multi-Terminal Hermetic Seals. The illustration at left is taken from Technical Data Sheet KV 7 published by Stupakoff in May 1937.

*TRADE MARK 337962 REGISTERED IN U S PATENT OFFICE

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Another New "AMPEREXTRA" for Designers of Industrial Equipment

AMPEREX 235-R

R. F. POWER AMPLIFIER AND OSCILLATOR

The AMPEREX 235-R is a forced-air cooled triode, particularly well suited for high-frequency industrial use. Characteristics of the grid have been given especial attention so that operation to full output may be obtained at comparatively low plate voltages. This is an advantage which should merit the interest of industrial equipment designers now working on postwar products. Built into the 235-R, of course, are those notable ***"Amperextras"*** which give ***Amperex*** tubes peak performance over a greater period of working life.

GENERAL CHARACTERISTICS

Filament: Voltage	14.5-15.0 Volts	**Direct Interelectrode Capacitance (approximate)**	
Current	39.0 Amperes	**Grid to Plate**	9.0-$\mu\mu f$
Amplification Factor	14.0	**Grid to Filament**	10.0-$\mu\mu f$
Grid to Plate Transconductance @ 500 ma.	6500 Micromhos	**Plate to Filament**	1.5-$\mu\mu f$

Write for Additional Information

ARMY NAVY

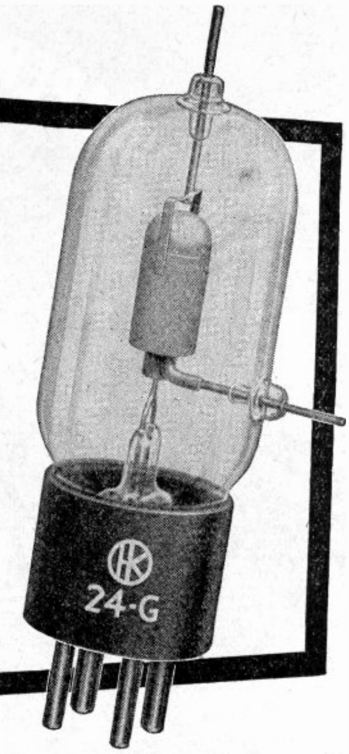
AMPEREX
the high performance tube

NOTE: The more popular types of ***Amperex*** tubes are now available through leading radio distributors.

AMPEREX ELECTRONIC CORPORATION
79 WASHINGTON STREET • • • • • • BROOKLYN 1, N. Y.
Export Division: 13 E. 40th St., New York 16, N. Y., Cables: "Arlab"

You haven't done everything you can . . . until you've donated a pint of your blood to the Red Cross Blood Bank

These 22 *Gammatron* types are being standardised by HEINTZ AND KAUFMAN LTD.



Heintz and Kaufman Ltd. is coming to the aid of equipment designers and manufacturers by standardizing the physical and electrical characteristics of 22 types of Gammatron tubes. These types will conform to Joint Army-Navy Specifications, where applicable.

So design your circuits around these Gammatrons—with the assurance that they will always meet the same high standards, and always be readily available, thus making unnecessary the problem of redesigning equipment because of changes or variations in tube types.

14 TRIODES

TUBE TYPE	PLATE DISSIPATION
HK-24	25 watts (Grid lead to base)
HK-24G	25 watts (Grid lead through envelope)
HK-54	50 watts
HK-254	100 watts
HK-354C	150 watts (Low Amplification Factor)
HK-354E	150 watts (High Amplification Factor)
HK-454L	250 watts (Low Amplification Factor)
HK-454H	250 watts (High Amplification Factor)
HK-654	300 watts
HK-854L	450 watts (Low Amplification Factor)
HK-854H	450 watts (High Amplification Factor)
HK-1054L	750 watts
HK-1554	1000 watts
HK-3054	1500 watts

1 PENTODE

HK-257B Plate Dissipation, 75 watts (Beam pentode)

4 RECTIFIERS

HK-253	Inverse Peak Volts, 15,000
HK-953B	Inverse Peak Volts, 30,000
HK-953D	Inverse Peak Volts, 75,000
HK-953E	Inverse Peak Volts, 150,000

3 IONIZATION GAUGES

VG-2 VG-24G VG-54

REPLACEMENT *Gammatron* TUBES

The following Gammatrons will be made available primarily for replacement use. Design engineers are asked to consider recommended standardized types when designing new equipment.

REPLACEMENT TUBE TYPE	DESCRIPTION	RECOMMENDED STANDARDIZED TUBE TYPE
HK-354	Triode, grid lead to base pin, ratings same as HK-354C	HK-354C HK-454L HK-454H
HK-354D	Triode, Medium Amplification Factor	HK-354C or E HK-454L or H
HK-354F	Triode, High Amplification Factor	HK-354E
HK-257A	Beam Pentode	HK-257B
HK-153	High Vacuum Rectifier, inverse peak volts, 5000	HK-253
HK-54S	Triode. Same as HK-54 except fil. current is 3.35 instead of 5 amps.	HK-54
HK-2054A	Triode	
HK-2054B	Triode	

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Gammatron Tubes

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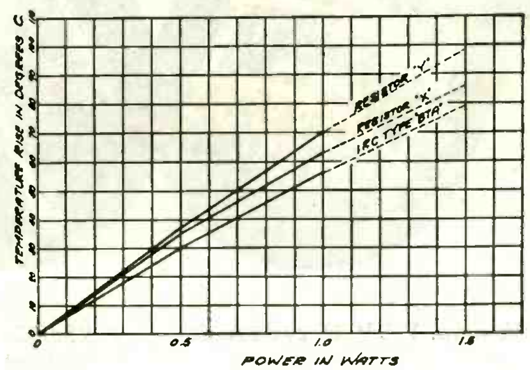
NO. 3 IN THE IRC NEW PRODUCT PARADE

IRC *is ready with...*

THE NEW BTA RESISTOR



Lowest Temperature Rise ➧

Like all BT Resistors, the operating temperature of the new BTA is *lower* than other resistors of comparative size!

Only the extreme pressure of essential war production has delayed our release of this small one-watt AWS RC 30 type *insulated* resistor. You'll find the BTA insulated resistor a worthy and important addition to the BT family. Built to meet American War Standards specifications, the BTA is only 0.718 inches long and 0.250 inches in diameter. Wattage rating, 1 Watt at 40° C ambient. Voltage rating, 500 volts. Minimum range, 330 ohms. Maximum range, Standard: 20 megohms.

Write today for comprehensive bulletin containing engineering data and charts. Address Dept. 10-F.

IRC

INTERNATIONAL RESISTANCE CO.

401 NORTH BROAD STREET PHILADELPHIA 8, PA.

IRC makes more types of resistance units, in more shapes, for more applications than any other manufacturer in the world.

NOTE: ALL CURRENT SHIPMENTS OF IRC BT AND BW RESISTORS ARE *FUNGICIDE TREATED*

Centralab

Medium Duty Power Switches

- 7½ amp. 115 V. 60 cycle A. C.
- Voltage breakdown 2500 V to ground D. C.
- Solid silver contacts
- 25,000 cycles of operation without contact failure
- Fixed stops to limit rotation
- 20° indexing

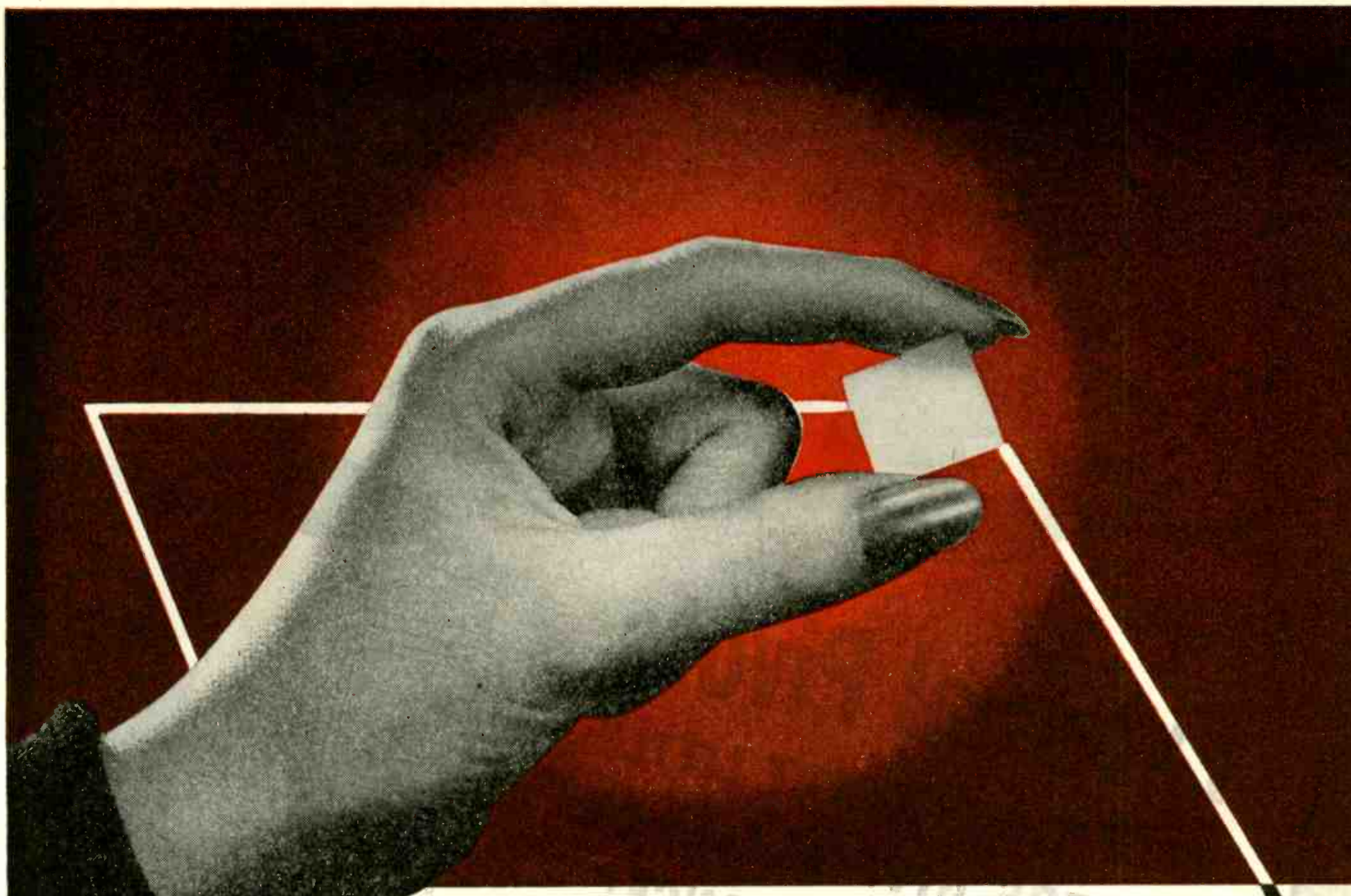
Centralab medium duty power switches are now available for transmitters (has been used up to 20 megacycles) power supply converters and for certain industrial and electronic uses.

It is indicated in applications where the average Selector Switch is not of sufficient accuracy or power rating. Its accuracy of contact is gained by a square shaft, sleeve fit rotor, and individually aligned and adjusted contacts. It is assembled in multiple gangs with shorting or non-shorting contacts. Torque can be adjusted to suit individual requirements. Furnished in 1 pole . . . 2 to 17 positions (with 18th position continuous rotation with 18th position as "off"); and 2 or 3 pole . . . 2 to 6 position including "off".

Centralab

Division of GLOBE-UNION INC., Milwaukee

PRODUCERS OF Variable Resistors • Selector Switches • Ceramic Capacitors • Fixed and Variable • Steatite Insulators and Silver Mica Capacitors



FITTING THE KEY TO THE LOCK

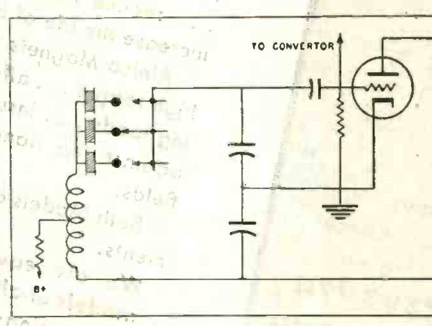
Deriving the most from frequency control and selection circuits employing quartz crystals calls for a recognition of the fact that a crystal is also a circuit element and, as such, is influenced by and in turn influences other circuit characteristics. It is a case of fitting the key to the lock.

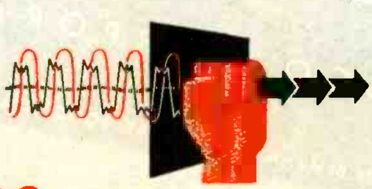
The interdependence of crystal and tube in any circuit application poses design problems that are common to the crystal engineer, the tube engineer and the circuit engineer. Solutions are more readily arrived at by a pooling of specialized knowledge.

As manufacturers of crystals *and* tubes, the North American Philips Company has an intimate knowledge of both. Our engineers are therefore particularly well equipped to coöperate with circuit design engineers in any application problems involving the use of crystals. As an example, the circuit shown at right was suggested by our crystal applications laboratory as one means of employing crystal control in a push-button tuned receiver.

Although the armed forces have first call on our crystal production facilities, we invite inquiries from manufacturers interested in the utilization of low-cost precision quartz crystals for industrial and commercial applications. A booklet "How Quartz Crystals are Manufactured" is available on request.

Crystal-controlled oscillator circuit for push-button tuned receivers, using the series resonance of the crystal as the control factor. No adjustment is required over a frequency range as great as 2 to 1.



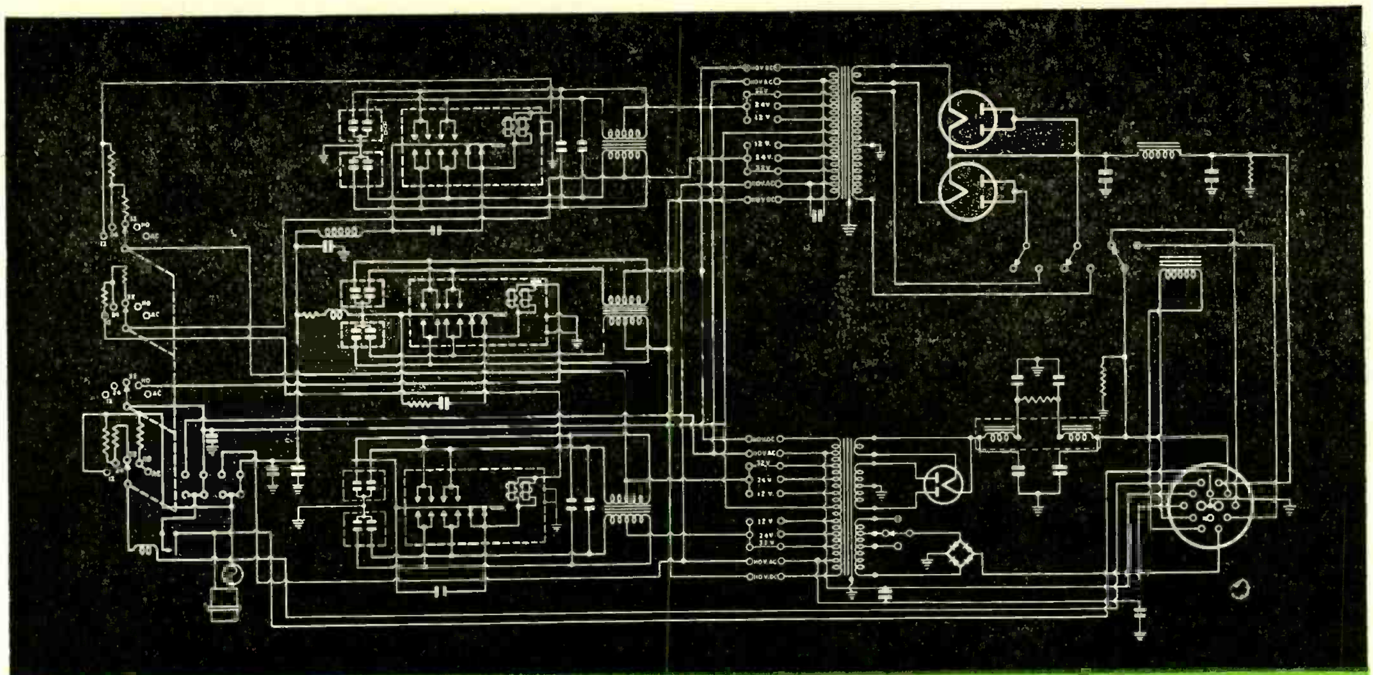


OTHER PRODUCTS: Amplifier, Transmitting, Rectifier and Cathode Ray Tubes; Searchray (Industrial X-ray) Apparatus; X-ray Diffraction Apparatus; Medical X-ray Equipment, Tubes and Accessories; Tungsten and Molybdenum products; Fine Wire; Diamond Dies. ●We invite you to visit our office and showroom when in New York City.

Norelco Reg. U. S. Pat. Off. *Electronic Products by* **NORTH AMERICAN PHILIPS COMPANY, INC.**

Dept. L-6, 100 East 42nd Street, New York 17, N. Y.
Factories in Dobbs Ferry, N. Y.; Mount Vernon, N. Y. (Metalix Div.); Lewiston, Maine (Elmet Div.)


External Pivots
HELP THESE GREAT LITTLE METERS GIVE A LOT OF EXTRA PERFORMANCE!
These two hermetically sealed 1½" DeJur Instruments — the Model 120 (right) and the Model 112 (left) — designed to aid in the development of small equipment for present and post-war applications, combine miniature size with the accuracy resulting from external pivot design.
External pivots used in both models, help provide better all-round performance because: external pivots provide maximum accuracy in mounting the moving element between the jewel bearings . . . prevent rocking of the pointer . . . reduce side friction between jewels and pivots . . . increase the life of bearing surfaces.
Alnico Magnets of the highest grade permit the use of high torque . . . afford instantaneous response under varying loads . . . insure stability . . . and provide protection against the damaging effect of surrounding magnetic fields.
Both Models are available either as D.C. or A.C. Instruments.
We are equipped to work with you on special models of all DeJur Products for present and postwar applications. Write for the latest DeJur catalog.
External pivots (above)—used in the design of DeJur 1½" Meters — provide greater accuracy in mounting the moving element between the jewel bearings. For this reason internal pivots (below) are not used in DeJur meters.
GIVE YOUR FULL SUPPORT TO THE SEVENTH WAR BOND DRIVE
ARMY E NAVY
DeJUR-AMSCO CORPORATION
GENERAL OFFICE: NORTHERN BLVD. AT 45th STREET, LONG ISLAND CITY 1, N. Y.



E·L DEVELOPMENTS PROVIDE MULTIPLE INPUTS AND OUTPUTS IN VIBRATOR POWER SUPPLIES

● Electronic Laboratories has greatly increased the flexibility of power supply design and versatility of power conversion circuits, through special new developments during the war period. One of these, resulting from intensified research to meet military needs, is vibrator power equipment capable of delivering various voltages, currents and frequencies from a variety of input voltages. This naturally has vastly broadened the field for vibrator power conversion equipment.

The typical circuit diagram shown above illustrates a multiple input and output system. This power unit is designed to be operated from either 12, 24, or 32 volts from storage batteries, or 110 volt DC or AC power lines. Various outputs are available to supply the high voltage plate current required for the grid, and the AC voltages suitable for operation of the filaments. In addition, a source of alternating current power for the operation of the automatic tuning system which is incorporated in this unit, has been provided. There is a current division system associated with the contacts of the vibrators and the circuit is so designed that the phase displacement provides equivalent performance of a two-phase rectifier system, assuring low hum level with a minimum amount of filter.

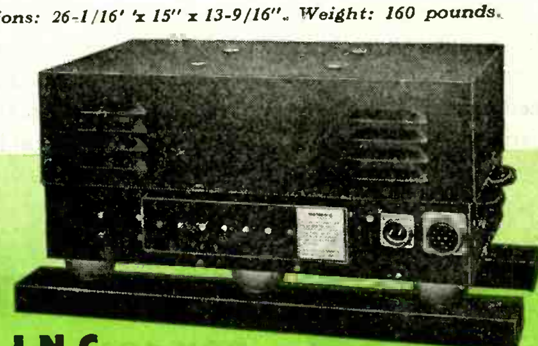
During the war period, E·L has designed many other similar units having a multiplicity of input and output voltages. In addition to DC sources, in many cases, AC sources of any frequency between 18 and 180 cycles have been made available to meet specific engineering problems.

The requirements for power equipment reach into many fields as war born inventions are applied to postwar needs. E·L Vibrator Power Supplies will have wide application because they are the most economical, efficient and versatile means of solving the many power supply problems that will arise. Electronic engineers will soon be at your service to help meet the power requirements presented by postwar industry.

E·L STANDARD POWER SUPPLY MODEL 1200

This E·L unit is a typical Vibrator Power Supply with multiple inputs and outputs and was designed for transmitter and receiver use. Inputs: 12 volts DC, 24 volts DC, 32 volts DC, 110 volts DC and 110 volts AC, 50-60 cycles; Outputs: 600 volts DC at 150-250 MA; 300 volts DC at 75-150 MA; 6-8 or 10 volts DC at 1 amp.; and 110 volts AC (50-60 cycles) at 75 watts.

Dimensions: 26-1/16' x 15" x 13-9/16". Weight: 160 pounds.

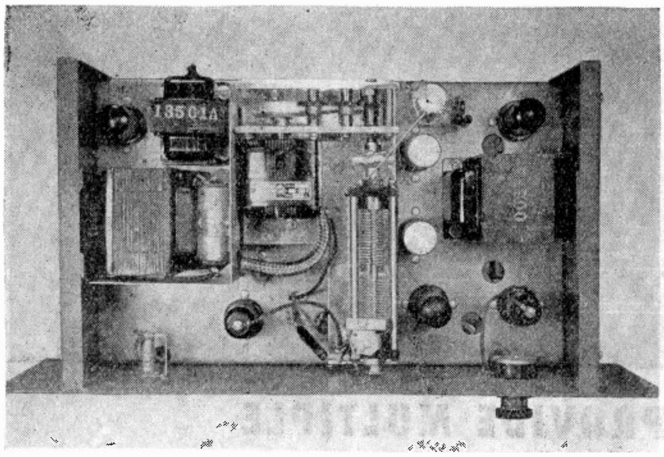


Electronic LABORATORIES INC.

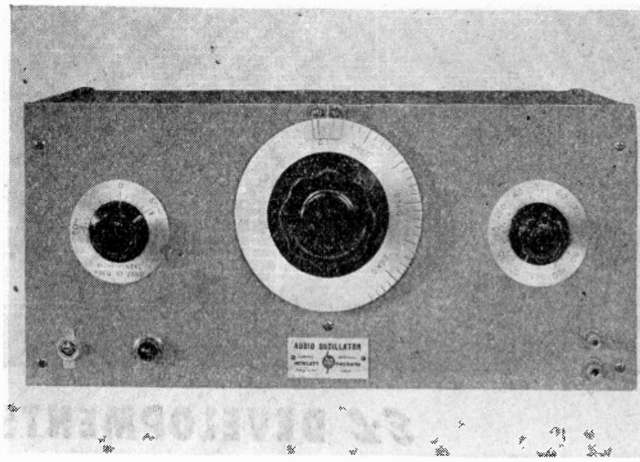
INDIANAPOLIS

VIBRATOR POWER SUPPLIES FOR LIGHTING, COMMUNICATIONS, ELECTRIC MOTOR OPERATION · ELECTRIC, ELECTRONIC AND OTHER EQUIPMENT

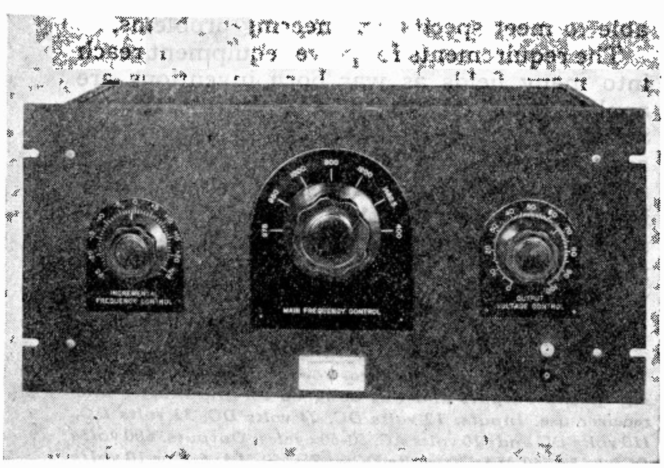
3 EXAMPLES OF *-hp-* ENGINEERING TO SOLVE SPECIAL PROBLEMS



This instrument automatically varies the output frequency from 1000 cps to 3000 cps and back to 1000 cps once each second. It's another example of a special oscillator on which information has not been restricted during the war.



This special unit was developed to supply a readily adjusted frequency between 24 and 26 kc, and is now in use testing secret devices for the war effort. To give an accurate incremental variation of the frequency, a separate control was provided.



To facilitate rapid production tests for a prominent western radio manufacturer, this special oscillator was designed and constructed. Seven fixed audio frequencies are instantly obtained by means of a single control knob. Small incremental variations of frequency are controlled by another knob.

The Hewlett-Packard organization has had wide experience in the development of special equipment for laboratory and production work where specific and exacting problems are encountered. The answer quite often requires only an adaptation of a standard *-hp-* instrument, but in some cases new instruments are developed for the particular problem. Today all of the standard *-hp-* instruments are confined to war work. However, *-hp-* engineering facilities are at your service to assist in solving your individual problem. A letter will bring further information without obligation.

HEWLETT-PACKARD COMPANY

BOX 1014 D • STATION A PALO ALTO, CALIFORNIA

Canadian Office: 560 King Street West, Toronto 2, Canada

7th WAR LOAN

We've just begun to fight

Our fighting men have accomplished miracles in the Pacific. Maybe that's led you to believe that Japan is a pushover. Think again. We still have to meet and crush the main body of the Japanese Army *inside the inner Empire.* To do this, we've got to move millions of fighting men—*freshly outfitted and equipped*—halfway around the globe! And *keep* them supplied over vast stretches of water. More of everything will be needed.

This is going to call for more money than your mind can grasp. Money that *has* to come from you. Not later, but *now*—during the 7th War Loan Drive. It'll take the larger part of a month's salary from most of us to meet the quota—*in addition* to the Bonds we're buying regularly. You *can* buy bigger extra bonds just as the Marines found a way to take Iwo Jima. *They* paid in coin they'll never get back. *You* get *yours* back with interest!

Aireon MANUFACTURING CORPORATION

Formerly AIRCRAFT ACCESSORIES CORPORATION

Radio and Electronics • Engineered Power Controls

NEW YORK • • CHICAGO • • KANSAS CITY • • BURBANK

New!

For improved rectifier service to broadcasters and industrial users

TYPE GL-673
PRICE $30

General Electric offers you a mercury-vapor rectifier tube with useful "in-between" ratings—priced economically—with heavy-duty base giving large pin-contact area

OF interest to designers and operators of radio transmitters and of electronic heating equipment, G.E.'s new Type GL-673 hot-cathode, mercury-vapor rectifier occupies a useful position between rectifiers of the higher and lower ratings, as exemplified by Types GL-869-B and GL-872-A/872 respectively.

● **The base** with which the improved GL-673 is equipped is of the heavy-duty type, with large pin-contact area, increasing the dependability of performance.

● **The anode** is zirconium-coated nickel for the sake of more uniform quality in production, and to avoid the gassing that occasionally results when carbonized nickel or graphite are employed.

● **The cathode** structure has been specially designed to withstand vibration and shocks in transit or in service.

● **A price of $30** reflects the line production methods, employing newly designed equipment, found in G.E.'s modern tube factory. Telephone your nearest G-E office or distributor for further information on Type GL-673 or other tubes in G.E.'s complete line, or write to *Electronics Department, General Electric, Schenectady 5, N. Y.*

Characteristics of Type GL-673

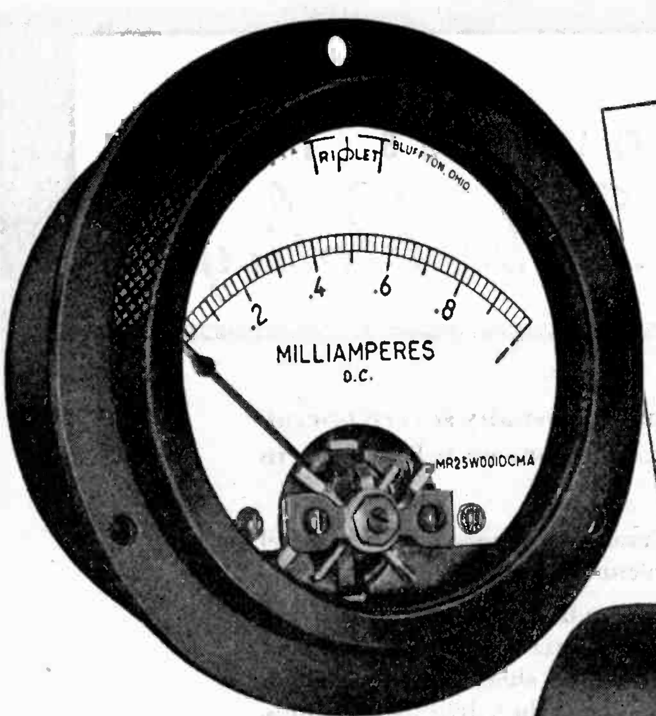
Half-wave, hot-cathode, mercury-vapor rectifier tube for use in radio transmitting and industrial heating applications. 2-electrode type, convection-cooled. Height 10½", diameter 3". Filamentary cathode, with voltage 5.0 v, current 10.0 amp, typical heating time 30 seconds. Maximum anode ratings are: peak inverse voltage 15,000 v, instantaneous current 6.0 amp, average current 1.5 amp. Fitted with heavy-duty base affording greater pin-contact area.

Type GL-673 is recommended for new installations. However, if desired, the same tube will be supplied as Type GL-575-A with 4-pin jumbo base, for replacement use in existing equipment.

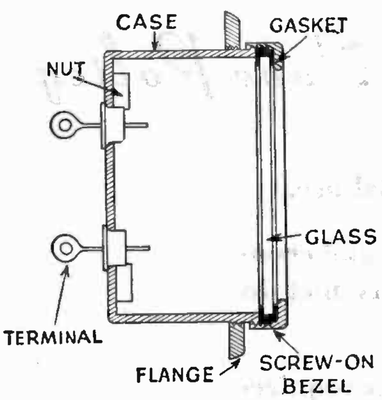
***Hear the G-E radio programs:** "The World Today" news, Monday through Friday 6:45 p. m., EWT, CBS. "The G-E All-Girl Orchestra," Sunday 10 p. m., EWT, NBC. "The G-E House Party," Monday through Friday, 4 p. m., EWT, CBS.*

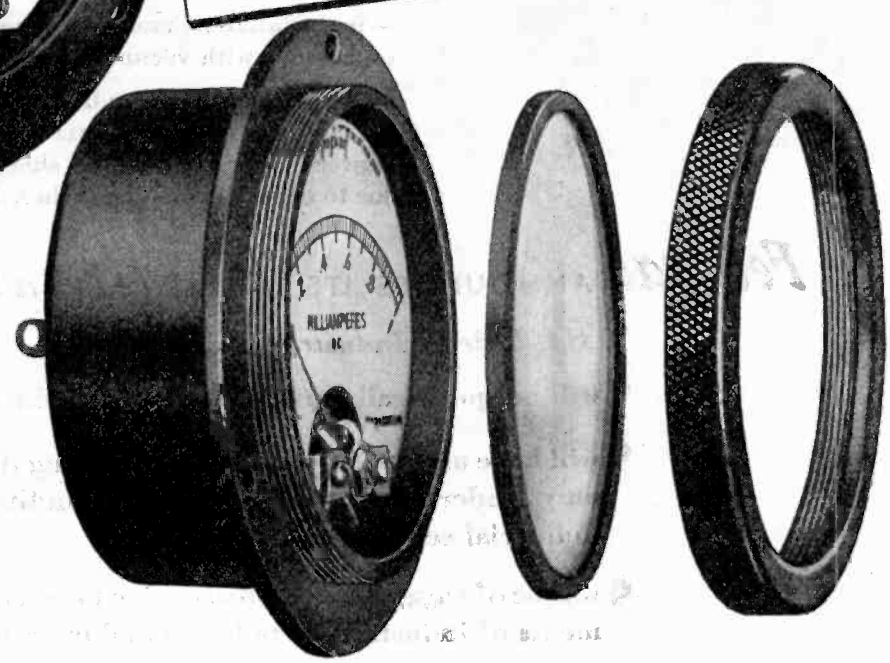
GENERAL ELECTRIC

161-D6-8850



INTRODUCING THE NEW TRIPLETT LINE OF HERMETICALLY SEALED INSTRUMENTS





ALL THE FEATURES of STANDARD INSTRUMENTS RETAINED
Withstands submersion tests at 30 feet

A screw-on bezel provides uniform pressure for hermetically sealing the glass to the case. The gasket is pressed into every crevice around the edge of the glass and the top of the case, where the permanent seal is made.

Tempered glass window and ceramic sealed terminals are used.

The knurled screw type bezel permits servicing when necessary and resealing without replacing a single part or the use of special tools or equipment.

Complete dehydration of the interior is readily accomplished by recognized temperature difference method (the bezel loosely attached for the escape of all moisture, after which the bezel is tightened to make the permanent seal). Interior is completely dry at slightly above atmospheric pressure.

These instruments comply with thermal shock, pressure and vibration tests. They also are resistant to corrosion. Instruments conform to S.C. No. 71-3159 and A.W.S. C-39.2-1944 specifications.

Furnished in 1½″, 2½″ and 3½″ metal cases with 1/16″ thick walls, in standard ranges. D.C. moving coil, A.C. moving iron and thermocouple types.

Write for circular

Precision first ...to last

Triplett

STANDARDS ARE SET BY TRIPLETT

ELECTRICAL INSTRUMENT CO. BLUFFTON, OHIO

V-E DAY

To All Hytron Employees:

Put yourself in the shoes of that friend of yours who is now a combat infantryman fighting Japs. How is he going to feel on V-E Day?

Sure, he is going to be pleased and proud that the Nazis have got the thrashing they asked for -- but his joy in that Victory is going to be overshadowed by the grim realization that he has a long, hard fight ahead.

All of us at Hytron will have a tough job ahead, too, after Victory in Europe. The production demands of the Navy alone for the Jap war are staggering. The tubes we are producing will go far toward making possible the bombing raids, the bold fleet actions, the many invasion thrusts that will bring Japan to her knees.

GI Joe will have no time out for celebrations. He doesn't want that now. He wants to finish the job, so that he may come home and join with us all in a real celebration.

The management feels that we, too, have no time to spare -- will have none to spare until final Victory is won. Hytron plants will not close down on V-E Day.

Those boys overseas expect us to keep on backing them up; the management believes you want to do just that. On V-E Day -- and until V-J Day -- let us all give vent to our enthusiasm by redoubling our production efforts for final Victory.

Bruce A. Coffin

Bruce A. Coffin
General Manager

Post: 3-31-45
Remove: After V-E Day

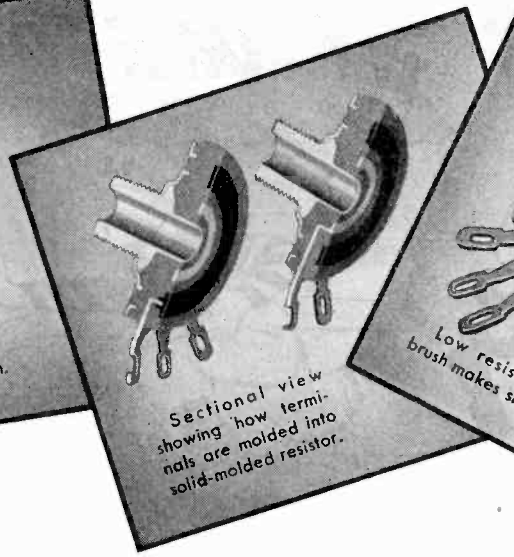
OLDEST EXCLUSIVE MANUFACTURER OF RADIO RECEIVING TUBES

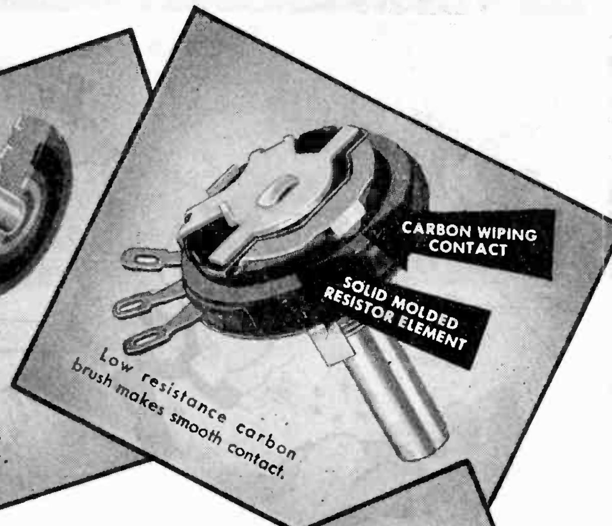
HYTRON RADIO TUBES

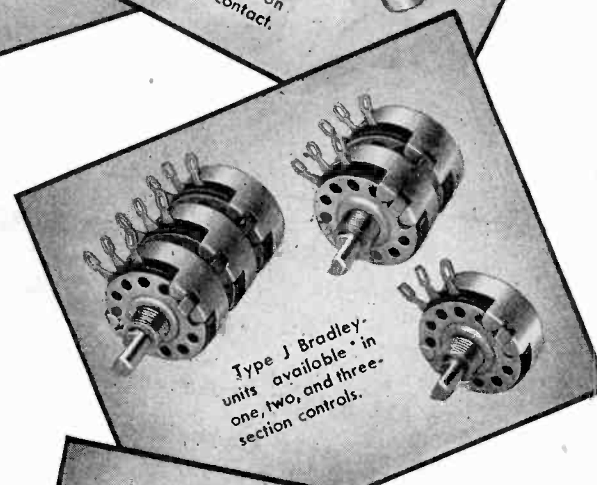
HYTRON RADIO AND ELECTRONICS CORP.

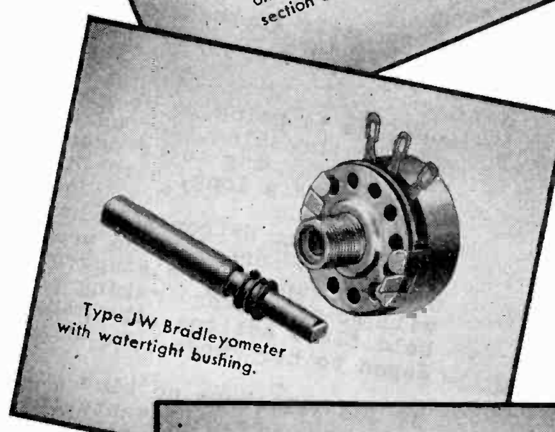
MAIN OFFICE: SALEM, MASSACHUSETTS
PLANTS: SALEM, NEWBURYPORT, BEVERLY & LAWRENCE

FORMERLY HYTRON CORPORATION









In War Service these Resistors are "TOPS"

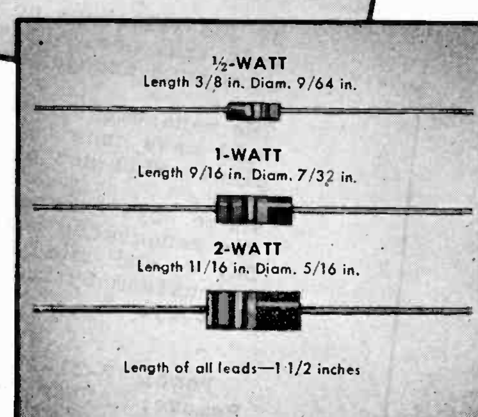
War Service . . . that's the real test for resistors! Only one thing that counts . . . unfailing dependability. And in every combat zone Allen-Bradley fixed and adjustable resistors have proved to be "tops." They are the choice of the experts because they withstand all extremes of temperature, pressure, and humidity.

Allen-Bradley insulated fixed resistors (Bradleyunits) are available in ½-watt, 1-watt, and 2-watt ratings with 1½-inch leads, and in tolerances of 5, 10, and 20 per cent.

Allen-Bradley adjustable resistors (Type J Bradleyometers) are the only continuously adjustable composition resistors of 2-watt rating with substantial safety factor. That is why they are preferred for war service.

Write for specifications today.

Allen-Bradley Company
114 W. Greenfield Ave., Milwaukee 4, Wis.



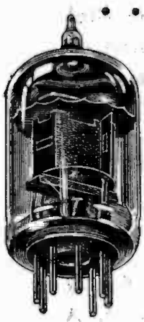
A-B Quality

ALLEN-BRADLEY

FIXED & ADJUSTABLE RADIO RESISTORS

QUALITY

more efficient . . . in miniature



It took a practiced eye and a steady hand to use the old mariner's telescope. In contrast, the compact modern binoculars may be used by anyone, with results far beyond those obtainable with the old instrument. Development that gains efficiency while reducing size is an indication of modern trend. This trend is seen in miniature electronic tubes.

In the new allocation of frequencies, Tung-Sol foresees great possibilities in high frequency application of miniature tubes . . . tubes that have proved their efficiency in military service. Advances have been made, using miniature tubes, that would not have been possible with larger tubes. In numerous other instances Tung Sol miniatures are doing a better job than large tubes, in similar circuits.

TUNG-SOL is not only a dependable source of supply for electronic tubes of all types, but provide an engineering laboratory service as well to aid set manufacturers in planning circuits and selecting tubes for more efficient operation. All consultations are held in strictest confidence.

TUNG-SOL

vibration-tested

ELECTRONIC TUBES

TUNG-SOL LAMP WORKS, INC., NEWARK 4, NEW JERSEY

Also Manufacturers of Miniature Incandescent Lamps, All-Glass Sealed Beam Headlight Lamps and Current Intermittors

ALL 5

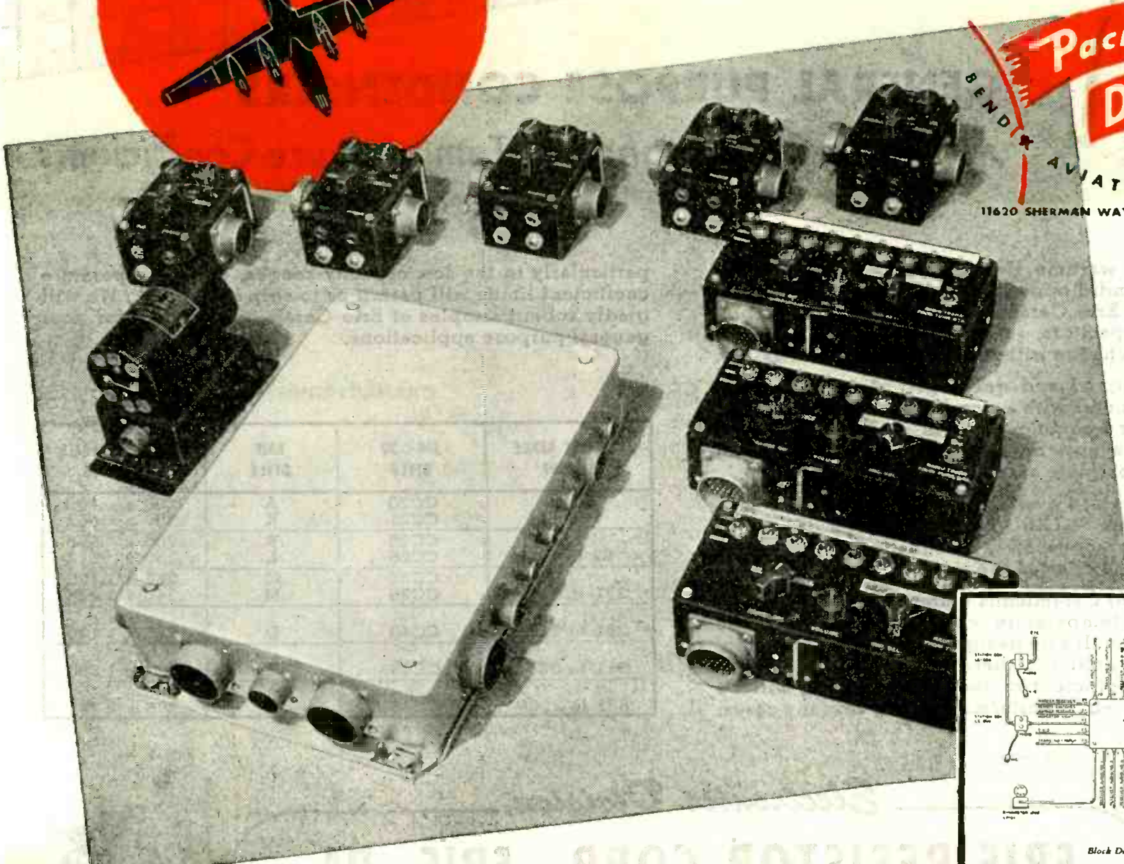
USE THIS STANDARDIZED INTERPHONE SYSTEM

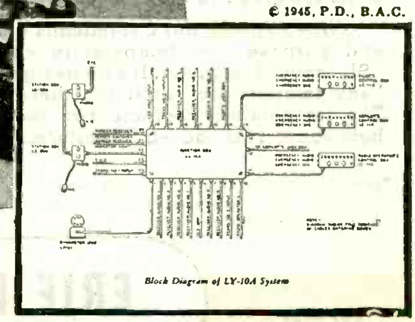
For the first time radio and interphone control systems have been completely standardized for more than one type of aircraft ... by Pacific Division. Altair Model LY-10A system is being used on the Lockheed *Ventura*, Martin *Mariner*, Consolidated-Vultee *Catalina* and *Privateer* and the Douglas *Skymaster*. Designed to Navy specifications by Bureau of Aeronautics and Pacific Division engineers, this is a complete system to control all communication and radio navigation equipment in large aircraft.

This feature alone is recognized as an important step forward in aircraft accessory design. Model LY-10A, however, incorporates—also for the first time—the use of isolation amplifiers which eliminate all crosstalk without the use of multiple audio output stages in each receiver. Selection of up to 9 receivers and 3 transmitters at flight deck stations can be provided.

Altair Model LY-10A, which provides a simple control for a large number of complex radio units, is an example of Pacific Division's understanding of a job that could result only from long experience. Pacific Division invites inquiries on any radio problem.

Pacific Division
BENDIX AVIATION CORPORATION
11620 SHERMAN WAY, NORTH HOLLYWOOD, CALIF.



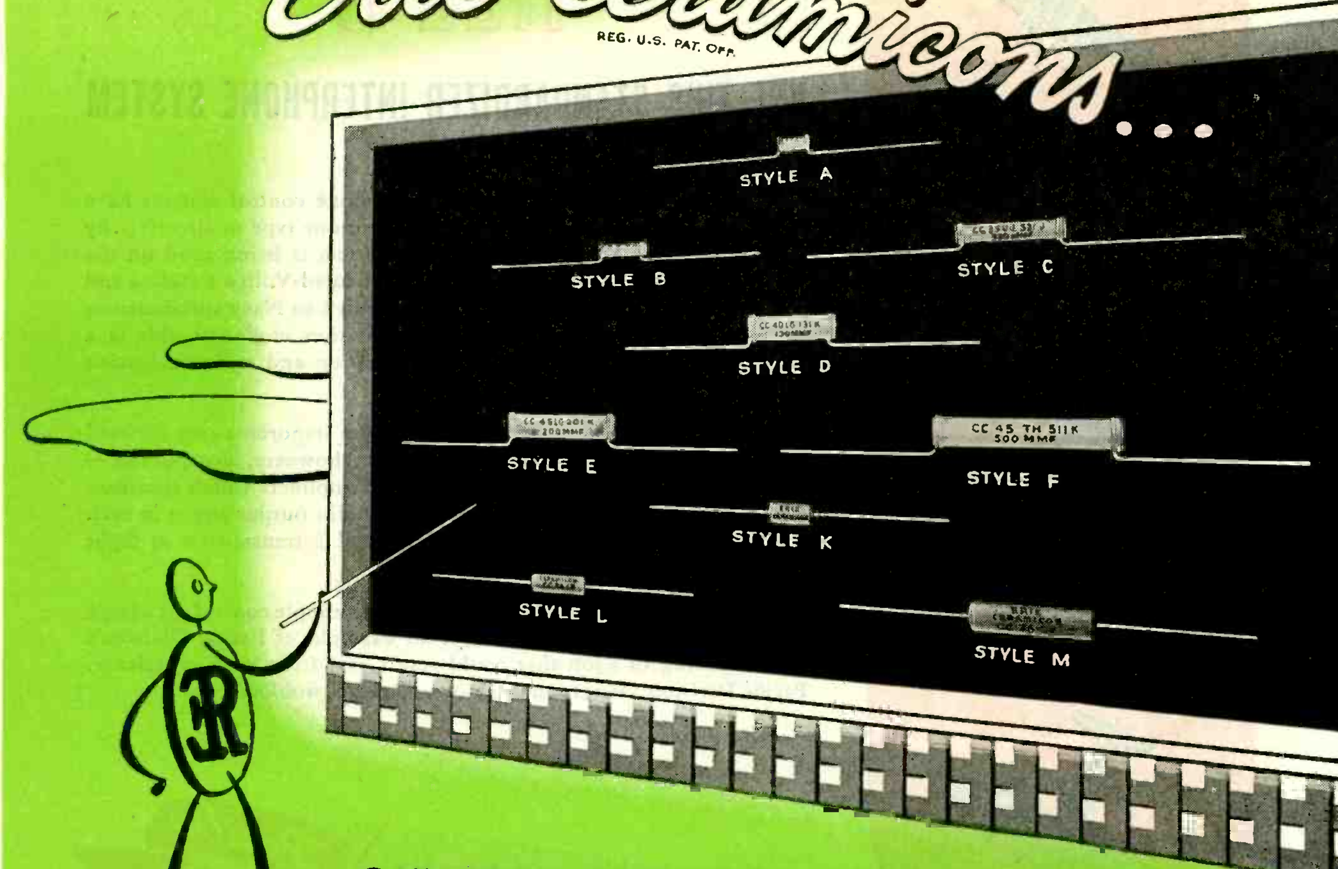


Block Diagram of LY-10A System

PACIFIC DIVISION, Bendix Aviation Corporation, 11620 Sherman Way, North Hollywood, California.
Sales Engineering Offices: Lincoln Building, New York City 17; Continental Building, St. Louis 8.

USE *Erie Ceramicons*...

REG. U.S. PAT. OFF.



GENERAL PURPOSE CONDENSERS

Available in 10 Standard Temperature Coefficients

THE tremendous wartime demand for condensers has provided a splendid opportunity to prove the reliability and adaptability of Erie Ceramicons* as extremely stable, general purpose capacitors, in circuits where a moderate degree of capacity change with temperature is permissible.

Originally designed and developed almost a decade ago to provide engineers with a simple and effective method of compensating for frequency drift in other components, Erie Ceramicons are now being used in a wide range of applications with complete success.

Erie Ceramicons are available in ten standard coefficients ranging from +120 to −750 parts/million/°C, inclusive. Capacity ranges, style designations, and dimensions are given in the chart at the right.

When specifying Ceramicons under JAN-C-20 for general purpose use, temperature coefficient characteristic "SL" should be given. If Erie designations are used, specify "any temperature coefficient between P100 and N750." The temperature coefficient of these Ceramicons will be between +150 and −870 parts/million/°C. In many cases, particularly in the low capacity ranges, these temperature coefficient limits will permit us to ship from stock. We will gladly submit samples of Erie Ceramicons to you for your general purpose applications.

CHARACTERISTICS

CAPACITY RANGE IN MMF	JAN-C-20 STYLE	ERIE STYLE	MAXIMUM OVERALL DIMENSIONS
1 to 51	CC20 CC21	A K	.200 x .400 .250 x .562
52 to 110	CC25 CC26	B L	.200 x .656 .250 x .812
111 to 360	CC35 CC36	C M	.265 x 1.125 .340 x 1.328
361 to 510	CC40	D	.375 x 1.110
511 to 820	CC45	E	.375 x 1.560
821 to 1100	CC45	F	.375 x 2.00

*CERAMICON IS THE REGISTERED TRADE NAME OF SILVERED CERAMIC CONDENSERS MADE BY ERIE RESISTOR CORPORATION.

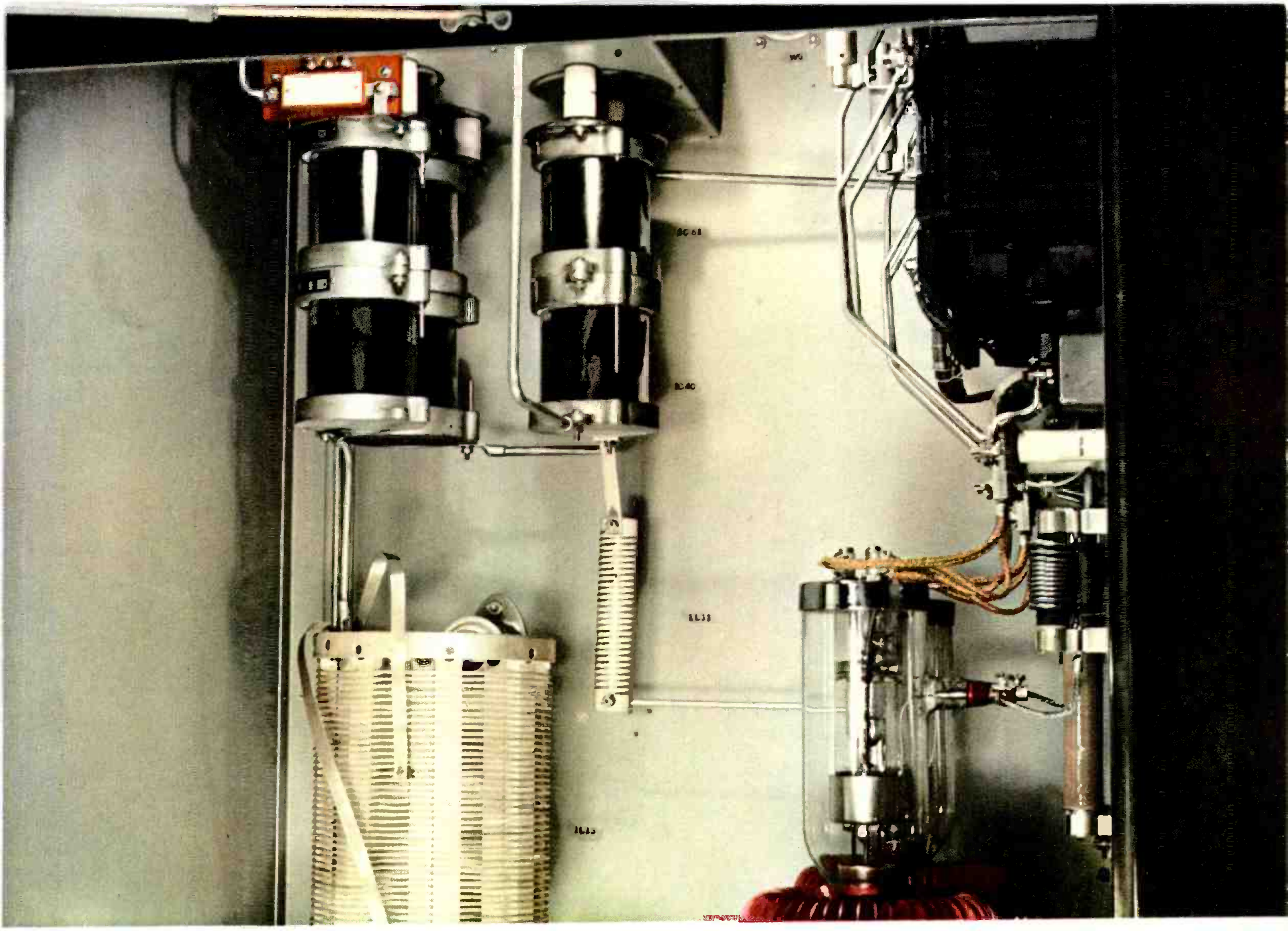
Electronics Division

ERIE RESISTOR CORP., ERIE, PA.

LONDON, ENGLAND • • TORONTO, CANADA

BUY MORE WAR BONDS

ARMY NAVY FOR HIGH ACHIEVEMENT IN WAR PRODUCTION



A NEW MINIATURE TUBE_

THE RCA-OA2

Actual Size

New RCA Miniature Voltage-Regulator Tube Operates at 150 Volts—Is Practically Equivalent to Standard OD3/VR150

FOR the first time, equipment designers have available in a miniature envelope a voltage-regulator tube capable of performing the functions previously requiring a standard-size tube. This space-saving feature is especially valuable where compact military equipment is being designed. The OA2 will provide as many hours of service as standard-size tubes.

Like standard-size voltage-regulator tubes, the OA2 is a cold-cathode, glow-discharge tube. It is intended for use as a voltage regulator in applications where it is necessary to maintain a constant d-c output voltage across a load, independent of load-current and moderate line-voltage variations.

The OA2, like other voltage-regulator tubes, can also be used for spark-over protection.

For information on this and other RCA Electron Tubes, mail the coupon or write to RCA, Commercial Engineering Section, Dept. 62-32P, Harrison, N. J.

TECHNICAL DATA

Maximum Overall Length, Inches	2⅝
Maximum Seated Height, Inches	2⅜
Maximum Diameter, Inches	¾
Bulb	T-5½
Base—Miniature Button, 7-Pin	Mounting Position—Any
D-C Anode Supply Voltage, Minimum, Volts*	185
D-C Operating Current	
Continuous Maximum, Milliamperes	30
Continuous Minimum, Milliamperes	5
Ambient Temperature Range, Degrees C	−55 to +90
D-C Starting Voltage, Approx. Volts	155
D-C Operating Voltage, Approx. Volts	150
Regulation (5 to 30 Milliamperes), Volts	2

* Not less than indicated supply voltage should be provided to insure "starting" throughout tube life.

The Fountainhead of Modern Tube Development is RCA

MAIL THIS TODAY FOR FREE DATA SHEET

RCA, Commercial Engineering Section, Dept. 62-32P, Harrison, New Jersey.

Please send data sheet on RCA's new miniature voltage-regulator tube, the OA2, giving ratings, operating and installation notes, terminal connections, and typical circuits.

Name ....

Position ....

Company ....

Address ....

City .... Zone .... State ....

62-6136-32

BUY BONDS

RCA

RADIO CORPORATION OF AMERICA

RCA VICTOR DIVISION • CAMDEN, N. J.

The interchange of viewpoints between the leaders in the communications and electronics field and the engineers active in that field is certain to promote the speedy advancement of the arts in which they are mutually involved and interested. To this end, there are presented in the PROCEEDINGS OF THE I.R.E., in the form in which they are received, guest editorials from major executives in the field in question. There follows such a statement from the vice-president and general manager of the manufacturing division of The Crosley Corporation, a radio pioneer who is also the president of the Radio Manufacturers Association.

The Editor

The Engineer's Response to the Nation's Call

R. C. COSGROVE

The world has been amazed, as the progress of the war has been speeded on towards victory, at the tremendous volume of the most accurate, the most effective, and the most deadly munitions of war that has poured out from the industrial plants of America to turn the tide of battle on every far-flung battlefront.

The perfection of these newly conceived and newly devised instruments of war has delighted and strengthened our Allies and has stunned and terrified our enemies.

To the engineers of America—notably the electronics engineers—is due a very great part of the credit for this epochal achievement. It was no easy task with which the nation's engineers were faced when war burst upon us.

American industry was called upon to devise and produce, without delay, highly specialized instruments with which our fighting men could outwit, outshoot, and outfight the best that the enemy could muster against us. The rapidity with which we are approaching victory testifies how well it has done this.

Electronics engineers in particular had to meet especially difficult requirements in the devices they were called upon to perfect. Electronic equipments had to be constructed to withstand temperatures ranging from arctic to tropical, from minus 70 degrees centigrade to plus 85 degrees centigrade. They had to function in humidity up to 100 per cent and at unprecedentedly high altitudes. They had to be proof against insidious attack by insects and tropical fungus. They had to withstand the severe vibration incidental to repeated shock and rough handling, under combat conditions. With all this, they had to be simple in operation.

That this was accomplished so effectively and in record time is a tribute to the soundness of the basic, fundamental knowledge of America's radio engineers which enabled them, quickly, to acquire the "wartime know-how" essential to the production of the highly specialized war instruments.

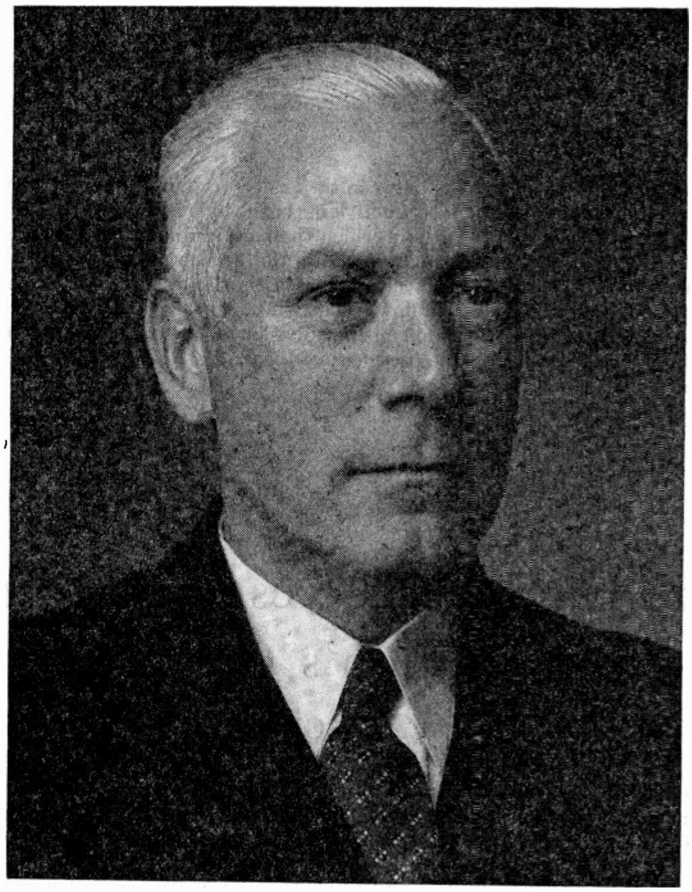
Most significant and most effective, perhaps, was the skill with which America's engineers applied the techniques of mass production, with which they had long been familiar, to the making of intricate products which had previously been made only in engineering model shops.

Nor will their contribution to the nation's progress and development end when there is no more need for the instruments of war they have so skillfully designed and produced.

The new knowledge and the new ideas they have acquired, the new materials they have created, the new processes and methods they have devised, under stress of war's demands, will be diverted, when victory comes, to the building of new and better peacetime products than man has ever known before.

Destructive as war inevitably is, it might be likened to a crucible in which the inefficient, the obsolete, the outdated devices for living are burned out, leaving, when the smoke has cleared away, a nucleus upon which to build a future of better living.

It is to America's electronics engineers whom we must look for the tangible application of the specialized skill that is helping to win the war when we are ready for the new wonders of peace.



Hendrik Johannes van der Bijl

Vice-President—1945

Hendrik Johannes van der Bijl was born on November 23, 1887, at Pretoria, South Africa. He received the B.A. degree from Victoria College, Stellenbosch; the D.Sc. degree from Stellenbosch University; the Ph.D. degree from the University of Leipzig; and the L.L.D. degree from Cape Town University.

While instructor in physics at the Royal School of Technology, at Dresden, during 1912 and 1913, Dr. van der Bijl continued a research started by him at Leipzig University, dealing mainly with the behavior of pure liquids under the influence of radium emissions, and also carried out work in the field of photoelectricity. It was during his researches on photoelectricity that he made the discovery of the extent to which an electric field acted or "strayed" through a metallic grid or gauze, which work brought Dr. van der Bijl into contact with Professor Millikin of the University of Chicago, and led to his joining the Western Electric Company in New York, as research physicist. He held this post from 1913 to 1920.

His work here had a direct bearing on his earlier researches, and led directly to important developments in long-distance wire and radiotelephony and high-fidelity radio-broadcast transmissions.

In 1920, General Smuts induced Dr. van der Bijl to return to South Africa, and from 1920 to 1922 he held the position of technical advisor on industrial development to the Department of Mines and Industries of the Union of South Africa. He took a leading part in the formation of the Electricity Supply Commission, established in 1923 under his chairmanship, to co-ordinate and develop South Africa's Power Supply Industry on a national basis. He also sponsored and became chairman of the South African Iron and Steel Industrial Corporation, in 1928.

In 1937 he founded the African Metals Corporation, Ltd., producing foundry iron, stainless steel, and a wide variety of ferro-alloys; and in 1939 he suggested the establishment of the Industrial Development Corporation of South Africa, Ltd., for the purpose of financing the building of industries on a sound economic basis. He accepted the chairmanship of this organization for the first few years until the corporation was established on a firm footing.

Soon after the outbreak of the war, Dr. van der Bijl was appointed Director-General of War Supplies, and, in 1943, his duties were enlarged to include the organization of civilian as well as war supplies, and he became Director-General of Supplies. In appreciation of what South African designed and built armored cars have meant to the Armed Forces, Dr. van der Bijl was made Honorary Colonel of the South African Tank Corps, in March, 1942.

Dr. van der Bijl is the author of a number of publications on scientific and engineering subjects. In 1943 he was elected Foreign Associate of the National Academy of Sciences, and in 1944 was made a Fellow of the Royal Society. He became a Member of The Institute of Radio Engineers in 1917, and a Fellow in 1928. He was elected vice-president of the Institute for 1945.

Looking Forward in Engineering Education*

DORMAN D. ISRAEL†, FELLOW, I.R.E.

LIKE ALMOST every other phase of our lives, the professions—and particularly Engineering—have undergone fundamental changes in concept and scope. There was a time when an engineer was nothing more than a fairly smart young person who had successfully completed a scientific and mathematic college course directed particularly to the application of the use of various materials needed in the design of a product. Nowadays, the engineer has not completed his training if the above is all he has to offer.

There are four major requirements, some of which can be taught in a college but others of which depend directly upon the prospective engineer's attitude and comprehension of what his chosen profession requires.

The Human Approach

Any engineering aspirant must realize that the preparation of a product requires the intelligent and orderly expenditure not only of material but also of labor. As a matter of fact, all material is really the output of labor. So, in the last analysis, an engineer finds himself dealing just as specifically with human beings as with lifeless materials. He must never forget that all his planning and specifying are to no avail if he does not inspire and attract the assistance and co-operation of his fellow men.

Interests Must Be Broad

Many engineering aspirants are so steeped in their technical hobbies and studies that they do not allocate time and effort to an appreciation and knowledge of what we sometimes call "the arts." Unfortunately, the regular "diet" in engineering courses is usually so packed with the proteins and carbohydrates of science, mathematics, and laboratory exercises that it is difficult to find the spare appetite for the more subtle vitamins of history, philosophy, and even music and art. Engineering colleges cannot always develop a means to encourage this, but the requirement exists nevertheless. The properly advised and conscientious engineering student owes it to himself to work out a system of allocating his personal endeavor to assure himself of these necessary extracurricular interests.

Engineering requisites, which should come within the college curriculum, (but even though absent, must be developed through outside interests) are the development of the ability to write clearly, particularly about technical matters, and the poise to talk before a gathering in a clear and convincing manner.

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† Emerson Radio and Phonograph Corporation, New York, N. Y.

Engineering-College Studies Must be General

During the war, scientific advancement has been so intensely accelerated that it is now especially important that one fundamental of all advanced education be adhered to in the classroom. Professional training, and again particularly engineering, must not be too specialized at the college level. This, of course, does not apply to the outside co-operative job to be discussed later. Our bank balance of engineering knowledge and achievement is compounding at an unbelievable rate. Engineering students, in their anxiety to make the most of what limited time is available, must not fall into the trap of specializing in the classroom. Such practices must be left for the trade schools, who can do this job adequately and who, in turn, attract students for whom such training is proper. An engineering student cannot possibly know what direction his career will pursue. He must, therefore, be well grounded in all fundamentals so that his individual aptitude, together with the environment of his postcollege work, will automatically specialize him where he will be most happy and productive. In college, an engineering student must be taught to acquire what is loosely termed "the engineering point of view or approach." This comes from properly directed training in fundamentals and its correlated teaching of the systematic approach to a problem.

An engineering student needs to realize that he must always have the courage to change the tack that he has taken immediately when it becomes evident that he is not showing progress or is losing interest. Many engineering students enter colleges to become chemical engineers, for instance, and discover, because of proper direction in the college and their own frankness with themselves, that they could never be happy in chemical engineering, and yet can be eminently happy in mechanical engineering or some other branch. It is one of the duties of the engineering college to point this up to the student. In fact, those who are not suitable to any kind of engineering are best off if they become aware of this early in their college life and change to that training or job which can give them a lifetime of happiness.

Engineering Training Must Be Practical

It may seem paradoxical to advocate the adherence to fundamentals rather than specialization in the classroom and in the next breath insist that engineering training must be directly geared to industry. However, the two requirements are intimately compatible, essential, and, in fact, complementary. The Co-operative Engineering Training System, initiated in 1906 at the University of Cincinnati by Dean Herman Schneider, has weathered the storm of two wars and a major economic depression. The theory of the co-operative system is very simple. Engineers, like doctors and lawyers, are trained for practice. Judgment based upon experience must join with theory. The four-year plan of training engineers, evolved in liberal-arts colleges, was merely a convenient extension, in form, of the liberal-arts system. Having been graduated, the engineer, like the doctor, could not practice. He had a fair amount of principles but lacked sadly in knowledge of the other elements of his profession—men, materials, methods, and mechanisms. Hence, an apprentice system came into being, covering a period of two or three years. Principles and practice were driven tandem instead of abreast. Prospective engineers were withdrawn from active life during their most impressionable years, in order to prepare for active life. They had no tests of their abilities in their chosen fields until the major part of their preparation was completed. In civil engineering, for example, more than half the men trained in colleges for that profession quit it after a few years of practice in the profession. (In the co-operative system, less than ten per cent do so.)

A student's fitness for his chosen profession is much more easily judged under the co-operative system than under the regular system. His experience in actual engineering work and his contacts with other students in many different phases of training, give him a real picture of what engineering is, rather than one drawn from popular magazines and movies, with the subsequent disillusionment when the hard grind is faced.

The co-operative system of education conserves time. By reason of the alternation of theoretical work and practical work, and the reduction of the long summer vacation, the student can carry a heavier load of studies than would be possible if he attended school full time. Upon graduation from the five-year co-operative course, a student has covered more theoretical work than a student does in the four-year full-time courses. This has been established by an investigation, covering the leading engineering colleges of the country, made by Professor William T. Magruder of Ohio State University, and published in the bulletin of The Society for the Promotion of Engineering Education, October, 1933. In addition, the co-operative student has been given 5500 hours of sequential practical training organized by the college as carefully as its curriculum, and co-ordinated with the theory taught. Hence, the co-operative student is as far advanced at the end of five years as the regular student is at the end of eight years. Further, the co-operative student's practical training has covered a broader field, and his theory has been crystallized by many hitching posts in his mind. His groundwork is more amply and more thoroughly established.

The money earned on practical work enables many young men of brains and backbone but without sufficient funds, to go to college, which is as it should be, especially in a democracy.

One reason for the ability of the co-operative system to cover so much ground in the relatively limited time is that much descriptive matter can be omitted from the classroom studies. The co-operative student spending, as he does, half of his time in practice is more familiar with industrial equipment than he could possibly be by reading textbooks. Classes in co-ordination are maintained in many co-operative colleges. These consist in a meeting of students of the same grade but frequently different branches of engineering. At these meetings, conducted by the co-ordinator who is responsible for obtaining jobs in industry for the students, individual students are required to address the class with a self-prepared formal paper and discuss as far as possible the co-operative job in which he is engaged. These co-ordination classes can be developed into the direct means for training the engineering student in the ability to write clearly and to talk convincingly before a gathering.

The co-operative plan of alternating classroom work with paid jobs has been adopted by 28 institutions of collegiate grade, including Alabama Polytechnic Institute, Antioch College, Carnegie Institute of Technology, University of Cincinnati, Western Reserve University, University of Detroit, Drexel Institute, Fenn College, University of Florida, Georgia School of Technology, General Motors Institute of Technology, Illinois Institute of Technology, Laurence Institute, University of Louisville, Marquette University, Massachusetts Institute of Technology, Mt. Holyoke College, Municipal University of Akron, Newark College of Engineering, Northeastern University, Northwestern University, University of Omaha, Shurtleff College, Southern Methodist University, Stevens Institute of Technology, University of Tennessee, University of Tulsa, and College of William and Mary. In addition, the plan has been adopted by secondary schools and technical schools in New York City and elsewhere.

Perhaps the basic benefit of the system is best summarized in the terse and descriptive sentence originated by Dean Schneider: "It is a good thing for a man to sweat his way toward the Truth."

Engineering Training for Industry*

F. J. GAFFNEY†, ASSOCIATE, I.R.E.

I SHOULD like to outline briefly my conception of what industry can and cannot expect of the engineering graduate. I shall define an engineering graduate as one who has successfully completed an adequate four-year course of training in engineering. In order to produce graduates who meet this definition, our present engineering curricula stand in need of considerable revision.

This discussion might well be prefaced by a consideration of the length of training stated in the above definition. This was the subject of considerable debate at the November, 1944, meeting of the Boston section. The speakers there were unanimous in their feeling that a training period longer than four years should be required of engineering graduates. It is my feeling, however, that before this matter can be decided, several pertinent aspects of the problem should be considered.

One important factor is concerned with the requirements for admission into an engineering college and the problem of elementary and high school training. If, in some way, the engineering educator could bring his influence to bear in this elementary realm, he could contribute more toward producing better-trained engineers than in any other way. It is certainly true that our engineering colleges today are required to accept students at an exceeding low level of accomplishment. The efficiency of our educational system seems to suffer a gradual decline from the first grade through high school. Much of the work given in high school is but a duplication on a slightly higher level of that presented in the grade schools. There seems to be no reason, for example, why mathematics in high school cannot proceed at least as far as an introduction to analytic geometry and calculus. Nowhere along the line is there any real attempt to develop in the student initiative or the desire to progress.

Until this situation improves, our engineering colleges will have to continue to accept poor material, and this, of course, has a profound effect on the amount of training which can be accomplished in whatever time is allowed.

Another consideration is that of the level of accomplishment at which a man should be called an engineer. This is, of course, entirely a matter of definition, but it is closely bound up with the consideration of the number of graduates who can profitably be used in industry. The problem can perhaps be expressed in the form of a curve similar to the demand-price curve encountered in economics. Here one finds that, over a limited region, if the price is reduced the demand will increase, whereas if the price is increased the demand will decrease until at some price the demand is essentially nil. Similarly with engineering graduates, if the requirements are made sufficiently low we can graduate tremendous numbers of so-called engineers, while if the requirements are made sufficiently high we shall have no output whatsoever. Obviously there exists an optimum point on the curve and, in the case of engineering graduates, this point is determined by the requirements of industry as regards both quality and quantity. In this connection, I believe that the great industrial supremacy of the United States of America is due in no small part to the fact that we have graduated engineers in considerable quantity, even though the quality of training may not have been all that could be asked for. This condition can be contrasted, for instance, with that found in England, where the quality of the graduates is, I feel, better but the number of graduates very much smaller.

For the above reasons, and the fact that many students are limited by force of circumstances to a four-year training period, I should not like to see the basic engineering curriculum extended beyond this time. There is already in existence a framework in which students of ability and circumstance may continue their studies into as many graduate years as seem desirable in a particular case. Perhaps this framework, too, could profit by some revision, but in basic principle it is sound, and every encouragement should be given to the promotion of graduate studies in engineering. This does not preclude, however, a four-year basic-training course which can be integrated in such a way as to insure real value of the graduates to industry and, at the same time, provide an acceptable foundation for graduate study.

Let us, then, consider the attributes which industry might legitimately expect to find in the graduate of a properly designed undergraduate engineering course, and the way in which present engineering curricula should be modified to achieve the desired results.

I shall list some of these attributes and discuss each briefly.

1. A Developed Engineering Approach

This broad concept is made up of many smaller ones. It involves, for instance, the ability to analyze a problem to determine the form of attack most likely to succeed and, having once settled on a modus operandi, the ability to pursue the chosen tack without deviation to a successful conclusion. It involves, also, the ability to ferret out information necessary to the solution of a problem from whatever source is available: texts, the literature, or other engineers. It involves originality in thinking; something more than the mere application

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with variations of a motif already expressed by someone else.

How can this be taught in an engineering school? In a sense, it cannot be taught, if by teaching we mean the process of assisting the student in learning by rote. It can, however, at least to a certain extent, be developed in the student during his college years by calling upon him to exercise these qualities from the beginning to the limit of his capabilities. In a college curriculum, the type of problem most often presented is one which has a single answer. In engineering practice, the type of problem most often encountered is one which has several solutions, and one of the most important functions of the engineer is to select the optimum solution of the many available. The ability to perform this function can best be developed by utilization of the thesis type of instruction for many of the subjects in an engineering curriculum. For instance, rather than to require a student to calculate the Q of a tuned circuit on one day, the power-output capabilities of a given vacuum tube on another, and the frequency range one can cover with a given variable condenser on the third, why not require the student to design an oscillator to give a certain power output and to cover a given frequency range, using any tube he chooses that will do the job. This type of instruction might well be correlated with the laboratory instruction, as I shall point out later.

It is realized, of course, that all subjects cannot be presented completely in this way. A certain amount of discussion of text material and of the solution of stock problems to give the student a "feel" for the subject being presented will continue to be an important part of the pedagogy in any field, but the necessity of developing originality and resourcefulness in the student is too often overlooked.

2. *The Ability to Work with People*

This part of an engineer's training, it seems to me, is the most neglected. To be sure, efforts have been made to accomplish the desired result by giving courses in history, psychology, and other so-called humanistic subjects. But these fall far short of reaching the desired objective, mainly because they are done in the abstract rather than the realistic manner. It is my feeling, for instance, that psychology might better stress the problems of employer-employee relationships, the necessity of satisfying man's desire to advance and improve himself, the advantages of leading rather than driving a subordinate, the manner in which problems may be presented to make them appear most interesting, the problems involved in leading a conference, and the psychology of selling. These subjects, it seems to me, might well take precedence in an engineer's education over such topics as the Freudian theory of basic drives, or the mental and physical characteristics of a paranoiac. Similarly, it would seem that, to an engineer, the history of labor unions in America might prove of considerably more value than a detailed account of the rise and fall of the Roman Empire.

The engineer of today is invariably required to work closely with others. The ability to understand others, to be tolerant of their faults, to appreciate their handicaps as well as their abilities, to be truly objective in approach is the sine qua non of a successful engineering career.

3. *A Sound Basic Knowledge of Mathematics and Science*

I fear that I must disagree with Dr. Everitt in his delineation of a scientist and an engineer in terms of analysis and synthesis. It is my feeling that the good physicist is an engineer, and that the good engineer is a physicist. One cannot stress too much the need for a thorough knowledge of the basic principles of physics, and complementary to this, the development of a facility with mathematics which will allow the student to deal with these basic principles in a quantitative way. Where-ever possible, mathematics should be taught as a part of physics rather than in separate isolated courses, so that its applicability will become immediately apparent. For instance, vector analysis might well be taught as part of a course on electromagnetic fields, and Laplace transforms as part of a course on circuit analysis. Except as an interesting mental exercise, mathematics has, of itself, no value. Only when it is made to shine by the reflected light of the science it quantitatively describes, does it exhibit its true usefulness. The student must become familiar with the limitations of a mathematical treatment. He must learn, for instance, that seldom in practice does one encounter geometries which are simple enough to permit of exact mathematical analysis. He must learn to utilize the analytical method as a guide, and to supplement it with experimental procedures.

4. *A Basic Familiarity with the Materials, Tools, and Processes of Industry*

While this attribute is seldom found in the present engineering graduate, I believe that it can legitimately be required by industry and that engineering curricula can be arranged to meet the requirement adequately. There is in most universities a severe distaste for any subject which smacks of the "trade school." But how can an engineer hope successfully to design equipments which must be built by the tools of modern industry, unless he understands these tools, their operation, and their limitations? To further this understanding, a semester laboratory course in machine-shop and foundry practice would accomplish much. It is often said that this type of practical instruction is best obtained in industry itself. This is not generally true, however, for seldom in industry is a young engineer allowed to work as a machinist unless he is fortunate enough to be able to take a training course, such as is offered by some of the larger companies. In practice, the difference between a successful design and an unsuccessful one is often determined by the cost of manufacture of the product as reflected by the choice of production method used by the designing engineer. One quickly discovers that the question of mechanical tolerances is a vital one. The engineer is required to develop judgment in these matters, and this can only be attained through a thorough knowledge of the processes involved.

Here, too, is where adequate laboratory courses utilizing the thesis type of instruction can contribute greatly. I should like to propose that the type of laboratory exercise which consists largely of the performance of routine experiments carefully laid out by the instructor be omitted, and in its place a form of laboratory course more nearly representative of industrial practice be substituted. This substitution would call for fewer experiments by far—perhaps only one or two each semester, but these would be undertaken as projects rather than as stereotyped exercises. Any capable instructor in electronics, for instance, can think with little effort of a more than adequate number of such projects. A few examples, would be: the design and construction of an audio oscillator and attenuator; the design and construction of a crystal standard and frequency-divider chain; and the design and construction of a fixed-tuned radio-frequency amplifier with stated bandwidth and gain. It is sometimes argued that this type of instruction requires a larger number of instructors. This need not necessarily be so. However, the instructors will certainly spend their time in a different and more energetic way! In order to provide the technician work required in this sort of program, lower classmen might well be used as engineering assistants. This would serve to give these younger students a familiarity with the materials used in industry and prepare them to become the "project engineers" of the following year. This type of laboratory course would certainly acquaint the student with the measuring techniques needed in practical engineering, and at the same time familiarize him with the actual problems encountered in the conversion of theoretical designs into brass and steel.

5. The Ability to Express his Ideas with Clarity

This can best be cultivated by having the students write engineering reports on the work done in a laboratory course such as that described above. Here, again, the student must be allowed to formulate the report himself and not simply be required to fill in the blanks on a stereotyped form. The instructor must present only a broad outline of the scope of the report and then be able to offer constructive criticism of the student's effort.

I have stated some of the qualities which I feel industry should legitimately expect to find in the young engineering graduate. It might be well to conclude by listing a few which it has no right to expect. Some of these are:

(*a*) *Judgment:* This can come only after many years of experience. Some of the methods of instruction suggested above will, I believe, help the student more quickly to reach the maturity which begets judgment, but it must be born, in the final analysis, of experience.

(*b*) *Great Analytical Ability:* This cannot logically be expected of the graduate of a four-year engineering course. It can be developed only by continued study and application. It is obviously most easily bred in the graduate school.

(*c*) *Detailed Knowledge of the "Tricks of the Trade" in Any Branch of Engineering:* This, again, is born only of experience of the type best obtained in industry itself.

Finally, while much has been said about the need for moral and ethical development, I feel that this belongs in the realm of the home and of the church, and little can be done in a college to promote such development other than to insure that the caliber of the instructing staff is of the highest and that men for this type of position are not selected on the basis of technical ability alone. Whether the Hipprocratic oath is also hypocritical depends on the man taking it, and the mere fomulation of such a group of words really avails nothing

A Summary and Interpretation of Ultra-High-Frequency Wave-Propagation Data Collected by the Late Ross A. Hull*

ALBERT W. FRIEND†, SENIOR MEMBER, I.R.E.

Summary—**Until his death in 1938, Ross A. Hull, late editor of *QST*, the official publication of the American Radio Relay League, had been studying the propagation of 60-megacycle waves between Blue Hill, near Boston, Massachusetts, and his home on Seldon Hill, near Hartford, Connecticut. He was aided in obtaining facilities for this work by the Blue Hill Observatory of Harvard University. An analysis of portions of the data recorded by Hull indicates that, with certain extensions and minor variations, his theories were leading toward the now apparently correct solution of the ultra-high-frequency propagation problems. It was indicated that propagation far beyond the horizon was produced by refraction or reflection in the tropospheric strata.**

Calculations of radius of ray curvature have been made from data provided by the United States Weather Bureau, from stations near the propagation terminals points. It is indicated that radii of curvature less than the radius of the earth are coincident with conditions favorable to the propagation of strong signals over this path extending far beyond the horizon.

A simple equation is given for calculating the radius of ray curvature. It is concluded that more accurate meteorological data with finer structure characteristics should make possible more precise calculation of propagation conditions. It also appears that certain meteorological conditions may be assumed when various propagation conditions are encountered.

Foreword

During the period between 1934 and 1937, Ross A. Hull, then editor of *QST*, collected large quantities of data concerning the propagation of ultra-high-frequency radio waves from various points in the vicinity of Boston, Massachusetts, to his home laboratory on a hill near West Hartford, Connecticut. Occasional articles and notes concerning these data were published in *QST*. Perhaps the most notable expositions are those of June, 1935,[1] and May, 1937.[2] The latter paper is indicated as "Part One" of a two-part report. Unfortunately, the second part was never published.

Although Hull found time to present several discussions of his work at various amateur and technical meetings, his time was so divided among his multiple activities that material for the second paper was not arranged for publication before his untimely death. He was electrocuted while experimenting with high-voltage television equipment at his home, in 1938.

By that time he had collected a large quantity of valuable ultra-high-frequency wave-propagation data which had not been evaluated for publication. It is unfortunate that he could not have had the opportunity of interpreting these data himself. In the manner of most experimenters, many of his excellent data were not arranged for evaluation by others. Complete records of dates, times, and equipment are not to be found in many instances, although the records appear quite interesting.

All of the collected signal-strength recordings, some evaluated charts, and the slides and notes found in Mr. Hull's residence were kindly turned over to C. F. Brooks, director of the Blue Hills Meteorological Observatory of Harvard University, by the executors of his estate. He had early directed Hull's attention to abnormal refraction by inversions of temperature as the apparent cause of the large variations in ultra-high-frequency transmission, and had assisted him in obtaining and interpreting upper-air meteorological data for comparison with his measurements of transmission. He had also been instrumental in supplying the transmitted five-meter signal for many of Hull's recordings of relative signal strength. Hull's work was deemed important as providing a quantitative test of the apparent effects of the layer structure of lower atmosphere on ultra-high frequency, as indicated by transmissions between Mt. Washington and Blue Hill beginning in 1933.

The establishment of a regular ultra-high-frequency radio circuit on five meters between Mount Washington (A. A. McKenzie) and Blue Hill (A. F. Sise), 142 miles distant, in December, 1933, and a qualitative correlation of the marked variations in signal strength on this path with the observed and surmised layer structure of the lower atmosphere, led G. W. Pickard (radio) and C. F. Brooks (meteorology) to the tentative hypothesis that the radio variations were largely caused by variations in refraction related to the lapse rate of temperature and the heights and intensities of inversions of temperature.[3,4]

In view of the foregoing interest of Harvard University in this subject, I have attempted to reconstruct Hull's record with as many interpretations as possible. Although other occupations have delayed this process, the results are presented here as a compilation of all

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† Formerly, Cruft Laboratory and Blue Hill Meteorological Observatory, Harvard University, Cambridge, Massachusetts; now, RCA-Victor Division of Radio Corporation of America, Camden, N. J.

[1] Ross A. Hull, "Air-mass conditions and the bending of ultra-high-frequency waves," *QST*, vol. 19, pp. 3–8; June, 1935.

[2] Ross A. Hull, "Air-wave bending of ultra-high-frequency waves," *QST*, vol. 21, pp. 16–18, 76–82; May, 1937.

[3] G. W. Pickard, "Variations in ultra-high-frequency radio transmission and possible correlation with the weather," *Bull. Amer. Met. Soc.*, vol. 15, pp. 5–6; January, 1934. (Abstract.)

[4] A. F. Sise and C. F. Brooks, "An investigation of ultra-high-frequency radio transmission in relation to weather," *Bull. Amer. Met. Soc.*, vol. 15, pp. 238–239; October, 1934.

information which could be interpreted readily at this time. Whenever possible, direct quotations from Hull's notes have been used. An attempt has been made to present the material as nearly as possible as he saw it. If any experimenters associated with him in this work care to contribute additions or make corrections, their comments will be most welcome.

Introduction

Ross Hull's early work involving the use of five-meter signals for communication far beyond the horizon is best described in his own words in various issues of *QST*.[1,2] In 1934 he found it possible to communicate with stations near Boston, Massachusetts, a distance of about one hundred miles, using directional antennas installed in his home near Hartford, Connecticut. The astonishing feature was that this transmission path embraced approximately "three horizons." At that time most five-meter work had been limited to distances only slightly beyond the first horizon.

On certain occasions, these contacts were extended as far as Mount Washington, New Hampshire, one hundred and eighty-five miles from West Hartford, Connecticut. The signals were also *heard* by Henry S. Shaw (W1FGA) (now W1JK), at Mount Cadillac, Maine, two hundred and eighty miles distant.[4]

Scheduled Measurements of Signal Strength

Early communication tests were quickly followed by several series of relative-field-strength measurements. From August 20, 1934, the Blue Hill Meteorological Observatory, near Milton, Massachusetts, provided the facilities of W1XW for special schedules each morning and night. In January, 1935, this was changed to an automatic hourly schedule of tone signals, which provided an extended series of valuable records.

The help of James Millen (W1HRX), Malden, Massachusetts, Harner Selvidge (W1FQV), Cruft Laboratory, Harvard University, Cambridge, Massachusetts, H. S. Shaw (W1FGA and W1JK), Exeter, New Hampshire, and many other amateur stations was enlisted in these early surveys of ultra-high-frequency propagation.[1] Later, it was found possible to make continuous recordings of the absolute field strength of crystal-controlled signals from ultra-high-frequency Yankee Network stations at Squantum, Mass.

More than six years have passed since the publication, in *QST*, of Hull's last paper on this subject. It was intended as a preliminary report to lead into the discussion of his later work. For completeness in this summary, the quotations of much of that material appear necessary. Those who have read the original should benefit considerably from Hull's clear analysis of the conditions of propagation. Quotations are in part from his published articles, but mostly from several of his groups of notes for talks and future papers.

From his viewpoint of 1937, I quote: "There are still many phases of amateur radio that we know very little about. One of these, and a particularly engaging one, is the behavior of ultra-high-frequency waves at distances beyond the line of sight. For many years we suffered from the erroneous impression that there was nothing left of the signals beyond the horizon. With frequencies slightly higher than 30 megacycles, it was assumed, the ionosphere became quite useless as a medium for bending the waves back to earth, and that, without this bending, there could be no signals beyond the line of sight. But early experimental work showed that the signals did *not* stop precisely at the horizon; that they could be detected slightly beyond this point. An explanation was readily available. It had been known for many years that light waves take a curved path through the lower atmosphere, and are spread behind obstructions through the phenomena of diffraction and refraction. Computations showed the ultra-high-frequency waves actually should not travel in straight lines across the surface of the earth, but that they should bend in a curve having a radius of approximately four times the earth's radius. Somewhat similar computations had been used long before to show that, because of this bending of electromagnetic waves in the atmosphere, the sun is visible for at least two minutes and twenty seconds after it has actually passed below the horizon. These computations are also used in astronomical work to correct for the apparent positions of celestial bodies."

"As a result of the work of Shellung, Burrows, Ferrel,[5] Englund, Crawford, Mumford,[6] Trevor, Carter,[7] von Handel, Pfister,[8] Eckersley,[9] and others, there has been provided a sufficiently wide variety of theoretical and experimental evidence to allow an approximate estimate of the field intensity of ultra-high-frequency waves propagated by the effects of diffraction to points beyond the horizon. Similarly comprehensive examinations of the refraction field have not been reported."[10] "The treatment which it has received, we believe, has been altogether inadequate. It is our intention to show some experimental results which suggest that the prevalence, the intensity, and the variability of the so-called 'refraction field' may be of greater consequence than we have, in the past, believed. In general, the published observational material has been the result of measurements made during the day, when conditions producing the refraction field are ordinarily least favorable. The

[5] J. C. Schelleng, C. R. Burrows and E. B. Ferrell, "Ultra-short-wave propagations," Proc. I.R.E., vol. 21, pp. 427–463; March, 1933.

[6] C. R. Englund, A. B. Crawford and W. W. Mumford, "Further results of a study of ultra-short-wave transmission phenomena," *Bell Sys. Tech. Jour.*, vol. 14, pp. 369–387; 1935.

[7] Bertram Trevor and P. S. Carter, "Notes on propagation of waves below ten meters," Proc. I.R.E., vol. 21, pp. 387–426; March, 1933.

[8] Paul von Handel and Wolfgang Pfister, "Ultra-short-wave propagation along the curved earth's surface," *Hochfrequenz. und Electroakustik*, vol. 47, pp. 182–190; June, 1936.

[9] T. L. Eckersley, "Ultra-short-wave refraction and diffraction," *Proc. Wireless Sec., Jour. I.E.E.* (London), vol. 80, p. 286; March, 1937.

[10] Since that time, noteworthy examinations have been made. One of these is C. R. Englund, A. B. Crawford and W. W. Mumford, "Ultra-short-wave transmission over a 39-mile 'optical' path," Proc. I.R.E., vol. 28, pp. 360–369; August, 1940.

theoretical approach has either been based on atmospheric conditions measured at the earth's surface, or on the assumption of an atmospheric structure inadequately described in earlier meteorological literature. The relatively recent extensive exploration of the lower atmosphere by meteorological airplane sounding flights[11–13] suggests that the assumption of a 'standard atmosphere' in the mathematical treatment must lead to a gross understatement of refraction effects."

" . . . Perhaps it would be well to digress long enough to review a few general ideas as we see them today. In very simple terms, it can be said that we would have no bending of radio waves were it not for the fact that their velocity varies in the different media through which they pass. All we need, to make a wave headed out for space bend back to earth, is to have an atmosphere in which the make-up is such as to increase the velocity of propagation the higher the wave front goes. This condition is satisfied most of the time for the lower frequencies because of the existence of layers of increasing ionization far above the earth's surface (the ionosphere). These gradients of ionization, however, are very rarely steep enough or low enough to bend back ultra-high-frequency waves to earth. That they do bend ultra-high-frequency waves back once in a while is fairly well established by the several instances of signals being heard and communication being established over distances of 1000 miles or more. The ionosphere, as we ordinarily consider it, may be the responsible agency. In this discussion, however, where we are to talk exclusively of a brand of bending that gives us signals at 50 or 100 miles, we believe firmly that we can forget ionization and look to other sorts of gradients in the very lowest reaches of the atmosphere, in this very same air in which birds (and men) fly.

"In this part of the atmosphere we know that the velocity of the upper edge of the wave front is increased, for instance, if it is traveling into a region of increasingly low atmospheric pressure (which it ordinarily does), or into a region of increasingly high temperature, or into a region of steadily decreasing water-vapor content. These sorts of conditions all provide a negative gradient in the index of refraction of the atmosphere; and a decrease in the index of refraction results in an increase in the velocity of propagation. Under ordinary, clear, settled weather conditions these requirements are partially satisfied in the lower atmosphere. The pressure drops off sharply with height, and the water vapor decreases also. During most of the day, unfortunately, the temperature drops off sharply with height above ground (the conditions we don't want). The result, as shown both in theory and practice, is a slight bending of five-meter waves in a trajectory or path having a radius of curvature of about four times the earth's radius. As a result, we can talk to points slightly beyond the horizon."

[11] More recently, the radio sonde has been extensively used for similar studies. Even sounding by radio waves has been developed. Samples of atmospheric sounding by airplane or radio sonde are to be found in most modern works on meteorology, and in numerous papers published in the United States Weather Bureau's *Monthly Weather Review* and the *Bulletin of the American Meteorological Society*. Comparisons between radio-sonde data and those obtained by the radio-wave method are found in the papers listed in footnotes 12 and 13.

[12] A. W. Friend, "Developments in meteorological sounding by radio waves," *Jour. Aero. Sci.*, vol. 7, pp. 347–352; June, 1940.

[13] A. W. Friend, "Further comparisons of meteorological soundings by radio waves with radio-sonde data," *Bull. Amer. Met. Soc.*, vol. 22, pp. 53–61; February, 1941.

Variations in Air-Wave Bending

" . . . this atmospheric condition is by no means a stationary one. Once the sun has set on our sample clear day, the temperature of the surface air begins to cool. By midnight, we may well have a gradient that gives a steady *increase* in temperature for the first 2000 feet above ground. At that time we have *all* factors tending to increase the velocity of the upper part of the wave front, and as a result we have much stronger ultra-high-frequency signals beyond the horizon. Such nighttime increase in signal level we will later show to be a very real effect, particularly in the summer when the day-to-night temperature contrasts are so great."

"This sort of stable, clear weather condition is, as it happens, the condition that ordinarily provides the least bending of all. It generally coincides with the prevalence of what weather men term polar air. Let an air mass from the tropics drift across this polar air, and we have a setup in which the temperature may increase *irregularly* all the way up to eight or ten thousand feet. The result is now a relatively tremendous bending, and very intense signals. Another result is the formation of clouds at the level where the warm and cool air mix, and, later, rain. Naturally, an almost indefinite number of other atmospheric conditions may exist, with the temperature, water-vapor, and pressure gradients doing all sorts of unexpected things. They all reveal themselves, we hope later to show, in changes in the order of bending and consequent variations in signal level."

"All this, of course, is based on what we now know about bending in the atmosphere. It was far from clear to us a few years ago. We have a picture of ultra-high-frequency propagation, but only a very meager one; no long-distance signals because the ionosphere was ineffective; good signals only along the line of sight; weak signals immediately beyond the horizon, possibly resulting from diffraction and refraction, and a rapid falling off beyond that."

Fading of Ultra-High-Frequency Signals

"In 1931, Jouast[14] reported some experiments made with five meters in France between stations slightly beyond the line of sight. The signals were found to vary in strength, and this fading was considered to be the result of slow changes in the makeup of the lower atmosphere, particularly in the gradient of the temperature of the air immediately above the earth's surface. This

[14] R. Jouast, "Some details relative to the propagation of very-short waves," Proc. I.R.E., vol. 19, pp. 479–488; March, 1931.

observation (we believe it to be the first on record) that ultra-high-frequency waves were subject to fading received very little notice at the time, and nothing much was done about it until 1934, when RCA engineers reported observing weak fluctuating signals beyond the horizon. Then G. W. Pickard and Dr. C. F. Brooks[15] began consistent observations on five-meter signals between the Blue Hill Observatory, Milton Massachusetts, Seabrook Beach, New Hampshire, and Mount Washington, both paths extending somewhat beyond the horizon."

"The first real jolt to our understanding of ultra-high-frequency behavior was had in August, 1934, when communication was more or less accidentally established[16] between West Hartford and Boston, a 100-mile path of *not one horizon but five*, with a radius for the clearing-ray path of but six tenths of the earth's radius. Here, obviously, was an order of bending far beyond our wildest expectations. More important still was the observation that the signals from these Boston low-powered stations held steadily at very high levels for many hours at a time on some occasions, while on others they would either be subject to violent slow variations, or be entirely absent. Naturally, there was a mad scramble to provide an explanation. It seemed obvious from the beginning that the ionosphere had nothing to do with it. This conclusion seemed reasonable, since the lowest signals were invariable during the day, with the strongest signals in the early hours of the morning. Then, the fading was much slower than that experienced on the lower frequencies. Further, the periods of very highest signal level invariably accompanied those atmospheric conditions which resulted in rain..There was nothing in any of the observations to suggest a relationship with the ionosphere. On the other hand, it was difficult to explain the performance as being the result of diffraction from the intervening ridges of hills. Such a phenomenon would not allow such variations in signal strength, and would certainly not permit the signal to drop out entirely. But, by the very same token, it was almost equally difficult to reconcile the very high signals with the estimates based on current refraction calculations. Indeed, calculations clearly showed that we should have no signals at all. The favorable location of the West Hartford station, on a small hill 180 feet above the surrounding country and 320 feet above sea level, did not offer a solution, since there still remained the five horizons to be bridged even to reach favorably located stations in Boston."

Recordings and Observations Concerning Propagation over Long Indirect Paths

The problem involved led to the institution of a two-and-one-half-year program of measurement, recording, and observation of ultra-high-frequency signals over several long indirect paths.

"During this work, the recordings of signal intensity were closely studied in conjunction with the data obtained in daily meteorological airplane sounding flights, which served to reveal the actual structure of the lower atmosphere and the relatively enormous day-to-day changes in it. This work has shown that, while the lowest signal intensity falls reasonably close to values computed by conventional methods, those values are considerably below the mean values taken over an appreciable period. Then, these lowest signal levels (which, we will show, obtain during the day when a homogeneous atmosphere, in which the temperature gradient is sharply negative, prevails over the path) in no way suggest the intensity to be observed on most summer nights, or any other periods when some stratification of the atmosphere exists."

"Hourly tone transmissions on 60.5 megacycles were made available by Brooks, of Blue Hill, and these were recorded photographically[17] at West Hartford during 1935 and the first few months of 1936. A super-regenerative receiver was used in conjunction with a 12-element directive antenna. The setup was such that only qualitative observation could be undertaken. Nevertheless, the recordings, studied in conjunction with the airplane soundings of the lower atmosphere made in East Boston and Mitchel Field, Long Island, proved invaluable in substantiating the belief that the signals, in spite of their high average level, resulted chiefly from refraction in the lower atmosphere, and that the enormous variations in the signal level were the result of changes in stratification in the air, so frequently found in the atmosphere itself but so infrequently given attention in previous studies. The product of the first few months' work was the basis of a paper read before a scientific group in Washington, in May, 1935, and published in revised form in June, 1935.[1] The one observation considered to be of importance was not that ultra-high-frequency waves were bent beyond the horizon, but that the bending could so frequently be of such an unexpectedly high order as to bridge a 100-mile path with intervening ridges of hills 1000 feet high, and to put down a field on many occasions as strong as one would normally expect along an unobstructed line-of-sight path."

Early Conclusions and Later Experimental Results

The observations reported in the first paper were made chiefly in the winter months, and the conclusions were: "It appears that an extensive subnormal temperature-lapse rate anywhere in the regions between 300 and 2500 meters above the surface of the earth is

[15] The actual measurements, mostly qualitative, at Blue Hill Observatory, C. F. Brooks, director, were made by Albert F. Sise, Arthur E. Bent, and (later) Alexander A. McKenzie, and Charles B. Pear, Jr.

[16] Ross A. Hull, "Extending the range of U.H.F. amateur stations," *QST*, vol. 18, pp. 10–13, 106; October, 1934.

[17] Ross A. Hull, "A simple photographic recorder for the experimenter," *QST*, vol. 19, pp. 27–28, 100–101; March, 1935.

accompanied by a high 60-megacycle signal level over the path. . . ." In other words, it was indicated that high signals coincided with an atmospheric condition in which the temperature of the air did not decrease with an increase in height as rapidly as during " . . . conditions considered normal for a clear, settled day. Observations which had been made prior to the installation of the recorder had indicated much higher signals during the fall of 1934, when temperature gradients were known to have been at least no more favorable than in the winter." "We expressed the thought then that the higher signal levels of the warmer months probably result from the higher specific humidity prevailing during that time." "Aside from the splendid assistance given us during this work by Dr. Brooks and his associates at Blue Hill, we had at all times the full co-operation of many Boston and New York amateurs, James Millen, W1HRX, and Harner Selvidge, W1FQV, at Harvard University, maintaining regular nightly observation schedules for several months."

"During 1935, 60.5-megacycle signals were continuously recording over a path shown in contour form in Fig. 1. The 75-watt transmitter was located at the Blue Hill Observatory of Harvard University, the dipole antenna being 200 (210) meters above sea level on a hill 200 (195) meters high. The recording receiver, using a 12-element directive array, was located 148 kilometers to the southwest, 10 meters above a hill 100 meters in height."

Fig. 2 is a plot of the daily mean values of the recorded signal, while Fig. 3 indicates the diurnal characteristics for the four seasons. "It will be noted that a very well-defined seasonal change occurred. The diurnal characteristics show that the greatest change throughout the day occurs in the warmer months, the minimum change occurring during the winter. It will be seen that the signal intensities are consistently higher than expectations based on conventional computations. Indeed, it has been observed that the signal even approaches the free-space value for considerable periods."

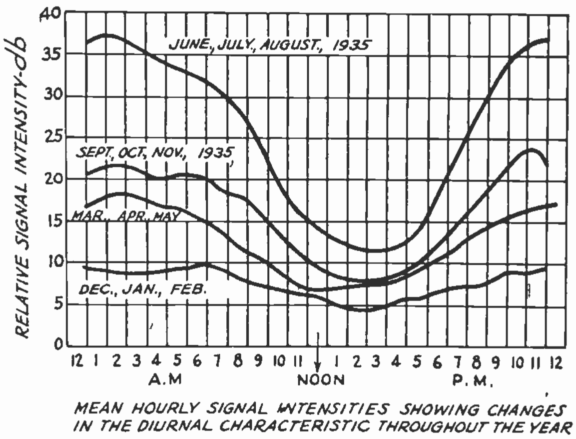

Fig. 3—Diurnal characteristics of 60.5-megacycle-per-second transmission path from Blue Hill, Massachusetts, to West Hartford, Connecticut, during the four seasons of 1935.

"By May of 1936, the recording receiver having been running some eleven thousand hours, we had accumulated a great deal more information on the way signals behaved under a great variety of atmospheric conditions, and were able to present, in a second paper, the

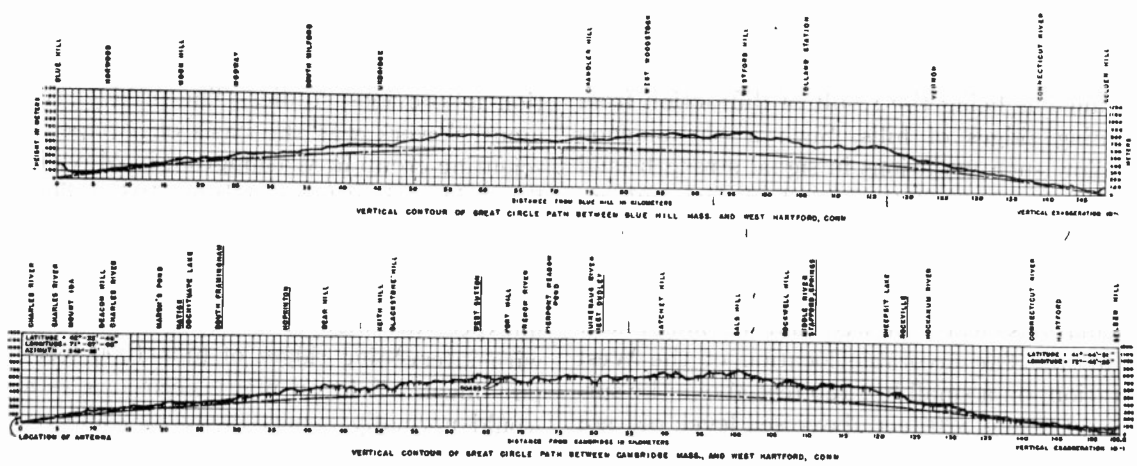

Fig. 1—Vertical contour of great-circle path between Blue Hill, Massachusetts, and West Hartford, Connecticut; and vertical contour of great-circle path between Cambridge, Massachusetts, and West Hartford, Connecticut.

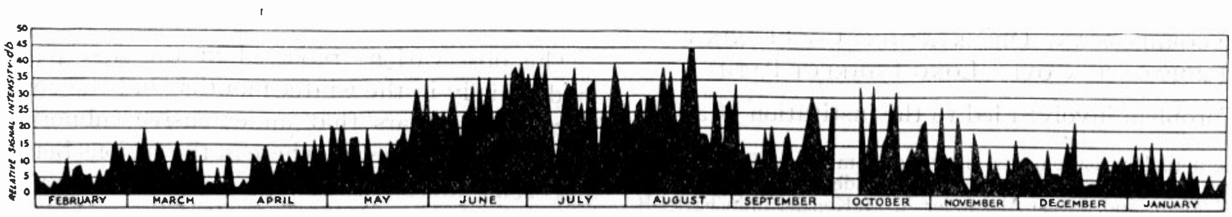

Fig. 2—Mean daily values of 60.5-megacycle-per-second signal from Blue Hill, Massachusetts, recorded at West Hartford, Connecticut, during 1935.

seasonal variations, which showed a very great increase in average signal during the summer, and curves showing the average hour-to-hour variations during the four seasons. These diurnal curves revealed that while the water-vapor characteristic was of tremendous importance, its effect in increasing the bending seemed to be dependent primarily on the existence of a favorable temperature characteristic.[18] This was indicated by the fact that the summer day signals were not greatly in excess of the winter signals, in spite of the much more favorable summer water-vapor condition. Only at nighttime when the cooling of the surface air provided the necessary temperature stratification, did the summer signals rise appreciably above those of the winter. Again during this period, splendid amateur co-operation was forthcoming, E. E. Stark (W1OM), Andover, Massachusetts; A. E. Ericson (W1NF), Beverly, Massachusetts; R. E. Burditt (W1MJ), Wakefield, Massachusetts; and others, maintaining nightly schedules continuously over a period of six months or so."

"All of this work was still qualitative, but it definitely clinched, in our own minds anyway, the belief that of the few possible agencies, temperature and water-vapor gradients in the lower atmosphere were giving us this extraordinarily pronounced bending. Diffraction, we were forced to admit, was probably providing us with a steady subaudible signal, but the observation that the signals disappeared entirely at times admittedly left us no better reason to include diffraction in the discussion than the theoretical demand for its existence."

Recordings on a Quantitative Basis

"By July, 1936, we had reached the point where further qualitative observations were considered to be unjustified. The existing transmission and reception equipment, because of various forms of instability, were obviously unsuited for quantitative work, and an entirely different line-up was planned. About that time, the Yankee Network had begun operation on the outskirts of Boston. This transmitter, being higher in power than that used at Blue Hill, and being crystal-controlled, was considered to be a particularly appropriate one for recording. For the West Hartford end, a crystal-controlled receiver (Fig. 4) was assembled for operation with a Leeds and Northrup recorder, loaned for the work by the Yankee Network. Calibration equipment was provided so that the signal field could be measured in microvolts per meter. Then, with a simple dipole antenna, a program of continuous recording of carrier level was begun in August. This installation has already piled up six thousand hours of operation and is headed for more. (1937.)

"Needless to say, these continuous records proved to be infinitely more informative than the hourly tone signals previously recorded. There was revealed at once a whole series of types of fading (each one obviously related to the type of air mass prevailing) and the records

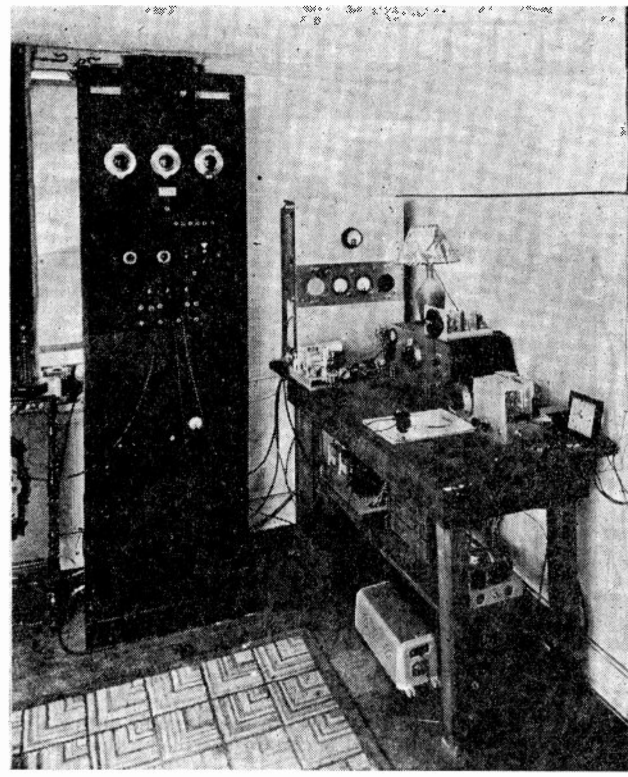

Fig. 4—A crystal-control receiver for operation with a Leeds and Northrup recorder, loaned by the Yankee Network for recording the 41-megacycle-per-second signal from their station, W1XER, at Squantum, Massachusetts.

in general showed all sorts of minor trends and irregular behavior not previously made apparent. In addition, the stability of both transmitter and receiver gave us more confidence in the recordings as an undistorted picture of actual signal variations along the path. Of course, this continuous recording immediately introduced new difficulties. The recorder, turning out some 50 feet of 10-inch-wide record each week, soon forged ahead of us so far that we seriously doubted our ability to get enough time to reduce the records to some working form. The hourly tones of the previous work had been measured from the photographic record, mean values being then taken for each day and for each hour of the day each week, a sufficiently tedious business. With this new program we required a reduction of the recording in terms of signal level versus percentage of time, a procedure which, when done by hand, takes almost as much time as did the production of the recording itself. The outcome was the development and construction of an automatic record analyzer (Fig. 5) to be described later. This same device, after having served to reduce all existing recordings, was fitted to the recorder itself so that the signal is now (1937) not only recorded but integrated automatically as well."

"In Fig. 6 is given the profile, and in Fig. 7 the mean signal values obtained over it on a frequency of 41 megacycles. The signals in this particular sequence were transmitted from Squantum, near Boston, Massachusetts. The output power was approximately 250 watts

[18] Note: This is believed to be not always true.

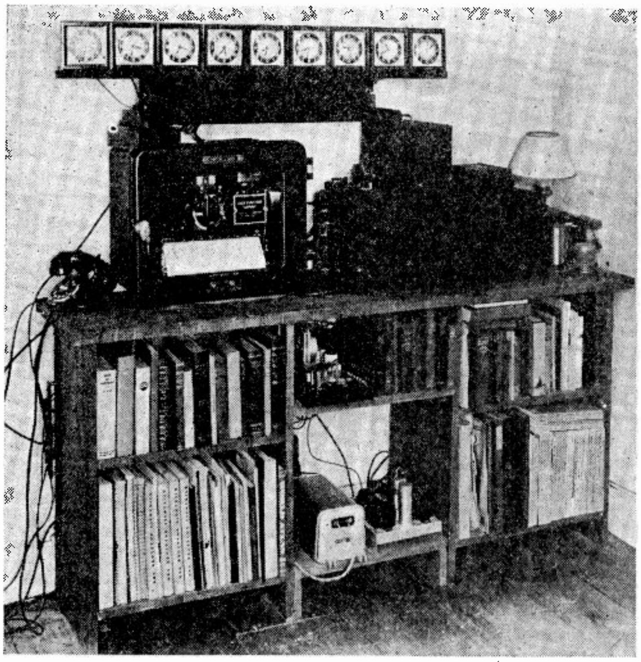

Fig. 5—Automatic analyzer for signal field strengths and recordings. This system was arranged for integrating the time during which the signal strength exceeded a certain specified value for each clock.

supplied to a dipole antenna. This dipole was located on a tower 110 meters high, erected substantially at sea level. The path in this case is 158 kilometers long, while the receiving antenna, consisting of two half waves in phase, is 10 meters above a hill 100 meters above sea level. The signal characteristics indicate a lesser change than that observed on 60.5 megacycles, but the day-to-day changes are of somewhat similar magnitude. It is of interest to note, here, that the signal intensity resulting from diffraction and computed for this path length and these terminal-station elevations on the basis of data provided by Eckersley, is of the order of 1 microvolt per meter, the zero level indicated on the signal curve in Fig. 7. This same signal data, reduced in months and for the entire period, is given in Fig. 8."

"In addition to the 41-megacycle receiver, two other crystal-controlled receivers were provided, one for the Yankee Network 61.5-megacycle station, W1XAC, and the other for the Blue Hill Observatory transmitter. These additional receivers, together with a new double-meter photographic recorder,[19] provided simultaneous recordings on different frequencies, and produced some extremely interesting results."

Fading Characteristics

"This recent (1937) phase of the program has brought to light a great many interesting phenomena which, unfortunately, space does not allow us to recount in detail. In general, however, the recordings show that on the three frequencies studied, signals are low, and subject to low amplitude and rapid fading (about one fade per minute) when a fresh air mass of polar origin prevails over the path during the day. The fluctuations show a definite slowing down towards evening, while simultaneously increasing in strength in the early morning hours. This high and stable signal is maintained until slightly after sunrise, when it again breaks up into increasingly rapid fading while dropping into a lower and lower level towards the middle of the day."

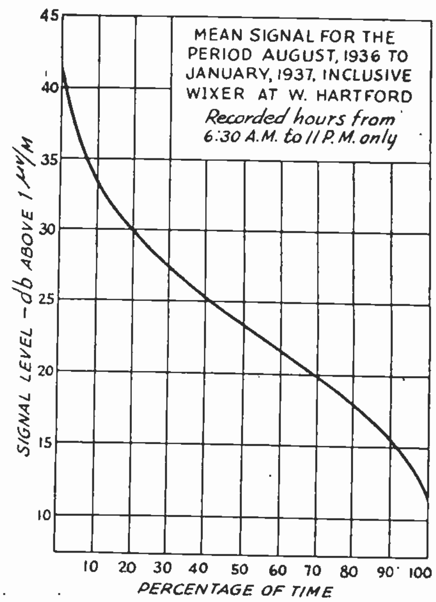

Fig. 7—Mean signal for the period August, 1936, to January, 1937, inclusive, transmitted on 41 megacycles per second from W1XER at Squantum, Massachusetts, and recorded at West Hartford, Connecticut.

"The explanation deduced to cover this behavior is that polar air has a relatively small water-vapor content and a temperature which drops off smoothly with height during the day. In such an air mass, appreciable turbulence is caused by the heating of the surface air and the resulting convection. It is the sort of air eagerly waited

[19] "Based on the same scheme employed in the earlier recorder but fitted out with many mechanical refinements, this apparatus was constructed with facilities made available through the courtesy of James Millen, and was contributed by him to the program."

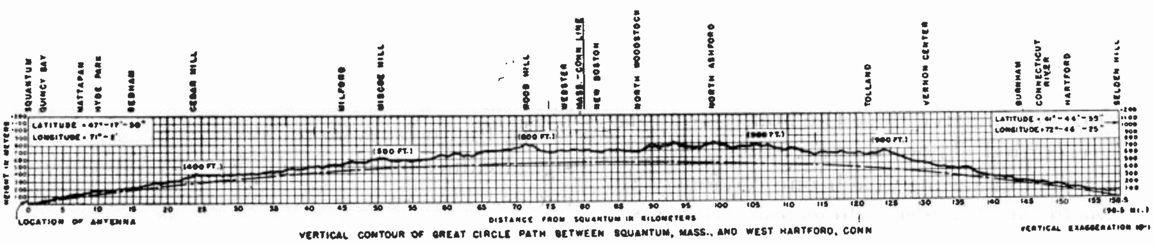

Fig. 6—Vertical contour of great-circle path between W1XER, Squantum, Massachusetts, and West Hartford, Connecticut.

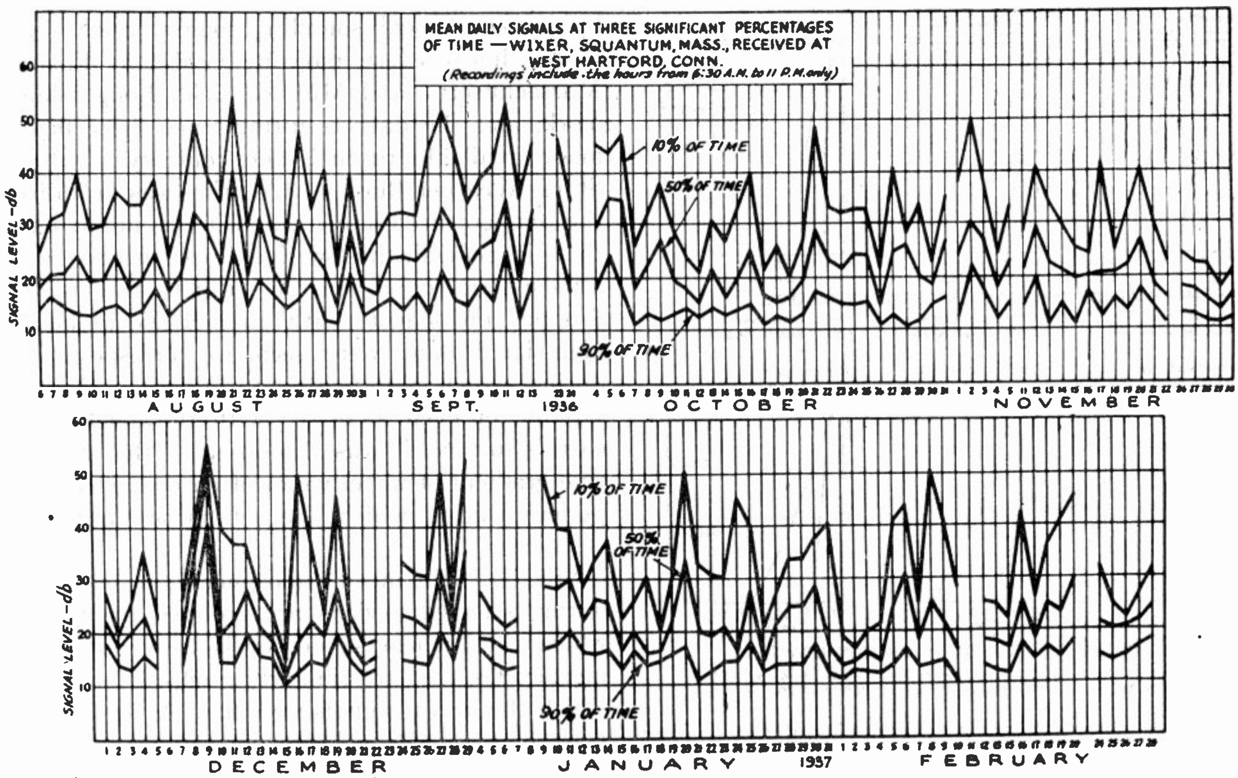

Fig. 8—Mean daily signals at three significant percentages of time for the 41-megacycle-per-second signal over the Squantum, Massachusetts, to West Hartford, Connecticut, path.

for by pilots of sailplanes who require, for effective flight, the upflow of heated air (thermals, they are called). This turbulence considered to be the direct cause of the rapid signal fading, is reduced after sundown because of the surface cooling. Gradually the lowest layer of the atmosphere drops to a temperature lower than that of the air above it. This condition, during the night, gives us the steady and relatively strong signals. Turbulence again sets in with the rising of the sun, and heating of the surface air again destroys the temperature inversion that has been so helpful in producing the strong bending during the night."

The Effect of Tropical Air

"This behavior, of course, applies only to a stable condition of fresh polar air. Such an air mass becomes rapidly modified by the continued heating of its lower level, and by the assimilation of added water vapor. This, as far as weather is concerned, involves the formation of cumulus clouds and a reduction in that high order of visibility which characterizes fresh polar air. During this phase, signals take on a much more ragged fading characteristic and attain a higher level for a given time of day than previously. This type of air rarely prevails for long in this part of the country, and within a day or two one ordinarily expects a low-pressure area to come in across the southwest part of the country, spreading over the Atlantic states a layer of warm tropical air. This circumstance shows itself in the signal recordings as a tendency for the minor fluctuations to group themselves in a sort of wave motion, the surges becoming longer in duration and higher in amplitude, as the tropical air reaches down toward the surface. By midevening on a day when such a tropical disturbance is approaching, the signal will ordinarily have reached a mean level of something more than 200 microvolts per meter, holding this level with very slight fluctuation over periods of an hour or more, then suffering a momentary deep fade For three or four hours prior to the actual beginning of precipitation, the signal is prone to ride, with substantially no variations, at a level in excess of 300 microvolts per meter."

"The beginning of precipitation is usually accompanied by a complete change in the character of the signal, the change being slow or rapid, apparently depending on the extent to which the area of precipitation covers the signal path. Ordinarily, the change is the development of very small amplitude and rapid fading, which carries the signal to a lower but still fairly steady level. This, however, is not always the case. In several outstanding instances, the extremely high level was maintained for several hours after precipitation had started. The study of conditions surrounding such exceptional cases, of course, is very much a part of the work."

The Relationship to Atmospheric Gradients

"During the whole period of recording, an attempt was made to establish a relationship between the signal level and gradients measured in the lower atmosphere

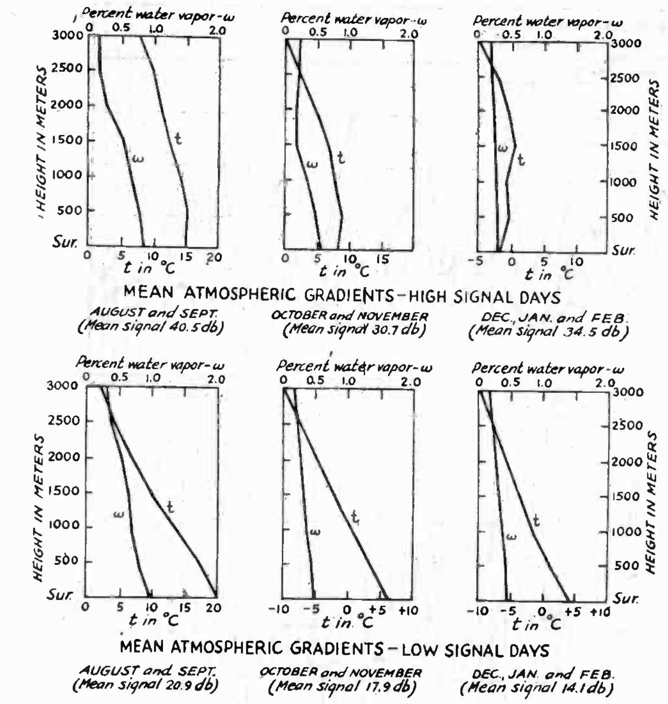

Fig. 9—Mean atmospheric gradients prevailing during selected periods and grouped for days during which the highest and lowest signal levels were obtained on 41 megacycles per second.

by meteorological sounding flights. Such flights are made almost every morning (1937) at East Boston, Massachusetts, and Mitchel Field, Long Island, New York, and the data resulting from these flights were made available through the courtesy of the United States Weather Bureau. Attention was first directed to the temperature gradient, and it was immediately seen that, in general, the low-signal periods corresponded to atmospheric conditions in which the temperature dropped off sharply with an increase in height. The high-signal days were seen to correspond to those during which the temperature decreased much less rapidly, or even increased with the height above the earth's surface. It was also observed that a steep negative gradient of water vapor often coincided with those periods during which the refraction appeared to be strongest."

"In Fig. 9 the mean atmospheric gradients prevailing during selected periods are grouped for the days on which the highest signal levels were obtained on 41 megacycles, and are similarly grouped for the days on which the lowest signals were had. A very definite contrast between the water-vapor gradients is not to be seen. On the other hand, one is forced to conclude that

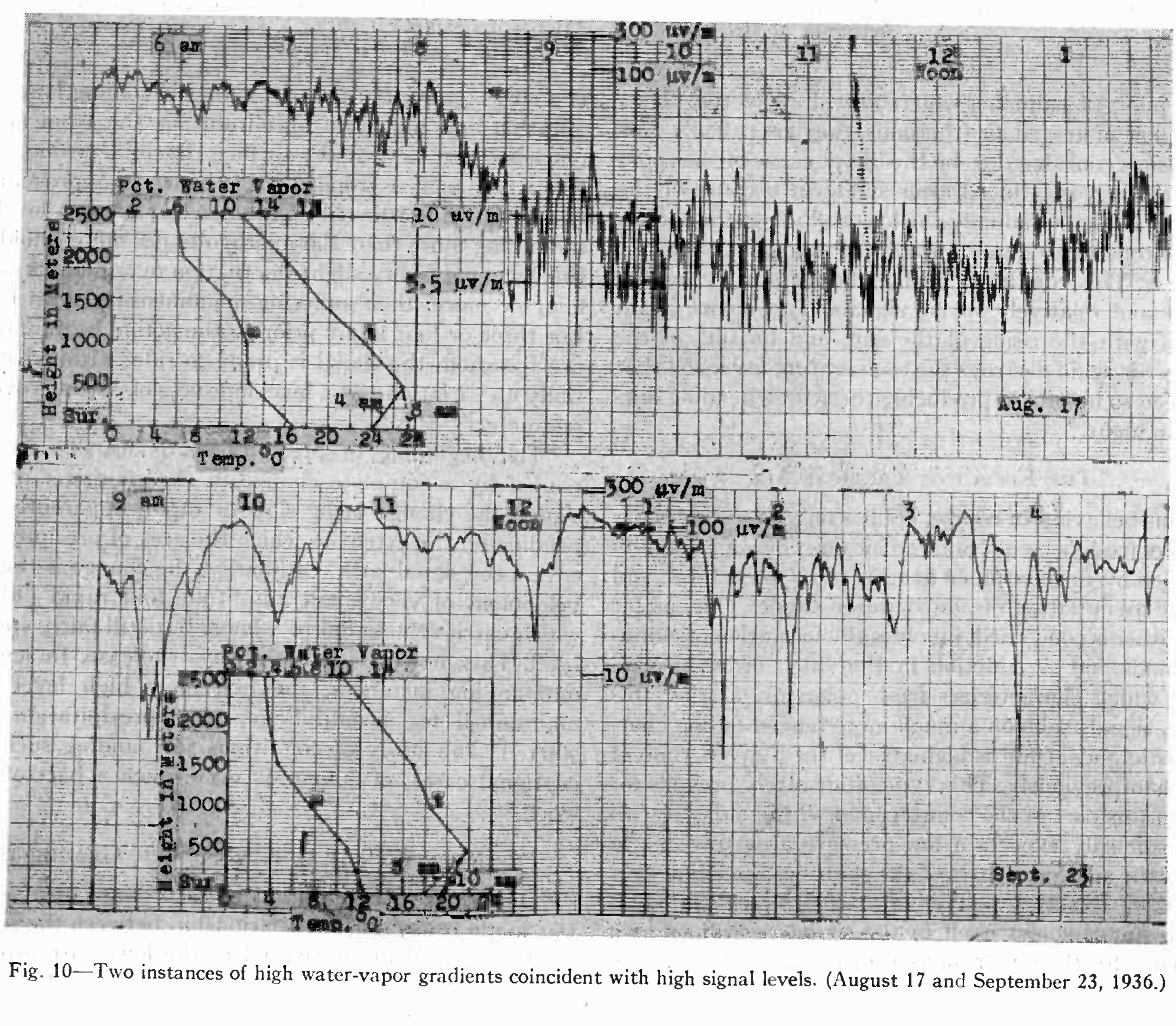

Fig. 10—Two instances of high water-vapor gradients coincident with high signal levels. (August 17 and September 23, 1936.)

the steep water-vapor gradient prevailing during the high days of August and September (Fig. 10) must have been concerned with the production of effective refraction, since the temperature characteristic for that period is considerably less favorable than that indicated for the colder months (Fig. 11)."

Fig. 10 is an excellent example of the morning wiping-out of the ground inversion with its coincident reduction in signal strength during the morning of August 17th. The approximate alteration of the lower air temperature is indicated by the dotted line. This new value was apparently assumed from the change in ground temperature. The lower part of Fig. 10 for September 23rd shows a simple type of fading with no reduction in field strength as the day progressed. In this case the ground inversion apparently persisted. On this date there was only one major region of refraction (or reflection) (Fig. 12) while in the case of the August 17th record (Fig. 13), two or three regions of rapid change of the dielectric constant of the air apparently produced strong multiple-path transmission with severe rapid-fading characteristics.

A fairly complete record of the upper-air characteristics obtained by airplane over Boston, Massachusetts, on September 23, 1936, has been interpreted (Fig. 12) in terms of the radius of curvature of a ray, or beam, of radio waves. The calculated radius of curvature just below 500 meters altitude is less than 60 per cent of the radius of curvature of the earth. This region, approximately 100 meters in thickness, is the apparent reason for the very strong signal observed in the September 23rd signal-strength recording of Fig. 10. A second region of somewhat reduced radius of curvature was similarly determined between 1085 and 1224 meters altitude. This does not appear to have provided sufficient refraction to produce enough bending of the ray path to cause marked fading by interference with the lower-level propagation. In fact, it appears that most of the energy must have been guided back toward the earth by the atmospheric region between 385 and 495 meters.

These radii have been determined by means of the theoretically derived equation

$$\bar{R} = (h_2 - h_1)/[78.75(p_1/T_1 - p_2/T_2)10^{-6} + 0.378(e_1/T_1^2 - e_2/T_2^2)] \qquad (1)$$

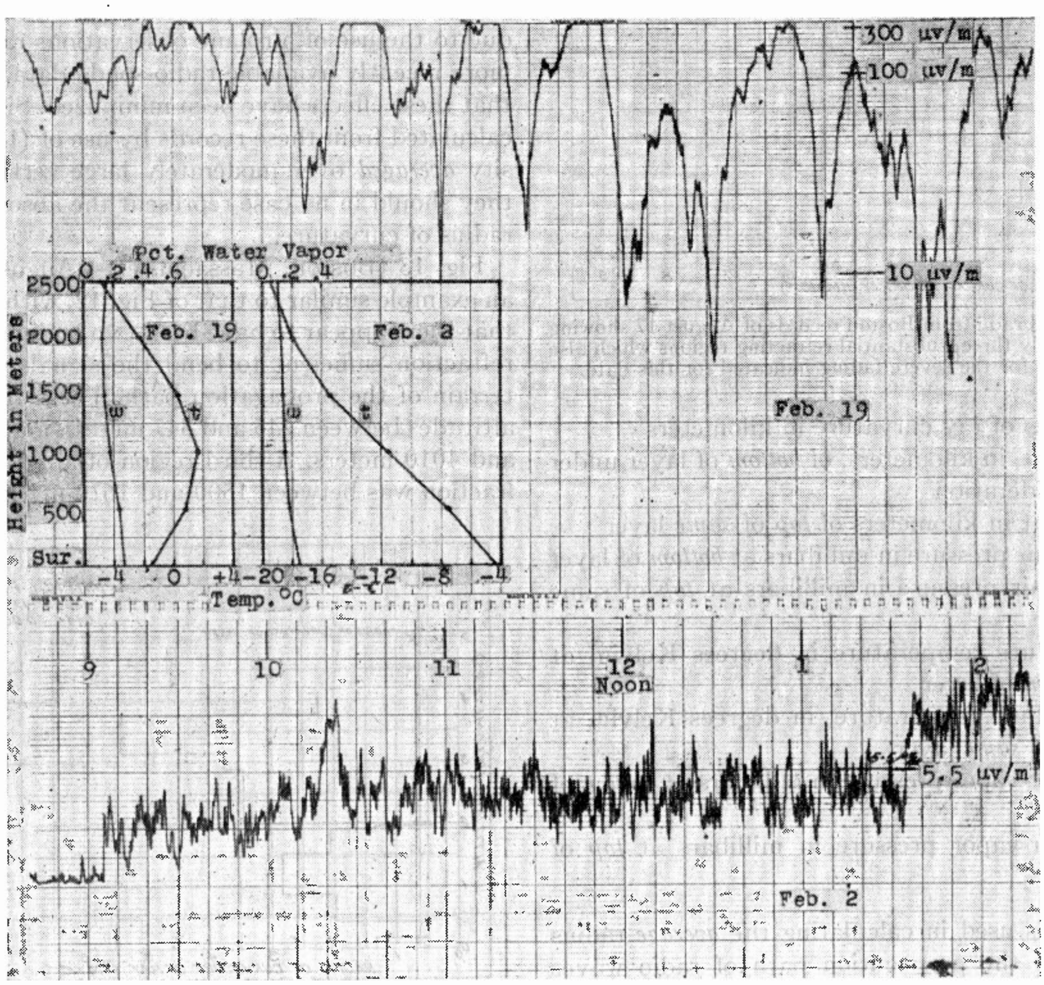

Fig. 11—Two examples of low-water-vapor-gradient conditions with different temperature gradients. On February 19, 1937, (upper) the temperature inversion apparently produced high signal levels, while on February 2nd (lower) the lack of any noticeable inversion was coincident with considerably lower signal levels.

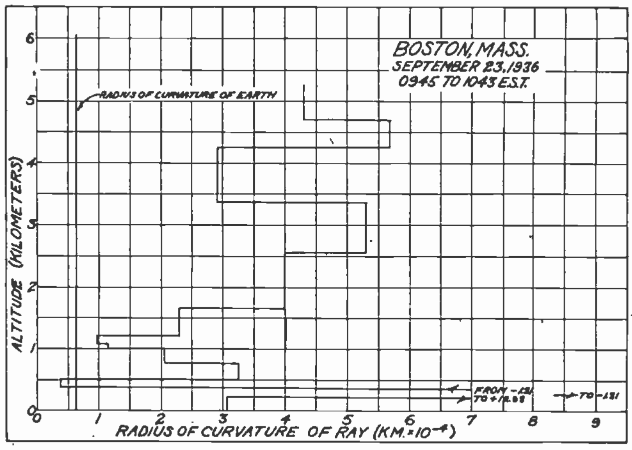

Fig. 12—Radii of curvature of ray paths of signals at various altitudes passing around the earth, calculated from more complete meteorological data from United States Weather Bureau meteorological recordings taken at Boston, Massachusetts, September 23, 1936. Between 385 and 495 meters altitude the ray would be bent toward the earth sufficiently to account for the observed strong signals of Fig. 10.

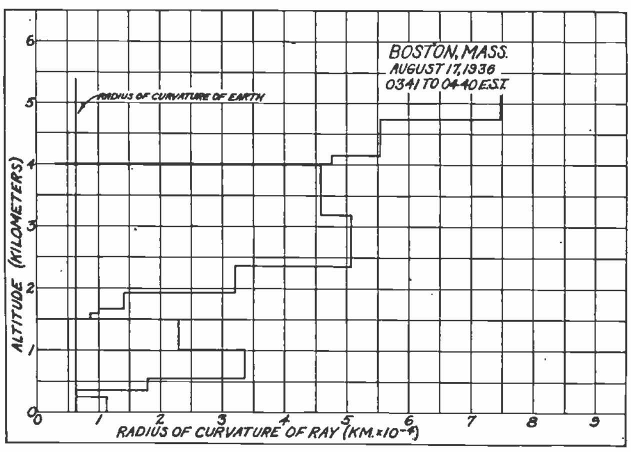

Fig. 13—Calculated radii from Boston records of August 17 showing two, and possibly three, substantial refracting regions which also help to account for the severe fading indicated for this date.

where $\overline{R}$ = radius of ray curvature in kilometers

h_1 = height, in kilometers, of *bottom* of layer under consideration

h_2 = height in kilometers of *top* of *same* layer

p_1 = dry air pressure in millibars at *bottom* of layer

p_2 = dry air pressure in millibars at *top* of same layer

T_1 = absolute temperature in degrees Kelvin, at *bottom* of layer

T_2 = absolute temperature, in degrees Kelvin, at *top* of *same* layer

e_1 = water-vapor pressure in millibars at *bottom* of layer

e_2 = water-vapor pressure in millibars at *top* of layer.

This equation is used in calculating the *average* radius of curvature of the propagation path of radio waves through a thin layer of air (spread out at an approximately uniform altitude) in a direction very nearly tangential to the stratum under consideration. The deviations from these calculated radii produced in attempting propagation of waves along the surface of the earth is of little consequence. Propagation between elevated points produces a closer approximation to the assumed ray path. The net result of ray bending in a very thin refracting layer of the sort encountered in Fig. 13 is practically the same as that which would be obtained if a true reflection occurred at grazing incidence along a sharp boundary. In the case of sufficiently long waves, such a layer *does*, in fact, represent a very sharp reflecting boundary.

The original evaluation of the aerometeorograph data as supplied by the United States Weather Bureau included insufficient detail of the meteorological fine structure. However, through the courtesy of J. B. Kincer, of the Weather Bureau, it was possible to obtain photostatic copies of the original meteorological recordings. These recordings were from the instruments carried by airplanes in the Weather Bureau flights on the dates of interest in this investigation. A careful point-by-point evaluation of these data has revealed the major regions of small positive radius of curvature.

Recording errors have been avoided wherever they were apparent. Instrumental time constants tend to obscure rather than emphasize sharp discontinuities, but due to the use of airplane observations rather than the more recently available radio-sonde data, it is believed that these effects have been minimized. Since the values calculated from these records by use of (1) are of necessity *averaged* over moderately large vertical distances, they should in no case represent the absolute minimum radius of curvature.

Fig. 13 (Boston, Massachusetts, August 17, 1936) is an example similar to that of Fig. 12, with the exception that there appear to have been two regions of downward refraction sufficient to bend the signals over the hilly terrain of the propagation path. These regions were at altitudes between 245 and 347 meters, and between 3980 and 4010 meters. A third region of almost sufficient refraction was between 1500 and 1610 meters.

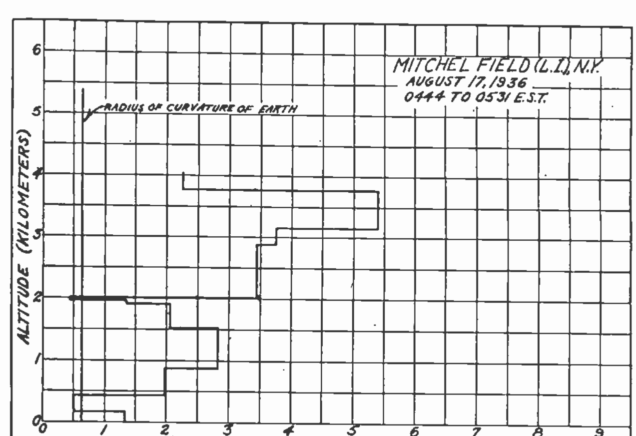

Fig. 14—Calculated radii from Mitchel Field records for August 17, 1936. This shows two substantially refracting regions which apparently produce, by interference, the rapid fading indicated in the corresponding recording of Fig. 10.

For this same date and at almost the same time, the record taken at Mitchel Field, Long Island, New York, shows small radii of curvature between 286 and 431 meters and between 1975 and 2010 meters altitude (Fig. 14). The actual propagation of the radio waves between Blue Hill Observatory in Milton, Massachusetts, and West Hartford, Connecticut, must have been via a path having meteorological characteristics intermediate between the Boston and Mitchel Field conditions. It was thus most certainly a region of multiple-refracting-layer conditions. The upper region of Fig. 13 appears sufficiently sharp to be called a reflecting boundary. The interference caused by multipath transmission is evident in the rapidly fluctuating signal strength of the recording for August 17, shown in Fig. 10.

Fig. 11 is a prime example of two very different types of winter conditions. The record for February 19th shows quite strong signals due to a moderate inversion extending upward from the earth to 1000 meters altitude. This condition produced excellent refraction effects along the path of transmission, and confined the signal to the earth. On the other hand, the lack of any such inversion, or even a considerable alteration in the lapse rate on February 2, apparently caused very inferior transmission conditions. The presence of rapid fading of small amplitude is here quite evident. This effect may be due to weak higher-level multiple-path transmission or to the possibility of several poor low-level alternative paths. Evaluation of radii of curvature from the Boston data of February 19, 1937 (Fig. 15) reveals no very small radius of curvature. It must be assumed that these data are incomplete or do not represent the mid-path conditions, in view of the signal recording of Fig. 11 (February 19th). The available data for February 2 are even less informative. "Since it is to be expected that the refraction effect will be proportional to the water-vapor gradient, and inversely proportional to the temperature gradient, it was considered that an approximate figure of merit for these gradients could be obtained by dividing one by the other. Values obtained in this fashion for the gradients between the surface and 2500 meters and plotted against mean signal values for the entire period show a surprising relationship. Two sample studies are given in Figs. 16 and 17."

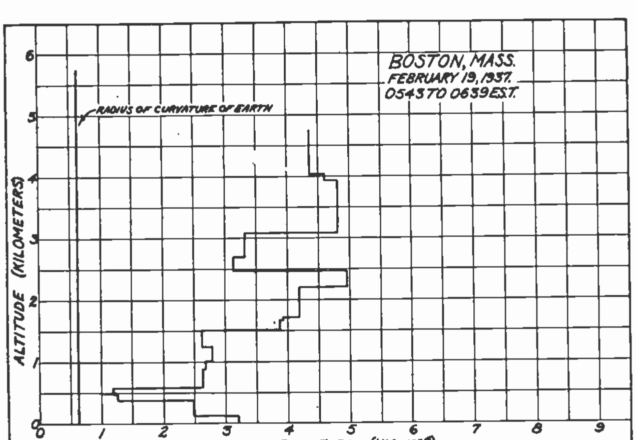

Fig. 15—Calculated ray curvatures fail to account for the observed transmission of February 19, 1937, but it is believed that the value calculated for the 500-meter level could easily meet the requirements if the meteorological data were sufficiently accurate for these calculations. On the other hand the weather may vary along the path of transmission.

Fading Character

"In addition to this day-to-day relationship between mean signal values and atmospheric gradients, it has been observed that a definite relationship exists between

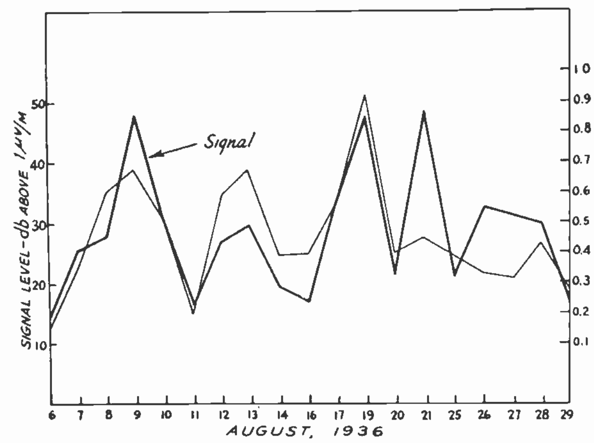

Fig. 16—Two-hour morning mean of 41-megacycle-per-second signal level compared with the ratio of water-vapor-to-temperature gradients at East Boston during August, 1936.

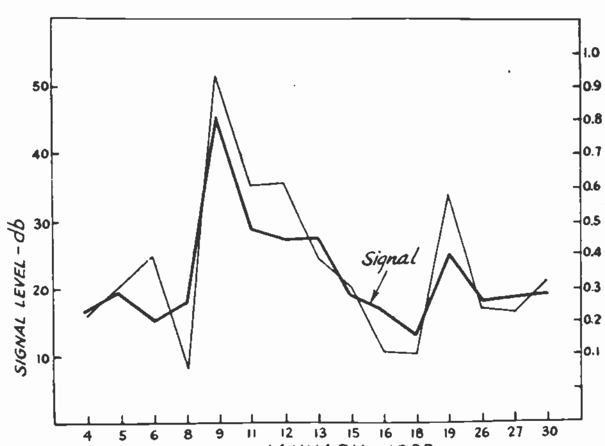

Fig. 17—Two-hour morning mean of 41-megacycle-per-second signal level compared with the ratio of water-vapor-to-temperature gradients at East Boston during January, 1937.

the types of signal fading and the accompanying atmospheric structure. In Fig. 18 are given two examples of strong refraction fields which accompany positive temperature gradients of different origin. The sample given for January 9 reveals a condition in which the temperature increased eight degrees between the surface and 500 meters. This 'temperature inversion' was the result of cold air flowing in under a warmer layer. The violent and relatively rapid fading shown is unquestionably related to the violent turbulence which invariably accompanies such an atmospheric condition.[20] The

[20] This type of fading is observed as a surging effect in tropospheric soundings by radio-wave pulse echoes.

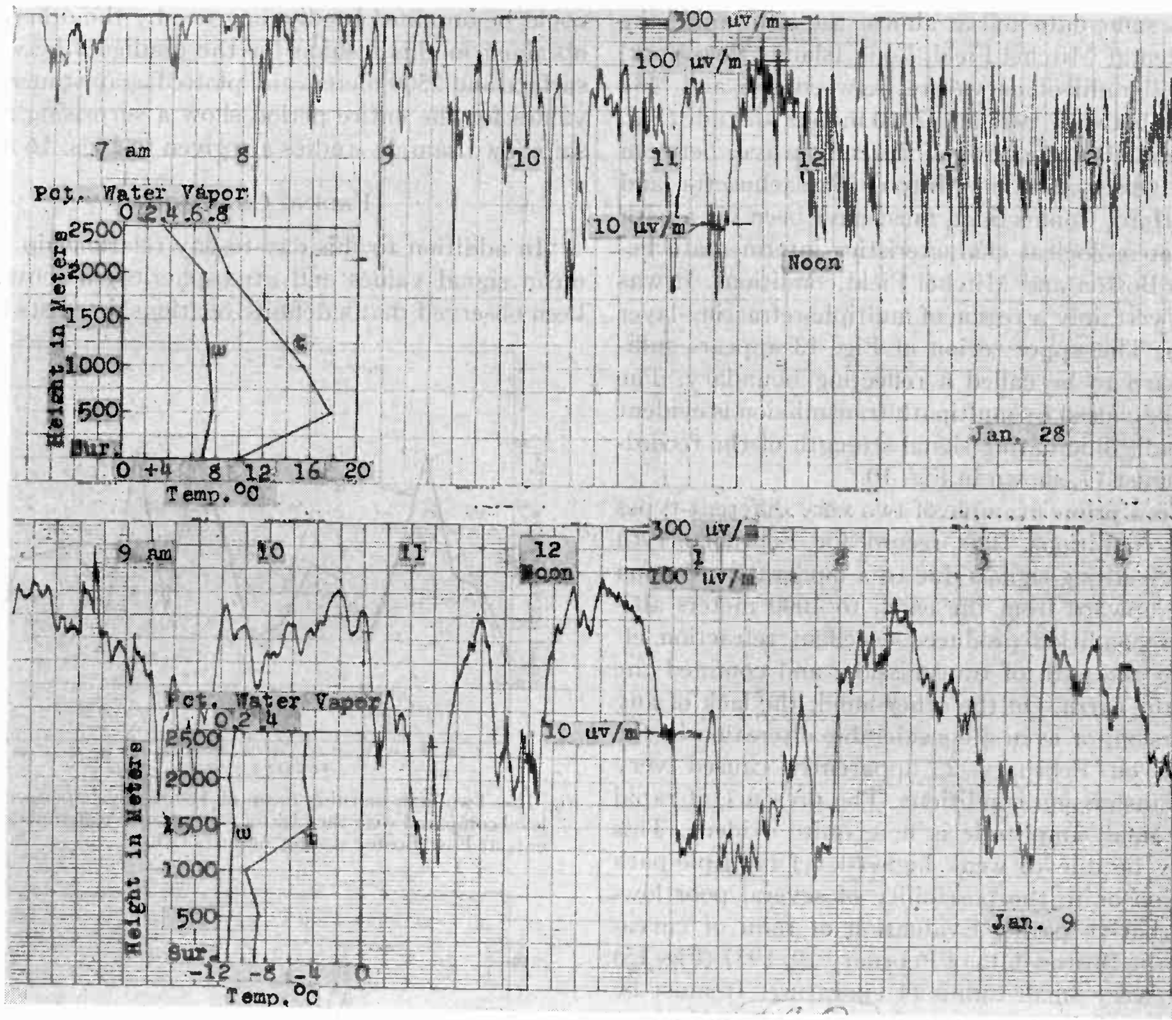

Fig. 18—Two examples of strong refraction (or reflection) fields accompanying positive-temperature gradients (temperature inversions) of different origin. January, 1937.

record for January 28 is a typical example in which a sharp positive temperature gradient has resulted from warm tropical air overruning colder surface air. The observed fading on all such occasions is in the nature of a series of slow surges, the interval between major depressions in the signal curve often being of a duration as great as two hours. This type of fading is considered to be related to the wave motion which invariably develops when a layer of warm air is overrunning a colder layer."

While this analysis by Hull appears to be generally correct, it has been found by examination of the original meteorological recordings and the use of (1) that the regions between 2350 and 2470 meters appear to have the power to produce greater bending of the path of wave propagation than the lower region (Fig. 19) between 300 and 459 meters. This lower region may actually have had a smaller minimum radius or curvature than the computed average value indicates. It is evident from the fading characteristic of Fig. 18 (January 9) that there must have been multipath transmission producing the recorded fading pattern.

The meteorological recordings taken at Boston on January 28, 1937, reveal no radii of curvature sufficiently small to explain the signal peaks shown in Fig. 18 (January 28), unless several small kinks in the humidity curve below the 1000-meter level are exploited to

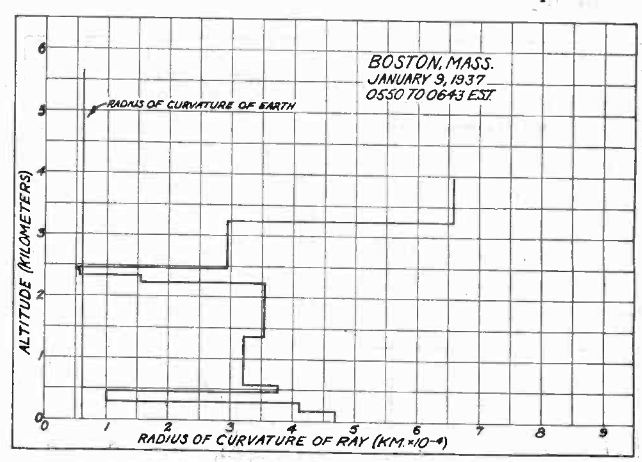

Fig. 19—January 9, 1937, meteorological recordings lead to calculations showing refraction at 2350 meters of more *apparent* importance than that at 300 meters. Meteorological-instrument time lag or reading errors could quite possibly account for the difference between these two minimum radii, so the lower-level refraction may be of almost equal importance.

their probably inaccurate limits. Here, again, more accurate meteorological data over the path of propagation might have aided the explanation.

"Fig. 20 contains a selected portion of the recordings made during three days when a typical 'warm-front' disturbance passed across the path. The first portion of the record (for the morning of December 18) shows irregular rapid fadings superimposed on an irregular slower fading. The airplane soundings[21] for this morning, given at the top of Fig. 20, indicate warmer air aloft. The recording for the evening of the same day shows the slow surges, which have been identified with tropical air aloft, and the existence of which is clearly shown in the airplane soundings for the following morning. The portion of recording given for that morning (December 19) shows a still-slower major-fade characteristic, which, coincident with the slow movement of the tropical air down toward the surface, carries the signal to a value some thirty times higher than that measured on the preceding day. The precipitation which invariably accompanies an atmospheric condition of this kind began approximately two hours after the highest-peak signal values had been reached. It was accompanied by an immediate change in the character of the signal fading. This precipitation was in the form of rain, frozen into sleet during its passage through the lower layers. The warming effect of this rain on the lower air, gradually destroying the favorable positive-temperature gradient which had existed, is soon to carry the signal to a much lower level. At a point indicated on the signal recording

[21] These are simplified approximate data showing only the values recorded at even 500-foot intervals of altitude.

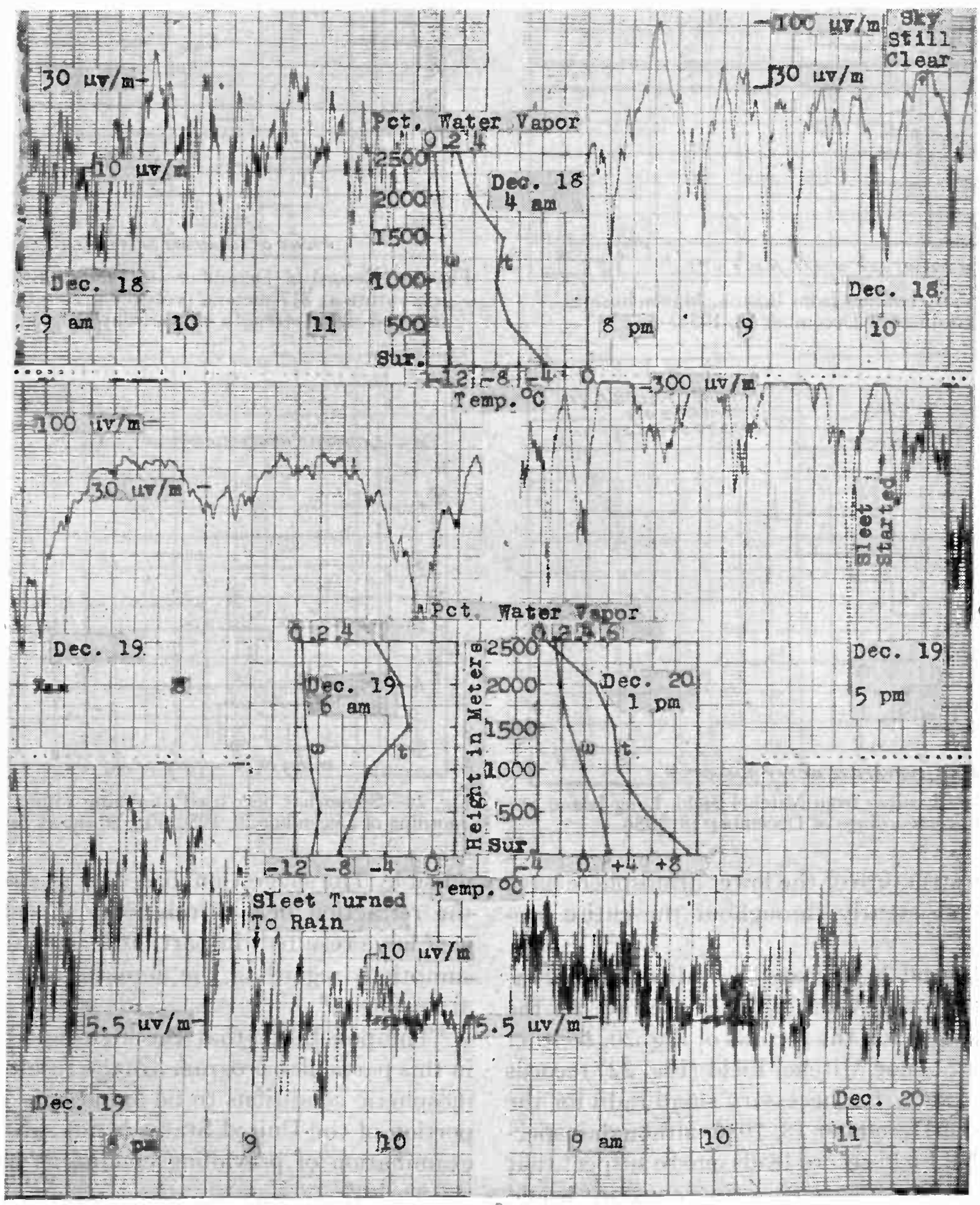

Fig. 20—Selected portions of recordings made during three days as a typical warm-front disturbance passed over the region containing the 41-megacycle-per-second transmission path. December, 1936.

where the sleet turned into rain, it was seen that the signal had dropped to approximately one-sixtieth of its value three hours before, and that the fading had become much less in amplitude. The airplane soundings for the following day (December 20) indicate a sharp negative level and show the rapid small-amplitude fading which has been observed to coincide invariably with the existence of such a temperature condition."

"These sample recordings, of course, are very restricted in scope, but it can be said that a similar relationship between the signal behavior and known variations in the structure of the lower atmosphere have been observed consistently throughout the entire program."

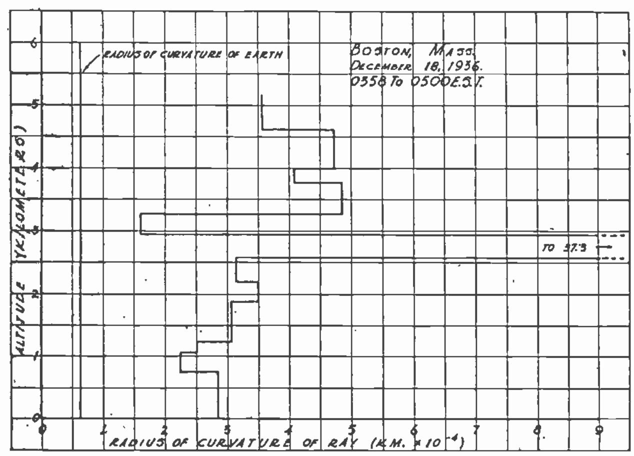

Fig. 21—Calculated values from Boston, Massachusetts, recordings of December 18, 1936.

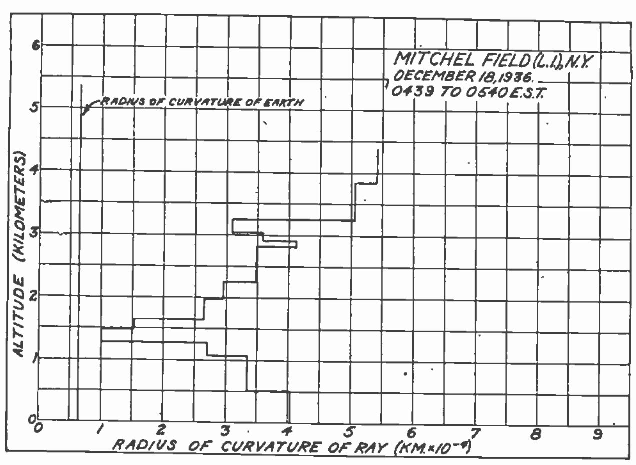

Fig. 22—Calculated values from Mitchel Field, Long Island, New York, recordings of December 18, 1936.

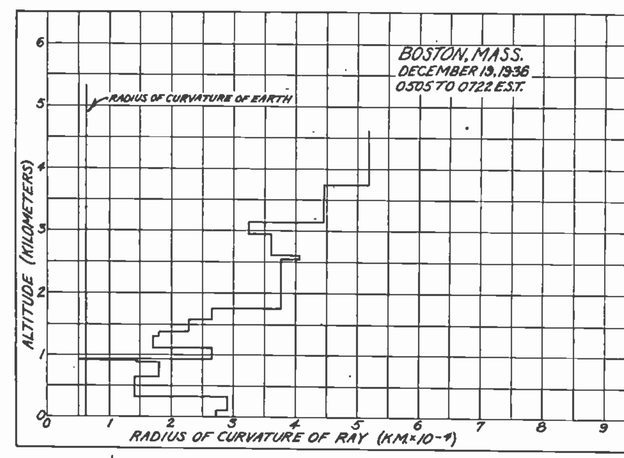

Fig. 23—Record of December 19, 1936, indicating small radius of curvature at 817 meters, probably accounting for the greatly increased signal strength on that day (Fig. 20).

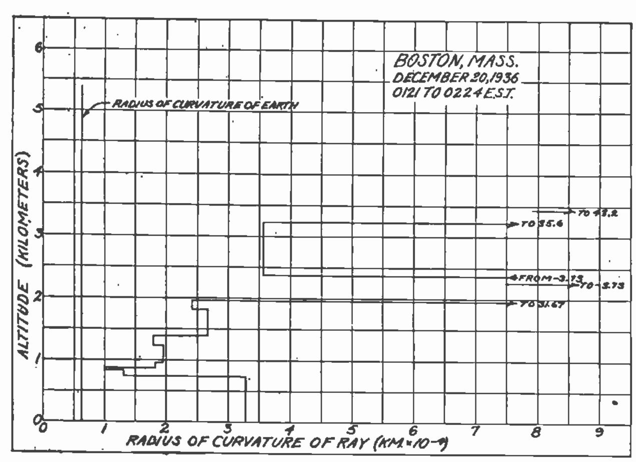

Fig. 24—Somewhat decreased minimum radius calculated for early morning of December 20, 1936. Fig. 20 shows decreased signal level.

Figs. 21, 22, 23, and 24 indicate the radii of ray curvature calculated from the Weather Bureau records for the period of time involved in the records of Fig. 20. Neither the Boston (Fig. 21) nor Mitchel Field (Fig. 22) records were adequate to show the necessary small radii for the observed signals of December 18, 1936, although inspection of the Mitchel Field record leads one to suspect that taking into account the hygrometer time constant would certainly reveal a much smaller radius of curvature. Fig. 23 shows the smaller radius of curvature, producing the much stronger signal of December 19. The December 20th meteorological record was taken previous to the very marked signal drop, but shows increasing calculated radii in accordance with the decreasing early-morning signal record of December 19 (Fig. 20).

Conclusions

"This survey, over these particular indirect paths, indicates that stratification of the lower atmosphere is responsible for the production of a refraction field of a much higher magnitude than that previously considered possible. The suggestion, based on theoretical work, that the refraction field is relatively inconsequential, may well have resulted, in part, at least, from erroneous assumptions regarding the actual structure of the lower atmosphere."

"The possibility that the high-signal levels obtained in this particular program are the result of abnormal atmospheric conditions to be found only in the northeast portion of the United States is not substantiated by an examination of prevailing conditions in other parts of the world."

"Over long, indirect paths of this type, diffraction effects undoubtedly provide a threshold signal. It is obvious, however, that the dominant phenomena with which we are concerned are those of refraction. Examination of the lowest signal intensities recorded suggests that a refraction field of the order of that computed by Englund, Crawford and Mumford[5] probably corresponds to that obtained under unfavorable atmospheric conditions."

"There is no reasonable doubt that the refraction field results from refraction produced by gradients of the index of refraction of the atmosphere itself between the surface and approximately 2000 meters.[22] A low negative isothermal or positive temperature gradient produced either by tropical air overrunning polar air; by polar air moving in under tropical air; by the phenomena of subsidence; or from the nocturnal cooling of the surface layer, has invariably been observed to produce a marked increase in signal intensity. Such temperature gradients, when accompanied by a steep negative gradient of water vapor, result in a still greater increase in signal level."

"It is obvious that, in addition to considerations of other well-recognized factors, due consideration must be given to typical atmospheric conditions and their variations characteristic of any particular location and its probable interfering capabilities."

Most attempts at correlating meteorological soundings with radio-wave-propagation data are not completely successful, due to the fact that the refraction or reflection coefficients are dependent upon the rate of change of dielectric constant with respect to altitude and the meteorological instruments having appreciable lag times (time constants) and limited fine-structure accuracy are not especially well suited for recording the required data. An instrument providing instantaneous response to dielectric constant conditions is indicated. The record from such a device could be differentiated with respect to altitude to supply the required data directly. There are a number of possibilities along this line which may find future exploitation.

[22] This figure could perhaps be revised upward somewhat.

Acknowledgments

"This study has been made possible through the cooperation of Dr. C. F. Brooks, of the Blue Hill Observatory, and the technical staff of the Yankee Network in Boston. We are also indebted to Mr. H. Selvidge, of Harvard University, E. Sanders, of WTIC, Hartford, and many amateurs in the Boston and New York areas."

The publication of these data could not have ensued without their careful preservation by Dr. Brooks and his generous advice concerning the history of these experiments. It is entirely possible that the contributions of many others have not been fully accredited. In particular, the early propagation investigations by Dr. G. W. Pickard have probably been given inadequate reference. The later work of various groups in the Bell Telephone Laboratories and other organizations has been omitted, since it was mostly done after the time of this investigation by Hull. Many of the meteorological data were evaluated by Miss S. H. Wollaston, of the Blue Hill Meteorological Observatory. The explanations and data concerning the radius of ray curvature represent the opinions of the author, and are not presented as a part of Hull's work, but merely in an attempt further to interpret selected portions of the voluminous signal recordings taken by Hull.

Cathode-Ray Tubes and Their Applications*

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Summary—A joint service-industry program of standardization and specification of cathode-ray tubes has resulted in improvements in performance as well as in uniformity of production and has laid the foundation for more intelligent design of electronic equipment using these tubes. Much progress has been made recently in both techniques and designs of cathode-ray tubes and circuits. Both brightness and resolution of the fluorescent spot have been improved. New intensifier-type tubes have been developed for high accelerating potentials with high deflection sensitivities, considerably extending the range of visual observation and photographic recording of cathode-ray traces.

Better response of deflection amplifiers to transient or pulse signals has been attained, together with improvements in linear time-base circuits for presenting such signals on scales measured in microseconds rather than milliseconds, and in timing circuits for calibrating them. Signal- and sweep-delay circuits have been developed to facilitate viewing certain types of patterns. New techniques have suggested new applications of cathode-ray equipment in many fields of laboratory, military, and industrial measurement. Mechanical devices can be tested readily for vibration, balance, and speed; electrical circuits and components may be inspected; optical problems may be studied, as by the cathode-ray spectrograph; and the nondestructive testing of many metals can be accomplished.

It is expected that the improved cathode-ray tubes and techniques developed during the past few years, many of which have not yet been publicly described, will be applied to laboratory and production equipment as well as to television transmission and reception.

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Introduction

DURING the past several years, under the impetus of preparation first for defense and then for war, tremendous strides have been made in the design, production, and utilization of cathode-ray tubes. Fortunately, a solid basis for progress had already been laid by those working in the field, so that the successive steps of standardization, improvement, and new development and invention were made with satisfying speed. Although much of what has been accomplished cannot yet be disclosed, for reasons of national security, it is the purpose of this paper to describe and to discuss some of the more important factors and advances leading to the enhanced usefulness of the cathode-ray tube and of cathode-ray equipment as tools for laboratory, field, and factory.

Recent Progress in Cathode-Ray Tubes

1. Standardization

As the national defense program got under way, it soon became evident that cathode-ray tubes were to be an important part of certain types of electronic equipment, and that these tubes would be required in large quantities. At that time, there was a small number of manufacturers, each producing a considerable number of types of tubes, some general-purpose and others highly specialized, but in relatively small quantities. Some published data on characteristics were available, but they were rather meager, almost totally devoid of information on many important points, including spot size and light output, and usually lacking tolerances on any but mechanical dimensions.

The immediate results of this situation tended to be twofold: First, the types of cathode-ray tubes being used in newly-designed equipments depended solely upon the judgment of each equipment designer, so that two or more types of practically identical characteristics and performance might be in use, making procurement and supply more difficult. Second, the equipments frequently were designed around one or a few sample tubes, which may not necessarily have been representative of production of their own or other manufacturers of that type, rather than around adequate specifications with tolerances. As a result, many tubes procured in quantity production were unusable in production equipments so designed, which had their own variations due to manufacturing tolerances.

Anticipating such a situation, the manufacturers of cathode-ray tubes, through the Radio Manufacturers Association, proceeded to prepare relatively complete specifications which were later to appear as a part of the Joint Army-Navy Specification JAN-1, Tubes, Radio Electron. But even before the specifications could be prepared, it was necessary to decide on the performance required and attainable, and to standardize on a relatively small number of tube types for the various applications. New conditions of operation of cathode-ray tubes were being imposed by the Services, both as to circuit and as to locale, this latter affecting temperature, humidity, and atmospheric pressure. On the basis of those decisions and the resulting specifications, equipments were built in many cases to use tube types which never had been in actual production, some not even designed; and the fact that the sockets did not go unfilled suggests a remarkable story of initiative and zeal in cathode-ray tube design and production.

Despite the magnitude of its initial task, the Radio Manufacturers Association Committee on Cathode-Ray Tubes completed it in record time, and then it proceeded on its continuing work of revising and expanding the scope of the specifications as new Service requirements or a need for more complete information arose. To this and associated groups is due a large measure of the credit for widespread improvement in the techniques of design of cathode-ray equipment.

2. Improvements in Standardized Types

While the issuance of a Joint Army-Navy Specification and of a list of preferred types of cathode-ray tubes brought about a certain degree of standardization, actual freezing of requirements was obviously impossible. Reports from the field began to show the need for improved characteristics in many respects, and in each case the designers and producers of tubes conferred with the designers and users of equipment and arrived at new specifications or proposals. The 3BP1, 3FP7, 5CP1, 5FP7, 5JP1, 7BP7, and other types which are now considered more or less standard, are continually being reviewed.

There have resulted a number of worth-while improvements in cathode-ray tubes. The mechanical structures of many types have been designed to withstand severe vibration and impact, making them suitable for operation in air and sea craft under combat conditions. This has entailed the use of new clamping and supporting means to hold the various electrodes rigidly with respect to each other and to support the electron gun solidly with respect to the walls of the tube. The bulbs themselves have been designed to withstand pressures several times atmospheric, as a safeguard against concussions sometimes encountered. In some types, high-voltage connectors sealed into the glass wall are designed to be flush with the wall, lessening the possibility of accidental breakage, and so shaped as to provide more reliable connections under vibration. Even the bases have been improved, a new type, the diheptal, having been designed to provide better mechanical strength as well as increased voltage insulation between pins.

Electrically, present-day cathode-ray tubes are generally far superior to those previously available. Beam currents in many types have been increased considerably, while spot sizes and distortion have been kept sufficiently small to provide the resolution needed. Since these two requirements ordinarily tend to oppose each other, it was not easy to attain the desired result, particularly since the new designs had to operate in existing equipments. In certain types of electrostatic-deflection tubes, higher deflection sensitivity was considered desirable; here again the designer was faced with the problem of keeping all other characteristics, including tube length, unchanged.

Still another report came in from the field; it was found that some of the gun parts of cathode-ray tubes were becoming magnetized, either as a result of current surges during accidental internal arcing, or because of their being used or stored in strong direct-current magnetic fields, such as exist around filter chokes, loudspeaker field coils, or permanent magnets. The results of this magnetization ranged from slight defocusing of the spot to unusability of the tube because of poor spot size or shape or permanent deflection of the spot, sometimes completely off the screen. While tubes so affected can be demagnetized by withdrawing them gradually and completely from a strong alternating magnetic field, facilities for accomplishing this are not always readily available; nor are they adequate when the tube must be operated in direct-current magnetic fields. Thus, it became necessary to determine what nonmagnetic materials were suitable for use in high-vacuum tubes and how to process them, and then to use those materials for the parts of the electron-gun structure most susceptible to magnetization.

The fluorescent screen, on which the electrons impinge to produce visible radiation, has received considerable attention from designers and users. Not only have the more usual commercial types, designated as P1, P2, P4, and P5, been used extensively, but a number of new types of screens has been developed to fill the special needs of new devices. Studies have been made to improve the luminous efficiency of screens and to permit closer control of their uniformity, color, light output, and persistence characteristics. The mechanical stability of screens, as well as their resistance to burning by the electron beam, have been the subject of investigation. In some cases, new manufacturing methods and processing techniques have had to be developed to achieve the desired results.

Additional work is being done continually. The problems and improvements described above represent only a few of the many that have been acted upon.

3. *Recent Developments in Cathode-Ray Tubes and Techniques*

While the above discussion has been concerned primarily with the more or less conventional types of tubes, much of it applies as well to those types which are somewhat unusual in some of their characteristics. Some of these latter tubes are not, strictly speaking, recent developments; but until recently it was not necessary to refine their designs to their present state because of the less stringent requirements imposed upon them and the considerably more limited demand for them. Others had not previously been announced commercially, and many in this class cannot be discussed at present. It is of interest, however, to describe briefly the features of new or less common types of cathode-ray tubes, and perhaps in that way to suggest further developments or applications.

One class of tubes closely related to cathode-ray tubes of the conventional type is that employing something other than a fluorescent screen as a target for the electron beam. Typical of this class are the iconoscope, the orthicon, and other types of television pickup tubes, in which light energy is used to control electrical energy. Still another type is that in which the target is some form of conductor and the beam is used to switch or commutate a circuit by being deflected on or off the conductor. This latter type of tube appears to hold considerable promise as a switching or control device, and numerous forms of it have been described.

In the class of tubes utilizing a fluorescent screen, certain types exist which, while not particularly unusual, nevertheless may not be widely known. One such type is the radial-deflection tube, particularly suited for displaying patterns on a circular rather than linear time base. Here, in addition to the usual deflecting means, which can be either electrostatic or magnetic, an additional set of electrostatic deflection electrodes is provided consisting of an inner conductor along the axis of the tube and projecting inward from the center of the screen and a concentric outer electrode commonly in the form of a conducting coating on the wall of the tube. Potential differences applied between these two electrodes will cause the beam to be deflected radially either inward or outward, depending upon polarity, from its position as determined by the usual rectangular-deflection system, thus permitting presentations better suited for certain applications than the more usual Cartesian co-ordinates.

Another type of tube of relatively conventional design but having outstanding advantages for some uses is that in which the deflection-plate terminals are located on the neck, adjacent to the deflection plates, rather than in the base of the tube. This design results in reduced capacitances between deflection plates of a given pair as well as between any plate and the plates of the other pair, and it also permits more suitable layout of associated deflection circuits. Circuit design for good transient or sinusoidal-frequency response is thereby facilitated, while freedom from capacitive interaction between X- and Y-axis circuits, commonly termed cross coupling, is made more readily attainable.

4. *High-Voltage Intensifier Tubes*

A new type of tube has been developed recently to provide considerably increased brilliance of fluorescent trace when operated at relatively high final-accelerating potentials, without the correspondingly low deflection sensitivities usually encountered. Other features of the design are freedom from spot distortion and increased useful screen area, as compared to older types of tubes operated under similar conditions. Fig. 1 shows a tube of this type in its developmental stage, having a bulb diameter of approximately five inches.[1]

As can be seen from the illustration, the intensifier principle is used to provide post-deflection acceleration of the beam. In place of a single electrode and a single intensifier-to-second-anode gap, however, a number of electrodes and gaps are used, with increasingly higher potentials being applied to the electrodes nearer the screen. These potentials may be derived from external

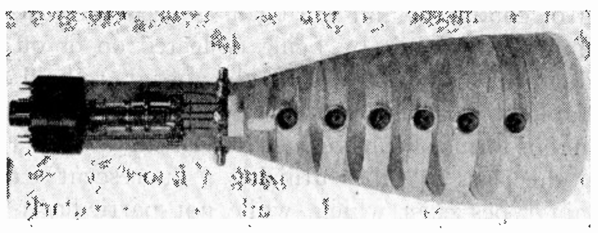

Fig. 1—High-voltage intensifier tube in its developmental stage.

voltage dividers or may be determined by high-resistance coatings on the wall of the tube. Not only are distortions of spot and of pattern kept small in this manner, but the tendency to arcing at the gaps is eliminated. Final-intensifier potentials of the order of five times the second-anode potential may be used without serious reduction of useful screen area. As a typical example, a tube has been operated with a second-anode potential of 3000 volts and a final-intensifier potential of 15,000 volts, applied in five approximately equal increments. The high-intensifier potentials are conveniently developed in the rectified radio-frequency type of power supply. The brightness increased by a factor of approximately ten to twenty-five over its value for operation without the intensifier, while the deflection factor increased by only 35 per cent as compared to 500 per cent had the same value of total accelerating potential been applied directly to the second anode. The spot size decreased by about 50 per cent; consequently the sensibility of the tube expressed by the beam deflection in line widths per volt had increased. The increased usefulness of the tube, in this case, is indicated by the increase from 35 kilometers to 1000 kilometers per second in the maximum photographic writing rate, corresponding to a single trace of 16 megacycles per second for 2-centimeter peak-to-peak amplitude. Many types of signals can be studied by the use of such a tube which on ordinary tubes would produce traces too dim to be seen.[2–5]

[1] A paper is in preparation giving more details on tubes of this type.

[2] Erich Schwartz "On the post acceleration problems in cathode-ray tubes," *Fernsehen G.m.b.H. Mitteilungen*, vol. 1, pp. 19–23; December, 1938.

[3] W. Rogowski and H. Thielen, "On post acceleration in cathode-ray tubes," *Arch. für Electrotech.*, vol. 33, No. 6, 1939.

[4] J. R. Pierce, "After acceleration and deflection," PROC. I.R.E., vol. 29, pp. 28–31; January. 1941.

[5] Rudolf Feldt, "Photographing patterns on cathode-ray tubes," *Electronics*, vol. 17, pp. 130–137; 262–266; February, 1944.

5. General-Purpose Oscillographs

A number of different designs of general-purpose cathode-ray oscillographs have been available commercially for some years. While they are entirely satisfactory for many types of measurements or indications, the changing requirements of laboratory and other problems have necessitated a number of improvements, extensions, and innovations in oscillograph circuits and designs; in some cases the availability of new types of vacuum tubes or other components has made possible improvements for which a need has long been felt.

6. Extension of Frequency Range of Amplifiers

As the wave forms of signals to be studied with the oscillograph became more complex, or as they began to include frequency components approaching the limit of zero, or direct current, at one end of their range, or several megacycles at the other, and as the studies of transient or transient-like signals became more common, the earlier concepts of oscillograph amplifiers have had to be revised. Fortunately, the field of television had encouraged a number of laboratories to explore the characteristics of video amplifiers, and much of what had been learned there was useful in oscillograph design. Whereas formerly deflection-amplifier response uniform to 100 kilocycles per second represented somewhat advanced design, present amplifiers operate over a band extending to two megacycles; new oscillographs have been announced having frequency response flat to five megacycles or higher. In most of these, not only is the sinusoidal response uniform, but the response of the amplifier circuits to transient or pulse signals is such that very little distortion occurs. For example, it is possible for an amplifier to respond to changes in voltage level of the order of 100 volts within a few hundredths of a microsecond, without objectionable overshoot or ringing. Performance such as this in a multistage amplifier requires not only careful circuit design but also close attention to selection and layout of components and wiring. Much of what has been accomplished would have been impossible but for the development of high-transconductance vacuum tubes and the improved designs of resistors, capacitors, and inductors.

The performance of amplifiers at low frequencies, in some cases extending to zero frequency or direct current, also is attributable in part to improvement in components, particularly in coupling capacitors. Regulated power supplies have been designed having exceedingly low output impedance, thus reducing the tendency toward instability of many types of amplifiers responsive to low- or zero-frequency signals. The use of inverse feedback or of other forms of stabilization has increased. Many of the developments that have helped improve low-frequency response have been beneficial to high-frequency response as well, or at least in some cases have reduced the need for sacrificing one to obtain the other.

Obviously, the usefulness of the oscillograph depends upon over-all performance, rather than on the performance of the deflection amplifiers alone. This is particularly true in the investigation of transient signals of short duration, for not only must the deflection amplifiers permit faithful reproduction of the wave form, but there must be available suitable sweep or time-base signals to delineate it, and, perhaps more important, the design of the cathode-ray tube and the conditions of its operation must be such as to produce a visible trace of sufficient intensity. This may also involve, particularly in the case of transient signals, the use of circuits to facilitate centering on the time-base trace the signal under observation. In many cases it is also desirable to indicate or measure time intervals of such signals, so that suitable circuits must be provided for this purpose.

Improvements in the cathode-ray tube have already been described; some of the other factors involved will now be discussed.[6]

7. *Improved Time-Base Circuits*

Although many types of sweep or time-base circuits are in use, including sinusoidal, logarithmic, circular, and others, the recurrent linear or saw-tooth time base is most commonly used in general-purpose oscillographic equipment. Such a time base may be derived from the potential across a capacitor being charged or discharged at a constant rate of current flow, a gaseous-discharge tube frequently being used as a switch in the saw-tooth-generating circuit. Improved deflection amplifiers made feasible the extension of the frequency range of time-base generators both upward and downward, so that it now ranges from one linear sweep in several seconds to several hundred thousand per second. Gaseous-discharge tubes are still in common use for sweep frequencies below about 50,000 per second, but for higher frequencies high-vacuum tubes are used, resulting in improved stability of frequency and linearity as well as of synchronization, particularly on signals of short duration.

Circuits for the generation of single or repetitive sweeps have also received attention. A single sweep represents only one cycle of a recurrent linear time base, while a repetitive sweep may be described as a single sweep repeated at some more or less regular period, usually considerably longer than the duration of the sweep itself. The first of these is useful in delineating single transients, since the time-base deflection occurs only when a transient signal appears, reducing the tendency of a continuous base line to obscure the desired display. The second permits careful study of signals of short duration repeated at long intervals, such as portions of the wave form of ignition impulses. The time-base scales attainable in several equipments announced commercially reach approximately one microsecond per inch.[7–9]

8. *Delay Circuits*

It is often desirable to have single or repetitive sweeps initiated by the electrical signals producing the vertical- or Y-axis deflection of the beam, particularly when, as in the study of lightning surges, it is not possible to anticipate the occurrence of the transient. Unfortunately, it often happens that the time required to initiate the sweep and to turn on the electron beam is greater than that for the transmission of the signal through the deflection amplifiers, with the result that the first part of the signal does not appear plotted out on the time base. This difficulty may be avoided for either transient or repetitive signals by the introduction

(a)

(b)

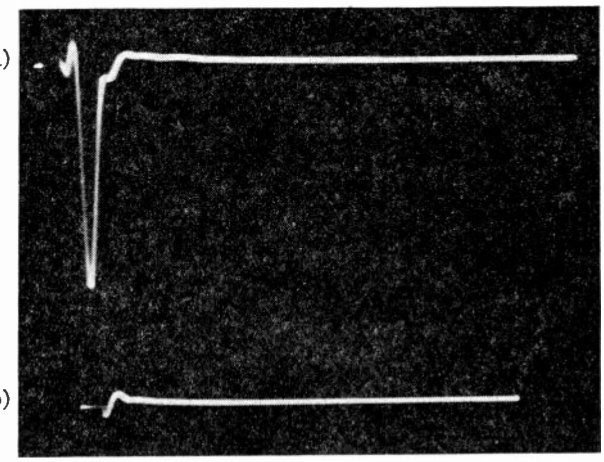

Fig. 2
(a)—Negative pulse on 5-microsecond linear time base.
(b)—Same signal as in (a) but without signal delay. Note that the duration of the pulse is shorter than the time required for it to initiate the sweep and trigger the beam-intensifying circuit.

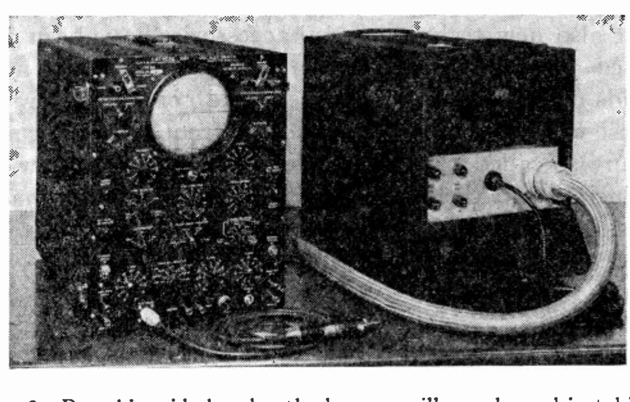

Fig. 3—Portable wide-band cathode-ray oscillograph used in taking photographs of Figs. 2 and 5.

of an artificial increase in transmission time of the deflection amplifier following the point at which the sweep-initiating signal is obtained. Lengths of transmission line, suitably terminated, have been used for this purpose, and other satisfactory means have been devised. Fig. 2(a) shows a signal which has been delayed with respect to the initiation of the time base, using

[6] J. O. Edson, "10-megacycle oscilloscope," *Bell Lab. Rec.*, vol. 20, pp. 95–98; December. 1941.
[7] Horace Atwood. Jr., and Robert P. Owen, "Oscilloscope for pulse studies," *Electronics*, vol. 17, pp. 110–114; December, 1944.
[8] G. Parr, "The Cathode-Ray Tube," Chapman and Hall, London, England; 1941.
[9] O. S. Puckle, "Time Bases," John Wiley and Sons, New York, N. Y.; 1943.

commercial equipment of the type shown in Fig. 3, while Fig. 2(b) shows, for the same signal, the complete loss of information resulting when the sweep-initiation and beam-intensifying time is long compared to signal-transmission time. The sweep duration is five microseconds.

In the case of repetitive signals, it may be found more convenient to delay the sweep, which may be accomplished in a number of ways. Where the repetition rate of the signal is not constant, this procedure results in some instability of position of the signal along the base line, since each signal is being displayed on a time base initiated by the preceding signal after a constant interval of delay.[7–10]

9. Timing Circuits

While the linearity of time-base deflections can be made to be entirely satisfactory for most purposes, use is generally made of some form of timing marks in calibrating or measuring time intervals along the time base. These may be provided in the form of short pulses deflecting the beam at regular intervals, or they may be either increases or decreases of spot intensity, often termed blanking, depending largely upon the nature of the wave form to be measured and the preference of the operator. Recent advances in circuits to accomplish time marking have been largely in the direction of reducing the relative duration of the marks, to preserve as much as possible the identity and completeness of the signal wave form.

10. Specialized Applications

Not only have cathode-ray tubes and their associated circuits been improved in performance and reliability, but also new techniques and accessories have been devised for applying oscillographic equipment to new fields of industrial measurement and control. A few of these will be described briefly. As is frequently the case, many so-called new applications are not at all new in principle, but their practical realization has been made possible only by the development of some of the components of the systems involved.[11]

11. Mechanical Testing

This is particularly true of mechanical testing, a field in which oscillography has come to be of considerable importance. The measurement or indication of stresses and strains is now conveniently done with the aid of resistance strain gauges attached to the member under test. Stresses in the member produce strains which in turn produce elongations of the gauge, resulting in changes in electrical-resistance value. Bridge circuits, energized by alternating currents and having the strain gauge as one arm, are commonly used; and the unbalance produces the electrical signals for indication. The advantage of the cathode-ray oscillograph over other indicators is its extended frequency range, permitting more nearly accurate presentation of impacts or of other rapidly changing stresses.

Measurements of pressure in engine cylinders can be made by means of the oscillograph and pressure pickups. These may take the form of quartz crystals, in which the mechanical pressure produces proportionate electrical potentials between its faces; inductors moved in a magnetic field by means of a pressure-actuated diaphragm, with consequent induction of electromotive forces which are used to deflect the beam of the cathode-ray tube; variable resistors compressed by a diaphragm which change the current in a biasing circuit; or one of several other types which have been devised. Voltages derived from these pickups are used to deflect the beam along the vertical axis, and horizontal deflection may be either linear or, more usually, sinusoidal. A number of methods for either synchronizing or deriving the time base from the crankshaft or accessory shaft have been described.

Vibrations and impact, both linear and torsional, are readily susceptible to study by means of the cathode-ray oscillograph, since the wave form of these disturbances often yields information not obtainable in any other way. Pickups of both the crystal and the magnetic type are available, similar in principle to those used in pressure studies.

The rotational speed of motors can be measured quite accurately with the aid of the oscillograph and a generator of variable-frequency sine waves. Signals may be generated in a simple magnetic-induction device, using a magnet fastened to the motor shaft, and a stationary pickup coil in which voltages are induced. If it is desirable to add no load to the motor shaft, an angular segment of the shaft may be painted to contrast with the remainder, so that light reflected from it to a photocell will produce pulsating signals, the frequency of which may be compared with that produced by the local signal generator, and from it the shaft speed calculated. Not only rotational speed but also slip may be measured in this or a similar manner.

Many other problems of mechanical testing or inspection may be facilitated by the use of the cathode-ray oscillograph, often in conjunction with accessory electrical, mechanical, or optical equipment.[12,13]

12. Electrical Testing

Many kinds of electrical tests in which the cathode-ray tube is used as the indicator have speeded up production processes and inspections. Insulation-surge tests on motors and transformers, speed of relay operation, and many other kinds of tests in the field of power can be made conveniently and accurately. In the communications field, the use of the oscillograph has always been widespread, but new uses are constantly being

[10] A. M. Angelini, "Voltage dividers and time delay cables for oscillographic recording of transients," *Bull. Assoc. Suisse des Elec.*, July 18, 1941.

[11] W. Wilson, "The Cathode-Ray Oscillograph in Industry," Chapman and Hall, London, England, 1943.

[12] Charles Lipson, "Methods of stress determination in engine parts," *Soc. Auto. Eng. Jour.*, vol. 51, pp. 105–124; April, 1943.

[13] Louis C. Roess. "A condenser-type high-speed engine indicator," *Rev. Sci. Instr.*, vol. 11, pp. 183–195; June, 1940.

found. The inspection and testing of radio-type components represents but one phase of oscillographic measurements in this field, and several examples will be given.

Potentiometers of the composition type are made with a wide variety of tapers, the term applied to the characteristic variation of resistance with rotation of the movable arm, and it is usually important that the taper be as specified. The taper can be plotted as a curve on a cathode-ray oscillograph by applying a constant potential across the potentiometer and using for vertical deflection that portion of it appearing between the arm and one end of the element, as the arm is moved. By coupling the test potentiometer to one of exactly linear taper similarly connected but producing deflection along the X or horizontal axis, there can be obtained a curve of resistance-versus-rotation angle. This curve can, if desired, be compared with limit curves drawn on a transparent sheet placed in front of the screen.

Noise, or spurious signals arising from inconstant contact between arm and element, can also be shown up in a test such as that described above, although somewhat higher amplifier gain would normally be used to provide a more sensitive test. The taper and noise tests can be carried out on the same equipment, which can also be made to indicate resistance value, total-rotation angle, and other characteristics.

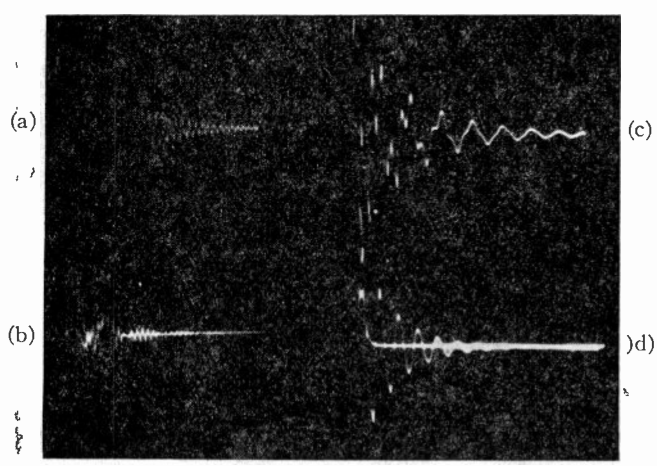

Fig. 4

(a)—Decay of oscillations in an L-C circuit excited by impulses.
(b)—Same as in (a) but for a transformer having primary and secondary windings tuned to different frequencies.
(c)—Oscillations in shock-excited iron-core inductor showing difference in damping for fundamental and harmonic frequencies.
(d)—Superimposed patterns showing effect of resistive damping on Q of inductor.

Certain characteristics of inductors, either single or coupled tuned circuits, filter networks, or amplifiers may be obtained with the oscillograph and a suitable impulse generator. When an inductor or tuned circuit is excited by a suitably applied impulse, oscillations are set up having a frequency equal to the resonant frequency of the inductor being tested, and an amplitude characteristic depending upon its Q.

The pattern of Fig. 4(a) is typical of those obtained for a single resonant circuit. If proper care has been taken in the design of the measuring equipment, the Q of the circuit can be read from a suitable scale placed in front of the cathode-ray tube. Fig. 4(b) shows the effect of detuning one winding of a 455-kilocycle tuned transformer. In Fig. 4(c), the odd harmonics generated in an iron-core transformer are shown, and the difference in damping for fundamental and harmonic frequencies is evident. The effect of shunt resistance on the Q of an inductor is shown in the superimposed patterns of Fig. 4(d). The oscillating curve gives information about the resonant frequency and Q of an inductor, while resistive damping makes the inductor nearly aperiodic.

This method of testing or indication has been applied to other devices as well. Loudspeakers, for example, may be tested for resonant frequency and damping. The results suggest extension of the method to include other electromechanical or mechanical testing.

Another interesting use of the cathode-ray oscillograph is in testing cables. As is well known, no reflections of signal voltage occur at the ends of a cable terminated in its characteristic impedance, while for any other terminations there will be reflections, with a reversal of phase of voltage for impedances lower than the characteristic impedance and without reversal for higher values. By means of the cathode-ray oscillograph, the conditions of termination can readily be determined, and adjustments made, or unintentional short or open circuits detected. Fig. 5(a) shows a typical pattern produced by the reflections of a pulse from the open end of a coaxial cable. The interval between the peaks of two successive pulses represents the time for transmission from one end of the cable and back, so that if either the velocity of propagation or the length of the cable is known, the other can be computed. When the termination is correct, as indicated by the straight line of Fig. 5(b), the surge impedance of the cable can

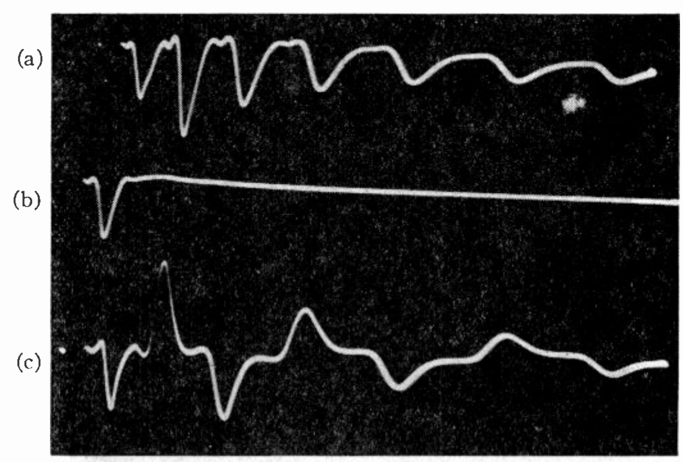

Fig. 5

(a)—Typical pattern produced by the reflections of a pulse from the open end of a coaxial cable.
(b)—Pattern obtained when the same coaxial cable is terminated in its characteristic impedance.
(c)—Pattern produced by the reflections from a short-circuited end of the same coaxial cable.

be obtained by measuring the value of resistance used. In Fig. 5(c) the termination is a short circuit. As the value of terminating resistance is increased from zero, illustrated in Fig. 5(c), the amplitude of reflections decreases to zero, when the terminating resistance equals the surge impedance, the phase of the reflected voltage changes, and then the amplitude increases as indicated[7-14] in Fig. 5(a).

13. *Optical Testing*

A number of tests and measurements in the field of light measurement can be made with the cathode-ray oscillograph, photocells, and other accessories. The characteristics of photographic shutters, synchronizers, and flashbulbs have been determined this way. The multiplier type of photocell permits a wide range of light levels to be used and, conveniently, can be operated in many cases from the cathode-ray tube power supply.

One particularly interesting and useful device is the cathode-ray spectrograph, which provides practically instantaneous plotting of spectral-response curves and thus permits the control of rapidly changing compositions when accompanied by color changes. The light to be analyzed, coming from a self-luminous source, a reflecting surface, or a transmission filter, is focussed on a slit and, by means of a grating or prism, is spread into a spectrum which is scanned by a photocell. The output of the photocell, which is proportional to the light reaching it at any frequency, is used to produce vertical deflection, while the horizontal deflection is related to the scanning and thus to frequency.[15]

Typical spectrum curves for one system are given in Fig. 6, the first three using as a light source a 75-watt projection lamp operated at approximately 3200 degrees Kelvin and having over-all sensitivity as indicated in the upper curves. The effect of a flesh-colored filter is shown in Fig. 6(a), while Figs. 6(b) and 6(c) were taken with orange- and blue-colored filters, respectively. Three lines of the spectrum of mercury are shown in Fig. 6(d).

A number of laboratory and production applications of equipment of this nature suggest themselves, not only in the field of light and optical devices, but in chemical and other industries.[16,17]

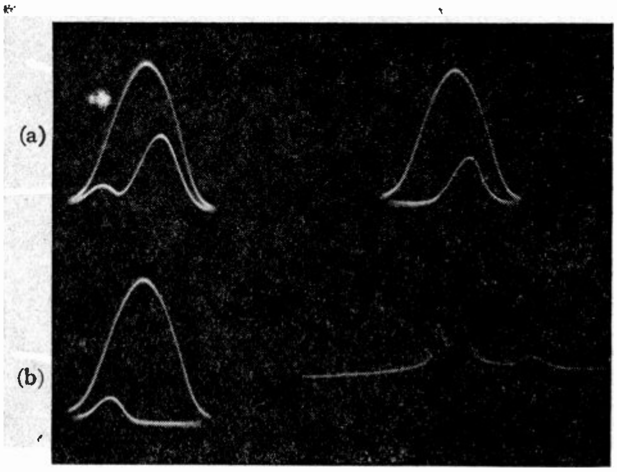

Fig. 6

(a)—Spectrum curves showing over-all sensitivity (upper curve), and response of a flesh-colored transmission filter in a cathode-ray spectrograph.
(b)—Same as (a) for an orange-colored filter.
(c)—Same as (a) for a blue-colored filter.
(d)—Three lines of the spectrum of mercury.

14. *Metallurgical Testing*

The application of electronics to metallurgical problems has received much attention, and the cathode-ray tube has proved useful as an indicator in many methods of testing. The present urgency of production, combined with the necessity for conserving both material and man-hours of labor, has spurred the development of nondestructive testing methods for metals.

One instrument that is being used successfully is the Cyclograph, designed for production testing of metals by the comparison method. Many kinds of tests can be performed, dealing with hardness, brittleness, case depth, structure, depth of carburization, cold-working, heat treatment, chemical analysis, thickness of plating or cladding, magnetic properties, size, wall thickness, etc. It operates on the general principle of core loss, the relative magnitude of which is indicated on the screen of a cathode-ray tube, so that it may be used for both ferrous and nonferrous metals. Since different characteristics may show different relative indications for different frequencies, the Cyclograph is arranged to operate at more than one frequency. Thus, it is not likely that counterbalancing changes in two

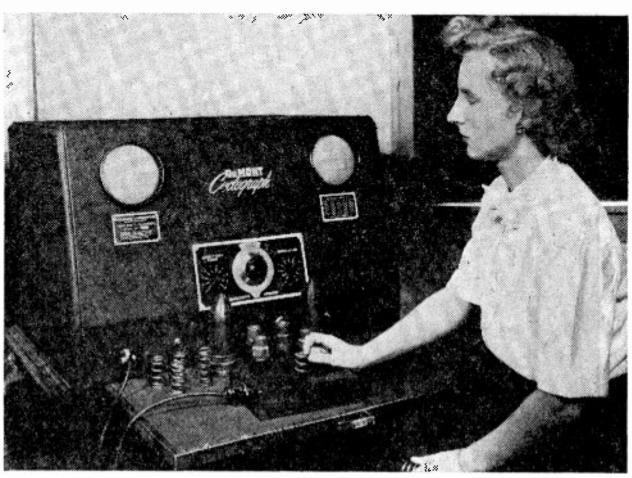

Fig. 7—The Cylograph, a device for metallurgical production testing.

[14] Rudolf Feldt, "Cathode-ray Q-meter," *Du Mont Oscillographer*, vol. 7; March–April, 1945.
[15] A paper is in preparation on the cathode-ray spectrograph.
[16] "Cathode-ray oscillograph applications in photography," *Du Mont Reference Manual*, Application Note No. 3.
[17] V. K. Zworykin, "An automatic recording spectroradiometer for cathodoluminescent materials," *Jour. Opt. Soc. Amer.*, vol. 29, p. 84; February, 1939.

characteristics could occur so as to indicate no change in either. In some cases, with equipment of this type, it is necessary to make a preliminary sorting for one of two varying characteristics, and then a test of each lot can be made. Fig. 7 shows the equipment being used in actual production sorting.[18]

The Outlook for the Future

Although the techniques and devices described above cover in themselves a wide range of applications, it is to be expected that many more will be developed both during and after the war. Not only will considerable information be made available for publication and use in commercial equipment, but a large number of trained technicians to assist in the development, installation, use, and maintenance of cathode-ray equipment will make inevitable its widespread use in new fields. The progress made during the past decade in the use of the cathode-ray tube in laboratory apparatus, in production test equipment, as the picture tube in television receivers, and in many military applications may soon be looked back upon as but a first step of a new industry.

[18] P. E. Cavanagh and E. R. Mann, "Practical metal testing by analysis of core loss characteristics," *Du Mont Reference Manual*, Du Mont Cyclograph (Type 244).

The Image Formation in Cathode-Ray Tubes and the Relation of Fluorescent Spot Size and Final Anode Voltage*

G. LIEBMANN†, ASSOCIATE, I.R.E.

Summary—**A new equivalent-optical system consisting of three lenses is proposed to represent the electron-optical system of a cathode-ray-tube gun. The image formation by these lenses is discussed. It is concluded that the fluorescent spot is an image of the cathode and that its size is almost independent of the value of the final anode voltage E_A if lens errors can be disregarded. The solid angle of the electron beam proceeding from the second lens to the main focusing lens contracts in inverse proportion to the final accelerating voltage, as expressed by the formula r^2E_A = constant, r being the radius of the electron beam. Measurements on a number of cathode-ray tubes of widely different design confirm these predictions. The new theory is compared critically with the earlier "cross-over" theory which led to different predictions. Some applications of the new conception to practical cathode-ray-tube design are briefly discussed.**

Introduction

The investigation of the image formation in cathode-ray tubes and the correlation of theoretically predicted and experimentally found tube performance has been one of the main subjects of applied electron optics. Numerous papers have been written dealing with various aspects of this problem, and it would appear that a certain finality is being approached in the theory of the cathode-ray tube. The position, however, is not entirely satisfactory as yet, as the correlation between theoretical prediction and experimental facts is not perfect in many cases of great practical importance. It is, of course, true that the theorist has to introduce certain simplifications to facilitate his computations, but the errors due to this should not lead to such discrepancies as are sometimes observed. It appears to the writer that the trouble lies somewhat deeper and is due to the choice of the equivalent-optical-lens system commonly used to represent the cathode-ray-tube gun.

A typical problem is the prediction of the change of fluorescent-spot size of a cathode-ray tube with a change of accelerating voltage. This problem enters into the design of every cathode-ray tube for television or oscillographic purposes, and is of great interest from the point of ultimate quality and of economical design of cathode-ray tubes and their ancillary apparatus.

The answer seems to be provided in some earlier papers and in the well-known textbooks by Maloff and Epstein,[1] Myers,[2] and Zworykin and Morton.[3] The general opinion expressed seems to be that the spot size should decrease in proportion to the square root of the increase in the final accelerating voltage of the electron beam, all other conditions being kept constant. The most concise mathematical treatment of this theory is given in Zworykin and Morton's book, leading to the statement, "It is evident from Equ.13.15a that the spot size is independent of the first lens voltage ϕ_1; furthermore, it is seen to be inversely proportional to the square root of the total voltage ϕ_2."

This theoretical prediction, however, does not agree at all with the change of spot size actually observed; the experimentally found change of spot size with a change of anode voltage is very much smaller than required by this theory. The rather wide discrepancy does not appear to be explained so far.

* Decimal classification: R388. Original manuscript received by the Institute, September 13, 1944; revised manuscript received, January 29, 1945.

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[1] I. G. Maloff and D. W. Epstein, "Electron Optics in Television," McGraw-Hill Book Co., Inc., New York, N. Y., 1938.

[2] L. M. Myers, "Electron Optics, Theoretical and Practical," Chapman and Hall, Ltd., London, England, 1939.

[3] V. K. Zworykin and G. A. Morton, "Television—The Electronics of Image Transmission," John Wiley and Son, New York, N. Y., 1940, pp. 370–374.

The purpose of this paper is to examine afresh the image formation in cathode-ray tubes, and particularly the question of the change of spot size with final anode voltage. A different equivalent-lens system responsible for the image formation in a cathode-ray tube will be suggested, and its consequences will be compared with experimental tests. The bearing of the new conception on the so-called cross-over theory and on practical cathode-ray-tube design will be discussed.

Fundamental Optical Relations

The equivalence of "electron optics" and ordinary or "light optics" has been established well enough in the past years. We can, therefore, make full use of the concepts and laws of ordinary optics if we assign an index of refraction

$$n = 1/c[(2e/m)E_A)^{1/2} - e/mA \cos \chi]$$

to the space under consideration, neglecting the relativity correction for the electron velocity in view of the low electron velocities normally encountered.[4] In this formula c is the velocity of light, e the charge of the electron, m its mass, E_A the accelerating voltage, A the magnetic vector potential and χ its angle with the path of the electron. If no magnetic fields are present, the index of refraction can be written as $n = \text{const.}\ x(E_A)^{1/2}$. As the properties of the final lens do not enter directly into our subsequent discussions, the conclusions reached, using the simplified expression for n, are valid not only for tubes with electrostatic focusing but also for tubes using a focusing coil as the main lens.

Before considering the electron-optical-lens system of a cathode-ray tube, let us look at the case of an optical system consisting of a spherical surface with the radius ρ and the center C (Fig. 1). To the left of this surface

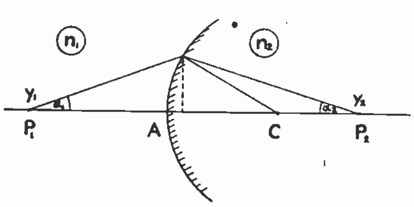


Fig. 1—Refraction by spherical surface.

we assume a refractive index n_1, and to its right a refractive index n_2. At the point P_1 on the optical axis we assume the object of the linear dimensions y_1. The image is located at the point P_2 and has the linear size y_2. The distance of the point P_1 from its principal plane is p_1, and the distance of P_2 is p_2. Using Conrady's[5] sign convention, p_1 and p_2 are negative if P_1 and P_2 are situated to the left of their principal planes; they are positive if they are lying to the right (in the case of a "thin" lens the two principal planes coincide and are located at the apex A). The following two fundamental relations are applicable:

$$n_1 y_1 \tan \alpha_1 = n_2 y_2 \tan \alpha_2 \text{ (Helmholtz-Lagrange's Law}^6\text{)}. \quad (1)$$

$$(n_2/p_2) - (n_1/p_1) = (n_2 - n_1)/\rho \text{ (Lens formula}^7\text{)}. \quad (2)$$
$$= n_2/f' = n_1/f.$$

In (2) f is the focal length of the lens on the object space (refractive index n_1), and f' is the focal length in the image space (refractive index n_2).

We assume now $n_2 > n_1$, and ask what happens to the size y_2 of the image and to the angle α_2 if we increase the refractive index n_2, keeping the other geometrical values ρ, p_1, α_1 and the refractive index n_1 constant ($\rho > 0$, $p_1 < 0$).

It will be found that two rather distinct limiting cases exist. The general case will lie somewhere between these extremes.

If we solve (2) for p_2 we obtain

$$p_2 = n_2 p_1 \rho / (n_1 \rho + (n_2 - n_1) p_1). \quad (3)$$

From (1) we can deduce for the linear magnification

$$m = y_2/y_1 = n_1 p_2 / n_2 p_1. \quad (4)$$

Inserting the expression for p_2 from (3) into (4) we find

$$m = 1/(1 + [(n_2/n_1) - 1]p_1/\rho). \quad (5)$$

Consider now the refractive index n_2 to be large compared with n_1, and p_1 to be of the same order of magnitude as ρ or to be greater than ρ. By neglecting 1 against n_2/n_1 and $n_2 p_1/n_1 \rho$ we find in the limiting case for m

$$m = n_1 \rho / n_2 p_1. \quad (6)$$

We see from (6) that the linear image size y_2 is proportional to $1/n_2$, as the values for y_1, ρ, n_1 and p_1 are kept constant. By combining (4) and (6) we find further that p_2 remains constant if the refractive index n_2 is changed, being approximately equal to ρ. From (1) we see that in this case the angle α_2 of the rays forming the image is constant as well. If no reflection or absorption losses and no lens aberrations exist, the brightness of the image increases in proportion to n_2^2. This case is the one usually quoted in text books on optics; nevertheless it is only a limiting case and one of many possible ones.[8]

Now take the other limiting case in which p_1 is so small compared with ρ that we have $|(n_2/n_1 - 1)p_1| \ll \rho$. Then the term $(n_2/n_1 - 1)p_1/\rho$ can be neglected against 1 in (5) and we find the simple relation $m = 1$, or

$$y_2 = y_1. \quad (7)$$

From (4) we find the further relation

$$p_2 = (n_2/n_1)p_1. \quad (8)$$

Combining (7) and (1), we obtain $n_1 \tan \alpha_1 = n_2 \tan \alpha_2$, and for small angles (paraxial rays)

$$n_1 \alpha_1 = n_2 \alpha_2. \quad (9)$$

In the second limiting case we find, therefore, that the size of the image does not change if the index of

[4] E. G. Ramberg and G. A. Morton, "Electron optics," *Jour. Appl. Phys.*, vol. 10, pp. 465–478; 1939.

[5] A. E. Conrady, "Applied Optics and Optical Design," Oxford University Press, London, England, 1929.

[6] R. A. Houston, "A Treatise on Light," Seventh edition Longmans Green and Co., New York, N. Y., 1938, p. 35, equation (ii).

[7] See p. 25 of footnote reference 6.

[8] The reason why this limiting case receives such preferential treatment in the textbooks may be that the question of the influence of a change of refractive index is a rather unimportant one in "light optics," as usually the medium on both sides of the lens is air, the only exception of practical importance being the immersion-microscope objective.

refraction is increased, but the angle with the optical axis of the rays forming the image is inversely proportional to the refractive index n_2. This result is trivial for a refracting plane $\rho=\infty$, but it is not restricted to this rather special case. The only requirement is that the object lies very close to its principal plane of the lens. Equation (8) shows that then p_2 and p_1 have the same sign; i.e. image and object lie on the same side of the lens. In other words, the image is upright and virtual.

It is a condition approximating the second limiting case ($y_2=y_1$, $n_1\alpha_1=n_2\alpha_2$) which we commonly meet in the lens system of a cathode-ray tube, as will be shown in the next section.

If we apply (9) to a cathode-ray tube ($n \propto E_A^{1/2}$) and transform it to give us the diameter of the cathode-ray bundle at any distance from the cathode after passing through the first beam-forming lenses we obtain, provided no limiting apertures are placed between the cross section in question and the first lenses

$$r^2E_A = \text{constant} \qquad (10)$$

where $2r$ is the diameter of the beam at the distance under consideration.

The Equivalent-Optical System of a Cathode-Ray Tube

Let us now consider briefly the potential fields of a cathode-ray-tube gun and their equivalent-lens properties. Fig. 2 shows the electrode structure of a typical cathode-ray tube with some equipotential field lines dotted in and its equivalent-light-optical-lens system.

The equivalent-optical-lens system suggested here differs from that used by other authors in the introduction of the additional lens No. 2, and by the role ascribed to this lens in the formation of the fluorescent spot on the tube screen.

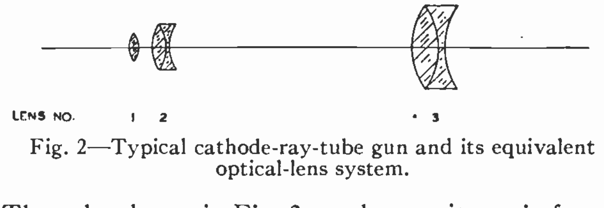


Fig. 2—Typical cathode-ray-tube gun and its equivalent optical-lens system.

The tube shown in Fig. 2 employs as its main focusing lens an electrostatic two-cylinder lens; it is the prototype of a television cathode-ray tube, and similar designs have been used frequently as oscilloscope tubes. A focusing coil could be substituted for the main lens without changing materially the shape of the electrostatic fields between cathode grid and first anode. Tubes of this type have been widely employed in television. Various other designs (see Table I) embody different electrode structures and different sequences of potentials, but if the shape of the electrostatic fields between the electrodes is analyzed, it is found that the electrostatic lenses participating in the formation of the electron beam can be described in an analogous way and have similar properties to those of Fig. 2.

One of the chief parameters of an electron-gun structure is the diameter of the hole in the grid or modulator electrode. The other critical dimensions are usually of the same order of magnitude. In estimating the focal length of lens No. 1 of Fig. 2, we use (2) in the rewritten form $f'_1=\rho/(1-n_1/n_2)$, the suffix 1 denoting the number of the lens. We find that f'_1 is nearly as great as the distance between the grid and the first accelerating electrode. If this distance is small, taking the grid-hole diameter as unit of measurement, most equipotential surfaces possess a radius of curvature slightly in excess of half the diameter of the grid hole, and the focal length of f'_1 is slightly greater than the grid-hole diameter. If the distance between grid and first anode is rather great, a considerable number of refracting surfaces have a large radius of curvature. Hence the focal length f'_1 of the lens, found by compounding the refracting powers of the successive refracting surfaces, comes out again as nearly equal to the distance between grid and first anode. This fact can be verified by analyzing the electrostatic fields measured in an electrolytic tank, and it agrees with the writer's experimental investigations of various electron-gun structures. The space charge between the cathode and the next electrode, be it a modulator or an accelerator, tends to lengthen the focal length f'_1 further as it flattens out the radius of curvature of the equipotential surfaces.[9]

The exact value of f'_1 depends, of course, on the detailed geometry of the electrode structure, on the voltages applied to the electrodes, and on the cathode current. For the purpose of this discussion, the approximate value of f'_1 as just derived suffices.

Thus, lens No. 1 images the cathode approximately in the plane of the entrance opening of the first anode or some distance further away from the cathode.

The optical center of the next equivalent lens, lens No. 2, is approximately located at the entrance hole of the anode or somewhat displaced towards the cathode. The real inverted cathode image, which is considerably smaller than the cathode, would therefore be situated well to the right of the left focal point of lens No. 2. Hence, the action of lens No. 2 on the electron bundle coming from lens No. 1 and converging towards the real image is such that the rays emerging from lens No. 2 and proceeding towards the main focusing lens No. 3 appear to come from an inverted virtual image of the cathode. This virtual image is situated rather near the cathode, between the cathode and the first anode.[10] This is exactly the situation which we called before the

[9] See p. 143 of footnote reference 1.

[10] K. Spangenberg and L. M. Field, "Some simplified methods of determining the optical characteristics of electron lenses," Proc. I.R.E., vol. 30, pp. 138–144; March, 1942.

"second limiting case," in which the magnification does not change appreciably with a change of refractive index. The image formation by lenses No. 1 and No. 2 is shown schematically in Fig. 3.

In the diagram of Fig. 3, lens No. 1 (focal points F_1 and F'_1) images the cathode B_0 into B_1. The image of B_1 formed by lens No. 2 (focal points F_2 and F'_2) is the virtual image B_2, displaced towards the cathode.

We have, therefore, to expect that the size of the final cathode image, i.e., the fluorescent spot on the screen of the cathode-ray tube, remains almost unchanged if the anode voltage is raised while the emitting cathode area is kept constant. What changes is the solid angle subtended by the electron beam proceeding towards the final lens; the cross section of the beam will contract in inverse proportion to the final anode voltage. This applies to magnetically focused and electrostatically focused tubes equally well, as the focusing voltage in the last case is a constant fraction of the final anode voltage, whatever absolute value the final anode voltage may have. In both cases, a change of final anode voltage affects directly only lens No. 2, whereas the focal length of lens No. 3 has to be kept constant or nearly constant.

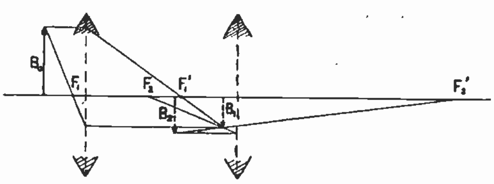


Fig. 3—Image formation by the first two lenses representing the action of the potential fields between cathode, grid, and first and second anodes.

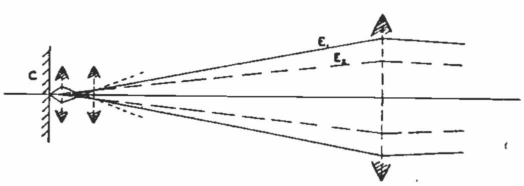


Fig. 4—Paths of electron beam through complete electron-lens system of cathode-ray-tube gun for two different final accelerating voltages ($E_2 > E_1$).

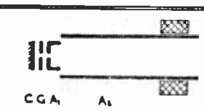
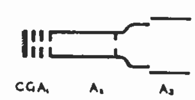
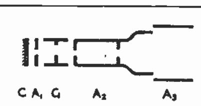
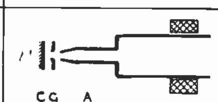
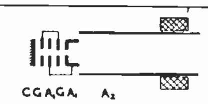
The actual path of a ray for two different accelerating voltages E_2 and E_1 ($E_2 > E_1$), taking the co-operation of all lenses into account, is shown in Fig. 4. It will be noticed that the position of the virtual cathode image which is, in turn, imaged onto the tube screen by lens No 3, changes only very slightly by comparison with the object and image distances of lens No. 3 if the accelerating voltage is changed.

If the fluorescent-spot size is calculated on the basis of our three-lens conception, the considerable discrepancy between calculated and observed values reported by Maloff and Epstein[11] disappears.

Experimental Investigations

The predictions of the preceding section were checked experimentally on a number of typical cathode-ray tubes. In order to test how far these conclusions apply generally, tubes of very different electron-gun designs were selected. All tubes investigated are British prewar television cathode-ray tubes of types which had been widely used in television receivers. Two types of tube employ electrostatic lenses as main focusing lenses, the other tubes a magnetic lens of standard design; the deflection system for all these tubes is electromagnetic. Some particulars of the electron-beam-forming structures of the investigated tubes are given in Table I. A

TABLE I
Electron-Gun Designs of Investigated Tubes

Tube No	Electron Gun Structure	Main Lens
1		Magnetic
2		Electrostatic
3		Electrostatic
4		Magnetic
5		Magnetic

full investigation of the spot size was carried out for one specimen of each type. Several further television cathode-ray tubes and a few oscilloscope tubes were tested visually but without taking photographic records.

The measurement of spot size was carried out in the following way. The tubes were set up in the same manner as for television purposes but a 50 cycles-per-second sinusoidal sweep, taken from the main supply, was applied to one set of deflecting coils, the length of trace being equal to the diameter of the tube screen. To the other set of coils a small out-of-phase 50-cycles-per-second current was applied separating forward and return trace. This proved the best way of producing a very steady trace. The return trace was covered by a strip of black paper, and the central section of the forward trace was photographed on a 4.8-times enlarged scale. This enlargement practically eliminated "aperture effect" in the subsequent densitometric measurement; the width of the densitometer slit was 0.15 millimeter. The traces produced when different final anode voltages were applied ranging from 500 volts to 8 kilovolts, were all taken on the same plate for each tube. The final anode current was kept constant throughout, usually at 10 microamperes. In tubes Nos. 1, 2 and 5 the grid bias and

[11] See p. 120 of footnote reference 1.

the first anode voltage were kept constant as well, whereas in tubes Nos. 3 and 4 the grid bias had to be readjusted to keep the anode current constant. The exposure time was adjusted to give approximately equal densities for all anode voltages; this time varied in a typical case from 1/10 second at 8 kilovolts to 18 seconds at 600 volts. The photographic plates were developed under standard conditions. The brightness-density relationship was established by calibrating several plates by photographing some of the cathode-ray-tube traces with varying exposure times under constant current and voltage conditions. The photographic records were

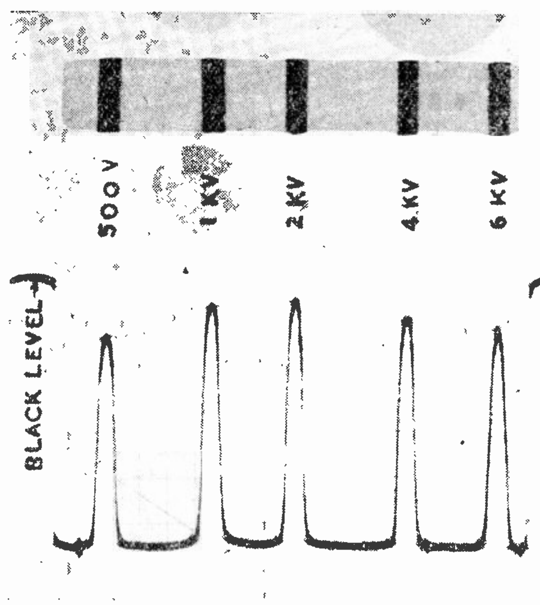


Fig. 5—Typical photograph of traces on fluorescent screen for different final-anode voltages (above), and corresponding photometer curve (below). Tube No. 1. Actual size.

then passed through a recording microphotometer. The "spot size" was defined as suggested by Zworykin and Morton[3] as width of line b_0 for which the brightness is decreased by a factor K from its maximum value. The factor K was usually taken as 1/5 in this particular investigation where a *change* of spot size was examined; other values of K between 1/2 and 1/10 gave the same result.

The chief source of error in the spot-size measurements was imperfect focusing, and great care was taken to align tubes and focus coil (which was the same for all magnetically focused tubes), and to adjust the focus as well as possible for smallest spot size in each case, using a low-power microscope as a focusing aid. The beam current used (10 milliamperes) represents, in view of the uneven scanning speed, about the same specific screen load at the place of measurement as the peak beam current (order of 200 milliamperes) would give on a 400-line interlaced raster. Saturation effects of the fluorescent screen should therefore not falsify the measurements.

A typical photograph and its corresponding photometric record are shown in Fig. 5. The strip shown in the upper part of Fig. 5 is a reproduction of the original photograph of the traces on the screen. The photometer curve, giving the intensity distribution in the photographs of the traces, is shown below. The voltage values at which the traces were photographed are those marked in the figure. This photograph demonstrates very clearly how little the spot size changes if the final anode voltage is varied, all other conditions being constant.

The result of the measurements taken on the five typical cathode-ray tubes are plotted in Fig. 6. The ordinates represent the definition expressed as number N of lines resolved, the abscissa being $E_A^{1/2}$. The number N

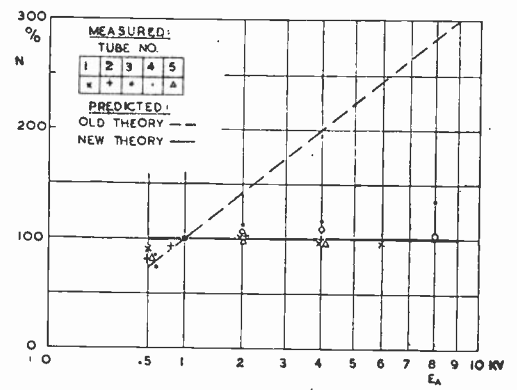


Fig. 6—Diagram showing the voltage-resolution relationship as predicted by old and new theories and the points measured for five cathode-ray tubes of different designs. The resolution was taken as 100 per cent at $E_A = 1$ kilovolt for all tubes and for the predicted curves.

is proportional to the reciprocal value of the spot size ($N \propto 1/b_0$). This way of representing the results allows best a comparison with the relationship $N \propto E_A^{1/2}$, predicted by the cross-over theory, which appears as a straight line. The measurements, in addition to giving information about the change of definition with anode voltage, allow comparison of the merits of various gun designs. Such a comparison is, however, outside the purpose of this paper, and the number of lines resolved at $E_0 = 1000$ volts was taken as 100 for each tube; the diagram shows, therefore, the relative percentage change of definition.

It can be seen from Fig. 6 that, for accelerating voltages above 1000 volts, the spot size remains unchanged within the errors of measurement (± 10 per cent) for all tubes except tube No. 4. Below a final accelerating voltage of 1000 volts the obtainable definition decreases, although the decrease is not as great as $(E_A/E_0)^{1/2}$. The amount of decrease appears to be significantly different for the various types of tubes. It is noteworthy that those tubes which show a greater decrease in definition at a low voltage have their "defocusing point" at lower beam-current values. It appears likely that both effects are due to the same reason, more pronounced spherical aberration in the main lens owing to a larger solid angle of the electron beam.

Only tube No. 4 shows an improvement in definition above 1000 volts, which is outside the error limit. This tube is a "triode" tube, in which an increase in anode voltage has to be offset by an increase in grid bias to keep the beam current constant (the grid bias had to be increased from −1 volt at $E_A=600$ volts to −22 volts at $E_A=8000$ volts in order to keep the current constant). This change in grid bias leads to a restriction of the cathode area delivering current into the beam, and the decrease in spot size is mainly due to this effect. This change of spot size in tube No. 4, if plotted against change of grid bias, ignoring the change of E_A, is of exactly the same kind as that given as example by Maloff and Epstein,[12] and that measured by L. Jacobs,[13] except that the change for tube No. 4 is only 60 per cent of that shown by Maloff and Epstein's, and Jacobs' examples. The change of spot size in tube No. 4 is therefore fully accounted for by the change in grid bias, and the influence of final anode voltage as such appears to be as negligible as in the case of the other tubes.

A check of the corollary of constant spot size, the change of the solid angle subtended by the beam as $1/E_A$ was taken in a series of experimental tubes which employed the same gun design as tube No. 1 of Table I. In these tubes, the neck was closed by a flat plate carrying a fluorescent screen in the approximate position of the gap in the shrouded focusing coil. The spot appearing on the fluorescent screen in the middle plane of the main lens (the lens current being switched off) was photographed for different anode voltages. The spot size was evaluated from a microphotogram as previously described. From this the half angle subtended by the cone of rays was calculated, and its change compared with the change of anode voltage. In other cases, parallel lines of measured distance were scratched into the cathode coating. From the change of their image on the screen the change of angle could be determined for different anode voltages. The spot was found to be the enlarged inverted image of the cathode surface projected on account of the small angle of image-forming bundles (order of 1/2 degree), with great sharpness. Owing to the great depth of focus, it was not possible to determine the exact locus of the cathode image proper.

If one directs the attention to the marginal rays only, the change of their angle with the axis can most easily be observed if the photographic records are somewhat overexposed for the center of the spot, giving a sufficient exposure for the image of the marginal rays to show up clearly. A typical photograph of this kind is shown in Fig. 7. The prints of Fig. 7 were prepared on "normal" gradation paper; it is noteworthy that the edge of the overexposed photograph appears quite clear cut (the faint outer ring of $1\frac{1}{4}$-inch diameter is due to internal reflections at the sealing edge of the closing plate).

From such photographs the half angle of the marginal rays can be determined. All these measurements confirm our equations (9) and (10) very well. One can rewrite (10) in the form $1/r=\text{const. } E_A^{1/2}$. If $1/r$ is plotted against $E_A^{1/2}$ a straight line passing through the origin should result. The values for $1/r$ taken from Fig. 7 are plotted in this way in Fig. 8, confirming this expectation.

[12] See p. 184 of footnote reference 1.
[13] L. Jacobs, "Electron distribution in electron-optically focused electron beams," *Phil. Mag.*, vol. 28, pp. 81–98; 1939.

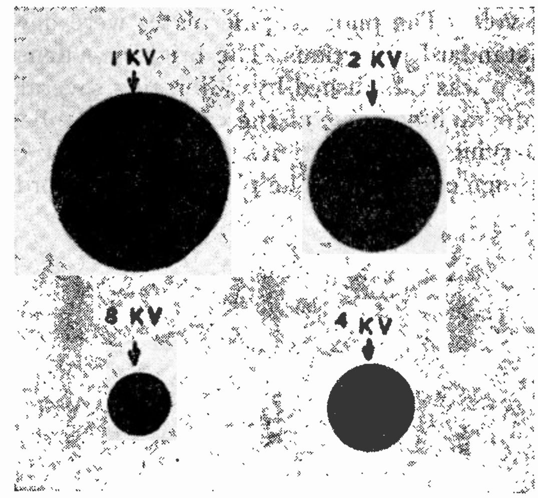


Fig. 7—Typical photograph of cross section of electron beam at the position of main lens for four different final accelerating voltages (electron-gun system as that of tube No. 1). Actual size.

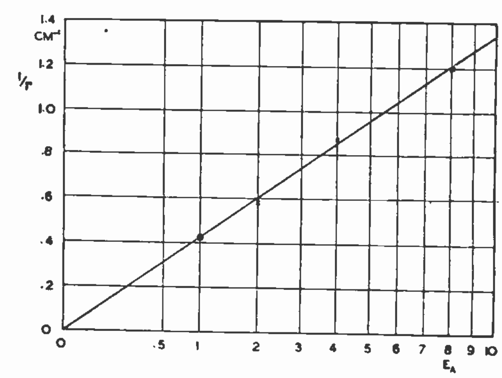


Fig. 8—Graph showing linear relation between reciprocal-beam diameter and square root of final-anode voltage. Values of $1/r$ taken from Fig. 7. Straight line connects origin and value of reciprocal-beam diameter measured at $E_A=1$ kilovolt. The other measured values are marked by crosses.

Some Consequences of the New Theory

In the introduction, reference has been made to the widely accepted view that the spot size should be inversely proportional to the square root of the final anode voltage and the proof given for this by Zworykin and Morton.[3] The considerations and experimental results presented in the preceding sections of this paper are contradictory to this conception. We have, therefore, to examine the cross-over theory, which underlies Zworykin and Morton's argument, in more detail.

Referring again to Zworykin and Morton's book, Figs. 13.3 and 13.4, we see that their proof is based on the assumption that the fluorescent spot projected onto the tube screen is an electron-optical image of a cross-over of bundles of electrons emerging from the cathode. The intensity distribution in the cross-over is due to the radial thermal velocities of the electrons leaving the cathode, and in consequence it should not possess any structure and its current distribution should be described by the formula $i_r = i_0\epsilon^{-ar^2E}$, r being the radial distance from the axis. If this conception of the equivalent-optical system of a cathode-ray tube were considered correct, the law of variation of the spot size $b_0 \propto 1/E_A^{1/2}$ would be an inescapable conclusion as shown by Zworykin and Morton, perhaps slightly modified in practice by the possibility that the approximations used by these authors may have simplified the matter too much.

The strongest argument against the cross-over theory as commonly understood is that the postulated inverse-square-root law for the spot size cannot be verified experimentally (see Fig. 6). A further argument is that many cathode-ray-tube spots, when focused for smallest spot diameter, show a greater or smaller amount of structure, which would be impossible if they were images of structureless cross-overs, but which is quite consistent with the assumption that the spot on the tube screen is an image of the cathode. We can go still further and say that the formation of a real, sharp cathode image between the cross-over and the tube screen (as shown in Figs. 13.2 and 13.3 of Zworykin and Morton's book) would be made impossible by the very existence of a cross-over with the properties commonly assigned to it.

The structureless property of such a cross-over and its radial current-density distribution is based ultimately on the random statistical fluctuations of the directions and speeds of the electrons leaving the cathode. Owing to the fundamental principles of thermodynamics, it is impossible to remove any such random statistical distribution superimposed on the current distribution of the electron emission at the cathode, whatever optical-imaging system is employed. If, in particular, the random statistical fluctuations are strong enough to obliterate the original intensity distribution *entirely* in a certain cross section, and to substitute their own distribution instead, as is usually assumed to be the case at the so-called cross-over, the original cathode-intensity distribution can never be reproduced beyond the cross-over. The optical system following the cross-over can then only reproduce an image of the cross-over, or an intensity distribution derived from that of the cross-over.[14]

Let us consider the influence of statistical fluctuations of the directions and speeds of the electrons leaving the cathode in more detail. Each electron follows a certain trajectory which is fully determined by the initial conditions (in a rotationally symmetrical field the distance of the starting point from the axis, and the direction and amount of initial velocity of the electron), and by the configuration of the electrostatic or magnetic fields through which the trajectory passes. It is known from the theory of electron optics that rotationally symmetrical fields constitute electron lenses, and that the trajectories originating at the same object point and being followed by electrons with identical initial speed intersect at the same point, the image, provided, of course, that the electron lenses are considered to be ideal lenses; i.e., being free from aberrations, and that the aperture of the bundle of trajectories is small.

If now a random statistical variation is superimposed on the velocity of the electrons when leaving a given point at the cathode, their trajectories will no longer intersect in one single point but will form a "disk of confusion" around the original image point. The intensity distribution in this disk of confusion is that calculated by Law,[15] assuming a Maxwellian distribution of electron velocities at the cathode. From an electron-optical point of view this disk of confusion can be considered as being produced by a certain form of chromatic aberration. This chromatic aberration certainly affects adversely the quality of the cathode image formed by the electron lenses, yet the relatively sharply defined cathode images obtainable in the emission type of electron microscope indicate that this effect need not be serious.

In addition to the experimental evidence against the cross-over theory and the theoretical argument just discussed, a further objection exists. It is a general property of optical systems that a cross section smaller than the aperture of the imaging lens or smaller than the image itself (whichever is the smaller of the two) cannot be formed if the imaged object is itself an emitter of radiation. In the particular case of the cathode-ray tube, the smallest cross section is a real image of the cathode situated fairly near the cathode itself. A cross-over, as defined in the earlier literature, should have no physical existence in the normal cathode-ray tube, and the question first posed by Brueche and Scherzer,[16] whether an image of the cathode or an image of a cross-over would give the smaller fluorescent spot on the tube screen would, therefore, be meaningless. Perhaps too great an emphasis was placed in the past on the purely formal representation by certain "principal rays" of the image formation by electron lenses, which is very helpful in determining the main properties of lenses but does not tell the whole story; for each intersection of principal rays with the axis there is a twofold infinite number of points of intersection of other rays with the same cross-sectional plane.

The current distribution in the first cathode image, which is, in turn, imaged by the main lens onto the tube screen to form the fluorescent spot, is chiefly determined by the local current distribution at the cathode, but

[14] Radio engineers are quite familiar with such phenomena. Once a radio signal has fallen well below the "noise level" due to random statistical current fluctuations, it has gone for good, whatever measures may be taken to retrieve it.

[15] R. R. Law, "High current electron gun for projection kinescopes," Proc. I.R.E., vol. 25, pp. 954–976; August, 1937.

[16] E. Brueche and O. Scherzer, "Geometric Electron Optics," Julius Springer, Berlin, Germany, 1934, p. 175.

due to the Maxwellian electron-velocity distribution at the cathode, chromatic aberration and lens aberrations are superimposed on this fundamental current-density distribution, making the cathode image less well defined. At high cathode-current densities, an additional current distribution becomes superimposed, due to the gradual formation of a space-charge cloud in front of the cathode which evens out local differences of electron emission; under certain conditions the fluorescent spot may, therefore, be an image of a structureless space-charge disk, although such high cathode-current densities are not frequently met in practice.

An experimental confirmation of the cross-over theory seemed to be provided in a paper by Law.[15] This apparent confirmation is based on the fact that the current through an aperture was found to depend on the parameter (r^2E_A), as demanded by the cross-over theory, The same law, however, is predicted by our equation (10), as long as the aperture is smaller than the cross section of the beam. Moreover, our relation (10) is fulfilled, or nearly fulfilled, quite generally for any beam cross section in the ordinary type of cathode-ray tube, and not only for a specially selected cross section, the crossover. As we have seen before, (10) does not confirm a cross-over formation, but contradicts it.

Tests, as illustrated by Fig. 7, give us a further check. The cross-over theory requires a current distribution $i=i_0\epsilon^{-aEr^2}$. This means that the edge of the beam should not be sharp, but that the intensity should die away gradually. In Fig. 7 we see, however, that the edge is quite well defined and not as predicted by the equation $i=i_0\epsilon^{-aEr^2}$.

We can go a step further. The radial-intensity distribution in the cross section of the beam approximately at the position of the main focusing lens was determined by the writer by two different methods for several experimental tubes. Such measurements show that the peak of the intensity distribution can indeed be represented approximately by an empirical formula $i=i_0\epsilon^{-aEr^2}$ if the constant a is chosen suitably, but that the flanks are steeper than demanded by this approximate formula. In particular, the intensity distribution shows only a slightly marked "toe" with a well-defined cutoff instead of decreasing very gradually. The writer has analyzed by a mathematical approximation method the radial distribution of the cathode current for a cathode-ray tube employing the same design parameters as the experimental tubes used for these measurements, and has found a current distribution which agrees well with the experimentally determined one. The quicker falling off of the intensity, and the reduction of the width of the toe are due to the appearance of Bessel functions of the type $J_0(br)$ in the approximation. For a certain value r, which corresponds to the first root of $J_0(br)$, the current intensity becomes zero, resulting in a sharp cutoff. This analysis and more detailed results of the measurements of the radial-current distribution will be published elsewhere at a later date. A similar current distribution is shown in Fig. 14 of Jesty and Winch's paper.[17]

The rather long "tail" frequently found in spot-size measurements, which makes the current-distribution curve resemble a Gaussian error curve, appears to the writer mainly due to the superposition of spherical aberration and other lens defects on a current-distribution curve showing a sharp cutoff. This would also explain the "wide spread of results on different cathodes" and the appearance of "abnormal intensity distributions" in Jacobs'[13] investigations. These "abnormal distributions" are probably due to uneven cathode emission, giving an uneven current distribution in the final cathode image; i.e. the fluorescent spot on the tube screen. Jacobs' "normal distribution" would belong to cathodes with even emission.

Application of New Theory to Cathode-Ray-Tube Design

The conception of the equivalent-optical-lens system of the cathode-ray tube as presented in this paper allows the formulation of some statements on questions of design and operation of cathode-ray tubes which are of practical importance.

The definition or sharpness of trace on the screen of a well-designed cathode-ray tube operated with constant current does not depend to any appreciable extent on the final accelerating voltage if a certain minimum accelerating voltage is exceeded. For a cathode-ray tube of the screen-grid type, this value of minimum accelerating voltage is quite low. It is slightly higher in tubes which employ virtual cathodes or double-intensity modulation. In triode tubes a slight improvement in definition with increased anode voltage is mainly due to a reduction in the effective cathode diameter owing to a greater negative grid bias.

In some cases, particularly at high beam currents, the spot size is largely determined by spherical aberration in the main focusing lens and by faults of alignment causing astigmatism and coma, and not only by the size of the effective cathode area and the laws of geometrical paraxial optics. In these cases, raising the accelerating voltage will bring a certain improvement owing to the contraction of the electron bundle, the obtainable improvement in definition being rather closely related to the amount and kind of lens errors present. The improvement is most marked if spherical aberration sets the limit for definition. Nevertheless, it would appear the better and more economical way to reduce the incidence of serious lens errors by careful design of cathode-ray tubes and their ancillary apparatus instead of minimizing their deleterious influence by increasing the anode voltage.

If a certain maximum anode voltage is available, a

[17] L. C. Jesty and G. T. Winch, "Television images—an analysis of their essential qualities," *Jour. Telev. Soc.*, ser. II, vol. 2, pp. 316–334; 1937.

reduction of spherical aberration or a decrease of the solid angle of the electron bundle emerging from the neighborhood of the cathode will permit a higher beam current before defocusing occurs. If the aberrations of the main lens are known our equation (10) will allow us to determine from simple tests the limit to which a certain design of electron-gun structure can be developed. There will be an optimum value for the definition which can be achieved, and this, in turn, involves an optimum distance of the final lens from the cathode, matching decrease in spot size owing to greater object-lens distance against increase of spot size due to spherical aberration (or a decrease in beam current, if a beam-limiting aperture is employed).

In cathode-ray tubes embodying a beam-limiting aperture of a diameter $2R$, which is considerably smaller than the diameter of the electron beam, the current passing through the aperture can be described by the approximate formula $I=I_0(1-\epsilon^{-aR^2E_A})$. Contrary to similar formulae given by Langmuir, Pierce, and Law,[15,18–20] the constant a has here no fundamental significance but represents an empirical parameter. The importance of this approximate formula lies in the fact that it refers, not to a limiting case or to a special tube construction, but to any type of cathode-ray tube employing a beam-limiting stop. The constant a is, of course, determined by certain design parameters and by certain operating conditions of the tube; the present knowledge of the beam-generating part of an electron gun does not seem to be far enough advanced, however, to write down a theoretical expression for a as determined by the tube-design parameters. A further point of interest is the rather complex part played by the limiting aperture. This aperture acts not only as a beam-defining and intensity-limiting stop, but as a field-limiting stop as well, owing to the small aperture of the image-forming electron bundle.

Acknowledgments

The writer is indebted to several members of the vacuum research laboratory for their valuable help in the experimental work. He also wishes to thank the Directors of Cathodeon, Ltd., for permission to publish this paper.

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[18] David B. Langmuir, "Theoretical limitations of cathode-ray tubes," Proc. I.R.E., vol. 25, pp. 977–991; August, 1937.

[19] J. R. Pierce, "Limiting current densities in electron beams," *Jour. Appl. Phys.*, vol. 10, pp. 715–724; 1939.

[20] R. R. Law, "Factors governing performance of electron guns in television cathode-ray tubes," Proc. I.R.E., vol. 30, pp. 103–105; February, 1942.

Characteristics of Chlorinated Impregnants in Direct-Current Paper Capacitors*

L. J. BERBERICH,† C. V. FIELDS,† AND R. E. MARBURY†

Summary—Direct-current capacitors of the impregnated-paper type play an important role in electronic equipment required by the Armed Services. In some of these applications good performance is required over very wide temperature ranges. A new chlorinated-hydrocarbon composition which maintains reasonable capacitance constancy over a wide temperature range is described. The properties of this liquid are compared with conventional chlorinated impregnants. Since some alternating voltages usually accompany the direct voltages applied to capacitors, the alternating-current behavior over wide temperature and frequency ranges is described for capacitors impregnated with three different liquids. The effect of voltage and temperature on the resistance of capacitors is discussed. Considerable attention is devoted to the life behavior of capacitors impregnated with chlorinated liquids under direct-current stresses at high temperatures. A life-testing procedure is described which has yielded very satisfactory results on capacitors of varying sizes and ratings. A means for prolonging the life of capacitors impregnated with chlorinated impregnants involving the addition of stabilizers is discussed. Data showing effect of a number of stabilizers are presented. Finally, some data are presented showing the effect of voltage on the life of direct-current capacitors.

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I. Introduction

THE ENORMOUS demand by the Armed Services for electronics equipment has not only resulted in a corresponding increase in capacitor production, but also has emphasized the need for good performance of capacitors in a wide variety of service conditions. Impregnated-paper capacitors are used in filter circuits, tuned audio-frequency circuits, and in circuits requiring blocking and by-pass elements. In some of these applications the capacitor is subjected to direct voltages accompanied by small, but not always negligible, alternating voltages. In other applications, capacitors must withstand sustained direct voltages under high ambient temperatures. Hence, not only is the performance of the capacitor on high direct voltages important, but also its response to alternating voltages over wide temperature and frequency ranges. It is, therefore, the purpose of this paper to present data on both alternating-current and direct-current properties which should be of aid in correctly applying capacitors containing chlorinated impregnants.

The alternating-current properties of an impregnated-paper capacitor are determined by both the paper dielectric and the impregnant. However, if the impregnant is a polar material, such as chlorinated biphenyl, it usually plays a dominant role in determining the alternating-current properties. Polar liquids depend on the rotation of molecules for part of the dielectric constant, and under certain conditions only part of the rated capacitance may be effective. At the higher frequencies, particularly if combined with low temperatures, the part of the dielectric constant contributed by molecular rotation may be lost through decreased response of the molecular dipoles to the applied field. A study of this problem led to the development of a new liquid composition which maintains its dielectric constant to considerably lower temperatures than is the case with the widely used chlorinated-biphenyl impregnant.

The chlorinated aromatic hydrocarbons are known to have excellent electrical properties and stability toward oxidation. Despite this, however, a capacitor impregnated with them and subjected to a combination of sustained direct voltage and high temperatures has a definitely limited life. Capacitors of standard design built to operate at ambient temperatures of 40–50 degrees centigrade will withstand high stresses for long periods of time, but must be operated at reduced stresses when ambient temperatures of 75–85 degrees centigrade are encountered. Both high temperatures and sustained direct voltages are likely to be encountered in direct-current filters and in blocking and by-pass applications. It therefore becomes important to study the life behavior of any new material in the finished capacitor. To this end a life-testing procedure has been developed which will be described fully. This test has proved valuable in studying means for prolonging the life of a capacitor. One method of producing longer life, consisting of the addition of stabilizers to the impregnant, will be described.

II. Physical and Electrical Properties of Several Chlorinated Impregnants

Chlorinated aromatic hydrocarbons have found considerable use as impregnants in the electrical industry because of their good oxidation stability, noninflammability, and desirable electrical properties. These materials have largely replaced mineral oil and waxes as capacitor impregnants because of their higher dielectric constants and good stability under high stresses at moderate temperatures. These materials have been the subject of a number of investigations and the results are reported in the literature.[1-4] While several types of chlorinated hydrocarbons have been used, the type which has come into the most extensive use in capacitors is a chlorinated biphenyl averaging about five chlorine atoms per molecule. Some of the physical and electrical properties of this liquid, which will hereafter be referred to as "conventional Inerteen," are given in the first part of Table I and by curves *A* and *B* of Fig. 1. The electrical properties apply only after the liquid has been carefully purified.

TABLE I

Some Physical and Electrical Properties of Chlorinated Capacitor Impregnants*

	Conventional Inerteen	Special Inerteen
Density 25 degrees per 25 degrees centigrade	1.542	1.525
Refractive index—25 degrees centigrade	1.638	1.614
Pour point—ASTM degrees centigrade	+10	−28
Flash point—open cup degrees centigrade	None	180
Fire point—open cup degrees centigrade	None	None
Viscosity-Saybolt seconds at 100 degrees fahrenheit	2800	125
Viscosity-Saybolt seconds at 210 degrees fahrenheit	46	35
Dissipation factor at 25 degrees centigrade—per cent**	<0.1	<0.1
Dissipation factor at 85 degrees centigrade—per cent**	0.1	0.1
Dielectric constant at 25 degrees centigrade**	5.0	4.5
Dielectric constant at 85 degrees centigrade**	4.5	4.0

* All values of the various properties listed are approximate only and they may vary slightly from batch to batch.

** All dissipation factor and dielectric constant values were determined at a frequency of 60 cycles per second after the liquids had been subjected to a thorough purification treatment.

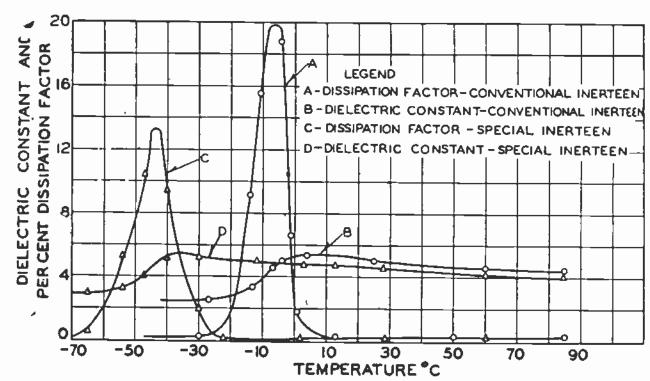

Fig. 1—Dissipation factor and dielectric-constant behavior as a function of temperature for two chlorinated impregnants, measured at 60 cycles per second.

As Table I shows, conventional Inerteen is a viscous liquid with a pour point of +10 degrees centigrade. Curve *B* of Fig. 1 shows that the dielectric constant at 60 cycles begins to fall with decreasing temperature at about 0 degrees centigrade. At higher frequencies, the dielectric constant starts to fall at even higher temperatures, as will become apparent later. For most normal applications, and particularly in direct-current filter circuits, this results in no serious difficulties. However, for certain uses, such as in tuned circuits and by-pass applications, it is desirable to have a liquid which does not suffer a marked reduction in dielectric constant until considerably lower temperatures are reached. For such applications a new liquid composition was developed consisting of chlorinated biphenyl blended with a substantial portion of polychloroethylbenzene (nuclearly chlorinated). The properties of this liquid, which will be referred to hereafter as "special Inerteen," are given in the last column of Table I and by Curves *C* and *D* of Fig. 1.

Comparison of the properties of special Inerteen with

[1] F. M. Clark, "Nonflammable dielectric organic compounds," *Ind. Eng. Chem.*, vol. 29, pp. 698–702, 1937.

[2] W. Jackson, "Dielectric loss characteristics of a chlorinated diphenyl," *Proc. Royal Soc.* (London), vol. 153 A, pp. 158–166; 1935.

[3] S. O. Morgan, "Two types of dielectric polarization," *Trans. Electrochem. Soc.*, vol. 65, pp. 109–118; 1934.

[4] A. H. White and S. O. Morgan, "The dielectric properties of chlorinated diphenyls," *Jour. Frank. Inst.*, vol. 216, pp. 635–644; 1933.

those of conventional Inerteen shows that the former has considerably lower viscosity and pour point than the latter. This makes possible unrestricted rotation of dipoles in special Inerteen at 60 cycles down to about −40 degrees centigrade as curve *D* of Fig. 1 shows. Thus, for any given frequency a capacitor impregnated with special Inerteen will maintain its capacitance to considerably lower temperatures than is the case for conventional Inerteen. Comparison of curves *A* and *C* of Fig. 1 shows that special Inerteen properly processed has a dissipation factor at 60 cycles which is as low as that for conventional Inerteen in the 20 to 85 degrees centigrade temperature region. In this temperature range, however, special Inerteen has a slightly lower dielectric constant than conventional Inerteen, as indicated by curves *B* and *D* of Fig. 1. This results in less than 5 per cent reduction in capacitance per unit of volume as compared with conventional Inerteen. Fig. 1 also shows the usual dissipation-factor peaks which always appear in polar substances in the middle of the dielectric-constant-dispersion region.

III. Electrical Properties of Capacitor Impregnated with Chlorinated Impregnants

1. *Effect of Temperature and Frequency on Capacitance and Dissipation Factor*[5]

In the foregoing, the electrical properties of the liquids alone have been treated. Of even more practical importance is the behavior of these liquids in combination with paper. The dissipation factor and capacitance behavior over wide frequency and temperature ranges should be an invaluable aid in properly applying capacitors. As far as the writers know, such data have not previously been published except for the case of a mineral-oil-impregnated capacitor.[6] For this reason, dissipation-factor and dielectric-constant data over the frequency range of 60 cycles to 1000 kilocycles and the temperature range from −70 to +85 degrees centigrade were obtained on capacitors impregnated with the two synthetic liquids just described. For purposes of comparison with a nonpolar impregnant, a similar study was also made on a mineral-oil-impregnated capacitor. The sample capacitors consisted of three layers of 0.4-mil kraft paper placed between aluminum-foil electrodes. The paper was carefully dried and thoroughly impregnated.

Results of capacitance and dissipation-factor measurements for a capacitor impregnated with conventional Inerteen are given in Figs. 2 and 3. The capacitance values are plotted in Fig. 2 in per cent of the 60-cycle capacitance at 25 degrees centigrade for five different frequencies. The accompanying dissipation-factor data are presented in Fig. 3. A similar set of data for a

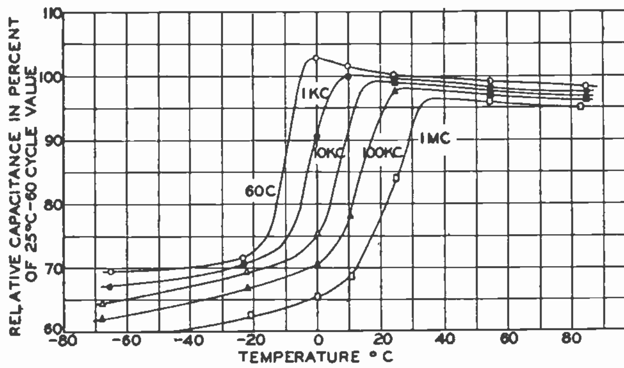

Fig. 2—Capacitance and temperature behavior at various frequencies of capacitor impregnated with conventional Inerteen.

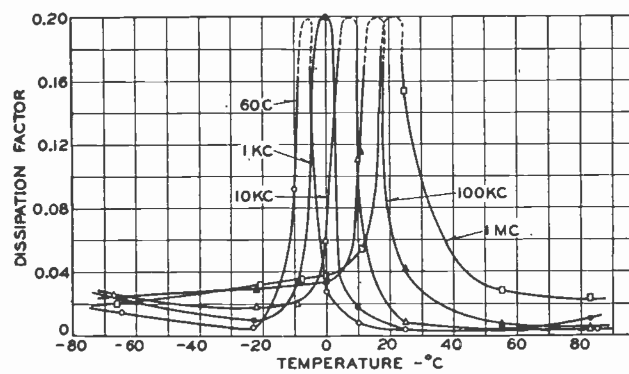

Fig. 3—Dissipation factor and temperature behavior at various frequencies of capacitor impregnated with conventional Inerteen.

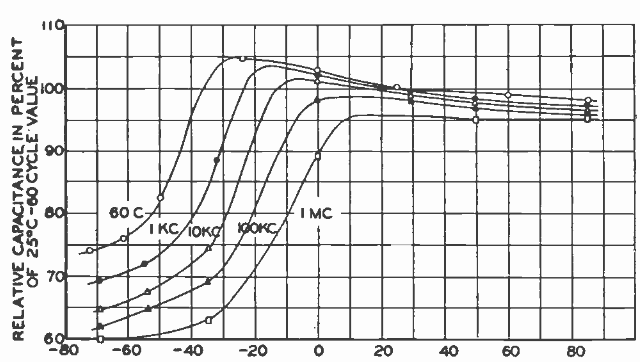

Fig. 4—Capacitance and temperature behavior at various frequencies of capacitor impregnated with special Inerteen.

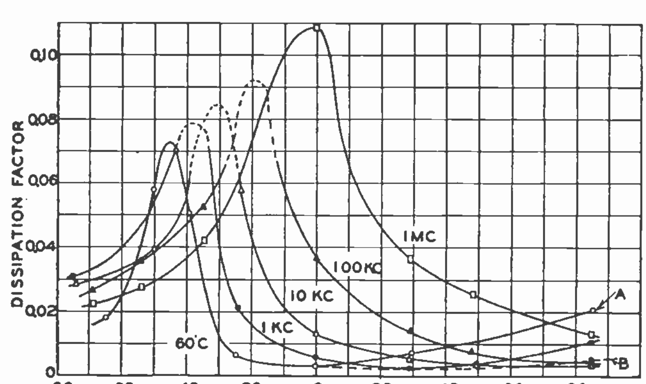

Fig. 5—Dissipation factor and temperature behavior at various frequencies of capacitor impregnated with special Inerteen.

[5] Dissipation factor is defined as the tangent of the loss angle or tan δ, whereas power factor is the sine of the loss angle or sin δ. For values of either less than 0.1 the two may be considered numerically equal for all practical purposes.

[6] H. H. Race, R. J. Hemphill and H. S. Endicott, "Important properties of electrical insulating papers," *Gen. Elec. Rev.*, vol. 43, pp. 491–499; 1940.

capacitor impregnated with special Inerteen is given in Figs. 4 and 5. A third set of data for a mineral-oil-impregnated capacitor is shown in Figs. 6 and 7. The mineral oil is of the highly refined and stabilized type, having a Saybolt viscosity at 100 degrees fahrenheit of 72 seconds and an American Society for Testing Materials pour point lower than −40 degrees centigrade.

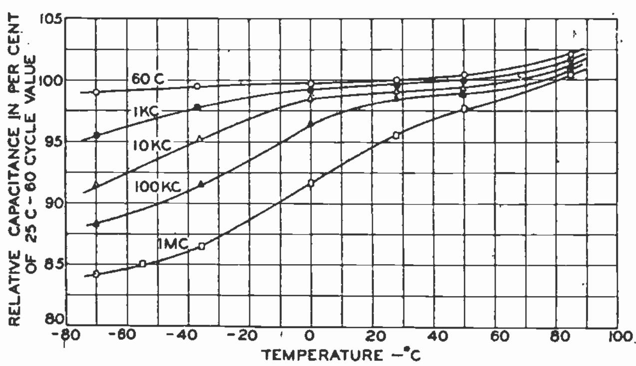

Fig. 6—Capacitance and temperature behavior at various frequencies of capacitor impregnated with mineral oil.

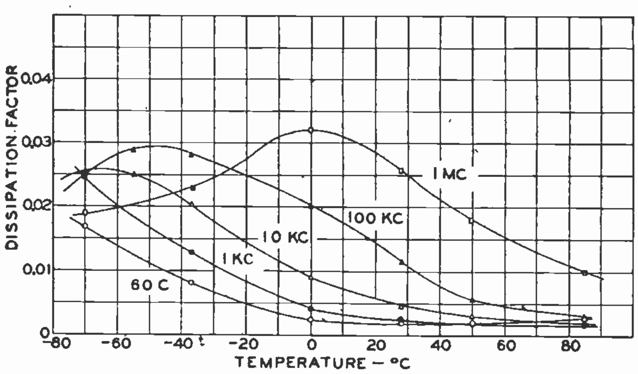

Fig. 7—Dissipation factor and temperature behavior at various frequencies of capacitor impregnated with mineral oil.

It is interesting to contrast the capacitance behavior of the capacitor impregnated with the nonpolar mineral oil with those impregnated with the polar liquids. Referring to Fig. 6, it is evident that, in the case of the mineral oil capacitor, the capacitance decreases gradually with decrease in temperature at all of the frequencies. This behavior is determined largely by the paper since the oil alone would be expected to show a slight increase in capacitance with decrease in temperature because of corresponding increase in density. It should be noted also that the rate of decrease of capacitance with decrease in temperature becomes greater with increasing frequency. Examination of Fig. 6 shows that at −40 degrees centigrade, for example, the capacitance at 60 cycles is more than 99 per cent of 25 degrees centigrade value. At one megacycle and −40 degrees centigrade, however, the capacitance is only 84.5 per cent of the 25 degrees centigrade-60 cycle value. This may be taken as the most constant capacitance characteristic obtainable with an impregnated-paper capacitor. Other mineral oils with higher liquid-to-solid transition temperatures result in decidedly greater decrease in capacitance at low temperatures.

In the case of the capacitors impregnated with the chlorinated polar liquids, the capacitance behavior is somewhat different, as Figs. 2 and 4 show. In the higher temperature region there is at first a slight increase in capacitance with decrease in temperature, which is followed by a sharp decrease in capacitance with further decrease in temperature. It is also apparent that the region of sharp decrease in capacitance, known as the dispersion region, is shifted to successively higher temperatures with increasing frequency. These capacitance changes are determined largely by the polar liquids, and the paper plays only a secondary role.

Comparison of the capacitors impregnated with the two polar liquids brings out some interesting facts. Fig. 2 shows that, for conventional-Inerteen-impregnated capacitors, the capacitance at −40 degrees centigrade and 60 cycles falls to approximately 70 per cent of the 25 degrees centigrade value. At one megacycle, the capacitance is reduced to 60 per cent of the 25 degrees centigrade-60 cycle value. For special-Inerteen-impregnated capacitors, on the other hand, the capacitance at −40 degrees centigrade and 60 cycles is still 95 per cent of the 25 degrees centigrade value. At one megacycle and −40 degrees centigrade, however, the capacitance of the special-Inerteen-impregnated capacitor is only slightly higher than that for conventional-Inerteen-impregnated capacitors. Thus, it is evident that a special-Inerteen-impregnated capacitor may be used in those applications where reasonable capacitance constancy is desired over a wide temperature range, particularly at the lower frequencies. In this respect, special Inerteen is intermediate between mineral oil and conventional Inerteen, but with the distinct advantage over mineral oil, as to higher dielectric constant.

Passing now to the dissipation-factor behavior, Fig. 7 shows the mineral-oil-impregnated capacitor has the broad dissipation-factor peaks characteristic of cellulose. It is well known that cellulose exhibits polar properties. Some interesting data on cellulose and cellulose derivatives are reported by Stoops.[7] Since the mineral oil investigated in this case is nonpolar, that is, it has no permanent dipole moment, the polar characteristics of the impregnated capacitor are entirely determined by the paper. It should be noted that the peaks in Fig. 7 shift to successively higher temperatures with increasing frequency. Furthermore, the peaks are located in the middle of the capacitance-dispersion regions given in Fig. 6, as is required by dipole theory.

The characteristics of the capacitors impregnated with the polar liquids are quite different from those of the mineral-oil-impregnated capacitor. Fig. 3 gives the data for conventional Inerteen. It is seen that the experimental data were not sufficient to outline the peaks in detail, and hence they were drawn in an approximate manner as is indicated by the dashed lines.

[7] W. N. Stoops, "The dielectric properties of cellulose," *Jour. Amer. Chem. Soc.*, vol. 56, pp. 1480–1483; 1934.

However, it will be noted that the peaks are much higher and much sharper than for the mineral-oil capacitor. In this case the polar behavior of the liquid and cellulose are superimposed, and that of the liquid is pronounced enough to mask that of the cellulose. The dissipation-factor curves for special Inerteen, shown in Fig. 5, are somewhat intermediate between the other two. The peaks are broader for special Inerteen than for conventional Inerteen, because of a greater distribution of relaxation times brought about by the greater molecular complexity of the former.

In addition to the frequency and temperature effects on the dissipation factor of a capacitor impregnated with chlorinated impregnants, there is also a voltage effect at the lower frequencies and the higher temperatures. This is indicated by the two branches of the 60-cycle curve marked *A* and *B* of Fig. 5. Branch *A* was determined at voltages of the order of 20 volts per mil, while branch *B* was determined at 200 volts per mil. The effect of voltage on dissipation factor is illustrated in more detail for both of the chlorinated impregnants in Figs. 8 and 9. This behavior is caused by the restricted motion of ions in the pores of the paper. The theory is very lucidly described by Garton[8] and will not be repeated here. This phenomenon has also been observed in oil-impregnated paper, but the effect is not so pronounced. Attention should be called to the fact that all of the data of Figs. 3, 5, and 7 were determined at low-voltage stresses except at 60 cycles, and then only in the higher temperature region. The voltage effect appears to be negligibly small above 10 kilocycles even at 85 degrees centigrade.

Considering the dissipation-factor data from the practical point of view, it is evident that high dissipation factors are encountered at the higher frequencies, regardless of the impregnant that is used. At 1 megacycle, even the mineral-oil-impregnated capacitor can have a dissipation factor greater than 0.03. In the case of capacitors with the chlorinated impregnants, considerably higher values are possible. Of course, if voltage of a given frequency is applied at a temperature where the dissipation factor is near a maximum, heat is generated which raises the temperature of the capacitor, thus tending to reduce the losses. However, at high ambient temperatures even these reduced alternating-current losses when added to the direct-current losses may bring about thermal instability.

Therefore, the designer of electronic equipment should consider the reaction of the circuit to capacitance and dissipation-factor changes with temperature and frequency. Furthermore, he should not overlook the possibility of thermal instability arising in the capacitor through superposition of alternating-current losses on the direct-current losses, especially if the ambient temperature is high. He should also remember that the average direct-current impregnated paper capacitor is not designed to carry large currents in attempting to apply it in circuits involving alternating voltages. In the higher-frequency by-pass applications, for example, the alternating currents can become quite large, even though the alternating voltage impressed on the capacitor be small. Such currents will add to the total heat generated through I^2R losses in the leads and even the metal foils. In many cases of this kind, specially designed high-current capacitors should be used.

[8] C. G. Garton, "Dielectric loss in thin films of insulating liquids," *Jour. I.E.E.* (London, England), vol. 88, III, pp. 23–40; 1941.

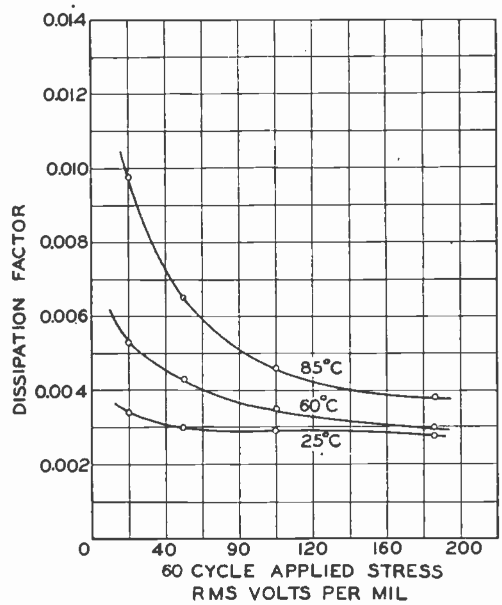

Fig. 8—Dissipation factor and voltage characteristics of capacitors impregnated with conventional Inerteen.

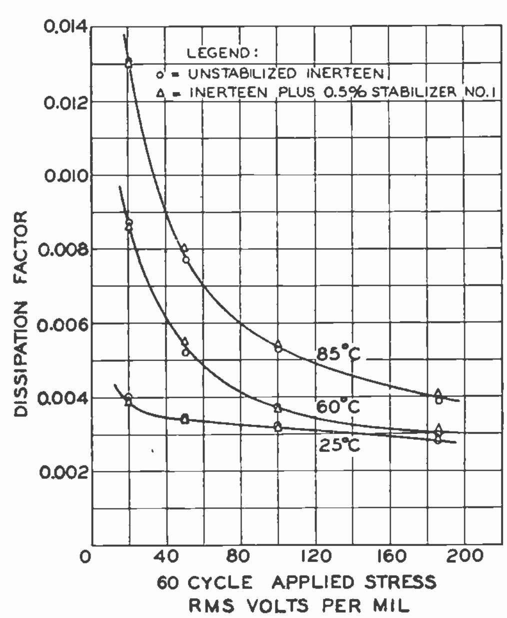

Fig. 9—Dissipation factor and voltage characteristics of capacitors impregnated with special Inerteen.

2. *Effect of Voltage and Temperature on Resistance*

The strictly direct-current losses in a capacitor are determined by its resistance. Not only is the magnitude of the resistance important, but also its change with temperature and voltage. It has been the practice in the capacitor art to report resistance values as the product of the resistance in megohms, and the capacitance in microfarads or *RC*. This not only gives the internal time constant of the capacitor, but also places capacitors of the same voltage rating but of different capacitances on the same basis. It is easy to see that the latter is true, when it is realized that, for the same thickness of dielectric, the resistance varies inversely as the area of the dielectric and the capacitance varies directly as the area. Since resistance varies with time of application of voltage, it is customary to read the resitance a fixed time after applying the voltage. In this work, readings were taken two minutes after application of voltage. The previous history of voltage application to the capacitor is also important. In order to avoid polarization effects,[9,10] it is advisable to short-circuit the terminals for a time before making the test.

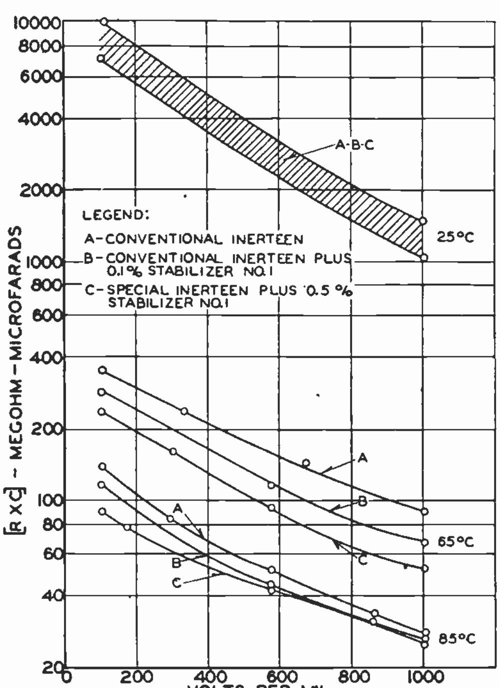

Fig. 10—Resistance characteristics of 1.0-microfarad 5000 direct-current capacitors, two-minute values.

Fig. 10 gives some typical data for 1 microfarad unit impregnated with the chlorinated impregnants. Several of the curves are for stabilized liquids. The function of stabilizers will be discussed more fully in the next section. It should be noted that the resistance not only decreases with temperature, but also with voltage. At 25 degrees centigrade there is little difference between the two liquids, even with stabilizers added, and the values usually fall within the shaded area between the curves. Such variations as do exist are due more to minor variations in processing than to differences in the impregnants.

[9] J. B. Whitehead, "Impregnated Paper Insulation," John Wiley and Sons, Inc., New York, N. Y., 1935.
[10] J. B. Whitehead, "Lectures on dielectric theory and insulation," McGraw-Hill Book Co., Inc., New York, N. Y., 1927.

At the higher temperatures, conventional Inerteen usually results in a capacitor with slightly higher resistance than is the case with special Inerteen. Some stabilizers, such as the one referred to in Fig. 10, reduce the resistance somewhat, though not seriously. In general, the resistance is a sensitive function of the processing, and careful processing is extremely important in maintaining high resistance. At normal ambient temperatures and voltage stresses the resistance of capacitors made with either liquid is high enough to be of little concern to the user. However, the fact that the resistance decreases with both temperature and voltage is an important consideration in establishing a life-testing procedure which shall now be discussed.

IV. Life Behavior under Direct-Current Stress

1. Description of Testing Procedure

It is most important that a capacitor have a long life under the temperature and voltage-stress conditions for which it was designed to operate. Unfortunately, tests under such conditions would require so long a time that it would be almost impossible to evaluate advancements in the art. Therefore, it is necessary to resort to an accelerated test in which the voltage stress or temperature or both exceed normal values. Extreme care, however, must be exercised in choosing the conditions in order to avoid introducing some factor which does not obtain in service. For example, if the voltage stress is too high, internal ionization may take place, or if the temperature is too high, a different type of chemical action may be induced. Also, excessive temperatures or voltages may result in internal thermal instability, a condition which would be predicted by the rapid decrease of resistance with increasing temperature and voltage as indicated in Fig. 10.

The actual test conditions used to obtain the results of this investigation were chosen after considerable exploratory work at voltage stresses in the range from 500 to 1500 volts per mil and temperatures varying from 70 to 100 degrees centigrade. It was found that the thermal rise in even the small commercial units has an effect on the life when tested at stresses and temperatures which will produce failures in less than one month. Under such conditions, even the capacitor case may reach temperatures appreciably above ambient. Low resistance and large size of test unit will, of course, accentuate both the internal rise and the case rise above ambient. Such a test would, therefore, not be indicative of the true life, since the result would be determined by these factors rather than the inherent chemical and electrical stability of the dielectric.

The insulation rise above test temperature reduces the resistance still further, thereby tending to make the rise greater until a critical condition is reached, after which the specimen will fail in a few hours, due to cumulative heating. For example, a 1-microfarad 5000-volt capacitor tested at twice rated voltage in quiescent air at 75 degrees centigrade became thermally unstable and drew 35 watts before the actual breakdown occurred after less than twenty-four hours on test. The dark brown color of the paper dielectric indicated that temperatures in excess of 150 degrees centigrade had been reached.

The temperature-rise variable has been largely eliminated in all of the experimental capacitors used in this work by stressing only a small part of the available volume. Commercial 600-volt 2-microfarad units were used in which regular production was duplicated except that the length of one foil was reduced to a few feet nearest the outside of the case. The dielectric consisted of three sheets of 0.4-mil kraft paper which, upon impregnation with the chlorinated impregnants, yielded a capacitance of approximately 0.25 microfarad. Such capacitors do not show a rise in case temperature over an ambient temperature of 85 degrees centigrade, even when stressed at 1200 volts per mil. These experimental units are particularly useful in studying the chemical and electrical stability of the dielectric and in investigating the effect of addition agents to the impregnant. Data on these small units can be applied in arriving at the life of much larger capacitors in which the actual hot-spot temperature is known or can be computed.

There is a necessity, however, for some tests which will integrate all variables and directly compare all sizes of capacitors. Although the internal rise varies somewhat with the resistance and size of the unit, a considerable degree of success at standardization of tests has been achieved by keeping the case temperature within a few degrees of ambient by means of air circulation. It was found that the case-temperature rise of most units could be held close to the desired ambient temperature by forcing air around them at velocities as low as 100 feet per minute. The actual air velocity required is not only a function of the size and the resistance of the unit, but also of the time in which it is desired to produce failures. There is, however, an obvious limit to which the testing time can be shortened, particularly on large units, because of the internal-temperature gradient. An air velocity of approximately 250 feet per minute was finally used in this work because it produced results in the desired time without excessive temperature rise. Attention was given to the uniform spacing of the units and even to the paint finish, which may affect the outcome of a test near the point of thermal instability.

In tests of this nature, voltage is usually applied to a considerable number of units in parallel. Unless precautions are taken, the surge resulting from the failure of one unit can cause damage to the remaining units under test. This problem was solved by placing a resistor and a 0.125-ampere fuse wire in the ground-return lead of each unit. The length of the fuse wire was such that an arc could not be maintained across its terminals. The use of a series resistor not only reduced the surge on the remaining units, but also provided a means for measuring the leakage currents from time to time. A vacuum-tube voltmeter connected across the resistor served as a microammeter. In the case of the larger units, a milliammeter could be shunted across the resistor and the current read directly, because the resistance of the milliammeter was small compared with that of the resistor. This made it possible to read the leakage currents without even momentary interruption of the test.

2. Life-Test Results and Discussion

Besides determining the life behavior of conventional-Inerteen- and special-Inerteen-impregnated capacitors, one of the principal purposes of this investigation is to ascertain how the life of these capacitors can be prolonged. McLean and co-workers[11] made an extensive study of the behavior of capacitors impregnated with chlorinated naphthalene under sustained direct voltage. They present some data which show that a chlorinated-biphenyl-impregnated capacitor possesses a higher order of stability than one impregnated with chlorinated naphthalene. They also present evidence that the mechanism of failure is essentially the same in both cases. It starts with the splitting off from the chlorinated-hydrocarbon molecule of hydrogen chloride, which attacks the aluminum foil to form aluminum chloride. Aluminum chloride, in turn, catalyzes further decomposition of the impregnant and perhaps even the paper.

The application of direct-current stress plays a dominating role as is indicated by the finding that the life under alternating-current stress is considerably longer than with direct-current stress of comparable magnitude, other conditions being the same. Some electrolysis phenomena, which would be expected to be more severe with direct current than with alternating current, undoubtedly take place. Assuming that hydrogen chloride is the chief product of this electrolytic action, an attempt was made to find chemical compounds which, when added to the chlorinated impregnants, would prolong the life of the capacitor. Such additional compounds are usually referred to as stabilizers. The possibility of stabilizing chlorinated impregnants is suggested by McLean and co-workers.[11]

That effective stabilizers for chlorinated impregnants can be found is illustrated in Table II. The various materials added to the impregnants are referred to by number, since a detailed discussion of the chemistry of stabilization is beyond the scope of this paper. The tests were made on experimental units previously described. It will be noted that the *RC* values for capacitors impregnated with both conventional and special Inerteen vary somewhat. This is attributed in part to small processing variations which did not appreciably affect the life behavior. Some stabilizers reduce the *RC* values for both liquids, while others result in increased *RC* values. Stabilizer No. 5, which produces a

[11] D. A. McLean, L. Egerton, G. T. Kohman, and M. Brotherton, "Paper dielectrics containing chlorinated impregnants," *Ind. Eng. Chem.*, vol 34, pp. 101–109; 1942.

TABLE II

DIRECT-CURRENT LIFE OF IMPREGNATED-PAPER CAPACITORS AT 85 DEGREES CENTIGRADE AND 1000 VOLTS PER MIL. CAPACITORS CONSIST OF 3 SHEETS OF 0.4-MIL KRAFT PAPER AND ALUMINUM FOILS

Impregnant	*RC* at 85 Degrees Centigrade Megohm-Microfarads	Average Life Hours
Conventional Inerteen	27–40	120
Same plus 0.1 per cent Stabilizer No. 1	21.5	336
Same plus 0.1 per cent Stabilizer No. 2	33	288
Same plus 0.1 per cent Stabilizer No. 3	33	360
Same plus 0.1 per cent Stabilizer No. 4	23	432
Same plus 0.1 per cent Stabilizer No. 5	50	600
Same plus 0.1 per cent Stabilizer No. 6	43	228
Special Inerteen	25–35	120
Same plus 0.1 per cent Stabilizer No. 1	20–27	384
Same plus 0.5 per cent Stabilizer No. 1	18–25	>3000

fivefold increase in life when 0.1 per cent is added to conventional Inerteen, is an example of the latter.

Table II shows also that not only does special Inerteen have approximately the same life as conventional Inerteen, but also, stabilizers are equally effective in both liquids. The life can usually be increased by increasing the amount of stabilizer. For example, special Inerteen with 0.1 per cent by weight of stabilizer No. 1 has an average life of 384 hours under the conditions of test. Increasing the stabilizer content to 0.5 per cent results in a life in excess of 3000 hours, despite the reduced resistance-capacitance value.

Additional data obtained on experimental capacitors showing the relative behavior of the two liquids are given in Figs. 11 and 12. In these, the leakage currents under test conditions are plotted as a function of time. The degree to which results can be duplicated is indicated by the twin curves shown. In many cases, warning of impending failure was given by a rapid rise in leakage current, although this was not always the case. Comparison of Figs. 11 and 12 shows that the two chlorinated impregnants have quite comparable behavior.

In the case of special Inerteen with 0.5 per cent of stabilizer No. 1, it is observed that the leakage current was rather high at the beginning of the test. As the test proceeded, however, there was a gradual decrease in current, and after 3000 hours the leakage current approached that of lowest value observed for an unstabilized capacitor. A lesser amount of the same stabilizer in conventional Inerteen also shows some decrease in leakage current before the final rise preceding failure, as is indicated in Fig. 11. However, not all stabilizers behave in this manner. Referring again to Fig. 11, it is observed that the leakage current in the case of curve *C* is not only low, but remains practically unchanged until the final rise takes place. This class of stabilizer is preferable to one of which stabilizer No. 1 is an example.

Fig. 13 gives some typical results obtained on commercial units impregnated with conventional Inerteen.

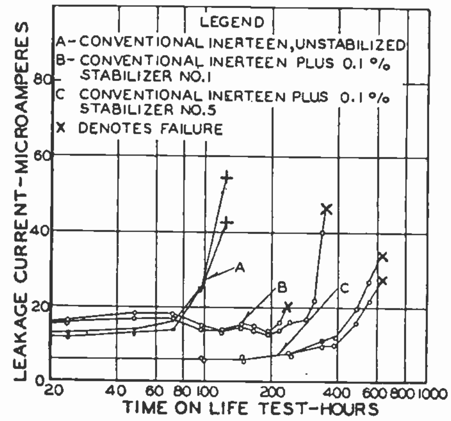

Fig. 11—Leakage current as a function of time on direct-current life test at 1000 volts per mil and 85 degrees centigrade for 0.25-microfarad capacitor made with 3 sheets of 0.4-mil kraft paper and impregnated with conventional Inerteen.

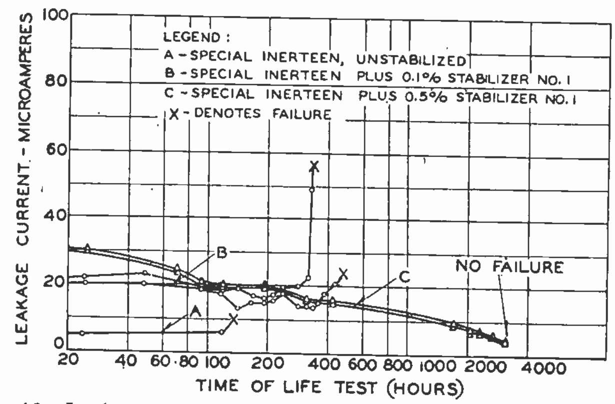

Fig. 12—Leakage current as a function of time on direct-current life test at 1000 volts per mil and 85 degrees centigrade for 0.25-microfarad capacitor made with 3 sheets of 0.4-mil kraft paper and impregnated with special Inerteen.

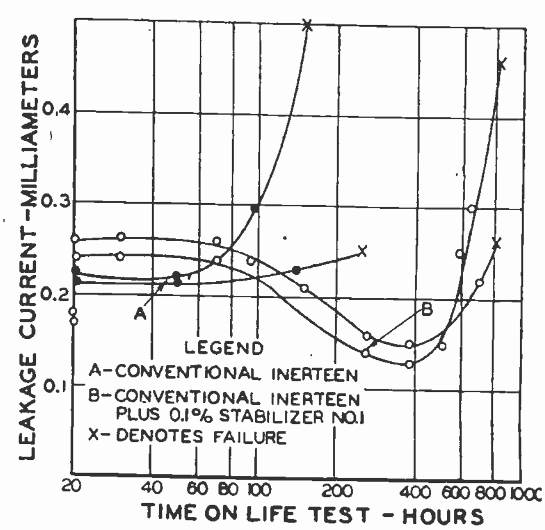

Fig. 13—Leakage current as a function of time on direct-current life test at 1160 volts per mil and 85 degrees centigrade for 1.0-microfarad 5000-volt capacitors.

Similar results were obtained with special Inerteen. The tests were conducted according to the special procedure already described. The general behavior is the same as that observed in the smaller experimental units as a comparison with Fig. 11 will show. It should be noted, however, that even though the stress is somewhat higher, a slightly longer life was observed for the larger units than for the small units of Fig. 11. This is attributed to the use of a greater number of sheets of paper in the larger units. The greater the number of sheets of paper, the less is the probability of superposition of conducting particles or other defects. This fact has been appreciated, and allowance is made for it in practical capacitor designs.

3. *Effect of Voltage on Life*

So far, all of the life data presented on capacitors impregnated with the two chlorinated impregnants are for voltage stresses in the neighborhood of 1000 volts per mil. For obvious practical reasons, it is important to be able to predict the life at other voltage stresses. The following power law has been used for many years to express the life of impregnated paper as a function of voltage stress: $L_1 = L_2(E_2/E_1)^n$ where L_1 is the life at the higher voltage stress E_1, L_2 is the life at the lower stress E_2, and n is a number reported by various investigators[9,10,12] to range between 4 and 8. Brotherton,[12] reporting on some recent work of this character, carried out at the Bell Telephone Laboratories, states that n varies from 4 to 6 for capacitor impregnants in general use at the present time.

Work of this nature is very time-consuming, and many capacitors must be tested to destruction over both a range of voltage and a range of temperature. The data available at the present time, obtained at several voltages and 85 degrees centigrade on conventional Inerteen, both unstabilized and stabilized, are presented in Table III. The data are based on a large number of experimental capacitors constructed and processed in an identical manner. Those few capacitors which failed in a short time, due to constructional and material defects, were eliminated from consideration.

TABLE III

DIRECT-CURRENT LIFE AS A FUNCTION OF VOLTAGE STRESS AT 85 DEGREES CENTIGRADE ON EXPERIMENTAL CAPACITORS MADE WITH 3 SHEETS OF 0.4-MIL KRAFT PAPER AND ALUMINUM FOIL. CAPACITANCE 0.25 MICROFARAD

	Life-Hours 720 volts per mil	Life-Hours 1000 volts per mil	n
For Conventional Inerteen			
Maximum	648	144	5.1*
Minimum	408	120	3.2**
Average	535	130	4.3
For Conventional Inerteen Plus 0.1 per cent Stabilizer No. 1			
Maximum	1920	384	6.3*
Minimum	1296	240	3.7**
Average	1584	322	4.8

* Based on maximum life at 720 volts per mil and minimum life at 1000 volts per mil.
** Based on minimum life at 720 volts per mil and maximum life at 1000 volts per mil.

Examination of Table III reveals that, for conventional Inerteen under the conditions of test, n varies from a maximum of 5.1 to a minimum of 3.2 with an average value of 4.3. For the same impregnant with stabilizer No. 1 added, the corresponding values are somewhat higher. However, before it can be concluded that stabilizers raise the value of n, many more tests must be made on other stabilizers. The average values of n found in this work lie within the range reported by Brotherton. Because of the similarity in chemical structure of two impregnants, it is to be expected that special Inerteen should show approximately the same value of n as that for conventional Inerteen.

[12] M. Brotherton, "Paper capacitors under direct voltages," PROC. I.R.E., vol. 32, pp. 139–143; March, 1944.

V. CONCLUSIONS

The more important results of this investigation which deserve emphasis are the following:

1. The alternating-current characteristics of the capacitor are important to the proper performance of both the circuit and the capacitor in circuits involving alternating as well as direct voltages.

2. Paper capacitors impregnated with conventional chlorinated biphenyl show a considerable decrease in capacitance at low temperatures.

3. A recently developed chlorinated-liquid composition maintains reasonably constant capacitance to considerably lower temperatures than is the case with the chlorinated-biphenyl impregnant.

4. Accelerated life testing, properly carried out and interpreted, is an important tool in evaluating new materials and processes.

5. The life of a paper capacitor impregnated with chlorinated hydrocarbon liquids when subjected to high direct-current stresses decreases appreciably with increase in temperature.

6. The life of a chlorinated-liquid-impregnated capacitor at high direct-current stress and temperature can be increased markedly by the addition of stabilizers to the impregnant.

7. The increase in life of a capacitor containing a chlorinated impregnant is a function of the amount of stabilizer added. In some cases, approximately ten-fold increase in life is obtained when the amount of stabilizer added is increased from 0.1 to 0.5 per cent.

8. The life of a chlorinated-biphenyl-impregnated capacitor under direct-current stress at 85 degrees centigrade varies inversely as 4.5th power of the voltage applied.

ACKNOWLEDGMENT

The authors are indebted to Dr. C. F. Hill and Mr. J. G. Ford who, with the co-operation of the Du Pont Company, were responsible for the development of polychloroethylbenzene used in the new impregnating composition. The authors also wish to express their appreciation to Messrs. R. Friedman, C. L. Cadwell, E. W. Lindsay, and Miss M. Rutter for carrying out the many tests upon which this paper is based.

Mutual and Self-Impedance for Colinear Antennas*

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Summary—In Part I a two-element colinear array, consisting of identical center-driven antennas of finite radius, is discussed as a boundary-value problem. A formulation is given for the distribution of current when the antennas are driven symmetrically and antisymmetrically. From these data the impedance properties of the array may be deduced.

In Part II a simplified, but much less rigorous investigation of the same problem is presented. The more important results include curves and tables for mutual and self-impedance.

Introduction

One normally conceives of a *colinear array* as comprising an arbitrary number of identical radiators, oriented axially in a straight line, with a constant separation distance between adjacent ends. The antennas may be center-driven, or if end-driven, use is often made of appropriate phase-reversing stubs or sleeves, in order that the currents in the individual antennas may be made to flow in the same phase. The present discussion is concerned mainly with the impedance properties of two-element colinear arrays, perfectly conducting center-driven antennas of identical length and radius being predicated. The theory, however, is not restricted to antennas in which currents of equal magnitude and phase are maintained, but rather is applicable when the antennas are driven in an arbitrary way, or when one antenna is driven, and the other parasitic and center-loaded. A symmetrical center-driven antenna, when located vertically over an imperfectly conducting earth, may be analyzed for the driving-point impedance by use of the present theory, for such an arrangement is in effect equivalent to a colinear array in which currents are appropriately defined as to magnitude and phase.

In a recent paper, King and the writer[1] disclosed a method for computing the current in coupled antennas, when the identical elements are parallel and not displaced in length. The intent of the present paper is to extend the method of solution, using symmetrical and antisymmetrical components, to include colinear antennas.

Part I

Formulation of Colinear-Array Problem[2]

Fig. 1 illustrates a two-element colinear array oriented along the z axis of a system of cylindrical co-ordinates r, θ, and z. Each antenna has a half-length $h_1=h_2$, a radius a, and a spacing between adjacent ends of $2s$. The distance between driving points is l, and the geometrical center of the array is at $z=0$. The upper antenna is labeled (1) and the lower antenna is denoted (2).

One may calculate the z component of electric field at any point in space by applying the familiar relation

$$E_z = -j(\omega/\beta^2)\{(d^2A_z/dz^2)+\beta^2A_z\}. \quad (1)$$

Here $\beta(=2\pi/\lambda)$ is the propagation constant (λ being the wavelength), ω is 2π multiplied by the frequency, and A_z is the *total* vector potential in the z direction.

A general boundary condition requires continuity of

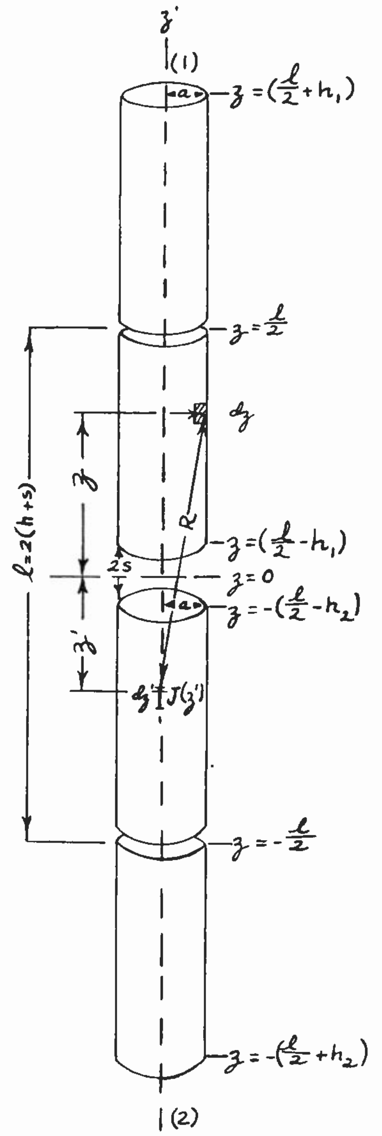

Fig. 1—Two-element colinear array consisting of identical center-driven antennas of half-length h, radius a, and distance between drive points of l. The antenna lies along the z axis of a system of cylindrical co-ordinates (r, θ, z). The point $z=0$ corresponds to the geometrical center of the array. $R=\{(z-z')^2+a^2\}^{1/2}$

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[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] Readers may be interested in the following papers: "On the calculation of the impedance properties of parasitic antenna arrays involving elements of finite radius," *Jour. Am. Soc. Naval Eng.*, May, 1945; and "On the distribution of current along asymmetrical antennas," *Jour. Appl. Phys.*, June, 1945; "A theory for three-element broadside arrays"; and "Symmetrical antenna arrays," both to be published.

the tangential component of the electric field across any boundary surface between two media. Accordingly, if one assumes antennas of infinite conductivity (within which an electric field cannot exist), E_z as given by (1), is zero *along the conductors*. Thus at $r=a$ (for the appropriate ranges of z),

$$(d^2A_z/dz^2)+\beta^2A_z=0. \tag{2}$$

For an interval of z in which A_z and all its derivatives are continuous, the solution of (2) may be written

$$A_z=k_1\cos\beta z+k_2\sin\beta z \tag{3}$$

where k_1 and k_2 are arbitrary constants. Since A_z depends only on z, it shall be denoted by $A(z)$ henceforth.

Let intervals be defined for the array as follows:

Interval (1) $l/2 \leqq z \leqq l/2+h_1$ (4a)

Interval (2) $l/2-h_1 \leqq z \leqq l/2$ (4b)

Interval (3) $-l/2 \leqq z \leqq -(l/2-h_2)$ (4c)

Interval (4) $-(l/2+h_2) \leqq z \leqq -l/2.$ (4d)

The complete solution of (2) is then

$A_1(z)=-(j/c)\{C_1\cos\beta z+C_2\sin\beta z\}$ for interval (1) (5a)

$A_2(z)=-(j/c)\{C_3\cos\beta z+C_4\sin\beta z\}$ for interval (2) (5b)

$A_3(z)=-(j/c)\{C_5\cos\beta z+C_6\sin\beta z\}$ for interval (3) (5c)

$A_4(z)=-(j/c)\{C_7\cos\beta z+C_8\sin\beta z\}$ for interval (4) (5d)

Here $c=1/\sqrt{\Pi\Delta}=3\times10^8$ meters per second (6)

$\Pi=4\pi\times10^{-7}$ henry per meter (7)

$\Delta=8.85\times10^{-12}$ farad per meter. (8)

Assume that the two antennas are driven in phase by identical generators maintaining voltages $V_1^e=V_2^e$ across the input terminals. The *total* current and the *total* vector potential satisfy the symmetry conditions

$J(z)=J(-z)$ and $A(z)=A(-z)$, respectively. (9)

Using (9) with (5),

$$C_1\cos\beta z+C_2\sin\beta z=C_7\cos\beta z-C_8\sin\beta z \tag{10a}$$

or

$$(C_1-C_7)\cos\beta z+(C_2+C_8)\sin\beta z=0. \tag{10b}$$

Since $\cos\beta z$ and $\sin\beta z$ are linearly independent functions, it follows that

$$C_1=C_7 \tag{11a}$$
$$C_2=-C_8. \tag{11b}$$

Similarly,

$$C_3=C_5 \tag{12a}$$
$$C_4=-C_6. \tag{12b}$$

The voltage across the input terminals of antenna (1) is given by

$$V_1^e=\lim_{z\to l/2}\left\{\underset{\text{Interval (1)}}{\Phi}-\underset{\text{Interval (2)}}{\Phi}\right\} \tag{13}$$

where

$$\underset{\text{Interval (1)}}{\Phi}=j(c^2/\omega)\{\partial A_1(z)/\partial z\} \text{ Interval (1)} \tag{14a}$$

$$\underset{\text{Interval (2)}}{\Phi}=j(c^2/\omega)\{\partial A_2(z)/\partial z\} \text{ Interval (2).} \tag{14b}$$

Upon differentiating (5) as required by (14) and substituting in (13), one obtains

$$V_1^e=-(C_1-C_3)\sin(\beta l/2)+(C_2-C_4)\cos(\beta l/2.) \tag{15}$$

Thus

$$C_4=(C_2\cos(\beta l/2)-V_1^e-(C_1-C_3)\sin(\beta l/2))/\cos(\beta l/2). \tag{16}$$

To summarize:

$$A_1(z)=A_4(-z)=-(j/c)\{C_1\cos\beta z+C_2\sin\beta|z|\} \tag{17a}$$

$$A_2(z)=A_3(-z)=-(j/c\cos(\beta l/2))\{C_3\cos\beta(l/2-|z|)+(C_2\cos(\beta l/2)-C_1\sin(\beta l/2)-V_1^e)\sin\beta|z|\}. \tag{17b}$$

The constants C_1, C_2 and C_3 remain to be evaluated later in the analysis.

When the antennas are driven antisymmetrically, that is, in phase opposition, the symmetry conditions

$$J(z)=-J(-z) \quad\text{and}\quad A(z)=-A(-z) \tag{18}$$

obtain. To satisfy (18) it is evident that $A(z)$ takes the following form for the indicated intervals:

$A_1(z)=-(j/c)\{C_1\cos\beta z+C_2\sin\beta z\}$ for interval (1) (19a)

$A_2(z)=-(j/c\cos(\beta l/2))\{C_3\cos\beta(l/2-z)+(C_2\cos(\beta l/2)-C_1\sin(\beta l/2)-V_1^e)\sin\beta z\}$ for interval (2) (19b)

$A_3(z)=-(j/c\cos(\beta l/2))\{-C_3\cos\beta(l/2+z)+(C_2\cos(\beta l/2)-C_1\sin(\beta l/2)-V_1^e)\sin\beta z\}$ for interval (3) (19c)

$A_4(z)=-(j/c)\{-C_1\cos\beta z+C_2\sin\beta z\}$ for interval (4). (19d)

It is to be observed that a shorthand for (19) corresponding to (17) cannot be written.

The vector potential at any point on the surface of either conductor comprising the array is given by

$$A(z)=(\pi/4\pi)\int J(z')\frac{e^{-j\beta R}}{R}dz' \tag{20}$$

where the integration is to be carried out over both antennas.

In (20), $J(z')$ is the complex current flowing in the element dz'. R is the distance from the point (a, θ, z) where the vector potential is computed to the element dz'. That is

$$R=\sqrt{(z-z')^2+a^2}. \tag{21}$$

If attention be directed to intervals (1) and (4), and the antennas are driven symmetrically, one may equate (20) to (17a). Thus

$$\int_{-(l/2+h_2)}^{-l/2}J_4(z')\frac{e^{-j\beta R}}{R}dz'+\int_{-l/2}^{-(l/2-h_2)}J_3(z')\frac{e^{-j\beta R}}{R}dz'+\int_{l/2-h_1}^{l/2}J_2(z')\frac{e^{-j\beta R}}{R}dz'+\int_{l/2}^{l/2+h_1}J_1(z')\frac{e^{-j\beta R}}{R}dz'=-j\frac{4\pi}{R_c}\{C_1\cos\beta z+C_2\sin\beta|z|\}. \tag{22}$$

In (22) the subscripts on the currents refer to the intervals within which the currents flow.

$$R_c=\sqrt{\pi/\Delta}\approx 120\pi \text{ ohms.} \tag{23}$$

Similarly, for intervals (2) and (3), (20) and (17b) give

$$\int_{-(l/2+h_2)}^{-l/2} J_4(z') \frac{e^{-j\beta R}}{R} dz' + \int_{-l/2}^{-(l/2-h_2)} J_3(z') \frac{e^{-j\beta R}}{R} dz' + \int_{l/2-h_1}^{l/2} J_2(z') \frac{e^{-j\beta R}}{R} dz' + \int_{l/2}^{l/2+h_1} J_1(z') \frac{e^{-j\beta R}}{R} dz'$$
$$= -\frac{j4\pi}{R_c \cos(\beta l/2)} \left\{ C_3 \cos\beta\left(\frac{l}{2} - |z|\right) + \left(C_2 \cos\frac{\beta l}{2} - C_1 \sin\frac{\beta l}{2} - V_1^e\right) \sin\beta|z| \right\}. \quad (24)$$

Solution of the Integral Equations

It appears convenient to begin the solution of (22) and (24) by defining auxiliary currents as follows:

Interval (1)	$I_1(z_1) \equiv J_1(z)$	(25)
Interval (2)	$I_1(-z_1) = I_1(z_1)$	(26)
Interval (2)	$I_2(-z_1) \equiv J_2(z)$	(27)
Interval (1)	$I_2(z_1) = I_2(-z_1)$	(28)
Interval (3)	$I_3(z_2) \equiv J_3(z)$	(29)
Interval (4)	$I_3(-z_2) = I_3(z_2)$	(30)
Interval (4)	$I_4(-z_2) \equiv J_4(z)$	(31)
Interval (3)	$I_4(z_2) = I_4(-z_2)$.	(32)

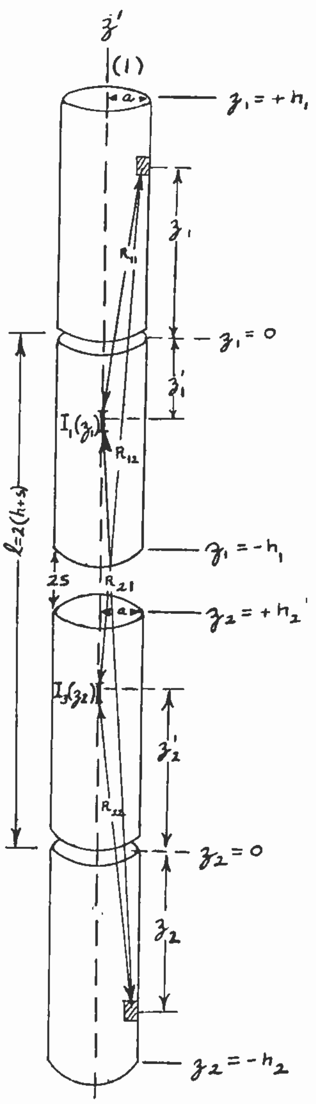


Fig. 2—Like Fig. 1, but origins for two co-ordinate systems are chosen at the centers of the antennas.
$z_2 = l + z_1$, $R_{11} = \{(z_1 - z_1')^2 + a^2\}^{1/2}$, $R_{22} = \{(z_2 - z_2')^2 + a^2\}^{1/2}$, $R_{12} = \{(z_1 + l - z_2')^2 + a^2\}^{1/2}$ and $R_{21} = \{(z_2 - l - z_1')^2 + a^2\}^{1/2}$.

Referring to Fig. 2,

$$z_1 = z - l/2 \quad (33a)$$
$$z_2 = z + l/2. \quad (33b)$$

Subject to errors of second order or higher, (22) and (24) may now be rewritten in the form

$$\int_{-h_2}^{+h_2} I_3(z_2') \frac{e^{-j\beta R_{12}}}{R_{12}} dz_2' + \int_{-h_1}^{+h_1} I_1(z_1') \frac{e^{-j\beta R_{11}}}{R_{11}} dz_1' = -j\frac{4\pi}{R_c}\left\{ C_1 \cos\beta\left(z_1 + \frac{l}{2}\right) + C_2 \sin\beta\left(z_1 + \frac{l}{2}\right)\right\} \quad (34)$$

provided

$$0 \leqq z_1 \leqq +h_1. \quad (35)$$

Similarly

$$\int_{-h_2}^{+h_2} I_3(z_2') \frac{e^{-j\beta R_{12}}}{R_{12}} dz_2' + \int_{-h_1}^{+h_1} I_2(z_1') \frac{e^{-j\beta R_{11}}}{R_{11}} dz_1' = -\frac{j4\pi}{R_c \cos(\beta l/2)}\left\{ C_3 \cos\beta z_1 + \left(C_2 \cos\frac{\beta l}{2} - C_1 \sin\frac{\beta l}{2} - V_1^e\right)\sin\beta\left(\frac{l}{2} + z_1\right)\right\} \quad (36)$$

when

$$-h_1 \leqq z_1 \leqq 0. \quad (37)$$

Here

$$R_{11} = \sqrt{(z_1 - z_1')^2 + a^2} \approx |z_1 - z_1'| \quad (38a)$$

and

$$R_{12} = \sqrt{(z_1 + l - z_2')^2 + a^2} \approx |z_1 + l - z_2'|. \quad (38b)$$

In writing (34) and (36), the assumption is made, for example, that the effect of the presence of the lower half of antenna (1) on the actual current distribution in the upper half of antenna (1), may be properly accounted for by requiring the current distribution in interval (2) to equal the actual current distribution in interval (1). This is an excellent approximation, inasmuch as the coupling between colinear antennas is small, implying current symmetry about z_1 to within a few per cent. The current $I_3(z_2')$ is used in the integral over antenna (2) in both equations because it is more important to represent the current correctly in interval (3) than in interval (4), when it comes to computing the current at the center of antenna (1).

The exact solution of (34) and (36) has not been accomplished. It is assumed that approximate results are obtainable by using the method of successive approximations employed by Hallén.[3] This method has been used in other papers by King and the writer, hence, in the interest of consistency, it seems desirable to use

[3] E. Hallén, "Theoretical investigations into the transmitting and receiving qualities of antennas," *Nova Acta Upsalienses*, ser. 4, vol. 11, pp. 3–44: November, 1938.

it here also. Alternatively, the method of expansion suggested by Gray[4,5] may give solutions for mutual and self-impedance in better agreement with measured values, if the method can be applied to colinear antennas. Proceeding then, as in other papers, one writes

$$\int_{-h_1}^{+h_1} I_1(z_1') \frac{e^{-j\beta R_{11}}}{R_{11}} dz_1' = I_1(z_1) \int_{-h_1}^{+h_1} \frac{dz_1'}{R_{11}} + \int_{-h_1}^{+h_1} \frac{I_1(z_1')e^{-j\beta R_{11}} - I_1(z_1)}{R_{11}} dz_1'. \quad (39)$$

The integral

$$\int_{-h_1}^{+h_1} \frac{dz_1'}{R_{11}} = \Omega + f(z_1). \quad (40)$$

Here Ω is the value of the integral at $z_1=0$, viz.,

$$\Omega = 2\, ln\, (2h_1/a). \quad (41)$$

$f(z_1)$ is an easily determined logarithmic function[6] of z_1.

Equation (34) may now be written in the equivalent form

$$I_1(z_1) = -j\frac{4\pi}{\Omega R_c}\left\{C_1 \cos\beta\left(z_1+\frac{l}{2}\right) + C_2 \sin\beta\left(z_1+\frac{l}{2}\right)\right\} - \frac{1}{\Omega} I_1(z_1)f(z_1) - \frac{1}{\Omega}\int_{-h_1}^{+h_1} \frac{I_1(z_1')e^{-j\beta R_{11}} - I_1(z_1)}{R_{11}} dz_1' - \frac{1}{\Omega}\int_{-h_2}^{+h_2} I_3(z_2') \frac{e^{-j\beta R_{12}}}{R_{12}} dz_2'. \quad (42)$$

By employing a similar technique, (36) becomes

$$I_2(z_1) = -j\frac{4\pi}{\Omega R_c \cos(\beta l/2)}\left\{C_3 \cos\beta z_1 + \left(C_2 \cos\frac{\beta l}{2} - C_1 \sin\frac{\beta l}{2} - V_1^e\right)\sin\beta\left(\frac{l}{2}+z_1\right)\right\} - \frac{1}{\Omega} I_2(z_1)f(z_1) - \frac{1}{\Omega}\int_{-h_1}^{+h_1} \frac{I_2(z_1')e^{-j\beta R_{11}} - I_2(z_1)}{R_{11}} dz_1' - \frac{1}{\Omega}\int_{-h_2}^{+h_2} I_3(z_2') \frac{e^{-j\beta R_{12}}}{R_{12}} dz_2'. \quad (43)$$

It is now desirable to introduce into the mathematics the following facts:

$$I_1(z_1) = 0 \quad \text{when} \quad z_1 = +h \quad (44a)$$

and

$$I_2(z_1) = 0 \quad \text{when} \quad z_1 = -h_1. \quad (44b)$$

Substituting (44a) in (42)

$$0 = -j\frac{4\pi}{\Omega R_c}\left\{C_1 \cos\beta\left(h_1+\frac{l}{2}\right) + C_2 \sin\beta\left(h_1+\frac{l}{2}\right)\right\} - \frac{1}{\Omega}\int_{-h_1}^{+h_1} I_1(z_1')\frac{e^{-j\beta R_1}}{R_1} dz_1' - \frac{1}{\Omega}\int_{-h_2}^{+h_2} I_3(z_2')\frac{e^{-j\beta R_2}}{R_2} dz_2'. \quad (45)$$

Equation (44b) employed with (43) gives

$$0 = -j\frac{4\pi}{\Omega R_c \cos(\beta l/2)}\left\{C_3 \cos\beta h_1 + \left(C_2 \cos\frac{\beta l}{2} - C_1 \sin\frac{\beta l}{2} - V_1^e\right)\sin\beta\left(\frac{l}{2}-h_1\right)\right\} - \frac{1}{\Omega}\int_{-h_1}^{+h_1} I_2(z_1')\frac{e^{-j\beta R_3}}{R_3} dz_1' - \frac{1}{\Omega}\int_{-h_2}^{+h_2} I_3(z_2')\frac{e^{-j\beta R_4}}{R_4} dz_2'. \quad (46)$$

The notation

$$R_1 = \sqrt{(h_1 - z_1')^2 + a^2} \approx |h_1 - z_1'| \quad (47)$$

$$R_2 = \sqrt{(h_1 + l - z_2')^2 + a^2} \approx |h_1 + l - z_2'| \quad (48)$$

$$R_3 = \sqrt{(h_1 + z_1')^2 + a^2} \approx |h_1 + z_1'| \quad (49)$$

$$R_4 = \sqrt{(h_1 - l + z_2')^2 + a^2} \approx |h_1 - l + z_2'| \quad (50)$$

is used.

Finally, upon subtracting (45) from (42) and (46) from (43),

$$I_1(z_1) = -j\frac{4\pi}{\Omega R_c}\left\{C_1\left(\cos\beta\left(z_1+\frac{l}{2}\right) - \cos\beta\left(h_1+\frac{l}{2}\right)\right) + C_2\left(\sin\beta\left(z_1+\frac{l}{2}\right) - \sin\beta\left(h_1+\frac{l}{2}\right)\right)\right\} - \frac{1}{\Omega}[I_1(z_1)]_0 f(z_1) - \frac{1}{\Omega}\int_{-h_1}^{+h_1} \frac{[I_1(z_1')]_0 e^{-j\beta R_{11}} - [I_1(z_1)]_0}{R_{11}} dz_1' + \frac{1}{\Omega}\int_{-h_1}^{+h_1} [I_1(z_1')]_0 \frac{e^{-j\beta R_1}}{R_1} dz_1' - \frac{1}{\Omega}\left\{\int_{-h_2}^{+h_2} [I_3(z_2')]_0 \frac{e^{-j\beta R_{12}}}{R_{12}} dz_2' - \int_{-h_2}^{+h_2} [I_3(z_2')]_0 \frac{e^{-j\beta R_2}}{R_2} dz_2'\right\}. \quad (51)$$

$$I_2(z_1) = -j\frac{4\pi}{\Omega R_c \cos\beta l/2}\left\{C_3\left(\cos\beta z_1 - \cos\beta h_1\right) + \left(C_2 \cos\frac{\beta l}{2} - C_1 \sin\frac{\beta l}{2} - V_1^e\right)\left(\sin\beta\left(\frac{l}{2}+z_1\right) - \sin\beta\left(\frac{l}{2}-h_1\right)\right)\right\} - \frac{1}{\Omega}[I_2(z_1)]_0 f(z_1) - \frac{1}{\Omega}\int_{-h_1}^{+h_1} \frac{[I_2(z_1')]_0 e^{-j\beta R_{11}} - [I_2(z_1)]_0}{R_{11}} dz_1' + \frac{1}{\Omega}\int_{-h_1}^{+h_1} [I_2(z_1')]_0 \frac{e^{-j\beta R_3}}{R_3} dz_1' - \frac{1}{\Omega}\left\{\int_{-h_2}^{+h_2} [I_3(z_2')]_0 \frac{e^{-j\beta R_{12}}}{R_{12}} dz_2'\right.$$

[4] Marion C. Gray, "A modification of Hallén's solution of the antenna problem," *Jour. Appl. Phys.*, vol. 15, pp. 61–65; January, 1944.

[5] S. A. Schelkunoff, "Antenna theory and experiment," *Jour. Appl. Phys.*, vol. 15, pp. 54–60; January, 1944.

[6] Ronold King and Charles W. Harrison, Jr., "The distribution of current along a symmetrical center-driven antenna," Proc. I.R.E., vol. 31, pp. 548–567; October, 1943.

$$-\int_{-h_2}^{+h_2}[I_3(z_2')]_0\frac{e^{-j\beta R_4}}{R_4}dz_2'\Big\}. \quad (52)$$

The zero-order approximations for the current are implied[7] by the symbol $[\ \ ]_0$.

One selects the trigonometric terms of (51), (written with symmetry about z_1) as the leading term in the current distribution along interval (1). Thus

$$[I_1(z_1)]_0=-j\frac{4\pi}{\Omega R_c}\Big\{C_1\Big(\cos\beta\Big(|z_1|+\frac{l}{2}\Big)-\cos\beta\Big(h_1+\frac{l}{2}\Big)\Big)$$
$$+C_2\Big(\sin\beta\Big(|z_1|+\frac{l}{2}\Big)-\sin\beta\Big(h_1+\frac{l}{2}\Big)\Big)\Big\}. \quad (53)$$

In writing an expression for $[I_2(z_1)]_0$ one must take cognizance of the fact that z_1 is negative in interval (2), and write

$$z_1=-|z_1|. \quad (54)$$

Thus

$$[I_2(z_1)]_0=-j\frac{4\pi}{\Omega R_c\cos(\beta l/2)}\Big\{C_3(\cos(\beta z_1-\cos\beta h_1))$$
$$+\Big(C_2\cos\frac{\beta l}{2}-C_1\sin\frac{\beta l}{2}-V_1^e\Big)$$
$$\cdot\Big(\sin\beta\Big(\frac{l}{2}-|z_1|\Big)-\sin\beta\Big(\frac{l}{2}-h_1\Big)\Big)\Big\}. \quad (55)$$

It is to be noted that $[I_1(z_1)]_0$ and $[I_2(z_1)]_0$ are both zero when $z_1=\pm h_1$. This is a required condition.

Remembering that symmetry (9) obtains for symmetrically driven antennas, and that the z and z_2 co-ordinate systems are related by (33b), it is clear that

$$[I_3(z_2)]_0=-j\frac{4\pi}{\Omega R_c\cos(\beta l/2)}\Big\{C_3\Big(\cos\beta z_2-\cos\beta h_2\Big)$$
$$+\Big(C_2\cos\frac{\beta l}{2}-C_1\sin\frac{\beta l}{2}-V_1^e\Big)$$
$$\cdot\Big(\sin\beta\Big(\frac{l}{2}-|z_2|\Big)-\sin\beta\Big(\frac{l}{2}-h_2\Big)\Big)\Big\}. \quad (56)$$

($[I_3(z_2)]_0$ is the same function of z_2 as $[I_2(z_1)]_0$ is of z_1).

The zero-order primed currents are obtained by priming every z throughout (53), (55), and (56).

The constants C_1, C_2 and C_3 are determined by employing the following boundary conditions:

(a). The total current $I_1(z_1)$ vanishes at $z_1=+h_1$ (Equation (45)). The currents $I_1(z_1')$ and $I_3(z_2')$ occuring under the integral signs are given by (53) and (56), respectively.

(b). The total current $I_2(z_1)$ vanishes at $z_1=-h_1$ (Equation (46)). The currents $I_2(z_1')$ and $I_3(z_2')$ occurring under the integral signs are given by (55) and (56), respectively.

(c). The total current is continuous across the driving point $z_1=0$. This condition assures continuity of the vector potential $A(z)$ across the same point. (It is not legitimate to require continuity of the vector potential in solving for the constants $C_1\cdots C_8$, for if this is done, only two constants remain to satisfy three conditions.) Continuity of current is achieved by equating (51) to (52) for $z_1=0$ throughout.

Having solved for C_1, C_2, and C_3, (51) or (52) gives the current flowing at the input terminals of antenna (1) for $z_1=0$. For reasons of symmetry, the current flowing at the center of antenna (2) is the same as the current flowing at the center of antenna (1). The input impedance is the applied voltage divided by the input current. This impedance must be determined for antennas driven in phase, and for antennas driven in phase opposition. An outline has been given for finding the input impedance for antennas driven symmetrically. For the antisymmetrical case, one must begin with (19), and repeat the analysis along entirely parallel lines.

Designating the input impedance to either antenna Z_s when the antennas are driven symmetrically and Z_a when the antennas are driven antisymmetrically, it can be shown that the self-impedance Z_{s1} of either radiator is

$$Z_{s1}=(Z_s+Z_a)/2. \quad (57)$$

(theoretically this impedance is different from the self-impedance Z_{00} of an isolated element), and the mutual impedance Z_{12} is

$$Z_{12}=(Z_s-Z_a)/2 \quad (58)$$

Z_{s1} and Z_{12}, as here defined, are to be used in the conventional formulas for coupled circuits. It is thus possible to obtain the input impedance to the individual antennas comprising the array when they are arbitrarily driven, or when one antenna is driven, and the other parasitic with or without center-loading.

Before continuing with Part II, justification is needed for the presumption that the only possible symmetry for the total current about z is given by (9) for identical antennas driven symmetrically, and by (18) for the same antennas driven antisymmetrically. The absolute equivalence of the generators is, of course, understood. Consider a symmetrical center-driven antenna located vertically with respect to a perfectly conducting plane earth. The lower end of this antenna clears the earth by a distance s. By the principle of *images* this system is equivalent to a colinear array comprising two center-driven elements. The spacing between adjacent ends of the radiators is $2s$, and the total current flowing in the array satisfies symmetry (9). ($z=0$ defines the earth plane.) It is, therefore, not possible for symmetries (9) and (18) to exist simultaneously for symmetrically driven identical colinear antennas.

It is logical to suppose that inasmuch as symmetry (9) obtains for symmetrically driven antennas, (18) will be the only symmetry existent for the antisymmetrical case. Thus, one may assume with confidence that the problem of the two-element colinear array, as treated here, has been completely stated.

The great complexity of the current equations (51) and (52) seems to preclude a general graphical

[7] Readers should bear in mind that $I_1(z_1)$ and $I_2(z_1)$, as given by (51) and (52), are not the exact currents flowing along antenna (1). They are approximate, since only the first two terms in each series expansion is represented.

description of colinear-array operation. However, persons operating these antennas will certainly find it worth the trouble to analyze their particular systems, using the formulation of the problem presented here. In this connection it may be well to point out that all integrals occurring throughout the paper are readily reducible to the tabulated sine and cosine integral functions, if the radius of the antenna is neglected in writing the exponents of integrals.

Part II

Alternative Solution of Two-Element Colinear-Array Problem

The purpose of this part of the paper is to present an alternative solution to the problem of the two-element colinear array. While much less rigorous than the method of attack already advanced, it closely parallels work on coupled antennas previously published, and accordingly will interest Proceedings readers. Additionally, this analysis enables persons interested in numerical work to employ certain impedance functions which have been tabulated.[8]

It has already been remarked that the only point of symmetry for the total-current or total-vector potential is about the centroid of the array, whether the antennas be driven symmetrically or antisymmetrically. However, for reasons that will become apparent in due course, one would like to express the total current in terms of two independent symmetries about each of the origins z_1 and z_2. Assuming that the antennas are driven symmetrically by equivalent generators, one achieves the desired result in the following way:

Let

$$\mathfrak{J}_1'(z_1) = \mathfrak{J}_1'(-z_1) = \mathfrak{J}_2'(z_2) = \mathfrak{J}_2'(-z_2) \tag{59a}$$

and

$$\mathfrak{J}_1''(z_1) = -\mathfrak{J}_1''(-z_1) = -\mathfrak{J}_2''(z_2) = \mathfrak{J}_2''(-z_2). \tag{59b}$$

The total current in antenna (1) is

$$\mathfrak{J}(z_1) = (1/2)\{\mathfrak{J}_1'(z_1) + \mathfrak{J}_1'(-z_1)\} - (1/2)\{\mathfrak{J}_1''(z_1) - \mathfrak{J}_1''(-z_1)\}. \tag{60a}$$

(For z_1 positive, the currents of the two symmetries about z_1 subtract, and for z_1 negative the currents add.) Similarly, the total current in antenna (2) becomes

$$\mathfrak{J}(z_2) = 1/2\{\mathfrak{J}_2'(z_2) + \mathfrak{J}_2'(-z_2)\} + 1/2\{\mathfrak{J}_2''(z_2) - \mathfrak{J}_2''(-z_2)\}. \tag{60b}$$

(For z_2 positive, the currents of the two symmetries about z_2 add, and for z_2 negative the currents subtract.) Upon taking note of (33) one may readily prove that (60) satisfies the symmetry $J(z) = J(-z)$. Thus, $J(z)$ (for positive values of z) =

$$(1/2)\{\mathfrak{J}_1'(z - l/2) + \mathfrak{J}_1'(l/2 - z)\} - (1/2)\{\mathfrak{J}_1''(z - l/2) - \mathfrak{J}_1''(l/2 - z)\} \tag{61a}$$

$J(z)$ (for negative values of z) =

$$(1/2)\{\mathfrak{J}_2'(z + l/2) + \mathfrak{J}_2'(-l/2 - z)\} + (1/2)\{\mathfrak{J}_2''(z + l/2) - \mathfrak{J}_2''(-l/2 - z)\}. \tag{61b}$$

The proof is completed by writing $-z$ for z in (61b) and employing (59). An entirely analogous argument may be developed for the antisymmetrical case, that is, when the symmetry condition $J(z) = -J(-z)$ obtains. It will not, however, be given here.

If $z_1 = 0$ in (60a) and $z_2 = 0$ in (60b) one observes that the $\mathfrak{J}''$ currents vanish at the driving points of the antennas. On the contrary, the $\mathfrak{J}'$ currents are nonvanishing across the driving points, and must be determined in order to obtain relations for mutual and self-impedance. *However, if one is interested in calculating correctly the distant field of this array, both current symmetries must be superimposed.* It is worth noting that symmetry (59b) is entirely absent in the case of parallel antennas not displaced in length.

One now assumes that the current satisfying symmetry (59a) may be found to a satisfactory approximation for colinear antennas by applying the "technique" used for finding currents of this symmetry developed in the earlier paper on coupled antennas.[1] In the interest of brevity, let attention be directed to the solution for the current at the driving point of antenna (1) only (Fig. 2), when the antennas are driven in phase. The current at the center of antenna (2) will be the same as that at the center of antenna (1), whether the antennas are driven symmetrically or antisymmetrically.

A re-examination of the previous paper on coupled antennas reveals that the integral equation for the current satisfying symmetry (59a) is obtained from an expression equivalent to

$$A_1(+z_1) = (1/2)\{A_{11}(+z_1) + A_{11}(-z_1)\} + 1/2\{A_{12}(+z_1) + A_{12}(-z_1)\} = -(j/c)\{C_1 \cos \beta z_1 + 1/2 V_1^e \sin \beta |z_1|\} \tag{62}$$

where

$$A_{11}(+z_1) = \frac{\pi}{4\pi}\int_{-h_1}^{+h_1} \mathfrak{J}_1'(z_1') \frac{e^{-j\beta R_{11}}}{R_{11}} dz_1'. \tag{63}$$

$$A_{12}(+z_1) = \frac{\pi}{4\pi}\int_{-h_2}^{+h_2} \mathfrak{J}_2'(z_2') \frac{e^{-j\beta R_{12}}}{R_{12}} dz_2'. \tag{64}$$

Substituting (63) and (64) in (62),

$$A_1(+z_1) = \frac{\pi}{4\pi}\int_{-h_1}^{+h_1} \mathfrak{J}_1'(z_1') \frac{e^{-j\beta R_{11}}}{R_{11}} dz_1' + \frac{\pi}{8\pi}\left\{\int_{-h_2}^{+h_2} \mathfrak{J}_2'(z_2') \frac{e^{-j\beta R_{12}}}{R_{12}} dz_2' + \int_{-h_2}^{+h_2} \mathfrak{J}_2'(z_2') \frac{e^{-j\beta R_{12}'}}{R_{12}'} dz_2'\right\}$$
$$= -\frac{j}{c}\left\{C_1 \cos \beta z_1 + \frac{1}{2} V_1^e \sin \beta |z_1|\right\} \tag{65}$$

where

$$R_{12}' = \sqrt{(z_1 - l + z_2')^2 + a^2} \approx |z_1 - l + z_2'|. \tag{66}$$

(One obtains the third integral in (65) from the second integral, by writing $-z_1$ for z_1. Notice also that

[8] Ronold King and F. G. Blake, Jr., "The self-impedance of a symmetrical antenna," Proc. I.R.E., vol. 30, pp. 335–349; July, 1942.

$$\int_{-h_1}^{+h_1} \mathfrak{J}_1'(z_1') \frac{e^{-j\beta R_{11}}}{R_{11}} dz_1' = \frac{1}{2}\left\{\int_{-h_1}^{+h_1} \mathfrak{J}_1'(z_1') \frac{e^{-j\beta\sqrt{(z_1-z_1')^2+a^2}}}{\sqrt{(z_1-z_1')^2+a^2}} dz_1' + \int_{-h_1}^{+h_1} \mathfrak{J}_1'(z_1') \frac{e^{-j\beta\sqrt{(z_1+z_1')^2+a^2}}}{\sqrt{(z_1+z_1')^2+a^2}} dz_1'\right\}). \quad (67)$$

A formally similar expression exists for $A_2(+z_2)$.

Proceeding now along lines parallel to those used in the previous paper, one finds that the P and Q functions for colinear antennas take the following form:[9]

$$P_1(h) \approx -\frac{1}{2}\int_{l-h}^{l+h} (\cos\beta(l-u) - \cos\beta h) \cdot \left\{\frac{e^{-j\beta|h-u|}}{|h-u|} + \frac{e^{-j\beta|h+u|}}{|h+u|}\right\} du \quad (68)$$

$$P_1(o) \approx -\int_{l-h}^{l+h} (\cos\beta(l-u) - \cos\beta h) \frac{e^{-j\beta|u|}}{|u|} du \quad (69)$$

$$Q_1(h) \approx -\frac{1}{2}\int_{l-h}^{l+h} (\sin\beta|l-u| - \sin\beta h) \cdot \left\{\frac{e^{-j\beta|h-u|}}{|h-u|} + \frac{e^{-j\beta|h+u|}}{|h+u|}\right\} du \quad (70)$$

$$Q_1(o) \approx -\int_{l-h}^{l+h} (\sin\beta|l-u| - \sin\beta h) \frac{e^{-j\beta|u|}}{|u|} du. \quad (71)$$

In (68) to (71), use has been made of the fact that

$$h_1 = h_2 = h. \quad (72)$$

The values of these integrals are given in Appendix I.

The Input Impedance to Symmetrically and Antisymmetrically Driven Colinear Antennas—Mutual and Self-Impedance

Designating the input impedance to either antenna Z_s when the antennas are driven in phase, and Z_a when driven in phase opposition, one has

$$Z_s, Z_a = -j\frac{\Omega R_c}{2\pi} \left\{\frac{\cos\beta h + (1/\Omega)\{(A_1^{I} \pm jA_1^{II}) \pm (C_1^{I} + jC_1^{II})\} +}{\sin\beta h + (1/\Omega)\{(B_1^{I} + jB_1^{II}) \pm (D_1^{I} + jD_1^{II})\} +}\right\} \cdots (73)$$

Here

$$C_1^{I} + jC_1^{II} = P_1(h) \quad (74)$$

$$D_1^{I} + jD_1^{II} = Q_1(h) - Q_1(0)\cos\beta h + P_1(0)\sin\beta h \quad (75)$$

$$A_1^{I} + jA_1^{II} = F_1(h) \quad (76)$$

$$B_1^{I} + jB_1^{II} = G_1(h) - G_1(0)\cos\beta h + F_1(0)\sin\beta h. \quad (77)$$

$F_1(h)$, $F_1(0)$, $G_1(h)$ and $G_1(0)$ have been defined in the literature.[6,10–12] When $h = \lambda/4$

$$A_1^{I} + jA_1^{II} = -0.7091 + j1.219 \quad (78)$$

$$B_1^{I} + jB_1^{II} = +1.816 + j1.143. \quad (79)$$

When $h = \lambda/2$

$$A_1^{I} + jA_1^{II} = +0.8805 + j0.672 \quad (80)$$

$$B_1^{I} + jB_1^{II} = -2.090 + j3.318. \quad (81)$$

The self-impedance of either antenna is given by (57), and the mutual impedance by (58).

Numerical Values for the Self-Impedance of Colinear Antennas

The following values for Z_{s1} were obtained under the stated conditions:

$h = \lambda/4$ $\Omega = 10$ $(h/a = 75)$.

Spacing $2s$ in wavelengths	Self-impedance Z_{s1} ohms
0.025	65.5+j28.7
0.1	64.4+j29.7
0.2	64.8+j30.0
0.3	64.9+j29.8

$Z_{00} = 64.8 + j29.8$ ohms. (When $2s > 0.3\lambda$, the maximum amplitude of oscillation of Z_{s1} from Z_{00} is $\pm 0.1 \pm j0.4$ ohms.) $h = \lambda/2$; $\Omega = 10(h/a = 75)$

Spacing $2s$ in wavelengths	Self-impedance Z_{s1} ohms
0.025	1047−j908.0
0.1	1107−j826.7
0.2	1123−j825.3
0.3	1128−j830.0

$Z_{00} = 1126 - j831$ ohms. (When $2s > 0.3\lambda$, the maximum shift of Z_{s1} from Z_{00} is $\pm 1.2 \pm j1.0$ ohms).

A conclusion to be drawn from these results is that, even for relatively thick elements having over-all dimensions comparable to a half wavelength, one may disregard the change in self-impedance due to the proximity of the other radiator for all spacings. For full-wave antennas, the self-impedance is essentially independent of spacing when $2s > 0.2\lambda$.

An important fact is that when $Z_{s1} \approx Z_{00}$, one may use the present theory to analyze colinear arrays consisting of *more than two elements* by appropriately applying conventional circuit methods.[13]

Numerical Values for the Mutual Impedance of Colinear Antennas

Values for the symmetrical resistance R_s and the antisymmetrical resistance R_a, are available in Figs. 3 and 4 for $h = \lambda/4$ and $h = \lambda/2$, respectively. In both figures,

[9] See equations (21) through (37) of footnote reference 1.

[10] See Table 1 of footnote reference 7.

[11] Charles W. Harrison, Jr., "The radiation field of long wires with application to vee antennas," *Jour. Appl. Phys.*, vol. 14, pp. 537–544; October, 1943.

[12] Ronold King and Charles W. Harrison, Jr., "The impedance of short, long, and capacitively loaded antennas with a critical discussion of the antenna problem," *Jour. Appl. Phys.*, vol. 15, pp. 170–185; February, 1944.

[13] One might reason that mutual and self-impedance, as calculated in this section, would apply when analyzing colinear arrays consisting of three identical antennas, even when the distance $2s$ is small. Imagine an antenna (3) to be situated above antenna (1) in Fig. 2. Then $z_1 = 0$ is the centroid of the array, and clearly $\mathfrak{J}(z_1) = \mathfrak{J}(-z_1)$. Now if Z_{23} and Z_{32} are considered negligible (an excellent approximation), and the assumption is made that the currents at the centers of *all three antennas* are equal, then the impedances Z_s and Z_a as determined at the input terminals of antenna (1), for antennas (2) and (3) driven as a unit symmetrically and antisymmetrically with respect to antenna (1), yield mutual and self impedances identical to those given in this paper. For a two-element colinear array, the currents at the input terminals are equal, but the symmetry condition implied in the analysis of Part II is not precisely satisfied in a practical array.

$\Omega=10$, and $0.025\lambda \leqq 2s \leqq 1.2\lambda$. The corresponding reactances, X_s and X_a are given in Figs. 5 and 6. Mutual impedances are found in Figs. 7 and 8 for $h=\lambda/4$. In the latter figure $\Omega=\infty$. The data of Fig. 8, while previously published in the literature, has been recalculated and is presented herewith to facilitate comparison with Fig. 7. The effect of the finite radius of the wire is thus clearly brought out. Figs. 9 and 10 make available mutual impedance for $h=\lambda/2$, $\Omega=10$ and $0.025\lambda \leqq 2s \leqq 1.2\lambda$. The case $\Omega=\infty$ has no meaning for $h=\lambda/2$ because the input current vanishes.

An interesting observation is that Z_s corresponds to the input impedance to a symmetrical center-driven antenna oriented vertically with respect to the surface of a perfectly conducting plane earth. The lower end of the antenna is at a distance s from the ground.

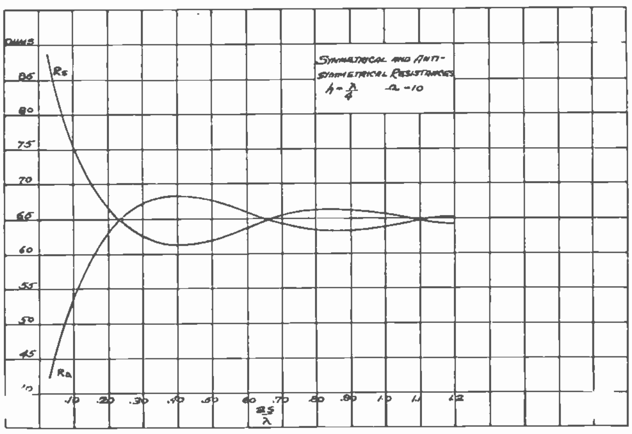


Fig. 3—Symmetrical and antisymmetrical resistances. $h=\lambda/4$, $\Omega=10$.

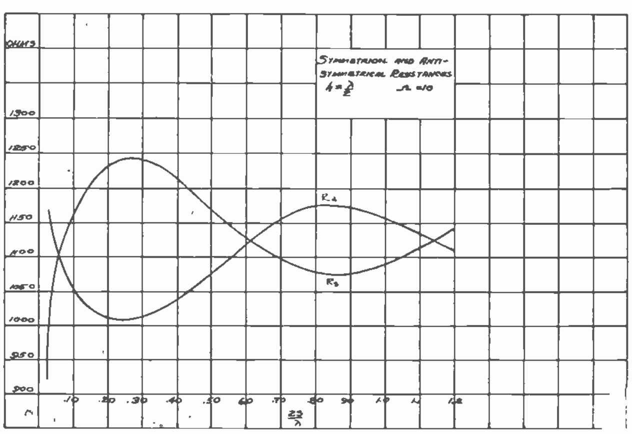


Fig. 4—Like Fig. 3 but $h=\lambda/2$.

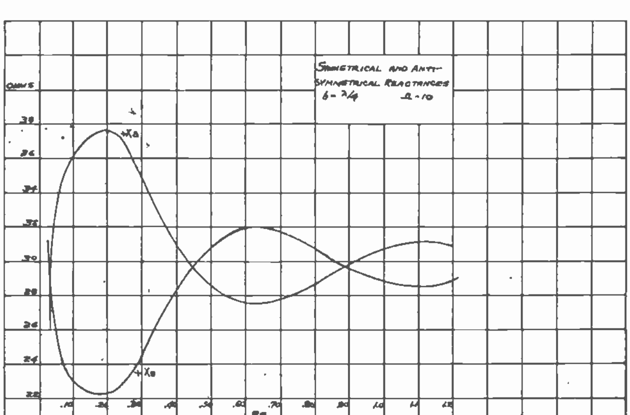


Fig. 5—Symmetrical and antisymmetrical reactances. $h=\lambda/4$, $\Omega=10$.

Conclusion

Two theories for colinear arrays have been presented. Calculations based on the equations of Part I should give results in quantitative agreement with measured values for mutual and self-impedance, provided sufficiently thin wires comprise the array. For conductors

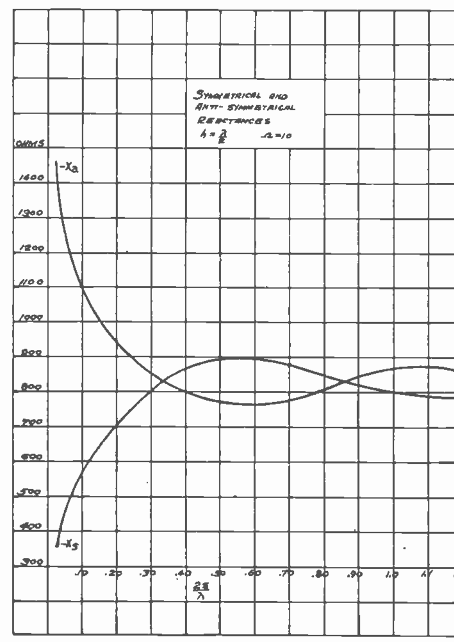


Fig. 6—Like Fig. 5 but $h=\lambda/2$.

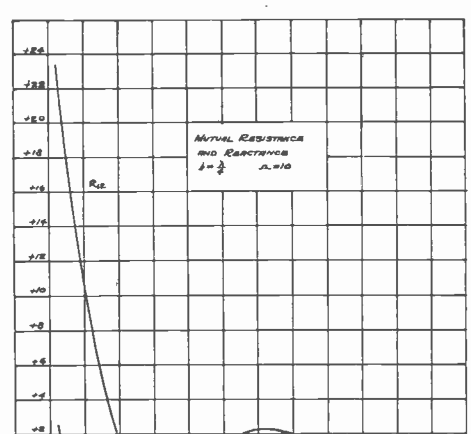


Fig. 7—Mutual impedance. $h=\lambda/4$, $\Omega=10$.

of appreciable radius, only qualitative accuracy may be expected. To prove that results based on Part II will be comparable to those obtainable from Part I appears to be a numerical problem of tremendous proportion, rather than a purely analytical one. The possibility that approximately the same answers are secured when the analyses are used to determine the *driving-point currents* should not be overlooked. However, it is evident that the current distribution along the antennas cannot be found from Method II.

Only two terms in the expansion for the current are retained in either analysis. A suitable zero-order term is selected, and is used in computing a first-order correction by a process of iteration. No proof is given that the actual series for the current is convergent. But, notwithstanding these comments, it is felt that either analysis will yield valuable information relative to colinear-array performance.

In Fig. 11 is shown an array consisting of two identical center-driven antennas in echelon. The colinear array described herein is a specialization of this system.

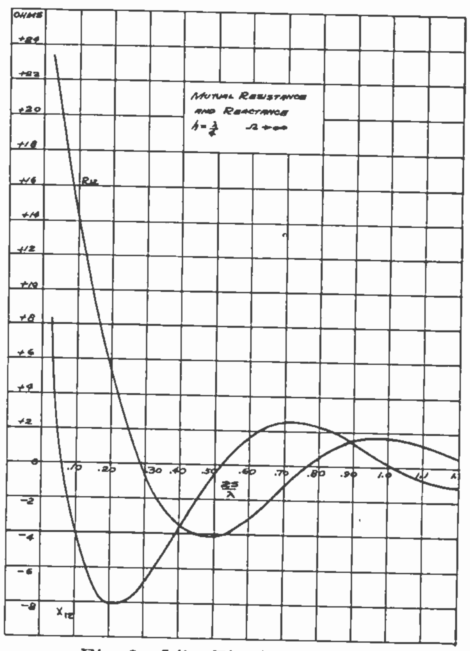


Fig. 8—Like Fig. 7 but $\Omega=\infty$.

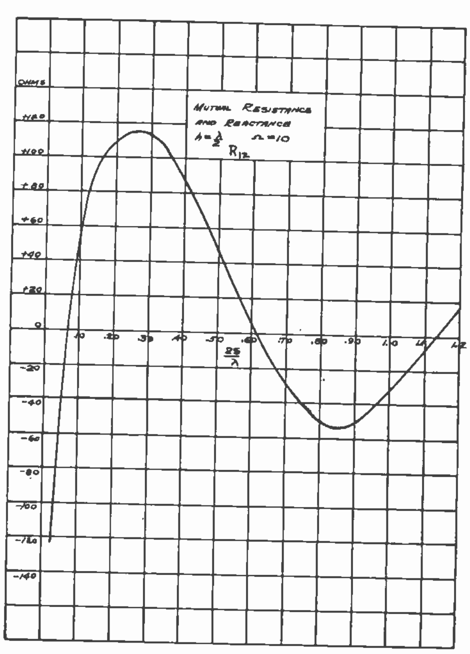


Fig. 9—Mutual resistance for $h=\lambda/2$, and $\Omega=10$.

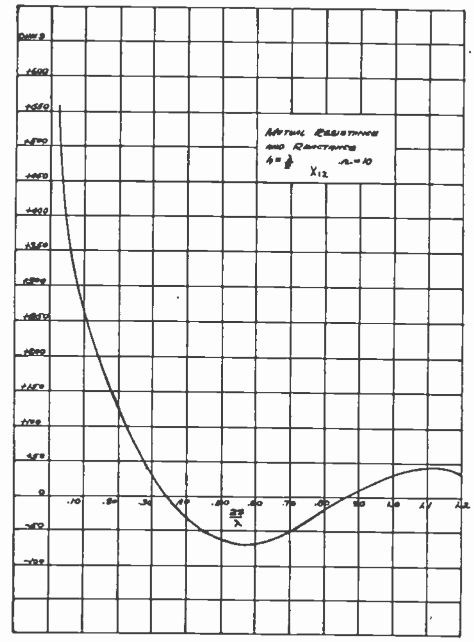


Fig. 10—Mutual reactance for $h=\lambda/2$ and $\Omega=10$.

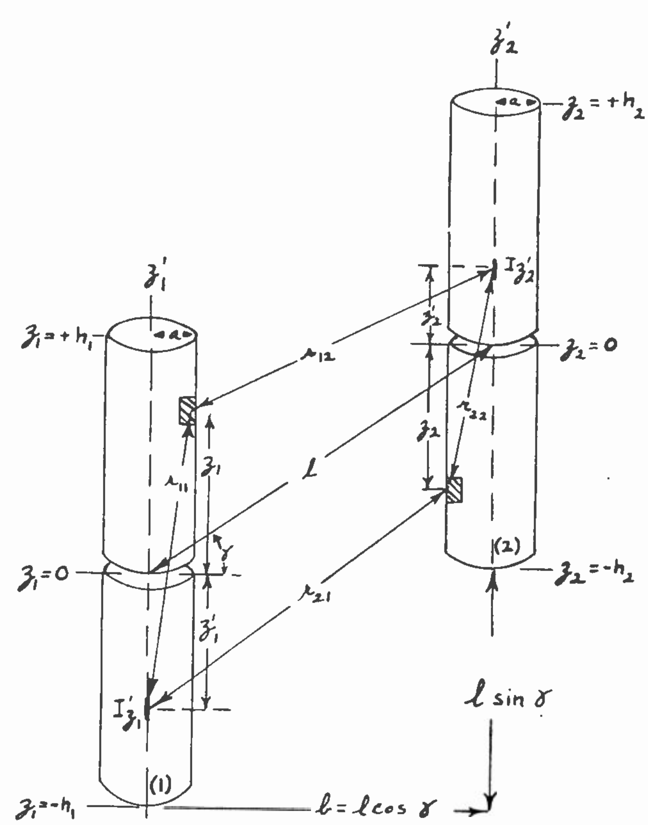


Fig. 11—Identical antennas in echelon. The methods developed in Parts I and II for the solution of the two-element colinear-array problem may be readily adopted to the solution of the problem of antennas in echelon. (Both radiators lie in the plane of the paper.)

The importance of the present analysis is that it is easily extended to include this case. However, certain integrals are encountered in the theoretical development which have not as yet been sufficiently well tabulated to warrant a discussion of this more general problem at the present time.[14,15]

Naturally, the opinions contained herein are strictly unofficial and therefore do not reflect the views of the Navy Department or the Naval Service. The paper is presented in accordance with Navy regulations governing the publication of professional articles by Naval personnel.

Appendix I

The integrals (68), (69), (70) and (71) have the following values:

$$\begin{aligned}P_1(h) = &-((\cos \beta l)/4)e^{+j\beta h}\{-\mathrm{Ci}\ 2\beta l+\mathrm{Ci}\ 2\beta(l+2h)\\ &-j\ \mathrm{Si}\ 2\beta(l+2h)+j\ \mathrm{Si}\ 2\beta l+\ln\ (l/(l-2h))\}\\ &+((\cos \beta l)/4)e^{-j\beta h}\{-\mathrm{Ci}\ 2\beta l+\mathrm{Ci}\ 2\beta(l-2h)\\ &-j\ \mathrm{Si}\ 2\beta(l-2h)+j\ \mathrm{Si}\ 2\beta l-\ln\ ((l+2h)/l)\}\\ &-j((\sin \beta l)/4)e^{+j\beta h}\{-\mathrm{Ci}\ 2\beta l+\mathrm{Ci}\ 2\beta(l+2h)\\ &-j\ \mathrm{Si}\ 2\beta(l+2h)+j\ \mathrm{Si}\ 2\beta l-\ln\ (l/(l-2h))\}\\ &+j((\sin \beta l)/4)e^{-j\beta h}\{-\mathrm{Ci}\ 2\beta l+\mathrm{Ci}\ 2\beta(l-2h)\\ &-j\ \mathrm{Si}\ 2\beta(l-2h)+j\ \mathrm{Si}\ 2\beta l+\ln\ ((l+2h)/l)\}\\ &+(1/2)\cos \beta h\{-2\ \mathrm{Ci}\ \beta l+\mathrm{Ci}\ \beta(l+2h)\\ &+\mathrm{Ci}\ \beta(l-2h)-j\ \mathrm{Si}\ \beta(l+2h)-j\ \mathrm{Si}\ \beta(l-2h)\\ &+j2\ \mathrm{Si}\ \beta l\}. \qquad (82)\end{aligned}$$

$$\begin{aligned}P_1(o) = &-((\cos \beta l)/2)\{\mathrm{Ci}\ 2\beta(l+h)-\mathrm{Ci}\ 2\beta(l-h)\\ &-j\ \mathrm{Si}\ 2\beta(l+h)+j\ \mathrm{Si}\ 2\beta(l-h)+\ln\ ((l+h)/(l-h))\}\\ &-j((\sin \beta l)/2)\{\mathrm{Ci}\ 2\beta(l+h)-\mathrm{Ci}\ 2\beta(l-h)\\ &-j\ \mathrm{Si}\ 2\beta(l+h)+j\ \mathrm{Si}\ 2\beta(l-h)-\ln\ ((l+h)/(l-h))\}\\ &+\cos \beta h\{\mathrm{Ci}\ \beta(l+h)-\mathrm{Ci}\ \beta(l-h)-j\ \mathrm{Si}\ \beta(l+h)\\ &+j\ \mathrm{Si}\ \beta(l-h)\} \qquad (83)\end{aligned}$$

$$\begin{aligned}Q_1(h) = &-((\sin \beta l)/4)e^{+j\beta h}\{-\mathrm{Ci}\ 2\beta l+2\ \mathrm{Ci}\ 2\beta(l+h)\\ &-\mathrm{Ci}\ 2\beta(l+2h)-j2\ \mathrm{Si}\ 2\beta(l+h)+j\ \mathrm{Si}\ 2\beta(l+2h)\\ &+j\ \mathrm{Si}\ 2\beta l+\ln\ ((l-h)^2/l(l-2h))\}\\ &+((\sin \beta l)/4)e^{-j\beta h}\{-\mathrm{Ci}\ 2\beta l+2\ \mathrm{Ci}\ 2\beta(l-h)\\ &-\mathrm{Ci}\ 2\beta(l-2h)-j2\ \mathrm{Si}\ 2\beta(l-h)+j\ \mathrm{Si}\ 2\beta(l-2h)\\ &+j\ \mathrm{Si}\ 2\beta l+\ln\ (l(l+2h)/(l+h)^2)\}\\ &+j((\cos \beta l)/4)e^{+j\beta h}\{-\mathrm{Ci}\ 2\beta l+2\ \mathrm{Ci}\ 2\beta(l+h)\\ &-\mathrm{Ci}\ 2\beta(l+2h)-j2\ \mathrm{Si}\ 2\beta(l+h)+j\ \mathrm{Si}\ 2\beta(l+2h)\\ &+j\ \mathrm{Si}\ 2\beta l-\ln\ ((l-h)^2/l(l-2h))\}\\ &-j((\cos \beta l)/4)e^{-j\beta h}\{-\mathrm{Ci}\ 2\beta l+2\ \mathrm{Ci}\ 2\beta(l-h)\\ &-\mathrm{Ci}\ 2\beta(l-2h)-j2\ \mathrm{Si}\ 2\beta(l-h)+j\ \mathrm{Si}\ 2\beta(l-2h)\\ &+j\ \mathrm{Si}\ 2\beta l-\ln\ (l(l+2h)/(l+h)^2)\}\\ &+(1/2)\sin \beta h\{-2\ \mathrm{Ci}\ \beta l+\mathrm{Ci}\ \beta(l+2h)+\mathrm{Ci}\ \beta(l-2h)\\ &-j\ \mathrm{Si}\ \beta(l+2h)-j\ \mathrm{Si}\ \beta(l-2h)+j2\ \mathrm{Si}\ \beta l\} \qquad (84)\end{aligned}$$

$$\begin{aligned}Q_1(o) = &-((\sin \beta l)/2)\{2\ \mathrm{Ci}\ 2\beta l-\mathrm{Ci}\ 2\beta(l+h)-\mathrm{Ci}\ 2\beta(l-h)\\ &+j\ \mathrm{Si}\ 2\beta(l+h)+j\ \mathrm{Si}\ 2\beta(l-h)-j2\ \mathrm{Si}\ 2\beta l\\ &+\ln\ (l^2/(l^2-h^2))\}+j((\cos \beta l)/2)\{2\ \mathrm{Ci}\ 2\beta l\\ &-\mathrm{Ci}\ 2\beta(l+h)-\mathrm{Ci}\ 2\beta(l-h)+j\ \mathrm{Si}\ 2\beta(l+h)\\ &+j\ \mathrm{Si}\ 2\beta(l-h)-j2\ \mathrm{Si}\ 2\beta l-\ln\ (l^2/(l^2-h^2))\}\\ &+\sin \beta h\{\mathrm{Ci}\ \beta(l+h)-\mathrm{Ci}\ \beta(l-h)-j\ \mathrm{Si}\ \beta(l+h)\\ &+j\ \mathrm{Si}\ \beta(l-h)\}. \qquad (85)\end{aligned}$$

It is of interest to observe that when $h=\lambda/4$, the leading term in Z_{12} is

$$\begin{aligned}Z_{12}= &-j(R_c/2\pi)P_1(h)=-15\cos \beta l\{-2\ \mathrm{Ci}\ 2\beta l\\ &+\mathrm{Ci}\ 2\beta(l-2h)+\mathrm{Ci}\ 2\beta(l+2h)-\ln\ ((l^2-4h^2)/l^2)\}\\ &+15\sin \beta l\{+2\ \mathrm{Si}\ 2\beta l-\mathrm{Si}\ 2\beta(l+2h)-\mathrm{Si}\ 2\beta(l-2h)\}\\ &-j15\cos \beta l\{2\ \mathrm{Si}\ 2\beta l-\mathrm{Si}\ 2\beta(l+2h)-\mathrm{Si}\ 2\beta(l-2h)\}\\ &+j15\sin \beta l\{2\ \mathrm{Ci}\ 2\beta l-\mathrm{Ci}\ 2\beta(l+2h)\\ &-\mathrm{Ci}\ 2\beta(l-2h)-\ln\ ((l^2-4h^2)/l^2)\}. \qquad (86)\end{aligned}$$

This is precisely the result published by P. S. Carter.[16] The fact that the leading term in Z_{12} (for $h=\lambda/4$) checks results obtained by applying the Poynting vector method constitutes no proof of the correctness of Part II.

Appendix II

Evaluation of Integrals Involving Moduli Signs

A typical integral occurring in the analysis is

$$\int_{l-h}^{l+h} \sin \beta \mid l-u \mid \frac{e^{-j\beta \mid h+u \mid}}{\mid h+u \mid} du. \qquad (87)$$

One notices that over the interval of integration $h+u$ is positive. Accordingly, the moduli signs may be dropped from the exponent, and from the denominator without changing the value of the integral. However, $l-u$ is positive only over the interval

$$l-h \leqq u \leqq l. \qquad (88)$$

It is negative over the interval

$$l \leqq u \leqq l+h. \qquad (89)$$

Therefore, (87) must be separated into two integrals, thus

$$\begin{aligned}\int_{l-h}^{l+h} \sin \beta \mid l-u \mid \frac{e^{-j\beta \mid h+u \mid}}{\mid h+u \mid} du &= \int_{l-h}^{l} \sin \beta(l-u) \frac{e^{-j\beta(h+u)}}{(h+u)} du\\ &- \int_{l}^{l+h} \sin \beta(l-u) \frac{e^{-j\beta(h+u)}}{(h+u)} du. \qquad (90)\end{aligned}$$

A representative integral in (90) is

$$\begin{aligned}\int_{l-h}^{l} \frac{e^{-j\beta(h+2u)}}{h+u} du &= e^{j\beta h}\int_{l-h}^{l} \frac{e^{-j2\beta(h+u)}}{h+u} du\\ &= e^{j\beta h}\int_{j2\beta l}^{j2\beta(l+h)} \frac{e^{-v}}{v} dv. \qquad (91)\end{aligned}$$

But it is well known that

$$\int_{ja}^{jb} \frac{e^{-v}}{v} dv = \mathrm{Ci}\ b - j\ \mathrm{Si}\ b - \mathrm{Ci}\ a + j\ \mathrm{Si}\ a. \qquad (92)$$

Hence

$$\begin{aligned}\int_{l-h}^{l} \frac{e^{-j\beta(h+2u)}}{h+u} du = e^{j\beta h}\{&\mathrm{Ci}\ 2\beta(l+h) - j\ \mathrm{Si}\ 2\beta(l+h)\\ &- \mathrm{Ci}\ 2\beta l + j\ \mathrm{Si}\ 2\beta l\}. \qquad (93)\end{aligned}$$

[14] Charles W. Harrison, Jr., "A note on the mutual impedance of antennas," *Jour. Appl. Phys.*, vol. 14, pp. 306–309; June, 1943.

[15] Sidney Weinbaum, "On the solution of definite integrals occurring in antenna theory," *Jour. Appl. Phys.*, vol. 15, pp. 840–841; December, 1944.

[16] P. S. Carter, "Circuit relations in radiating systems and applications to antenna problems," Proc. I.R.E., vol. 20, pp. 1004–1041: June, 1932.

ACKNOWLEDGMENT

Professor Ronold King, of the Cruft Laboratory and the Research Laboratory of Physics at Harvard University, and Mr. V. H. Rumsey, of the British Mission to the United States Naval Research Laboratory, offered useful suggestions. The author hopes to use an expanded version of the paper as a thesis to fulfill partially the requirements for the D.Sc. degree from Cruft Laboratory. Mr. Rumsey checked the P and Q functions listed in Appendix I. The antenna sketches are by W. Thomson.

Note on Impedance Matching of Shunt-Fed Half-Wave Dipole*

G. GLINSKI†, ASSOCIATE, I.R.E.

Summary—**The formula for the spacing between feeding points of the shunt-fed, horizontal, half-wave dipole is obtained. The spacing is found to be a function of radiation resistance and characteristic impedance of the dipole, and of the characteristic impedance of the feeding line. Curves are calculated showing that the assumption of equal dipole and feeder-line characteristic impedance may lead to considerable error in the calculation of the spacing of feeding points.**

A CURVE illustrating the dependence of the spacing between the feeding points of a shunt-fed, horizontal, half-wave dipole on the height above the ground, has been calculated[1,2] from a formula assuming the equality of the characteristic impedances of the dipole and of the feeding line.

The purpose of this note is to present more general

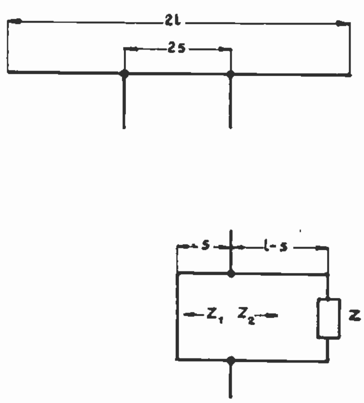


Fig. 1—Shunt-fed dipole and its equivalent circuit.

formulas giving the dependence of the spacing between the feeding points, not only upon the height above the ground but also upon the characteristic impedances of the dipole and feeding line as well. It will be shown also that the physical length of the nominal half-wave dipole is a function of the spacing of feeding points and of the characteristic impedances of the dipole and the feeding line.

The problem to be solved will be stated as follows: A horizontal half-wave dipole of length $2l$ (Fig. 1) is placed at a given height above a perfect ground. A symmetrical and uniform transmission line of characteristic impedance Z_{ol} is provided as a feeder. Find the spacing $2s$ of the feeding points on the dipole when shunt fed, matching a given line. Following Siegel and Labus,[3] as a first approximation, we replace the dipole by the equivalent uniform transmission line of a length l (Fig. 1) and of an average characteristic impedance given by[4]

$$Z_{od} = 120(\ln (2l/d) - .55) \tag{1}$$

where d = diameter of dipole conductor.

The curve of Z_{od} versus $2l/d$ is also shown in Fig. 2.

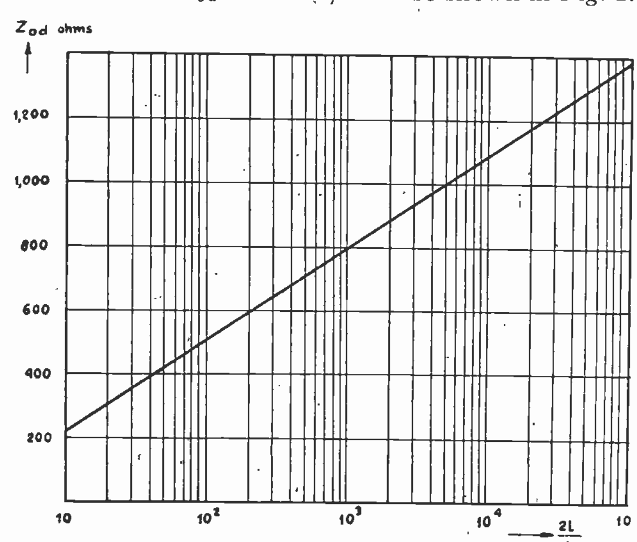


Fig. 2—Characteristic impedance of the dipole.

According to our assumption, this line is equivalent to a dipole. To account for a radiation from the dipole one should assume further that the equivalent transmission line has a certain amount of attenuation. Again according to Siegel and Labus, the total attenuation of a line of length l is given by

* Decimal classification: R125. Original manuscript received by the Institute, June 9, 1944; revised manuscript received, December 18, 1944.

† Northern Electric Company, Ltd., Montreal, Que., Canada.

[1] F. E. Terman, "Radio Engineers' Handbook," McGraw-Hill Book Co., New York 18, N. Y., 1943, p. 851.

[2] P. S. Carter, "Circuit relations in radiating systems and applications to antenna problems," PROC. I.R.E., vol. 20, pp. 1004–1042; June, 1932.

[3] E. Siegel and T. Labus, "Sheinwiderstand von Antennen," *Hochfrequenz. und Elektroakustik*, vol. 43, pp. 166–172; May, 1934.

[4] H. Kaufmann, "Der Eingangswiderstand der Dipole-Antennen," *Hochfrequenz. und Elektroakustik*, vol. 60, pp. 160–168; December, 1942.

$$\alpha l = (R_s/Z_{od})(1 - (\sin 4\pi l/\lambda)/(4\pi l/\lambda)) \qquad (2)$$

where R_s = radiation resistance of a dipole.

Since we are discussing only $\lambda/4$ nominal dipoles, (2) can be simplified further to

$$\alpha l = R_s/Z_{od}. \qquad (2a)$$

The open-circuited and attenuating transmission line can be replaced, as far as its input impedance is concerned, by a lossless line with a definite load Z at its end. This equivalent load can be calculated from the formula[5]

$$Z = Z_{od}/\alpha l. \qquad (3)$$

Or taking into account (2a)

$$Z = Z_{od}^2/R_s. \qquad (4)$$

As a first approximation we may assume that the radiation resistance R_s of the horizontal dipole is only a function of its relative height h/λ above the ground and its behavior is illustrated in Fig. 3.

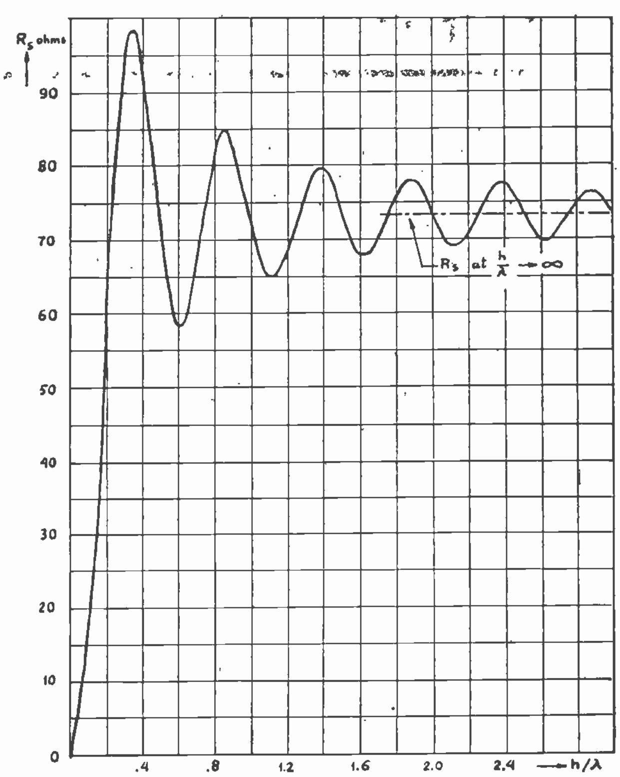


Fig. 3—Radiation resistance of the dipole.

In this way the original dipole of length $2l$ is now replaced by the lossless line of characteristic impedance Z_{od} and of length l terminated at the right end in the equivalent load Z (Fig. 1). This equivalent line is fed, at distance s from the left end, from the transmission line of characteristic impedance Z_{ol}.

The load of the feed line Z_{ol} consists of two impedances in parallel: 1. The input impedance Z_1 of the short-circuited line of length s (to the left of the feeding point). 2. The input impedance Z_2 of the line of length $(l-s)$ (to the right of the feeding point).

The matching problem can be restated now as follows: Both impedances Z_1 and Z_2 being functions of the separation s (l is assumed to be constant), find the value of s for which the parallel combination of Z_1 and Z_2 gives a purely resistive impedance equal to the characteristic impedance of the feeding line.

In this way the original problem is reduced to a simple one of matching two transmission lines in parallel

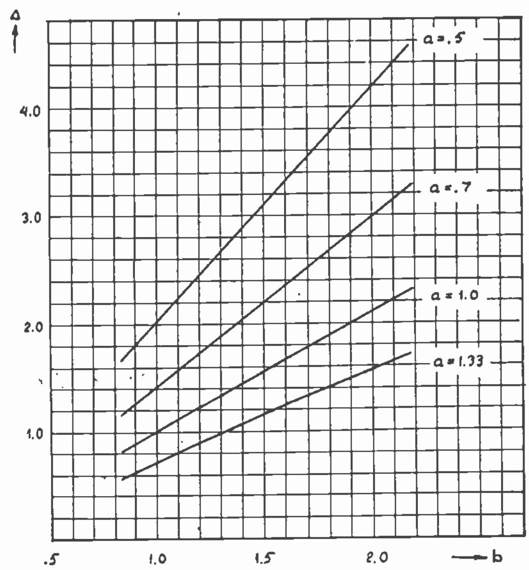


Fig. 4—Correction for the spacing of the dipole feeding points.

to a third one. The solution of this problem[6] gives the two following equations

$$\tan(2\pi(l-s)/\lambda) = \sqrt{Z(Z-Z_{ol})/(ZZ_{ol}-Z_{od}^2)} \qquad (5)$$

$$\cot 2\pi s/\lambda = \sqrt{(Z-Z_{ol})\left(Z-\frac{Z_{od}^2}{Z_{ol}}\right)\Big/ZZ_{ol}}. \qquad (6)$$

Equations (1), (4), (5), and (6) give all necessary information relative to the design of a shunt-fed dipole.

If in (6) we assume that $Z_{ol} = Z_{od}$ we shall obtain the special case treated previously by Carter:

$$\cot 2\pi s/\lambda = (Z - Z_{ol})/\sqrt{ZZ_{ol}}. \qquad (7)$$

For $Z_{ol} = 600$ ohms and $R_s = 73$ ohms this formula yields $2s/(\lambda/2) = 0.24$. This checks with the value of the spacing given on Fig. 20 of Carter's paper for h/λ increasing indefinitely.

Since the ratio $2l/d$ in practice varies between 10^2 to 10^5, the range of variation of Z_{od}, as calculated from (1), is 500 to 1300 ohms. If, as above, $Z_{ol} = 600$ ohms and $R_s = 73$ ohms, then for the lower limit $Z_{od} = 500$ ohms, equation (6) yields $2s/(\lambda/2) = 0.29$ whereas for the upper limit $Z_{od} = 1300$ ohms, the same equation (6) yields $2s/(\lambda/2) = 0.11$. Hence, if we were using Carter's curve (or equation) in these two extreme cases, the spacing would be 17 per cent too small or 118 per cent too large, respectively.

To show the range of variation of spacing between the feeding points as the R_s, Z_{od} and Z_{ol} are changed, (6)

[5] S. A. Schelkunoff, "Electromagnetic Waves," D. Van Nostarnd and Company, New York, N. Y., 1943, p. 200.

[6] See page 220 of footnote reference 5.

can be modified by the introduction of the following notation: $a=Z_{ol}/600$; $b=Z_{od}/600$; $c=R_s/73$. Then

$$\Delta_1=\cot 2\pi s/\lambda=\sqrt{73(8.2b^2-ac)(8.2a-c)/600a^2c}. \quad (9)$$

If $a=b=1$, then this equation yields

$$\Delta_2=\cot 2\pi s/\lambda=\sqrt{73(8.2-c)^2/600c} \quad (10)$$

which corresponds to Carter's equation (7) when $Z_{ol}=600$ ohms.

Dividing (9) and (10) side by side

$$\Delta = \Delta_1/\Delta_2 = \sqrt{(8.2b^2 - ac)/a^2(8.2 - c)}. \quad (11)$$

In practice, a ranges from 0.5 to 1.33 ($Z_{ol}=300\div800$ ohms), b from 0.83 to 2.17 ($Z_{od}=500\div1300$ ohms), c from 0.69 to 1.37 ($R_s=50\div100$ ohms). Calculations show that for the above-mentioned range of a and b the variation of c has very little effect on the required spacing. Fig. 4 shows the variation of Δ, equation (11), versus b with a as a parameter when $c=1$. As we see, the correction Δ is quite important.

Up to this point we were discussing (6) only. Referring to (5) it is sufficient to notice that the length $2l$ of the dipole is also the function of all Z's and s. Hence, the physical length of the dipole will be different from the nominal length $\lambda/2$. (Calculation shows that in the case when $Z_{ol}=Z_{od}=600$ ohms and $R_s=73$ ohms $2l$ is of the order of 0.51λ). This point is not too important, since in any case the physical length of the dipole is shorter than its nominal length due to the end effect.[7] According to Wells[8] the physical length is 0.475λ; that is, about 95 per cent of the half wave length in free space.

[7] See page 454 of footnote reference 5.
[8] N. Wells, "Short-wave dipole aerials," *Wireless Engineer*, vol. 20, pp. 219–232; May, 1943.

Institute News and Radio Notes

Board of Directors

April 4 Meeting: At the April 4, 1945, meeting of the Board of Directors, the following were present: W. L. Everitt, president; G. W. Bailey, executive secretary; S. L. Bailey, L. M. Clement, Alfred N. Goldsmith, editor; R. F. Guy, R. A. Heising, treasurer; Keith Henney, F. B. Llewellyn, Haraden Pratt, secretary; B. E. Shackelford, D. B. Sinclair, W. O. Swinyard, H. M. Turner, H. A. Wheeler, L. P. Wheeler, and W. C. White.

Executive Committee Actions: The actions of the Executive Committee, taken at its April 4, 1945, meeting, were unanimously approved.

Committees and Appointments

BUILDING-FUND: Dr. Shackelford, chairman of this Committee, reported that 182 subscribers had pledged $184,290, and that all pledges, with the exception of that of one corporation, were paid; that the campaign among the membership had just started; 12 Sections completely organized and 6 partially. Several Sections have slightly lagged, but early action is expected from them. The campaign is going at least as well as can be expected; and there are a number of large organizations still to be heard from.

Mr. Raymond F. Guy was appointed a vice-chairman of the Building-Fund Committee.

CONSTITUTION AND LAWS: Chairman Guy of the Constitution and Laws Committee reported on the following matters:

a. Proposed Amendments: The following proposed amendments to Bylaw Sections 3, 10, and 47 were unanimously approved:

"*Section 3:* Applicants for membership ship shall furnish names of references as follows:

"For Senior Member—Five Fellows or Senior Members.

"For Member—Four Fellows, Senior Members, or Members.

"For Associate—Three Fellows, Senior Members, Members, Associates, or other responsible individuals.

"For Student—A member of the faculty of his school."

"*Section 10:* Admission or transfer to any grade except Fellow may be proposed by any member acting as sponsor, or by the Membership Committee, by supplying to the Admissions Committee sufficient information and testimonials from the required number of references to satisfy the Admissions Committee as to qualifications. Such proposals shall be acted upon by the Admissions Committee, and, if approved, transmitted to the Board of Directors for their action. If approved by the Board of Directors, an Invitation Blank shall be sent to the proposed member inviting him to accept the grade of membership proposed, which membership grade shall become effective automatically and immediately upon his supplying the biographical and professional information required, and paying the necessary dues and fees. The name of an invitee shall be placed on the mailing list for the PROCEEDINGS immediately upon recept of dues and fees. The proposal and invitation blanks shall be drawn up by the Membership Committee so as to avoid unconstitutional action due to the sponsor supplying incorrect information."

"*Section 47:* The Membership Committee shall include the Chairman of the Membership Committee of each Section, ex officio."

It was unanimously approved that the Constitution and Laws Committee be instructed to prepare and submit amendments to the Constitution as follows: (1) that Senior Members should have the right to hold the offices of President and Vice-President; and (2) that the offices of Chairman, Vice-Chairman, Secretary, Treasurer, and the Chairmanship of the standing committees of the Sections be restricted to those members of Member grade or higher.

EDUCATION: The following members were appointed to the Education Committee:

Ralph Bown	E. Weber
H. A. Chinn	W. C. White
J. D. Cobine	Irving Wolff

ORGANIZATION OF RESEARCH: On recommendation of the Executive Committee, Dr. G. R. Town was appointed chairman of the Committee on Organization of Research.

The following Committee appointments, recommended by the Executive Committee, were unanimously approved:

BOARD OF EDITORS

J. D. Cobine — A. W. Graf

PAPERS

E. W. Herold — D. O. North
E. K. Van Tassel

PAPERS PROCUREMENT

Ralph Bown	H. J. Reich
H. A. Chinn	E. Weber
J. D. Cobine	Irving Wolff

APPOINTMENTS: The Executive Committee, on its recommendation, was authorized to act for the Board in the appointment of those committees which are mentioned in the Bylaws, for which the Executive Committee is now responsible for proposing appointments to the Board. The Board approval for these appointments will be given at the time the Executive Committee Minutes are approved, instead of by separate, individual action.

INSTITUTE REPRESENTATIVES: On recommendation of the Executive Committee, Lieutenant Colonel P. M. Honnell was appointed IRE representative at the United States Military Academy at West Point, and Professor W. F. Hardgrave was appointed IRE representative at the University of New Mexico.

(*Continued on page 412*)

Why the Building Fund Must Grow

The remarkable aspects of the growth of the radio industry in the past have been not only its impact upon activities in many other fields but also the great number of new industries that have been created from the developments of the radio engineers.

* * *

The art is highly specialized, and the wartime military-security rules which have been in force have narrowed down the activities in each individual's field to but a few specialties. A far-reaching, guided program of co-operation is needed to make such developments of greatest utility to the growth of a world-wide market.

* * *

Wartime research has made many a spectacular electronic device of the past a commonplace necessity of today. Why can there be any question as to future expansion in the radio and the electronics field?

* * *

The trend toward electronic methods utilizing war-born developments will revolutionize many other industries and start new ones previously unknown.

* * *

In spite of the greatly enlarged activities of the industry as a whole, the production effort in military equipment has usually been narrowly confined to one or a few projects for any one group of engineers. A broad viewpoint as to what has gone on and what has been accomplished is still lacking by most of the membership.

* * *

Keeping informed as to current practices is not solely a problem for laboratories in smaller industries, but applies equally to those of the larger companies.

* * *

The factor which will have a great influence in getting these new projects under way toward their peacetime applications as quickly as possible will be the rapid dissemination to radio engineers of the available information relative to all phases of electronic development.

* * *

In The Institute of Radio Engineers, the radio industry has had (for over thirty years) the benefits of a co-operative organization that has promoted discussions and demonstrations of new discoveries, theories, practices, and designs. Hundreds of meetings have been sponsored in some twenty-five centers of activity accessible to the great majority of its 15,000 members.

* * *

The most important of the disclosures at these meetings invariably have been followed by reports to the Institute members in their own publication, the PROCEEDINGS OF THE I.R.E. There are already in print some 34,000 pages as testimony of the work of its members, constituting the most extensive and far-reaching "compendium" of radio-electronic knowledge in the world.

* * *

It is a fact, not widely heralded, but nevertheless true, that a great deal of the information which forms the basic parts of the war's most intriguing devices—the existence of which is not even admitted openly at present—is spread out here and there among the pages of the PROCEEDINGS in issues appearing throughout the years of its publication.

* * *

The Building-Fund program of The Institute of Radio Engineers, on June 1, passed the $400,000 mark, well over the half-way point toward making this greater service activity a reality. Interesting notes that indicate progress follow.

The first committee to function in raising the I.R.E. Building Fund was the Initial Gifts Committee of 47 members, headed by Dr. W. R. G. Baker, vice-president, General Electric Company.

Dr. Austin Bailey of the American Telephone and Telegraph Company heads the I.R.E. Section Solicitation Committee which includes membership solicitation and other local solicitation in 33 United-States and Canadian I.R.E. Sections. The Section work is now getting under way and, it is expected, will be completed during the next month.

The first 1272 subscriptions to the I.R.E. Building Fund included 239 corporate and 1033 individual subscriptions.

The wide-spread interest in the I.R.E. and its Greater Service Building-Fund program is shown by the fact that the first 500 subscriptions came from 37 States, Canada, Hawaii, Alaska, and the District of Columbia.

* * *

Industrial and retail sales depend upon the quality and performance of equipment and products which clearly depend upon the competency of engineers who, in turn, will depend increasingly for knowledge, high morale, and professional solidarity upon an efficient and progressive I.R.E.

* * *

The first I.R.E. Section to reach its goal was Cincinnati. To date, 178 per cent of its goal has been reported.

The first Building-Fund report from the Washington, D. C., I.R.E. Section was $4010 from 20 subscribers.

Foreign subscriptions are in from Mexico, Brazil, Colombia, and the Canal Zone.

(*Continued from page 410*)

Sections

CHICAGO: On recommendation of the Executive Committee, the Chicago Section was enlarged to include the following counties in Indiana:

Allen	Kosciusko	Noble
DeKalb	Lagrange	Starke
Elkhart	Marshall	Steuben
Jasper	Newton	Whitley

SEATTLE: Permission was given to the Seattle Section to become a charter member of the proposed Puget Sound Council of Engineering and Technical Societies which had been requested by that Section and recommended by the Executive Committee.

CONSTITUTION: The recommendation of the Executive Committee to adopt the following amendments to the Sections' Constitution, passed by the Sections Committee, was unanimously approved.

ARTICLE III—Territory

Add:

"*Section 2*—Whenever, within a Section, circumstances arise which indicate the need for meetings in different areas, it shall be permissible for the Section to foster and inaugurate one or more subsections locally to carry out the functions of obtaining speakers and holding meetings.

"*Section 3*—A subsection may be formed and operated on any plan not inconsistent with the powers of the Executive Committee."

ARTICLE V—Officers

Cancel Section 2 and substitute:

"*Section 2*—The terms of office for all officers shall begin at the close of the annual meeting, or as soon thereafter as the election result is determined, and shall end at the close of the next annual meeting, or as soon thereafter as the result of the election of new officers is determined, and, in any case, continue until their successors are duly elected and take office.

"*Section 3*—The terms of office set forth above shall be approximately one year and may exceed this interval only in the case where the date of the annual meeting is being changed and a continuation in office is necessary to effect the new schedule, or no successor has been elected or appointed."

ARTICLE VI—Management

Cancel present Section 1 and substitute:

"*Section 1*—There shall be an Executive Committee consisting of at least the officers, the junior past-chairman, and the chairmen of all the standing committees listed in Section 5 of Article VI.

"The chairmen may appoint, subject to confirmation by a majority vote of the above members of the Executive Committee, additional members to the Executive Committee from the Section membership."

ARTICLE VII—Nomination and Election of Officers

Add these Sections between present Sections 1 and 2 and renumber accordingly:

"*Section 2*—When at an annual meeting there is more than one nominee for any one of the offices of chairman, vice-chairman, or secretary-treasurer, the chairman of the Section may conduct the election at the annual meeting if it is evident that a fair expression of the wishes of the membership can be then determined. As an alternative, he may announce that the results shall be determined by a letter ballot to be taken prior to the next regular meeting of the section.

"*Section 3*—In the event that election of officers is to be determined by letter ballot, the secretary shall provide promptly to each voting member of the Section a letter ballot with return envelope as used by the Institute and with a return date specified, which shall in no case be later than six weeks after date of the annual meeting.

"The chairman shall call a meeting of the Executive Committee to constitute a tellers committee to count the vote and determine the successful candidate.

"The chairman shall inform the successful candidates of their election and arrange for the transfer of responsibility to the new officers without delay."

ARTICLE VIII—Meetings

Cancel present Sections 4 and 7 and substitute:

"*Section 4*—At least fifteen members shall be present to constitute a quorum at all meetings of the Section called for the transaction of regular business and requiring a vote to be taken, but a higher number may be set to constitute a quorum, such number to be determined by a Bylaw voted upon by the Section membership."

"*Section 7*—A majority of the members of the Executive Committee shall constitute a quorum at all meetings of the Executive Committee, except as otherwise provided herein."

Society for the Promotion of Engineering Education: It was unanimously approved that the recommendation of the Executive Committee that the Institute become an Institutional member of the Society for the Promotion of Engineering Education be approved.

Executive Committee

April 4 Meeting: The Executive Committee meeting, held on April 4, 1945, was attended by W. L. Everitt, president; G. W. Bailey, executive secretary; S. L. Bailey, W. L. Barrow, E. F. Carter, Alfred N. Goldsmith, editor; R. A. Heising, treasurer; Haraden Pratt, secretary; D. B. Sinclair (guest), and W. B. Cowilich, assistant secretary.

Membership: The following transfers and applications for membership were unanimously approved: For transfer to Senior-Member grade (plus the invitation to Ralph R. Beal), Charles Blahna, J. T. Brothers, W. N. Brown, Jr., C. M. Daniell, R. L. Freeman, G. W. Fyler, R. N. Harmon, W. P. Hickson, E. C. Jordan, A. C. Matthews, K. N. Pezopoulos, D. C. Prince, J. G. Ruckelshaus, L. E. Swedlund, G. H. van Spankeren, W. T. Wintringham, and S. B. Wright; for admission to Senior-Member grade, G. H. Fett, J. C. Lozier, V. C. Marsolan, and H. A. Thomas; for transfer to Member grade, Q. L. Bonness, J. S. Brown, L. L. Caudle, Jr., P. E. Chamberlain, F. C. Chien, B. H. Ciscel, J. D. Colvin, R. M. Daugherty, W. W. H. Dean, M. P. Feyerherw, J. A. Fitch, C. I. Fonger, F. J. Fox, W. H. Freund, Joseph General, Walter Kenworth, T. I. Kimzey, H. B. Lippert, John Markus, A. G. Nekut, F. A. Olson, E. C. Peet, D. W. Pugsley, J. A. Rado, H. S. Renne, M. T. Reynolds, C. S. Root, Samuel Sabaroff, N. E. Schick, R. F. Shaw, G. E. Sheppard, M. L. Snedeker, L. F. Spangenberg, R. R. Thompson, R. W. Tuttle, John Vergeichik, L. O. Vladimir, R. W. Wagner, Louis Weiss, C. C. Wilson, J. A. Worcester, Jr., and H. J. Zimmermann; for admission to Member grade, G. R. Berry, R. A. Bierwirth, Hendley Blackmon, R. H. Brown, H. A. Cook, N. J. Cooper, G. W. Diem, Joseph Goldsmith, C. E. Howe, Nels Johnson, Joseph Lorch, A. S. Marthens, R. H. Olson, W. B. Pearce, J. H. Reynolds, L. M. Rodgers, Leon Rubin, J. H. Ruiter, Jr., P. J. Santos, G. F. Schiffmayer, C. A. Shank, C. P. Smith, W. F. Stewart, and W. S. Thompson; Associate grade, 176; and Student grade, 84.

William B. Cowilich: It was moved and approved that the resignation of William B. Cowilich as assistant secretary, effective June 30, 1945, be accepted.

Radio Wave Propagation Committee

A meeting of the Technical Committee on Radio Wave Propagation was held in New York on January 17, 1945, under the chairmanship of Charles R. Burrows. H. R. Mimno, T. J. Carroll, and J. L. Barnes, secretary of the committee, were in attendance. The business of the meeting was the revision of the Committee's 1942 Standards on Definitions of Radio Wave Propagation Terms.

Accordingly, the definitions of Section 1 (General Terms) were carefully considered. A letter to the committee from the chairman formed the basis for discussion of revised definitions and new definitions. However, a number of terms not mentioned in that letter were also redefined.

Cedar Rapids Section

The Cedar Rapids Section of The Institute of Radio Engineers held its first major meeting on March 19, 1945. Ninety-six persons attended the dinner meeting, at which Dr. W. L. Everitt, president of the Institute, was guest speaker.

Frank M. Davis was installed as section chairman; L. A. Ware, vice-chairman; and John A. Green, secretary-treasurer. This newly formed Section is growing rapidly, and is expected to prove a most welcome addition to the Institute membership.

Correspondence

Correspondence on both technical and nontechnical subjects from readers of the PROCEEDINGS OF THE I.R.E. is invited, subject to the following conditions: All rights are reserved by the Institute. Statements in letters are expressly understood to be the individual opinion of the writer, and endorsement or recognition by the I.R.E. is not implied by publication. All letters are to be submitted as typewritten, double-spaced, original copies. Any illustrations are to be submitted as inked drawings. Captions are to be supplied for all illustrations.

Simplification of Complex Switching Analysis

This paper outlines a method whereby the designing of complex switching arrangements may be resolved into the least possible number of switches in a fraction of the time ordinarily required.

(1) Draw both circuits using arrows at the heads of all impedances. The arrows are used at the heads of the impedances in order that the correct placement of said impedance is ascertained. This is particularly important in the case of coils, used in radio-frequency circuits, where an aiding or canceling inductive effect is desired.

(2) Using X to indicate "closed circuit" and O to indicate "open circuit," make the latter circuit the same as the former circuit.

(3) Number all switching junction points.

(4) Write all junction points down in numerical order.

(5) Starting at junction point one, place the number of the junction point, with respect to which one is closed, in a column marked X. Then place the number of the junction point, with respect to which one is open, in the O column. If any junction point (central) is open to two or more other junctions, then repeat the central junction number until all opposing junctions are listed. Proceed similarly in the case where a central junction is closed to two or more junction points.

(6) Definitions.

(a) A set of numbers consist of three numbers. One in the X column, the O column, and the central column.

Example:	X	C	O
	3	1	4

(b) X group. An X group consists of one number in the X column and another in the central column.

Example:	X	C	O
	3	1	-

(c) O group. An O group consists of one number in the O column and another in the central column.

Example:	X	C	O
	-	1	4

(7) Cancellation:

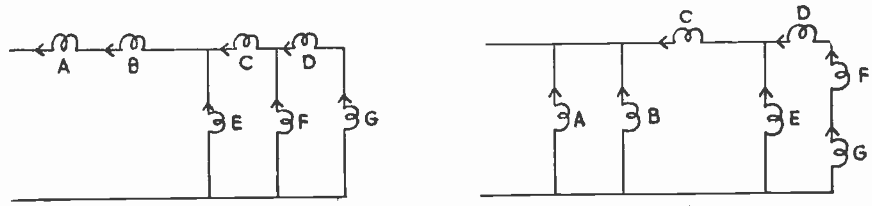
(a) If one set of numbers is the same as another set of numbers, one of the sets may be crossed out. Similarly for the X groups and the O groups.

(b) If an X group has the same numbers as the X group in a set, then the former group may be crossed out. Proceed similarly in the case of an O group and an O group in a set.

(c) If an X group of one set has the same numbers as the X group of another set, cover the X column number of the first set and observe if the remaining O group connects anywhere else in the O group columns. If it is found to connect somewhere else in the O-group columns, then the first set may be crossed out. If it is found that it does not connect anywhere else in the O-group columns, then apply the same procedure to the second set. If the O group remaining in the second set is found to connect somewhere else in the O-group columns, then the second set may be crossed out. If neither set may be crossed out by the above procedure, one of the X numbers may be crossed out in one of the two sets.

(8) Connect similar numbers together, and place parts between corresponding junction points obtained from step three, observing the correct placement of arrows. When the switch is thrown into the X position, the first circuit is realized.

Example: It is desired to design a switching arrangement to change the circuit of Fig. 1(a) to that of Fig. 1(b).



(a) (b)

Fig. 1

By rule (2), in order to make circuit 1(a) the same as 1(a), coil A must be opened to ground (drawn in as o to ground) and must then be short-circuited to coil B, (indicated by x). The "arrow portion" of coil A must be opened to coil C.

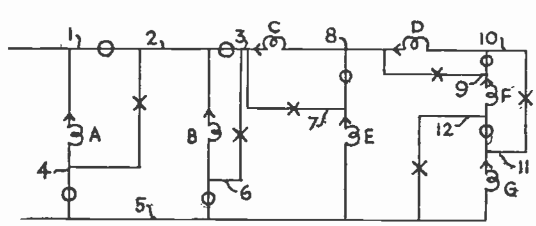


Fig. 2

NOTE: This procedure is similar to using single-pole, single-throw switches to make the change from circuit 1(b) to 1(a). Fig. 2 results from following the above procedure and labeling junction points.

By rule (4) there are twelve junction points, and these are listed in the C column of Table I(a). From Fig. 2, junction point 1 is not closed respective to any other junction point, therefore the X column (Table I(b)) is left blank. Junction point 1 is open with respect to junction point 2, and therefore, the number 2 is placed in the O column.

As we proceed to junction point 2, on Fig. 2, we see that this is closed to junction point 4 and open to junction point 1. It is also open to junction point 3. Therefore, according to rule 5, 4 is placed in the X column and 1 and 3 placed in the O column with junction point 2 duplicated in the C column.

Following the above procedure, Table I is completed.

TABLE I

(a)			(b)		
X	C	O	X	C	O
	1		—	1	2
	2		4	2	1
	3		—	2	3
	4		6	3	2
	5		7	3	—
	6		2	4	5
	7		12	5	4
	8		—	5	6
	9		3	6	5
	10		3	7	8
	11		9	8	7
	12		8	9	10
			11	10	9
			10	11	12
			5	12	11

Cancellation

Since the O group (1 and 2) has the same numbers as the O group of set (4, 2, and 1), O group (1 and 2) may be crossed out, as in Table II(a). We proceed similarly with the O and X groups (2 and 3), (7 and 3), and (5 and 6). Since X-group numbers 4 and 2 are the same in sets (4, 2, and 1), and (2, 4, and 5), rule (7c) may be applied. Covering the number 4 in the X column of set (4, 2, and 1) leaves O group (2 and 1). By then following the O-group columns it is seen that 2 does not connect to 1 in any way. However covering the number 2 in set (2, 4, and 5) leaves O group (4 and 5). Looking through the O group column, it is seen that number 4 connects to 5 in set (12, 5, and 4). Set (2, 4, and 5) therefore may be crossed out. Similarly sets (11, 10, and 9), (9, 8, and 7) and (5, 12, and 11) may be crossed out. It is now seen that the X group (6 and 3) in set (6, 3, and 2) has the same numbers as the X group (3 and

TABLE II

(a)			(b)		
X	C	O	X	C	O
	1	2	4	2	1
4	2	1	—	3	2
	2	3	12	5	4
6	3	2	3	6	5
7	2		3	7	8
2	4	5	8	9	10
12	5	4	10	11	12
	5	6			
3	6	5			
3	7	8			
9	8	7			
8	9	10			
11	10	9			
10	11	12			
5	12	11			

6) in set (3, 6, and 5), but that the remaining *O* group, upon covering one of the *X* numbers, does not connect together. Therefore either one of the *X* numbers may be canceled: it is optional which one is crossed out. In this case the author chose *X* number 6 of set (6, 3, and 2). Upon the completion of the cancellation, we obtain Table II.

Connecting the like numbers together in Fig. 4b, and placing the parts between their respective junction points, from Fig. 2 we obtain the final circuit, Fig. 3, and this has the least possible number of switches. In Fig. 3, *C* represents the rotor arm of a single-pole double-throw switch. Therefore, in this particular problem, a 7-gang 2-position switch is required.

T/4 Melville Byron 32652453
A.P.O. 322 c/o Postmaster
San Francisco, Calif.
176th Signal Repair Co.

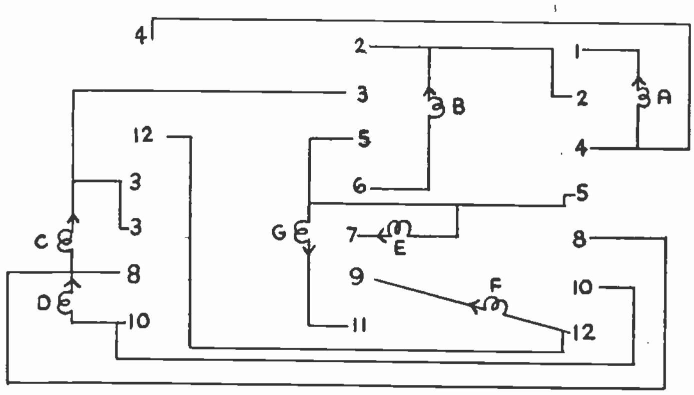


Fig. 3

One wonders if Clerk-Maxwell based his theory at first on this experiment and the opinion of Morse. It seems most unfortunate that more exhaustive research has not been conducted into the history and development of one of the most important technical factors in this age of war and of a science that assuredly will play a great part in the building of a better world.

Colin Johnston Robb
Drumharrif Lodge
Loughcall, County Armagh
Ireland

High Light on an American Pioneer of Radio

The question of the early development of radiotelegraphy has never been thoroughly studied in the light of the scattered and scanty data pertaining to the subject. In this short article, the writer wishes to call attention to an obscure source of information which is of the greatest importance to those interested in the history of radio.

In 1632, the philosopher Galileo expressed the opinion that, by the sympathy of magnetic needles, it would be possible to communicate over great distances but the real germ of the ideal of communication over space by listening in at the trunks of trees dates back to remote antiquity.

In Scandinavian mythology, Vigfusson's version of the "talking tree" relates that it was more than a myth, as the early Norse actually could send and receive messages by this system of sylvan telephony.

To the great Scottish scientist, James Clerk-Maxwell, we no doubt owe the concrete conclusion that there is a common medium through which electricity, magnetism, and light are transmitted. This was made known to the world in 1867; and in 1888 Heinrich Hertz made an apparatus by which he proved Maxwell's theory to be correct. He found that the propagation means consisted of waves which he produced, and that these could pass through stone walls as easily as light waves pass through glass.

Much earlier in the last century, however, Samuel Finley Breese Morse, the celebrated American thinker and inventor, conceived the idea of a basic physical connection between the transmission of electricity and light.

In a letter dated March 10, 1843, and addressed to Professor Stevelly, professor of natural philosophy at the Royal Belfast Academical Institution, Morse states:

"The protracted correspondence of the past two years that has passed between us has proved that we respectively agree that the passage of electricity and light is due to a common agent about which nothing has been discovered by man. You enquire further regarding my experiment with the Franklin lightning rods. The two poles were one mile apart on two high hills about the same level and 50 foot high. Iron rods of one-half inch in diameter were used, sunk 6 feet down in the earth and the one sharp at the point and the other was terminated by a disc 24 inches in diameter of iron about a full quarter thick. The first test proved during a thundery afternoon that the pointed rod though emitting vivid sparks at the top was quite harmless though live and the disced rod was highly charged and dangerous. I conclude that I had here an ambit of electricity by which intelligence could be instantaneously transmitted without a wire. Whatsoever agent may exist in the atmosphere at high levels in thunderstorms must exist in a lesser degree all the time I am convinced. In the same way a light in the black of night on being exposed must travel by some physical means afar in an instant."

This experiment, carried out by Morse in a simple way, proved the first essential component parts necessary in radio and used in the Hertzian-wave system, minus a definitely selected form of oscillator and resonator. The pole with the pointed rod clearly established modern scientific principles underlying the erection of an efficient lightning conductor. His comparison of radio waves to those of light was borne out by Maxwell and the Hertzian-wave signaling on a lower frequency, but on a greater wavelength than heliography. The propagation of the disturbance was, of course, the same, and Marconi's transmission from Nova Scotia to England is stated to have been based on the theory that it would proceed at the velocity of light, thus taking 1/60th of a second to complete the journey.

Wallace Burnside Caufield, Jr.

Wallace Burnside Caufield, Jr., was fatally wounded on December 31, 1944, in Luxembourg, when the automobile in which he was riding was strafed. He was at that time in charge of the continental activities of an American laboratory located in England and operating under the auspices of the Office of Scientific Research and Development.

Mr. Caufield was born in Portland, Oregon, on September 25, 1920. He received the A.B. degree from Stanford University in 1941, and was a member of Phi Beta Kappa, Tau Beta Pi, and Chi Psi.

Because of his extraordinary height of six feet, six inches, he was rejected for service by the Army, Navy, and Marine Corps, but in his determination to be of service to his country in wartime, Mr. Caufield elected to interrupt his studies in order to become a special research associate with the Radio Research Laboratory at Harvard University. As a result of his excellent record there in research and development of specialized radio equipment, he was selected to go on a technical-observer mission in the Mediterranean theater of operations, a mission which lasted from October, 1943, to April, 1944. His work was outstanding, and in May, 1944, he was assigned as head of a group on an urgent scientific mission in England, connected with invasion planning. On the completion of this mission, Mr. Caufield became connected with the American-British Laboratory in England, and was shortly thereafter promoted and placed in charge of all Continental activities of the Laboratory. He met his death while on a mission for this organization.

A memorial fund has been established in the School of Engineering at Stanford University by Mr. Caufield's many friends.

He was an Associate member of The Institute of Radio Engineers.

Korea Economic Digest

The Korea Economic Society of 1775 Broadway, New York 19, N. Y., publishes a monthly magazine: "Korea Economic Digest." It is one of the stated aims of the Society "to interest technical experts and practical engineers in Korea in order that they might assist in the country's rehabilitation upon the expulsion of our common enemy." The Society is a nonprofit and nonpolitical organization which also plans to disseminate information concerning Korea. Further information concerning the publications of the Society may be obtained by addressing them directly.

I.R.E. People

E. M. DELORAINE

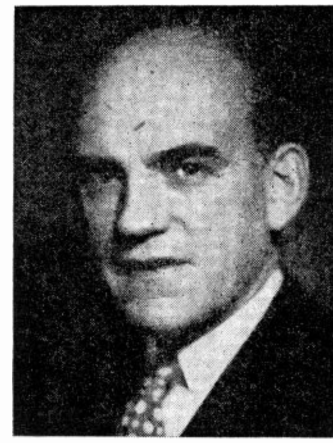
E. M. DELORAINE AND HAROLD H. BUTTNER

E. M. Deloraine (M'25–F'41) has been appointed president, and Harold H. Buttner (M'27–SM'43) vice-president, of International Telecommunication Laboratories, Inc., a newly created corporation under the sponsorship of the International Telephone and Telegraph Company. The purpose of the new organization is to make possible exchange of inventions and closer co-ordination of I. T. and T.'s world-wide research in electronics in the fields of radio and television.

The subsidiary laboratories of I. T. and T. (Federal Telephone and Radio Laboratories, in New York; Standard Telephones and Cables, in London; and Les Laboratoires, Le Materiel Telephonique, in Paris) have contributed much to the war effort, pioneering in such fields as pulse time modulation and the microray system, first demonstrated across the Strait of Dover in 1931. When Paris was recently retaken by the Allies, Les Laboratoires were found to be intact and are now producing communication equipment.

Included in the wartime contributions of the Federal Telephone and Radio Laboratories are the development of marine direction finders, radio direction finders, the radio instrument landing system for aircraft now used by the United States Army Air Force, aerial navigation systems providing aid in the operation and guidance of airplanes in flight, and 200-kilowatt vacuum tubes for the Office of War Information's new global short-wave transmitters.

The establishment of the International Telecommunication Laboratories, Inc., is expected to produce significant contributions in the postwar period.



HAROLD H. BUTTNER

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RALPH R. BEAL

RALPH R. BEAL

Ralph R. Beal (A'15–SM'45), assistant to the vice-president in charge of RCA Laboratories, and for nine years research director of the Radio Corporation of America, has been elected vice-president of RCA Communications, Inc., in charge of engineering. The election was announced on April 6, 1945, by Brigadier-General David Sarnoff (A'12–M'14–F'17), president of the Radio Corporation of America.

Mr. Beal is a pioneer in radio and electronics. In the early days of radiotelegraphy, he was associated with the development of high-power point-to-point radio transmission. Later, as research director, he was responsible for co-ordinating research and advanced engineering development activities of RCA and its subsidiaries, and for originating and supervising programs of research aimed at broadening the field of radio's products and services. Among major developments in this field were the application of radio-electronics to numerous noncommunication purposes, such as the electron microscope, television, theater television, radar, radio relays, and the opening of the microwave section of the radio spectrum.

Upon graduation from Leland Stanford University, in California, Mr. Beal joined the Federal Telegraph Company in San Francisco, and subsequently supervised the installation of continuous-wave equipment in radio stations in Panama, Hawaii, the Philippines, and Bordeaux, France. Later, he made engineering investigations in the Orient, related to establishing direct overseas radio communications between the United States and China.

His association with the Radio Corporation of America began in 1926, when he was appointed Pacific division engineer for that organization. In 1934, he was transferred to New York as research supervisor, and was made research director in 1937. For nine years he was chairman of the RCA committee formed in 1935 to study television broadcasting.

Mr. Beal is a Fellow of the Society of Motion Picture Engineers, and a member of the Microwave Committee of the National Development Research Committee of the Office of Scientific Research and Development.

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POSTWAR RADIO TO BE BASED ON PERFORMANCE

Quality products always head the sales list in any field, and after the war this will be especially true of radio sets, according to Garrard Mountjoy (A'37–M'40–SM'43), radio research and development director of Lear, Inc. "The prewar years in radio were rather hectic ones, with the public being sold sets on the basis of one improvement or another. Cessation of radio production changed the picture radically. During the past few years, it was not the novelty feature, but the over-all performance of the radio set that counted. It made the radio public conscious of the fact that quality in a radio is important; that the basic principles of the maker should guide the purchase of radio sets."

Mr. Mountjoy thus emphasized the importance of basic quality in a radio set, as opposed to so-called "outstanding" improvements which have hitherto been stressed at times. Before Mr. Mountjoy joined the Lear organization as head of the radio development division, he served as head of the licensee consulting section of the RCA industry service division, and in almost a decade of that work he was in touch with

GARRARD MOUNTJOY

FREDERICK R. LACK

practically every change in radio design and structure. Having observed radio performance from the technical side as an engineer, and from the side of the public in watching the reactions to improvements which were real advancements in the field as against those which were simply novel, he has drawn the preceding conclusions.

Mr. Mountjoy holds over 30 patents in radio design, and in 1940 received a Modern Pioneer Award from the National Association of Manufacturers, for "contributions which improved the American standard of living." He is a graduate of Washington University, having received his B.S. degree in 1929, and he has lectured in the graduate school of the Stevens Institute of Technology.

FREDERICK R. LACK

Frederick R. Lack (A'20–F'37), vice-president of the Western Electric Company and manager of its radio division, was elected to the Company's Board of Directors on April 10, 1945.

RALPH C. AYRES

Mr. Lack has been associated with the Western Electric Company and its research affiliate, Bell Telephone Laboratories, for 33 years, engaged in work on the development of radiotelephony and vacuum-tube development until 1939, when he was appointed manager of the specialty products division. Elected vice-president in 1942, Mr. Lack became manager of the radio division in the same year.

Mr. Lack is a director of the Radio Manufacturers Association and the American Standards Association, a member of the American Institute of Electrical Engineers, the American Physical Society, and the Harvard Engineering Society.

RALPH C. AYRES

Appointment of Ralph C. Ayres (A'38–M'41–SM'43) as systems superintendent of communications for Transcontinental and Western Air, Inc., was announced recently by J. C. Franklin (M'41–SM'43), vice-president of engineering and maintenance.

Mr. Ayres replaces Gordon A. O'Reilly (A'41–M'41–SM'43), who has accepted a position as vice-president and general manager of Aeronautical Radio Incorporated of America with offices in Washington, D. C. Mr. Ayres' appointment marks the ninth anniversary of his employment with TWA in Kansas City. Starting as a technician in the communications department, he became aircraft radio engineer in 1937, and was named chief radio engineer in 1942, a post which he will retain, together with his new position. He has been variously associated with work on the installation of static loops on the DC-3, developments in very-high-frequency and experimental markers in conjunction with instrument landing, and static-precipitation tests, on which he is considered an outstanding authority.

Mr. O'Reilly became a radio operator for TWA in 1930, a radio technician in 1937, and engineer in 1939, and was appointed engineer in charge of ground stations in 1940. In the same year, he was appointed assistant superintendent of communications, and was promoted to the position of superintendent in 1944.

ALLAN R. ELLSWORTH

Allan R. Ellsworth (A'41) has been named director of research of the Packard-Bell Company, of Los Angeles, California, and is in charge of the organization and activities of this division. For twelve years he has been the chief engineer of this company.

EVERETT L. DILLARD

Everett L. Dillard (A'38) has been named to a position on the National Advisory Committee of the American Public Relations Association. He will represent the activities of the radio division of the national association, and direct the organization and promotion of public-relations procedures in

J. N. A. HAWKINS

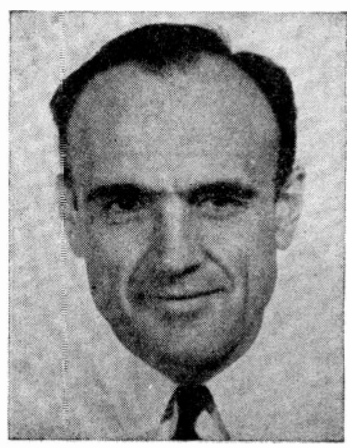
amplitude-modulation, frequency-modulation, and television fields, serving in a key post in the association's co-operation with the public-relations program of radio facilities throughout the nation.

Mr. Dillard is general manager of the Commercial Radio Equipment Company, of Washington, D. C., and is owner and operator of frequency-modulation station KOZY, in Kansas City, Missouri, and two frequency-modulation outlets in Washington, D. C.

J. N. A. HAWKINS

Appointment has been announced of J. N. A. Hawkins (A'36) as general sales manager of industrial electronic products for Sylvania Electric Products, Inc., in New York City. He will be responsible for products involving applications of electronics to commerce and industry, and will also be concerned with some products in their developmental stages.

Mr. Hawkins has served as technical editor of *Radio*, partner with Eitel-McCullough (Eimac), and chief transmission engineer of the sound department at Walt Disney's studios, where he developed the three-channel "fantasound" pilot-tone re-



A. R. ELLSWORTH

Harold P. Westman

cording and reproducing systems used in the motion picture "Fantasia."

Since 1941, Mr. Hawkins has been engaged in classified research in naval warfare methods and equipment, and has served overseas in Central America, South America, Europe, Africa, and Asia. He has been an active radio amateur since 1919.

Amory H. Waite, Jr.

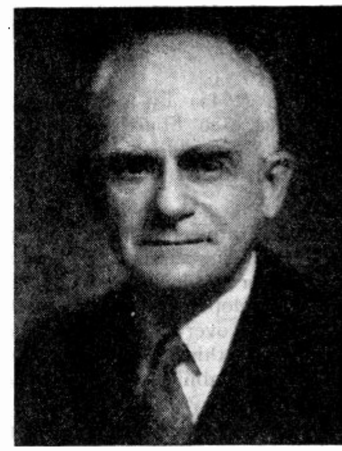
Amory H. Waite, Jr. (A'44) was one of two civilian engineers who helped establish cross-channel communications for the First Army in the opening of the second front on Normandy Beach in June, 1944. In response to a request from General Eisenhower for engineers to install, maintain, and instruct in the usage of six 100-mile systems of a radio set designed to replace wire communications where the circuits were greatly extended over broken terraine, making a multichannel radio-relay system the only source of uninterrupted communication, Mr. Waite carried out a difficult assignment.

The citation awarded Mr. Waite and his colleague from Brigadier-General G. C. Black states in part: "These men were extremely helpful to the operation of the Twelfth Army Group during their tour of duty in this theatre and are to be highly commended for their contribution to the success of our combat forces."

Harold P. Westman and H. T. Kohlhaas

Harold P. Westman (J'24–A'25–M'30–SM'43) has recently been appointed Associate Editor of *Electrical Communication*, published by the International Telephone and Telegraph Company, with H. T. Kohlhaas as Editor.

Mr. Westman was assistant secretary of The Institute of Radio Engineers from 1929 to 1930 and secretary from 1930 to 1942. In



H. T. Kohlhaas

1943 he was associated with the American Standards Association, and in 1944, with the Institute of the Aeronautical Sciences.

Mr. Kohlhaas was employed by the Bell Telephone Laboratories from 1905 to 1924, when he was transferred to the Western Electric headquarters. When the International Western Electric Company was purchased by International Telephone and Telegraph he became associated with the latter organization, developing and becoming editor of *Electrical Communication*, and having charge of all technical publicity for his Company.

Books

Flexible Shaft Handbook

Published (1944) by S. S. White Dental Manufacturing Company, Industrial Division, 10 East 40 Street, New York 16, N. Y. 255 pages+1-page index. $8\frac{1}{2}\times5\frac{1}{2}$ inches. Available on request.

The first two parts of the book are devoted to applications of flexible shafts to power-drive and remote-control problems respectively. The third part considers the design of combinations and connecting methods. Illustrations are used effectively to show the wide range of applications, and shaft specifications are listed for many of the applications shown. The shaft data tables and the casing information are complete and well organized.

The table of contents is sufficiently detailed to permit the rapid location of the desired material and a "Ready Reference Index" provides a conveniently rapid reference to data frequently used by the design engineer. An appendix of twenty-six pages includes many applicable engineering tables and standards. Collected between one pair of covers are the essential data needed by the design engineer. Many engineers will find the handbook most helpful.

D. E. Noble
Galvin Manufacturing Corporation
Chicago 51, Illinois

Elektrische Schwingtöpfe und ihre Anwendung in der Ultrakurzwellen-Verstärkertechnik (Electric Cavity Resonators and Their Application in Ulta-Short-Wave Amplifier Engineering), By Alfred De Quervain

Published (1944) by A. G. Gebr. Leemann and Company, Zurich, Switzerland. 86 pages+2-page index+vi pages. 47 illustrations. 6×9 inches. Price, F 6; RM 3.60.

This publication is apparently a summary of thesis work for a degree. As such, the material is restricted to the subject as stated. Experimental results are presented to substantiate the calculations and theoretical discussions. All the experimental work was carried out between 1 and 2 meters. Most of the techniques described can be extended to somewhat lower frequencies and to considerably higher frequencies.

The discussions are presented clearly without recourse to complex mathematics. Equivalent circuits are used throughout. Although the generator-amplifier-load circuit is treated thoroughly, no discussion is made of regeneration and problems encountered with the use of the amplifier tubes. From the pictures and data it would seem that the mechanical work and electrical measurements were of very high quality.

The cavity resonator used was of the quarter-wave coaxial-line type with one end short-circuited and the other end loaded by capacitance between a large disk on the center conductor and the closed end of the outer conductor. The inductance and capacitance are calculated from the dimensions of the cavity. The losses in the walls are computed and used to obtain an expression for Q and for the "antiresonant" impedance across the open end of the quarter-wave line. An expression is derived for the capacitance coupling between two adjacent resonators through an aperture in the end wall. No similar calculation is made for magnetic coupling although another paper is referred to and data given on the subject. Temperature compensation of frequency drift is discussed. A method of using two metals of differing expansion coefficients is described. Part of the center conductor is made of copper while the remainder of the cavity is made of aluminum.

A detailed description is made of a band-pass amplifier, fed from a coaxial line, with two pentode amplifier tubes and six cavity resonators, and output into a diode detector. Direct coupling from tube to resonator is used at the high impedance end of the cavities. Magnetic coupling through irises was used between resonators. Band-pass characteristics are shown for several degrees of coupling. A gain of 26 decibels per stage was achieved. Several pieces of test equipment are described with measurements of Q and resistance.

G. L. Tawney
Hudson American Corporation
Brooklyn 1, New York

Aviation Radio, by Henry W. Roberts

Published (1945) by William Morrow and Co., Inc., 386 Fourth Avenue, New York, N. Y. 622 pages+11-page index+xv pages. 465 illustrations. 8½×6 inches. Price, $5.00.

In two separate fields as rapidly expanding and progressing as are aviation and radio, it is a major problem to present a picture of current developments and achievements in the region of overlapping activities that is the subject of this book. The author has demonstrated his ability and experience as a writer and editor by producing a vivid and fascinating semitechnical volume for pilots and radio technicians. He assumes that the pilots want to know more about the radio equipment on which their lives may depend and that radio technicians have the curiosity to investigate, and the necessity to learn the aeronautical use of radio. One can scarcely resist the appeal of the author's words, "The greatest single factor shaping our lives today is aviation, and it is aviation radio that makes modern flying possible."

We may see how the reader who is a pilot—or plans to be one—is led in simple fashion from the rudiments of electricity to a general qualitative knowledge of equipment and facilities in use or planned for use in aviation. This is made evident by the sequence of subjects: Understanding Aviation Radio; Primary Radio Facilities; Advanced Radio Facilities; Radio Navigation; and Aviation Radio Apparatus. The last four topics broaden the horizons for those who have some familiarity with elementary radio principles and who aspire to understand not only past progress in the air navigation and communication field, but also wish information on the principal trends and the future prospects. Hardly a topic of airways facilities, air line and private communication equipment, or navigation apparatus is discussed without the introduction of ideas for future expansion and suggestions of expected developments. The author shrewdly includes a chapter entitled "Looking Forward." In this he minimizes the effects of a dilemma that might be encountered in a book in which wartime achievements—though known to capable of revolutionizing the entire field—must remain untold for the present.

The topic "Understanding Aviation Radio" represents a most ambitious attempt to tell all about the universe. Unfortunately, this choice made difficult and unsatisfactory a picture which otherwise was simplified enough for the nontechnical reader but accurate enough to satisfy the physicist. Fortunately, succeeding sections are accurate and adequate from the pilot's point of view, at least.

By its very nature of presenting a fresh picture of aviation radio that is up to date and reasonably complete at the time of publication, the author is compelled to realize in such a fast-changing field of endeavor that much of the story will be obsolescent as the war comes to an end. The author's emphasis on the use of higher radio frequencies and on new direction finding and navigation devices shows that he has kept foremost the experience and viewpoint of a pilot.

The significance of the achievements that have already been made by the joint efforts of aviators and engineers is summed up in the conclusion, "Practically, there is no weather bad enough to prevent scheduled completion of a flight, provided that the airplane carries the necessary advanced radio apparatus, and that corresponding advanced radio aids are available to it on the ground."

Donald S. Bond
Radio Corporation of America
Camden, New Jersey

Contributors

L. J. Berberich was graduated from Johns Hopkins University, and received the degree of Doctor of Engineering from the same institution in 1931. After short periods of employment with the National Bureau of Standards and the Westinghouse Electric and Manufacturing Company, he became associated with the research and development division of the Socony-Vacuum Oil Company, Inc., at Paulsboro, New Jersey, in 1931. During his employment by this organization, Dr. Berberich was engaged largely in the development of insulating oils and the study of the influence of refining on the chemical and electrical properties of this type of petroleum product.

In 1937, he joined the Westinghouse research laboratories staff at East Pittsburgh, Pa., as research engineer in the insulation department. In 1943, he was appointed section engineer in charge of the physical section of the insulation department, a position which he still holds. Dr. Berberich's work at Westinghouse has centered chiefly in research in the nonmetallic-materials field and their application to the insulation of electrical equipment.

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P. S. Christaldi (S'35–A'40–SM'44) was born on November 26, 1914, at Philadelphia, Pennsylvania. He received the E.E. degree, in 1935, from Rensselaer Polytechnic Institute at Troy, N. Y., and was a graduate fellow in physics at the same institution from 1935 to 1938, when he received his Ph.D. degree, specializing in wave-guide communications.

In 1938 Dr. Christaldi joined the Allen B. Du Mont Laboratories, Inc., at Passaic, N. J., as a development engineer engaged in the development of cathode-ray tubes and cathode-ray oscillographs. Since 1941 he has been chief engineer of the Du Mont Laboratories.

He is a member of Sigma Xi and the Radio Club of America.

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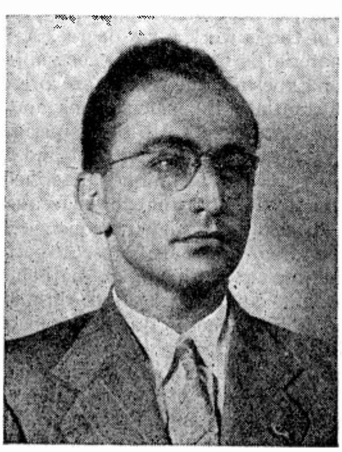
C. V. Fields received the B.S. degree in electrical engineering from the University of Colorado in 1936. He was assistant instructor at the University of Minnesota for two semesters, and both instructor and student in the extension division of the University of Pittsburgh.

L. J. Berberich



P. S. Christaldi

C. V. Fields

Albert W. Friend

In 1937 Mr. Fields joined the Westinghouse Electric and Manufacturing Company as a graduate student, and after completing the student course, worked in the engineering laboratories and later, in the protective devices section of the switchgear engineering division. He is now development engineer, and has been responsible for capacitor development and for the application of fundamental research to manufacturing practice. He has also been identified with the design of high-frequency capacitors, surge generators, and other lines of apparatus involving capacitors.

Albert W. Friend (A'34–M'39–SM'43) was born at Morgantown, West Virginia, on January 24, 1910. He received the B.S.E.E. degree in 1932, and the M.S. degree in physics in 1936, from West Virginia University. He has been active in experimental or amateur radio since 1920.

F. J. Gaffney

Between 1929 and 1939 Mr. Friend consulted on radio interference and police radio problems, and was employed in electric power transmission and distribution engineering. He was assistant professor of physics at West Virginia University from 1934 to 1939, on leave to date.

From 1939 to 1941, Mr. Friend continued his research on the tropospheric reflection of radio waves, at Cruft Laboratory and Blue Hill Meteorological Observatory of Harvard University. During that time he was instructor, research fellow, and student, completing a large portion of the requirements for the Sc.D. degree.

From 1941 to 1942, he was engaged in research, development, and teaching in the Radiation Laboratory of the Massachusetts Institute of Technology. From 1942 to 1944 he directed developments in the Heat Research Laboratory there, and acted as special consultant to Division 5 of the National Defense Research Committee. Recently he transferred to the Radio Corporation of America, at Camden, New Jersey.

Mr. Friend is a member of the American Institute of Electrical Engineers, Sigma Xi, Tau Beta Pi, and Sigma Pi Sigma, and an Associate member of the American Meteorological Society.

F. J. Gaffney (A'38) was born on June 27, 1912, at Middleton, England. He received the B.S. degree in electrical engineering from Northeastern University in 1935, and did graduate study at Tufts College and Massachusetts Institute of Technology from 1940 to 1942.

During 1935 and 1936, Mr. Gaffney was employed by the B. F. Sturtevant Company, in Hyde Park, Massachusetts, as mechanical design draftsman. He was a radio engineer for the National Company of Malden, Massachusetts, in 1936 and 1937, and chief engineer of Browning Laboratories, in Winchester, Massachusetts, from 1937 to 1941. Since 1941 he has been on the staff of Radiation Laboratory, Massachusetts Institute of Technology, and since 1942 has been in charge of measurement and test apparatus with that organization.

Mr. Gaffney is a member of Tau Beta Pi, and the American Institute of Electrical Engineers.

G. Glinski (A'42) was born at Petersburg, Russia, on March 11, 1912. He received the degree of Electrical Engineer from the Warsaw Institute of Technology (Politechnika Warszawska), in Poland in 1937. From 1935 to 1939 Mr. Glinski was a member of the engineering staff of the research division of the State Telephone and Radio Factory at Warsaw, Poland, and was engaged in work on magnetics and audio frequency. During 1940 he was a member of the engineering staff of the aircraft division of Thomson-Houston at Paris, France,

G. Glinski

working on superregenerative receivers, and, in 1941, was engaged in research in magnetics at the Institute of Technical Physics of the University of Grenoble, France, under Prof. L. Néel. Mr. Glinski came to Canada in 1942, and to date he has been connected with the electronics division of the Northern Electric Company, Montreal. Since 1944 he has been a special-studies engineer in the research department, engaged chiefly in antenna developments.

Mr. Glinski is an Associate member of the American Institute of Electrical Engineers, and a member of the Association of Polish Engineers in Canada.

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 at Annapolis, Md. 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 was graduated with the S.M. degree in communication engineering from the Cruft Laboratory, Harvard University, and during the summer was a

C. W. Harrison, Jr.

C. P. Healy

student of 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. Mr. Harrison was advanced to the rank of lieutenant commander early in 1944. He is a member of the American Physical Society and Sigma Xi.

C. P. Healy* was born in Melbourne, Australia. He was graduated as Associate in electrical engineering from Melbourne Technical College in 1922, and received the B.E.E. degree from the University of Melbourne in 1926. He entered the Government Service and spent three years as engineering instructor and one year as examiner of patents. From 1929 to 1934 he was chief engineer of Airzone, Ltd., of Sydney, Australia, and from 1934 to 1936 was engaged in research for radio components manufacturers. In 1936 he joined Amalgamated Wireless (Australasia), Ltd., in Sydney. Throughout the war he has been conducting tropical research work on materials and components for the Allied Forces.

* Paper published in May, 1945, PROCEEDINGS.

Dorman D. Israel

Dorman D. Israel (A'23-M'30—F'42) was born on July 21, 1900, at Newport, Kentucky, and received the E.E. degree in 1923 at the University of Cincinnati. He has been chief development engineer of Crosley Radio Corporation and chief engineer of Grigsby-Grunow Corporation. In 1936 he became chief engineer of Emerson Radio and Phonograph Corporation and its vice-president in charge of engineering in 1942. Mr. Israel became a member of the Board of Directors of Emerson Radio in 1943 and in 1944 assumed the duties of vice-president in charge of engineering and production. He is general chairman of the Papers Procurement Committee of The Institute of Radio Engineers and chairman of the receiver section of the engineering department of Radio Manufacturers Association. In 1931, Mr. Israel was chairman of the Cincinnati Section of The Institute of Radio Engineers. He was an instructor in radio engineering at the Evening College of the University of Cincinnati for three years.

G. Liebmann (A'40) was born in Berlin, Germany, on June 29, 1906. He received his Ph.D. degree in physics in 1930 from the University of Berlin. After work as student research assistant in the laboratories of the Osram company, Berlin, in 1929, and in Dr. Seemann's X-Ray laboratory, Freiburg, he was, in 1930, a post-graduate research fellow at the Physical Institute of Berlin University. From 1930 to 1936 he was a research physicist and development engineer in the radio-tube factory of Radio A.G.D.S. Loewe, Berlin-Steglitz. Since 1937 he has been in charge of the vacuum electronic research laboratory of Pye, Ltd., Cambridge, England, being transferred in 1939 in the same capacity to a subsidiary company, Cathodeon Ltd., Cambridge, England. Dr. Liebmann is a Fellow of the Institute of Physics.

R. E. Marbury

R. E. Marbury studied engineering at Georgia School of Technology, and later at Carnegie Institute of Technology. He joined the Westinghouse Electric and Manufacturing Company staff in 1917, and became section engineer in charge of capacitors in 1929. In 1930, Mr. Marbury was appointed assistant manager of the supply engineering department, and in 1931 was promoted to the position of manager of that department. Since 1934 Mr. Marbury has been section engineer in charge of capacitors in the switchgear engineering department.

J. C. Niven* was born in Melbourne, Australia, and received the degree of B.Sc. from the University of Melbourne in 1940. He entered the Government Service and spent two years on optical design. In 1942 he joined Amalgamated Wireless (Australasia), Ltd., in Sydney, and has been working on tropical research on materials and components for signals equipment for the Allied Forces.

* Paper published in May, 1945, PROCEEDINGS

J. C. Niven

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E.M.

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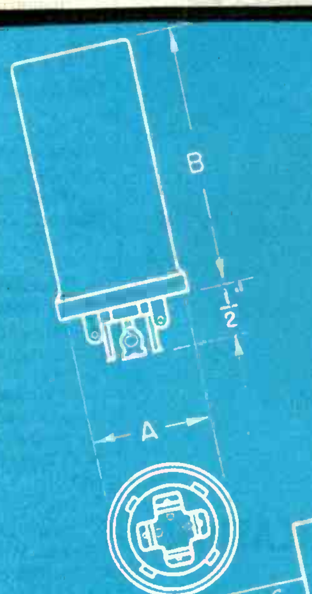

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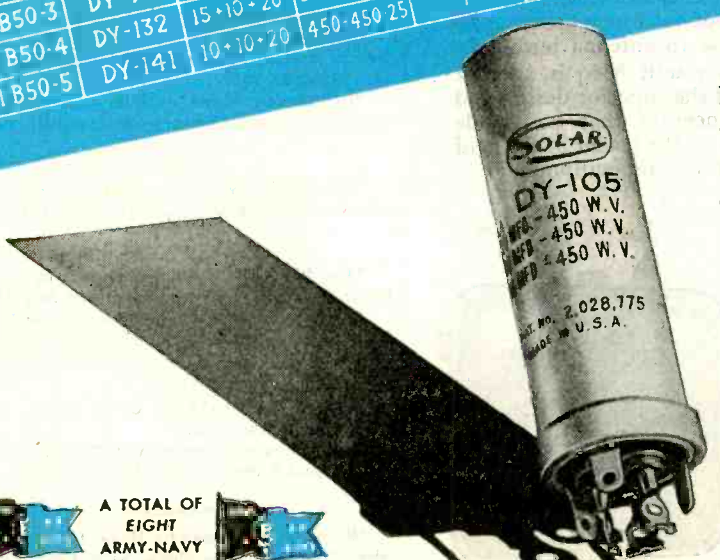

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SECTION MEETINGS

Baltimore

"Railroad Radio," by J. W. Hammond, Bendix Radio Division; February 27, 1945.

"Wartime Developments in Electronics," by W. L. Everitt, President, The Institute of Radio Engineers, Inc.; March 27, 1945.

Symposium, "Blue Print of Progress," by W. L. Everitt, President, The Institute of Radio Engineers, Inc.; L. P. Wheeler, Federal Communications Commission; C. J. Burnside, Westinghouse Radio Division; E. M. Webster, United States Coast Guard; R. R. Batcher, Caldwell-Clements; J. R. Poppele, Bamberger Broadcasting Service; G. W. Bailey, Executive Secretary, The Institute of Radio Engineers, Inc.; A. L. Aderton, I.R.E. Building Fund.

"Industrial Electronics," by M. P. Vore, Westinghouse Electric and Manufacturing Company; April 24, 1945.

"2-B Regretter," by W. L. Webb, Bendix Radio Corporation; April 24, 1945.

Cedar Rapids

"Facts About Quartz Crystals, Part I," by R. E. Colander, Collins Radio Company; April 11, 1945.

"Facts About Quartz Crystals, Part II," by R. L. Campbell, Collins Radio Corporation; April 11, 1945.

Chicago

"Management Problems of the Maker of Engineering Products," by A. E. Thiessen, General Radio Company; April 20, 1945.

Connecticut Valley

"Spectroscopic Reception," by Dale Pollack, Templetone Radio Corporation; March 15, 1945.

"Mechanics of Phonograph Reproduction," by W. C. Bachman, General Electric Company; April 10, 1945.

Dayton

"Radio-Frequency Spectrum Analyzers," by E. M. Williams, Wright Field; April 19, 1945.

Election of Officers, April 19, 1945.

Emporium

"Induction Heating," by N. Levin, Induction Heating Corporation; April 6, 1945.

Indianapolis

"Radio—Past and Present," by C. B. Jolliffe, RCA Laboratories; March 23, 1945.

"Wartime Developments in Electronics," by W. L. Everitt, President, The Institute of Radio Engineers, Inc.; April 11, 1945.

Kansas City

"Wartime Developments in Electronics," by W. L. Everitt, President, The Institute of Radio Engineers, Inc.; March 20, 1945.

"16-millimeter Sound on Film Recording," by Allen Jacobs, Calvin Company; April 24, 1945.

London

"High-Frequency Measurements," by D. B. Sinclair, General Radio Company; March 23, 1945.

Los Angeles

"Television Broadcasting—Postwar," by C. G. Pierce, General Electric Company; March 20, 1945.

"Wartime Developments in Electronics," by W. L. Everitt, President, The Institute of Radio Engineers, Inc.; April 24, 1945.

Ottawa

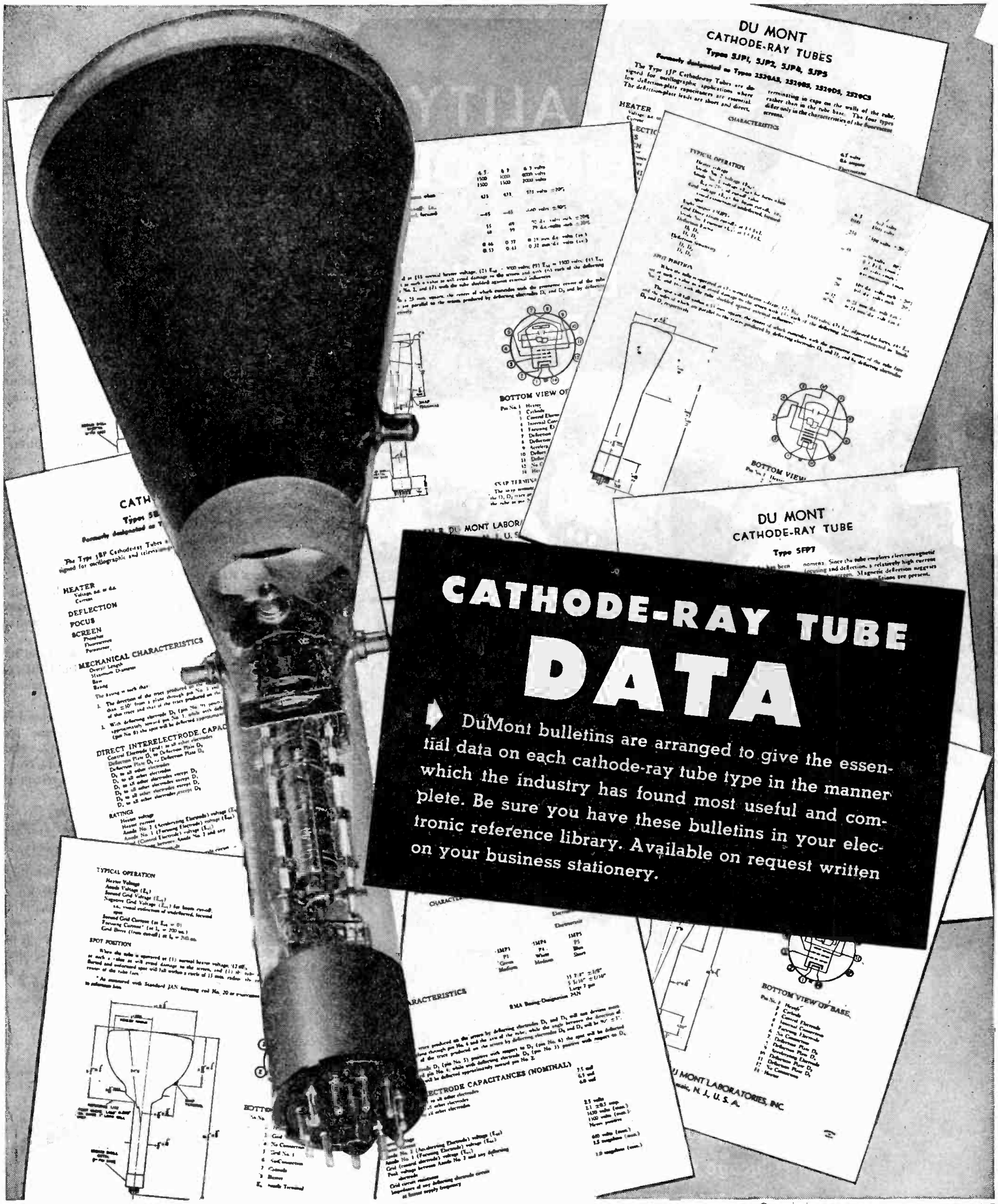
"Air-Traffic Control," by C. C. Bogart, Civil Aviation; March 14, 1945.

"High-Frequency Measurements," by D. B. Sinclair, General Radio Company; March 27, 1945.

Philadelphia

"Projection Kinescopes for Home Television Receivers," by L. E. Swedlund, RCA Laboratories; April 5, 1945.

(Continued on page 36A)



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SECTION MEETINGS

(Continued from page 34A)

"Oscilloscope Tube Performance," by D. F. Holshouser, RCA Laboratories; April 5, 1945.

PITTSBURGH

"Theory of High Frequency Heating," by T. P. Kinn, Westinghouse Electric and Manufacturing Company; April 9, 1945.

ROCHESTER

"Quartz Crystals from an Engineer's Viewpoint," by A. A. Leonard, North American Philips Company; April 19, 1945.

ST. LOUIS

"Hearing Characteristics and the Communications Industry," by C. E. Harrison, Techsonic Recording Laboratories; February 22, 1945.

"Wartime Developments in Electronics," by W. L. Everitt, President, The Institute of Radio Engineers, Inc.; March 21, 1945.

SEATTLE

"Wartime Developments in Electronics," by W. L. Everitt, President, The Institute of Radio Engineers, Inc.; April 16, 1945.

TORONTO

"Aircraft Radio and Electrical Systems," by D. R. Taylor, Trans-Canada Air Lines; January 12, 1945.

"Technical Library Facilities in the Toronto Area," by G. J. Irwin, Philco Corporation of Canada; January 22, 1945.

"The Association of Professional Engineers and Its Accomplishments," by T. M. Medland, Public Relations Association of Professional Engineers; January 22, 1945.

"Response Curves and Frequency Compensation of Resistance-Capacitance Coupled Amplifiers," by W. B. Ball, University of Toronto; February 12, 1945.

"High-Frequency Heating of Metallic and Non-metallic Materials," by K. E. Robinson, University of Toronto; February 12, 1945.

"Ultra-High-Frequency Oscillators," by G. C. Eastwood, University of Toronto; February 12, 1945.

TWIN CITIES

"Extreme Selectivity Without Crystals," by Ray Robel, Northwest Airlines, Inc.; April 10, 1945.

WILLIAMSPORT

"Telephone Service for Vehicles and Vessels in Urban Areas," by R. T. Griffith, Bell Telephone Company of Pennsylvania; April 6, 1945.

"General Mobile Radiotelephone Service for the Nation's Highways," by Austin Bailey, American Telephone and Telegraph Company; April 6, 1945.

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Fay, C. E., 463 West St., New York 14, N. Y.
Fernsler, G. L., 36 Green Ave., Lawrenceville, N. J.
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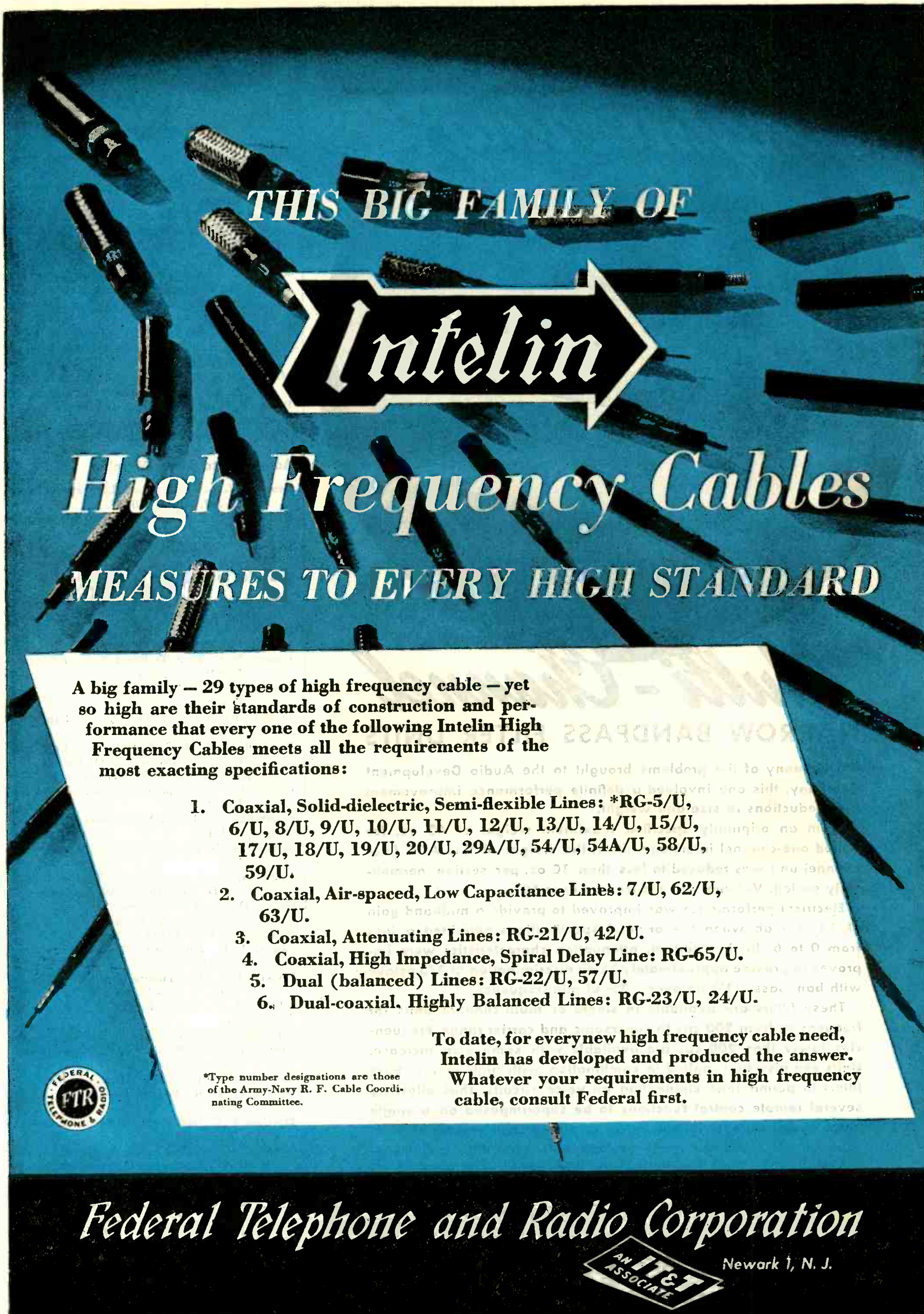
(Continued on page 38A)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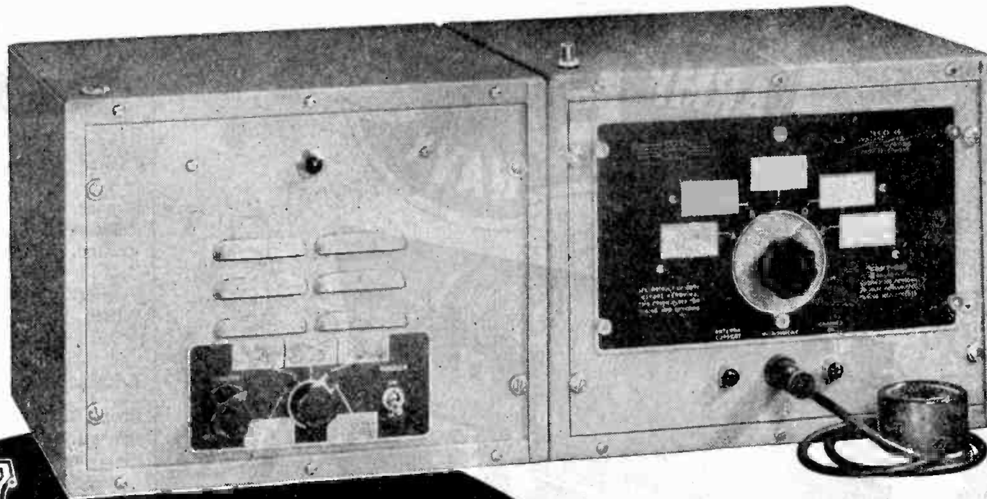

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ABOVE: Series 46 KAAR radiotelephone, showing 5 channel transmitter and crystal-controlled receiver mounted side by side.

BELOW: Same units mounted in a different manner, and showing how transmitter slides out for servicing.

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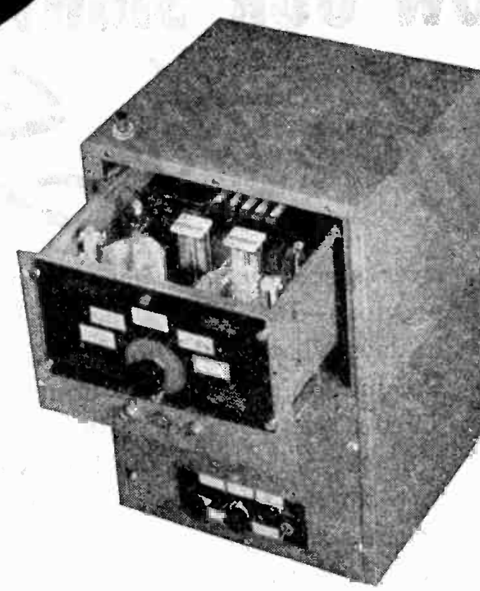

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SYLVANIA NEWS

ELECTRONIC EQUIPMENT EDITION

JUNE *Published by* SYLVANIA ELECTRIC PRODUCTS INC., Emporium, Pa. 1945

SYLVANIA'S CHART AIDS STANDARDIZATION OF TUBES

Reference List Recommendations Reduce Radio Tube Types

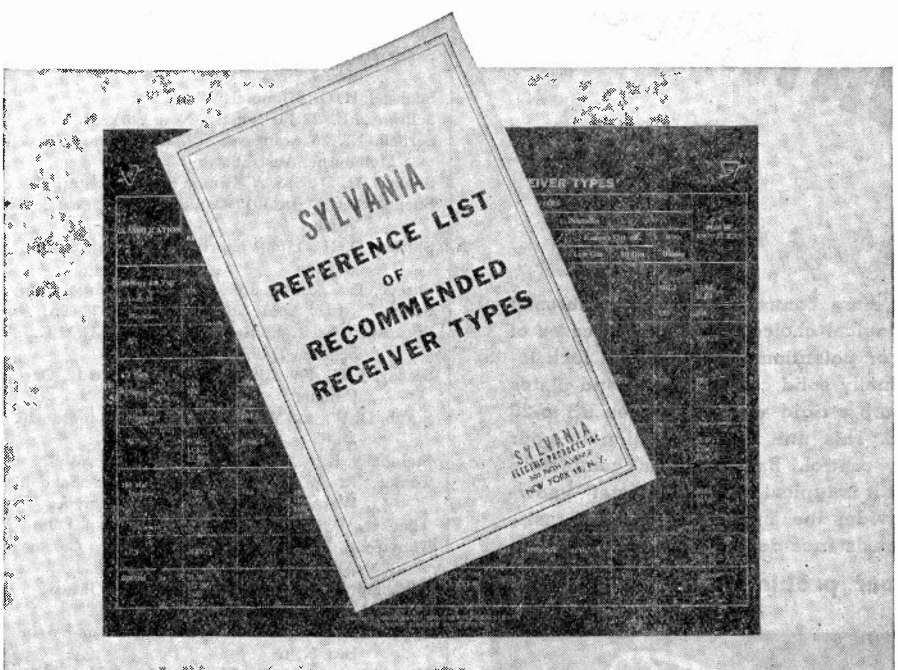
AS an aid to the standardization of radio receiver tube types, Sylvania has prepared the chart reproduced below—another item in Sylvania's long-time program of technical assistance to the radio industry.

The number and variety of tube types have grown in recent years, and this trend has intensified war scarcities.

Naturally, it would seem to be advantageous to radio set manufacturers to further standardize tube selection and limit their variety. This would probably meet with approval in many parts of the radio industry, particularly among radio servicemen since they are in an active position when it comes to tube replacement and general radio set repairing.

(An indication of their opinion concerning tube types was revealed in Sylvania's survey in which 90.5% of the servicemen questioned said they would prefer fewer and simpler tube types.)

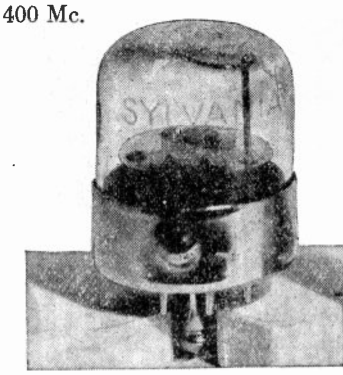
This handy reference chart will help smooth some of the wrinkles of the problem and act as a future guide. Write for it to Sylvania Electric Products Inc., 500 Fifth Ave., New York 18, N. Y.

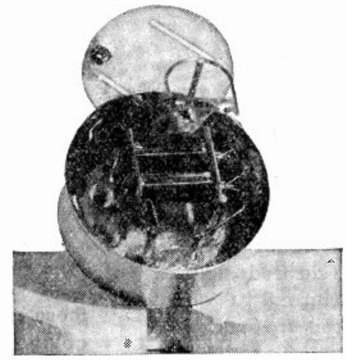


Double Triode Tube Has Two Uses

Acts As Converter Or Amplifier

Sylvania's new high mutual conductance double triode tube—Type 7F8—is designed for use at frequencies up to 300 or 400 Mc.





With precautions the two sections may be used separately, saving space and the number of tubes required for a given performance since all the elements except the heaters are independent.

The cascade operation thus made possible is useful in u-h-f grounded grid and cathode follower amplifier service. It may also be used as a push-pull u-h-f amplifier.

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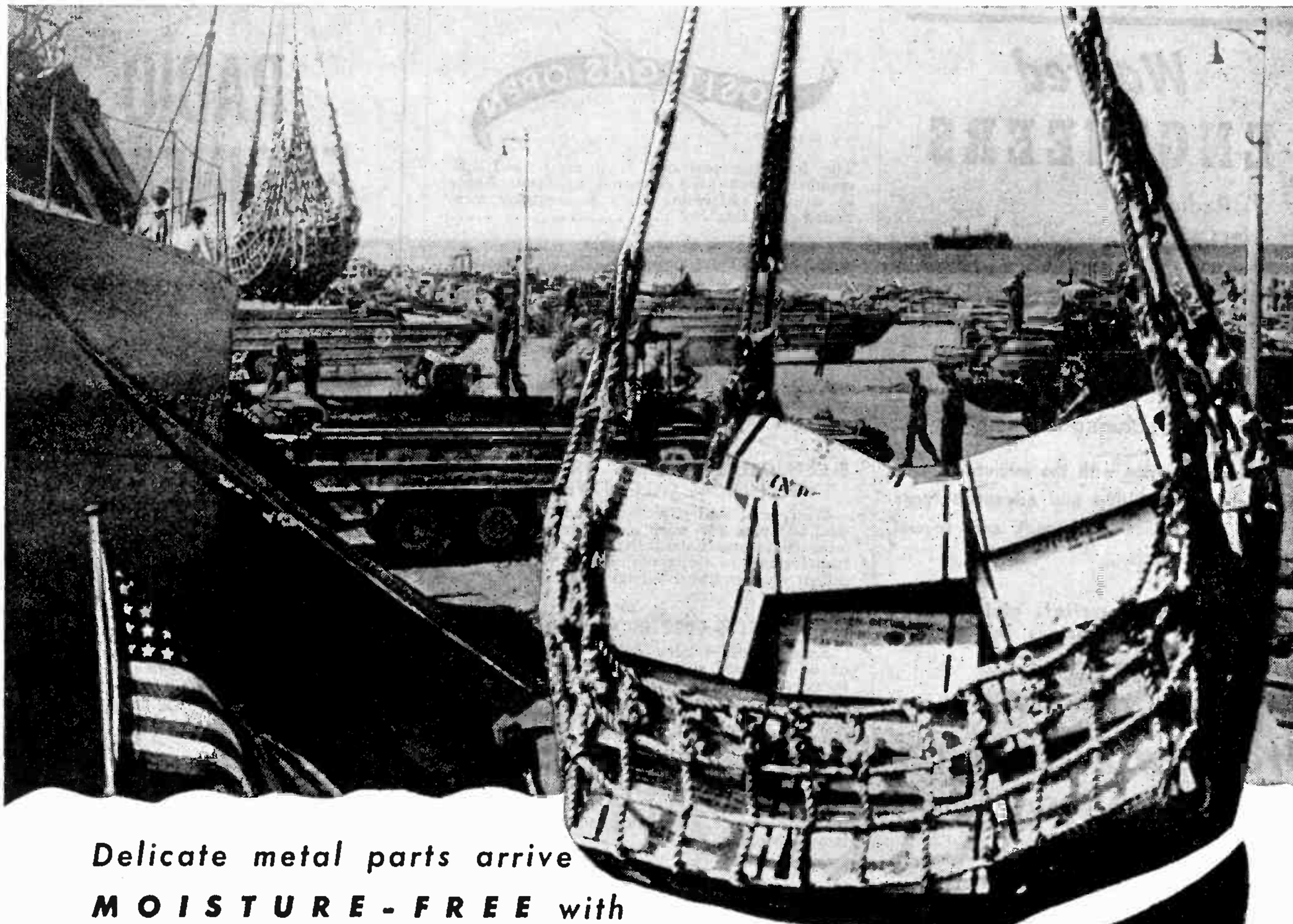
(Continued on page 68A)



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Materials Handling
Manufacturing Planning

Work in connection with the manufacture of a wide variety of new and advanced types of communications equipment and special electronic products.

Apply (or write), giving full qualifications, to:

R.L.D.
EMPLOYMENT DEPT.

Western Electric Co.

100 CENTRAL AVE., KEARNY, N.J.

*Also: C.A.L.
Locust St., Haverhill, Mass.

Applicants must comply with WMC regulations

POSITIONS OPEN

The following positions of interest to I.R.E. members have been reported as open. Apply in writing, addressing reply to company mentioned or to Box No. ....

The Institute reserves the right to refuse any announcement without giving a reason for the refusal.

PROCEEDINGS of the I.R.E.
330 West 42nd Street, New York 18, N.Y.

RADIO ENGINEER

Graduate, 5 years experience laboratory design and construction, receivers and associated equipment. Premier Crystal Laboratories, Inc., 63 Park Row, New York, N.Y.

ELECTRICAL ENGINEERS OR MEN WITH TECHNICAL SALES EXPERIENCE

Well-established Chicago concern will hire qualified men for work as design engineers or sales engineers. Familiarity with application of transformers in electronic circuits required. Excellent opportunities. Write qualifications in detail to Box 374.

EXECUTIVE ELECTRICAL ENGINEERS

Experienced in sales, design and manufacture of oil-immersed distribution and power transformers. These positions offer excellent post-war opportunity with forty-year-old eastern pioneer transformer manufacturer. Write outlining full details to Box 375.

RADIO AND ELECTRONIC ENGINEER

Experienced on high-frequency receiver design and development. Excellent post-war opportunity. State age, experience and salary expected. Brooklyn plant. Box 376.

ENGINEERS

ELECTRONIC ENGINEER, with laboratory experience and familiarity with circuit design

(Continued on page 52A)

RADIO ENGINEERS

Medium - sized, progressive, Midwest manufacturer has openings for one senior and two junior engineers. Desire men for work on military projects now who will be adaptable later to postwar engineering. Prefer men with experience in radio receiver or television laboratory, and with college education in communication engineering.

Our staff knows of this advertisement.

Box No. 355
PROCEEDINGS OF THE I.R.E.
330 West 42nd Street
New York 18, N.Y.

FIELD SERVICE ENGINEERS

For Domestic and Foreign Service.

And

INSTRUCTORS

Must Possess Good Knowledge of Radio.

Essential workers need release

HAZELTINE CORPORATION

58-25 Little Neck Parkway
Little Neck, Long Island

ELECTRONIC ENGINEERS

LABORATORY ASSISTANTS

Men—Women

Positions available with post-war possibilities. Accredited engineers and others with experience and background in radio and electronics are needed immediately.

Write or call Chief Engineer, giving details of education, experience and salary requirement.

ALLEN B. DUMONT LABORATORIES, INC.
Passaic New Jersey
WMC RULES APPLY

WANTED

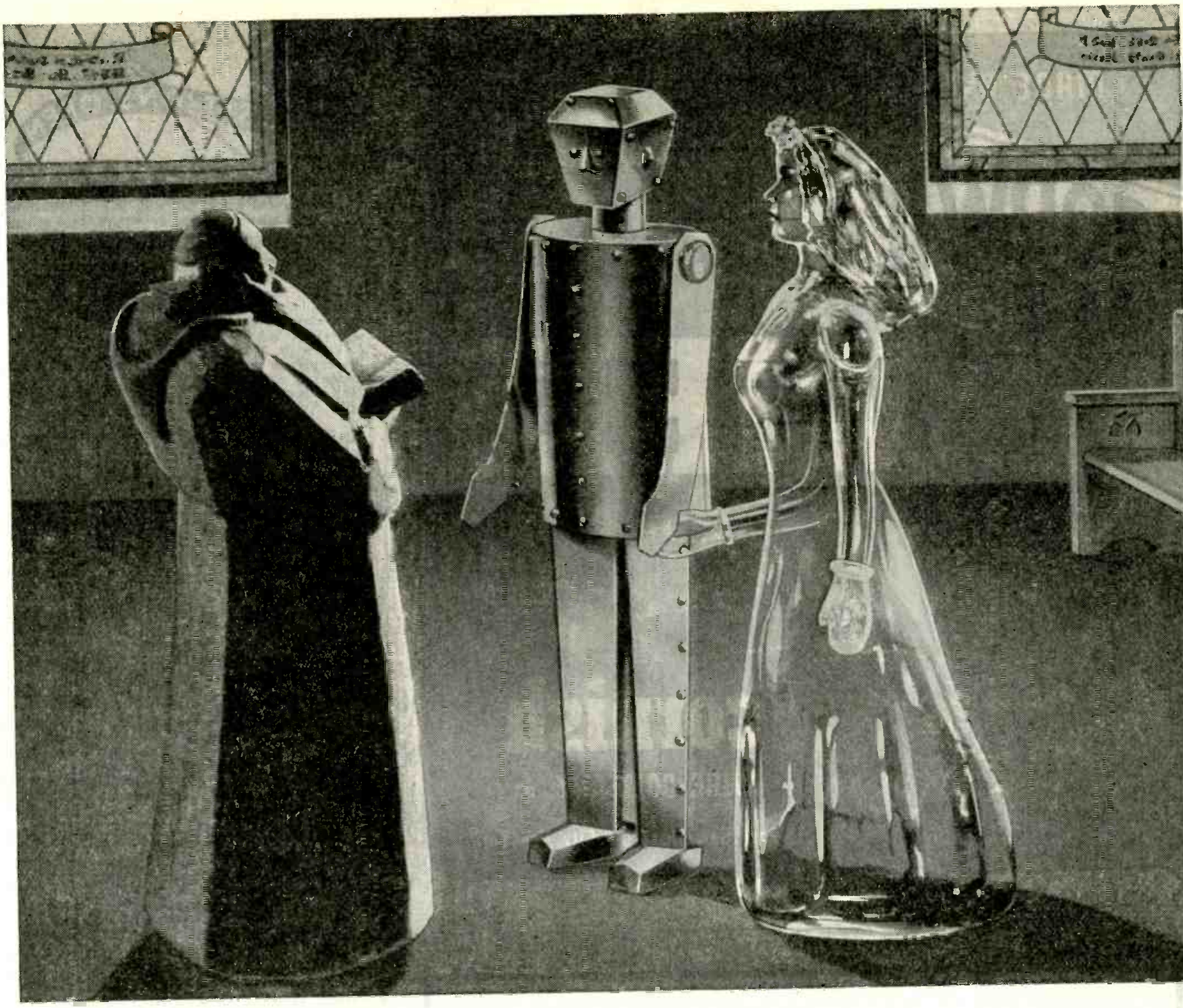
Telephone Engineers and Draftsmen

We have several attractive openings for engineers and draftsmen with experience on central office telephone switchboard equipment, especially Strowger step-by-step systems. Consideration will be given to men without manufacturing-engineering experience who are familiar with dial system principles and operation. College education is desirable but not essential. Plans for widespread postwar adoption of dial equipment in the United States and abroad make this an unusual opportunity for progress with the leading organization in its field. Applications treated in full confidence. Write Mr. E. C. Seepe, Personnel Director.

AUTOMATIC ELECTRIC COMPANY

Originators of the Dial Telephone

1033 West Van Buren Street
Chicago 7, Ill.



JOINED...FOR LIFE *through Corning Metallizing!*

REMEMBER when glass and metal just wouldn't stay hitched? They joined together readily but when the going got rough they parted company in the best Hollywood tradition.

Things are different now. *Corning's* metallizing process weds glass and metal with a bond that lasts like an old-fashioned marriage. Through heat and cold . . . under severe conditions of stress and strain, they stick together in a lasting union.

This happy union can boast a whole family of fine qualities:

HERMETIC SEALING . . . PRECISION METALLIZING . . . SUPERIOR PHYSICAL PROPERTIES . . . PERMANENCE . . . THERMAL ENDURANCE . . . MECHANICAL STRENGTH

Which of these can you use? Write us about it. We'll be glad to work with you to see if metallized glass can help solve your problem. Address Electronic Sales Department, P-6, Bulb and Tubing Division, Corning Glass Works, Corning, New York.

CORNING
means
Research in Glass

Electronic Glassware

VYCOR CORNING PYREX

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

POSITIONS OPEN

(Continued from page 50A)

and development work. Job will be in connection with high frequency heating generators and other industrial applications of electronics. Graduate in electrical or radio engineering.

JUNIOR ENGINEER, preferably engineering graduate, with experience in radio engineering laboratory, factory or engineering department. Job will be in connection with H.F. and A.F. measurements, and general development work.

JUNIOR RADIO ENGINEER OR PHYSICIST, with good mathematical background.

In replying give complete information as to experience, education, marital, draft status, and salary expected. Illinois Tool Works, 2501 North Keeler Avenue, Chicago 39, Ill.

RADIO AND ELECTRONIC ENGINEERS

For research and development in the field of radar, radio communications and electrical test equipment, good post-war opportunity, also openings available for draftsmen and junior designers. Allen D. Cardwell Manufacturing Company, 81 Prospect Street, Brooklyn, N.Y.

ASSISTANT CHIEF ENGINEER

Mid-west radio-electronics manufacturer, engaged exclusively on electronic war projects at present, requires experienced engineer to assume complete supervision of post-war development of household and auto radio receivers. Television receiver experience desirable but not essential. All inquiries confidential. Write Box 377.

SENIOR DEVELOPMENT ENGINEERS

Large mid-west manufacturer, now exclusively on war radio and radar work, has immediate openings for post-war radio and television development for three senior radio project engineers, two mechanical engineers and one engineer on specifications and standards. Confidential inquiries respected. Write Box 378.

RESEARCH ENGINEERS

Prominent radio and electronics manufacturer located in mid-west has immediate openings for three research men preferably with engineering background, on post-war problems in electrical and electronic fields. Confidential inquiries respected. Write Box 379.

ELECTRICAL ENGINEER

For research and development of automotive electrical systems. General knowledge of suppression of electrical interference to radio reception necessary. Give full particulars—background, experience and availability. Box 380.

RADIO ENGINEERS

Radio, Research and Development Engineers and Draftsman needed for key positions by manufacturer of diversified line of aircraft accessories, small motors, and aircraft radio who will be in the home radio field postwar. Salaries open. Full compliance with WMC regulations necessary. Confidential inquiries respected. Live in the midst of the best hunting and fishing in Michigan. Our employees know of this ad. Address Box 381.

PHYSICIST AND ELECTRICAL ENGINEER OR ENGINEERING PHYSICIST

Physicist qualified to supervise industrial and fundamental research in acoustics. Ph.D. with industrial experience preferred.

Also an electrical engineer or engineering physicist for research position in fundamental and applied electronics. Some industrial experience preferred. Write Armour Research Foundation, 35 West 33rd Street, Chicago 16, Illinois.

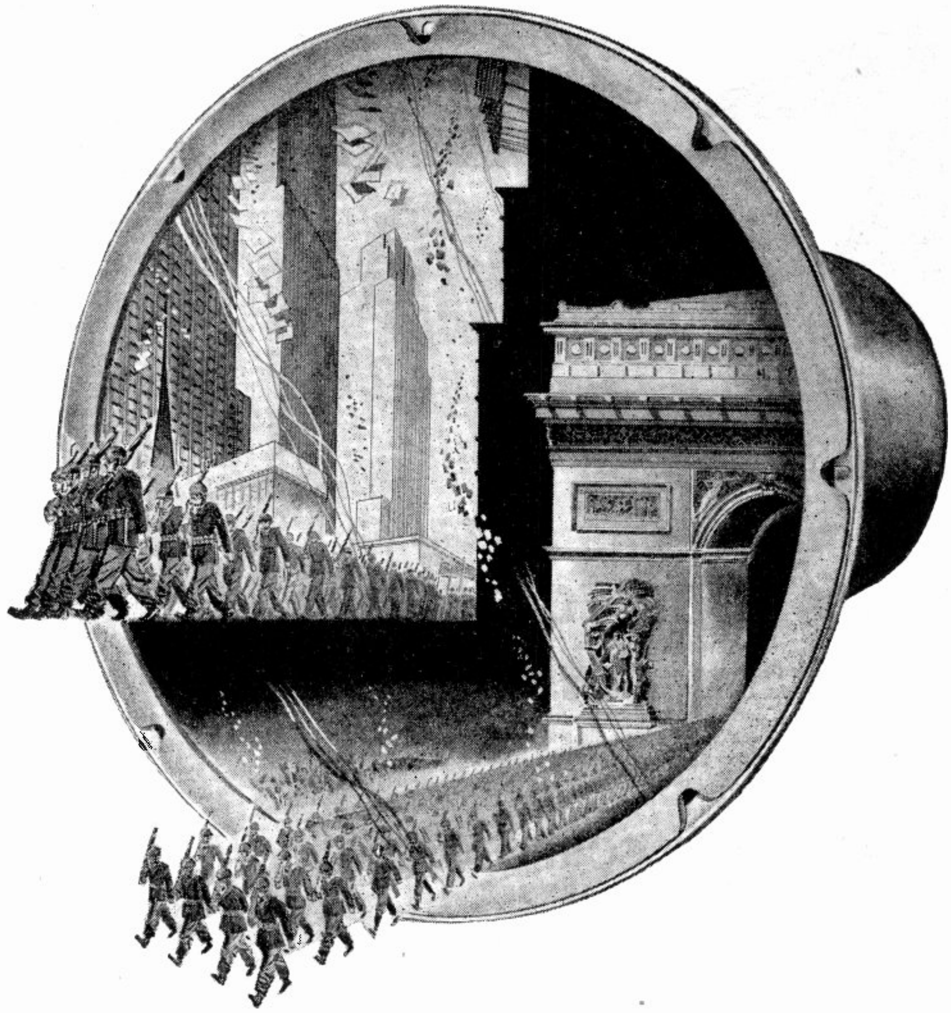
COMMUNICATION OR RADIO ENGINEERS AND PHYSICISTS

A leading Eastern University is in immediate need of several communication or radio engineers and physicists for a war research project, the importance of which is certified by the armed services. This is an opportunity to make a real contribution to the successful and rapid completion of the Pacific War. The location is on an attractive campus and satisfactory salary arrangements can be made. Write to Box 370.

ELECTRONIC AND AUDIO ENGINEER

Electronic and audio engineer for key position in established manufacturing concern with its own laboratories and wide range of facilities. Liberal salary. Post-war opportunities assured

(Continued on page 54A)



The Loudspeaker Everyone is Waiting for

NO, it isn't necessarily a Rola. The sound for which the Nation is so eagerly and confidently waiting is the news that Victory is ours . . . that men and women will come home . . . that the bright dawn of world peace is in sight.

In many homes it *will* be a Rola, for millions of radio sets have been Rola equipped, but regardless of who made it, the loudspeaker that brings this welcome news will be the sweetest sounding speaker anyone ever listened to.

Afterward will come still finer Rola speakers, improved by discoveries and developments that can't be talked about now. Meanwhile, busy as it is in highly important war work, Rola can do no more than provide speaker models for authorized experimental work and consult with Manufacturers on their peacetime plans.

THE ROLA COMPANY, INC. • 2530 SUPERIOR AVENUE, CLEVELAND 14, OHIO

ROLA

ARMY E NAVY

MAKERS OF THE FINEST IN SOUND REPRODUCING AND ELECTRONIC EQUIPMENT

POSITIONS OPEN

(Continued from page 52A)

by civilian markets. Design and production experience in audio frequency and R. F. fields desired. For confidential interview address Box 371 stating background and qualifications.

TRANSFORMER DESIGN ENGINEER

Transformer design engineer for one of the leading transformer manufacturers. Located in New York metropolitan area. If you are E.E. graduate and interested in becoming associated with a company which has real post-war possibilities write to Box 372 giving detailed information about yourself.

SALES MANAGER—PARTS JOBBER

Somewhere there is a radio parts salesman or sales engineer now working for a manufacturer's agent, jobber, or manufacturer of radio parts who has cut his eye teeth and is ready for a bigger job.

To such a man we offer a real post-war opportunity, with a hard hitting aggressive organization located in metropolitan area of New York. This company will have a quality line of parts and test equipment to be merchandised and sold through the electronic jobber. Salary and participating basis. If you have the necessary qualifications we want to hear from you. Write fully, in confidence to Box 373.

RESEARCH ENGINEERS

Several positions for Physicists, Analysts, and Electronic Engineers are open with the University of California Division of War Research. For further details write, giving personal history, education and qualifications, to Personnel Manager, University of California Division of War Research, U. S. Navy Radio & Sound Laboratory, San Diego 52, California.

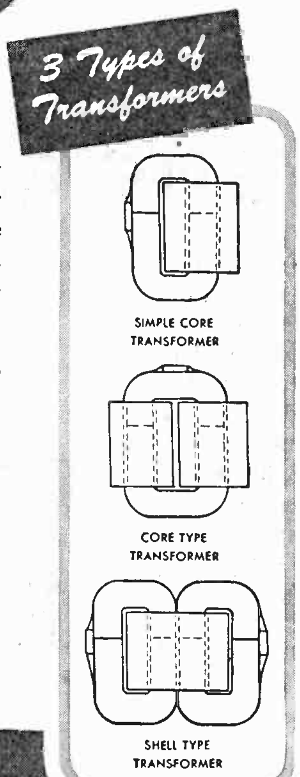
ELECTRONIC ENGINEERS AND TECHNICIANS

These war jobs, with peace-time opportunities, are open in research laboratory and two manufacturing plants in Newark, N.J., and plant near Philadelphia, Pa.

ENGINEERS: SENIOR TUBE, COMMERCIAL, QUALITY CONTROL MEN AND WOMEN. TEST EQUIPMENT.

JUNIOR ENGINEERS: Men and women with degrees in physics, electrical engineering, chemical engineering, mechanical engineering, mathematics, or chemistry.

(Continued on page 56A)



POSITIONS OPEN

(Continued from page 54A)

FOREMEN AND ASSISTANT FOREMEN, experienced in radio or radio tube manufacture. TECHNICIANS, CIRCUIT MEN, to do wiring and construction.

Address replies to National Union Radio Corporation, Plane St. at Raymond Blvd., Newark 2, N.J. (WMC rules apply.)

RADIO AND RADAR ENGINEERS

Your services are vitally needed by the Army Air Forces for the development of ground communication systems peculiar to the Air Forces. These projects are now under development at the newly activated AAF, Watson Laboratories, Red Bank, N.J.

These are Civil Service positions and the pay scale ranges from $2600 to $5600 per annum.

Application may be made to the Civil Service Commission, 641 Washington St., New York, N.Y. or by contacting the Personnel Officer of the Watson Laboratories, Red Bank, N.J.

RADIO, ELECTRICAL AND MECHANICAL ENGINEERS

Opportunity for men with experience in design of receivers and allied equipment. Extensive post-war program. Write fully outlining experience, salary desired, etc. Address Bernard Fein, Electronic Corporation of America, 45 West 18th St., New York, N.Y.

RADIO ENGINEERS

Southern California manufacturer has openings for senior radio engineers with design experience in home receivers, communication receivers, and phono play-backs. Communicate with A. O. Williams, 703 West Ivy St., Glendale 4, Calif.

THE OHIO STATE UNIVERSITY

Announces Westinghouse Educational Fellowships in Electron Optics

A post-doctoral fellowship—$3600 per year. Two pre-doctoral fellowships—$1000 per year.

Open to graduates in Physics, Mathematics or Electrical Engineering.

Application forms may be secured from the Dean of the Graduate School, Ohio State University, Columbus 10, Ohio

---

OPENINGS FOR

RADIO

ENGINEERS

ELECTRICAL

ENGINEERS

MECHANICAL

ENGINEERS

In the development and production of all types of radio receiving and low-power transmitting tubes. Excellent post-war opportunities with an established company in a field having unlimited post-war possibilities.

Apply in person or in writing to:

Personnel Manager

RAYTHEON MANUFACTURING CO.

Radio Receiving Tube Div.

55 Chapel St., Newton, Mass.

10 Wattage Sizes

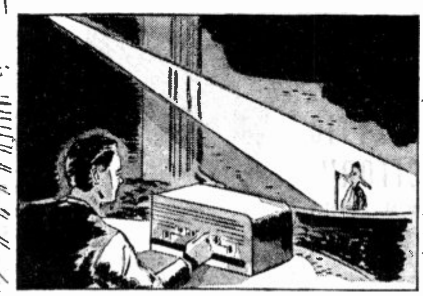
. . . in a variety of types to meet every need

There's an Ohmite Rheostat to assure the best unit for each control need . . . from the 1000 watt, 12″ diameter, Model "U" to the 25 watt, 1$\frac{9}{16}$″ diameter, Model "H". Made in single or tandem units, with uniform or tapered windings, in stock or special resistance values. And large or small—each Ohmite Rheostat is designed to give smooth, close control—long life—and trouble-free service. In Resistance Control, Ohmite Experience Makes a Difference.

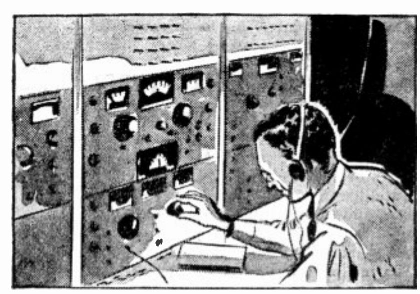
Write on company letterhead for Catalog and Engineering Manual No. 40.

OHMITE MANUFACTURING CO.
4861 Flournoy St., Chicago 44

AMATEUR



SOUND AMPLIFIER



COMMUNICATIONS

EXPERIMENTAL

INDUSTRIAL

FIELDS OF TOMORROW

will be developed more efficiently because of Thordarson Transformers being designed TODAY!

Our 50 years of general experience, plus the many new results of war-time research are a guarantee that Thordarson will have the right transformer for every need, when civilian orders may again be accepted.

ARMY E NAVY

THORDARSON

TRANSFORMER DIVISION
THORDARSON ELECTRIC MFG. CO.
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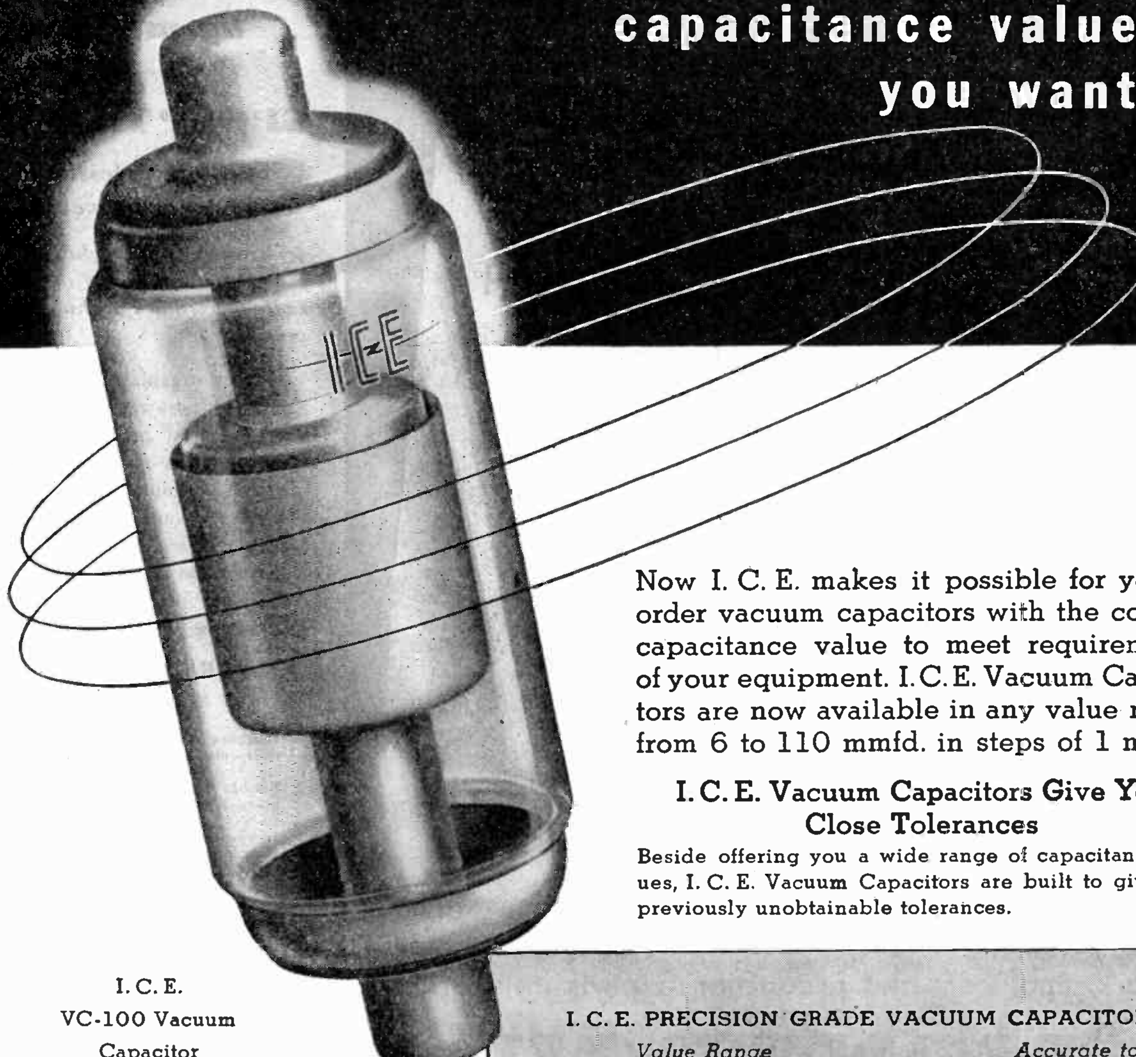
Transformer Specialists Since 1895

. . ORIGINATORS OF TRU-FIDELITY AMPLIFIERS

ONLY I.C.E. VACUUM CAPACITORS give you the precise capacitance value you want



I. C. E.
VC-100 Vacuum
Capacitor

Now I. C. E. makes it possible for you to order vacuum capacitors with the correct capacitance value to meet requirements of your equipment. I. C. E. Vacuum Capacitors are now available in any value range from 6 to 110 mmfd. in steps of 1 mmfd.

I. C. E. Vacuum Capacitors Give You Close Tolerances

Beside offering you a wide range of capacitance values, I. C. E. Vacuum Capacitors are built to give you previously unobtainable tolerances.

I. C. E. PRECISION GRADE VACUUM CAPACITORS

Value Range	*Accurate to*
6 mmfd. to 25 mmfd.	±0.5 mmfd.
26 mmfd. to 60 mmfd.	±1.0 mmfd.
61 mmfd. to 110 mmfd.	±1.5 mmfd.

I. C. E. XX GRADE VACUUM CAPACITORS

Value Range	*Accurate to*
6 mmfd. to 25 mmfd.	±0.2 mmfd.
26 mmfd. to 60 mmfd.	±0.3 mmfd.
61 mmfd. to 110 mmfd.	±0.5 mmfd.

Full Details in the New I. C. E. Catalog

For full information on these outstanding I. C. E. Vacuum Capacitors, as well as other precision I. C. E. products, write today for the new I. C. E. Catalog.

ELECTRONIC TUBES
RESEARCH • DESIGN • PRODUCTION

INDUSTRIAL & COMMERCIAL ELECTRONICS
BELMONT, CALIFORNIA • NEW YORK CITY, N. Y.

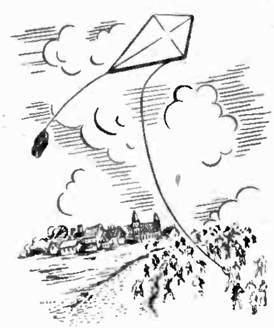
"NOTHING BUT THE TRUTH"

by
ALEXANDER McQUEEN
Famous Radio Feature Commentator

A Monarch Fact Story

THEY TESTED THE AIR WITH A PIECE OF RAW BEEF . . .

In London, about 1730, when doctors wanted to test the air for purity, they would send up a piece of beef on the tail of a kite. After 10 minutes the beef would be pulled down, and if it was not spoiled the air was considered healthful. Actually this was NOT a scientific test, because the composition of the upper air is almost surely different from that of the air at ground level.



. . . and that's "NOTHING BUT THE TRUTH"

. . . BUT TODAY

For the exacting measurements and calibrations which are desirable in every phase of radio and electronic work, engineers and production experts insist upon

MONARCH

TESTING • MEASURING • CALIBRATING EQUIPMENT

. . . and that's "nothing but the truth"

MONARCH MFG. CO.

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CREI *suggests that you—*

Modernize

The Technical Knowledge of Your Employees

by means of

CREI GROUP TRAINING

For Professional Self-Improvement

★ ***Prepare your technical staff to meet the challenge of post-war radio-electronics technological demands.***

If your organization plans engagement in post-war radio-electronics, your technical personnel must know FM—television—Ultra High Frequency Techniques, and all other phases of war-developed electronics technology; and, of course, a thorough and complete knowledge of the fundamentals of practical radio-electronics engineering.

The CREI "Employers' Plan" for group training will:

1. *Increase the technical abilities of your radio-electronics personnel.*
2. *Enable them to perform their duties more efficiently and in less time.*
3. *Increase the value of their services to your organization.*

No company time is required for this training . . . it is accomplished by spare-time, home study.

The CREI "Employers' Plan" is useful for the up-grading of technical personnel in manufacturing, AM, FM, and television broadcasting, communications, industrial electronics, including the following:

Engineers	**Testers**
Engineering Aides	**Technicians**
Laboratory Assistants	**Field Servicemen**
	Installers
Inspectors	**Maintenance Men**

The CREI "Employers' Plan" for group training is tailored to meet each individual organization's requirements.

Your request will promptly bring an outline of the plan, as now in use with other organizations, and intimate details will follow when your particular needs are known. No obligation or cost, of course.

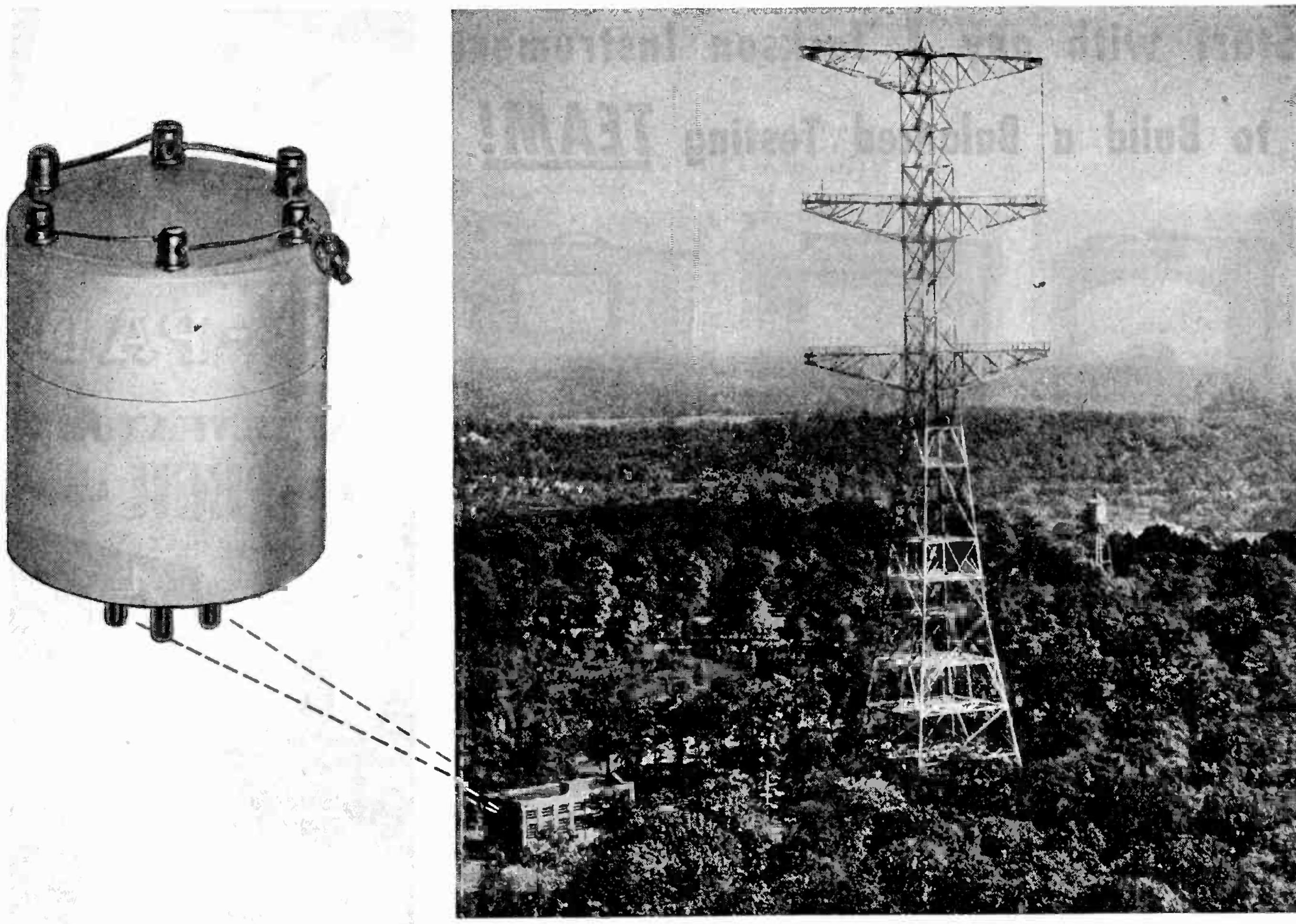
CAPITOL RADIO Engineering Institute

E. H. RIETZKE, President

Home Study Courses in Practical Radio-Electronics Engineering for Professional Self-Improvement

Dept. PR-6, 3224—16th St., N.W. WASHINGTON 10, D.C.

Contractors to the U. S. Navy—U. S. Coast Guard—Canadian Broadcasting Corp. Producers of Well-trained Technical Radiomen for Industry.



Pioneer FM station uses BLILEY CRYSTALS

When Major Armstrong's station W2XMN went on the air from Alpine, New Jersey on July 18, 1939, radio history was in the making. This first FM transmitter to be put in service, built by REL, employed the Armstrong crystal-controlled phase shift modulation.

Bliley crystals are doing an excellent job in this outstanding pioneer FM installation.

For advanced engineering it is always worthwhile to specify Bliley crystals. An outstanding example of this is the discovery and development by Bliley engineers of ACID ETCHED CRYSTALS*. This technique was an established part of Bliley production before Pearl Harbor. It is now recognized as a prerequisite to dependable service in military equipment.

It is a good habit to consult Bliley engineers when new developments are in the making. Our specialized engineering can often be of real assistance toward solution of your design problems. This kind of service has made Bliley the foremost producer of quartz crystals for amateur and commercial radio in peacetime and for our armed forces in time of war.

* * *

**Acid etching quartz crystals to frequency is a patented Bliley process. United States Patent No. 2,364,501.*

ARMY E NAVY

Bliley CRYSTALS

Do more than before...

buy **extra** War Bonds

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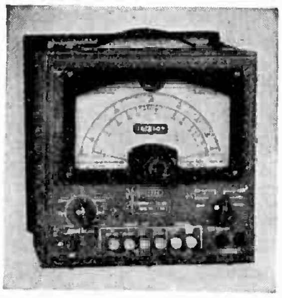
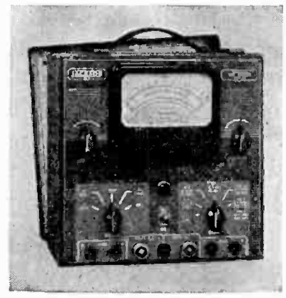
UNION STATION BUILDING • ERIE, PENN.

Start with any 1 Jackson Instrument to Build a Balanced Testing TEAM!

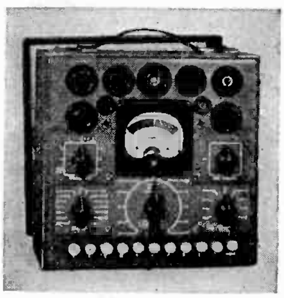


Condenser Tester
Model 650A—Measures Capacity, Power Factor and Leakage

Sensitive Multimeter
Model 642—20,000 ohms per volt—complete ranges

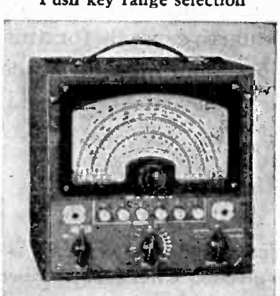


Electronic Multimeter
Model 645—A new Jackson instrument of advanced design



Tube Tester
Model 634—Uses exclusive Jackson "Dynamic" Test Method

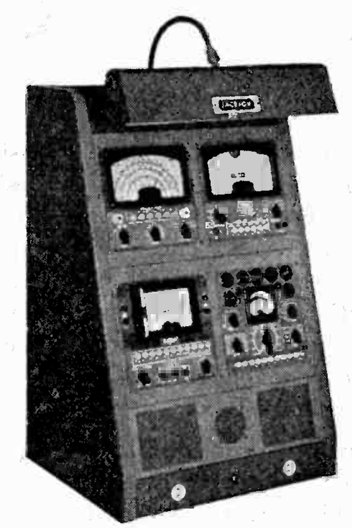
Multimeter
Model 643—1000 ohms per volt. Push key range selection



Test Oscillator
Model 640—Accurate to ½%, covers full frequency range

IT'S A PLUS VALUE of the Jackson line. Each instrument is engineered and manufactured for long accurate life, as today's users know — but every one is carefully matched in appearance, dimensions and finish as well.

Start with whichever Jackson instrument you need first. Add to it as occasion demands. Your foresight will be repaid with a matched and balanced set of instruments built to give you testing results that you just can't get with hit-or-miss assemblies. Plan now to equip your shop with these Jackson instruments. See your distributor.



Service Lab
Assembly of *Standard Size* Jackson Instruments

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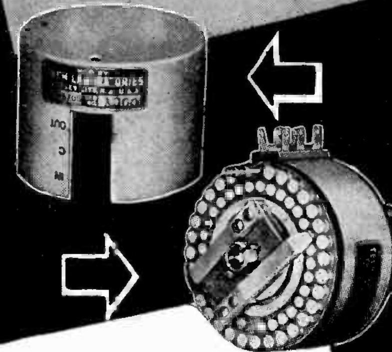
JACKSON

Fine Electrical Testing Instruments

JACKSON ELECTRICAL INSTRUMENT COMPANY, DAYTON, OHIO

NEW IMPROVED "T"-PAD ATTENUATORS BY TECH LAB



- Stainless Silver Alloy contacts and wiper arms.
- Rotor hub pinned to shaft prevents unauthorized tampering and keeps wiper arms in perfect adjustment.
- Can be furnished in any practical impedance and db. loss per step upon request.
- Write for our Bulletin No. 431.

TECH LAB MICROHMMETER

Direct and instantaneous resistance readings down to 5 microhms and up to 1,000,000 megohms. Write for Bulletin No. 432.

TECH LABORATORIES
7 LINCOLN STREET
JERSEY CITY 7, N. J.

SCOVILL charted a new "course" for radio compass terminals and made them faster and better for less

Scovill Electrōnents may give you the same competitive advantages*

Electric terminals for radio compasses were needed faster than screw machines could turn them out of rod stock. Asked to suggest a speedier method, Scovill recommended stamping them out of sheet metal. Given the job, Scovill produced many more terminals per day at a much lower cost . . . and paid an extra dividend in the form of better electrical properties. That was because the sheet brass used had a higher copper content and higher conductivity than the brass rod necessary in the former method.

With the same kind of ingenuity applied to your small electronic components or complete assemblies, the chances are that Scovill can save you time and money. Investigate the designing service, manufacturing ability in all metals, and wide range of metal-working facilities that have won for Scovill the title of "Masters of Metal". Fill in coupon below and mail today.

*Electrōnents = Electronic Components

Scovill
MANUFACTURING COMPANY
WATERBURY, CONN.

Please send me a free copy of "Masters of Metal" booklet describing your facilities. I am interested in the ELECTRŌNENT* applications checked.

☐ Batteries ☐ Dials ☐ Panels
☐ Record Changers ☐ Escutcheons ☐ Sockets
☐ Clips ☐ Jacks ☐ Stampings (misc.)
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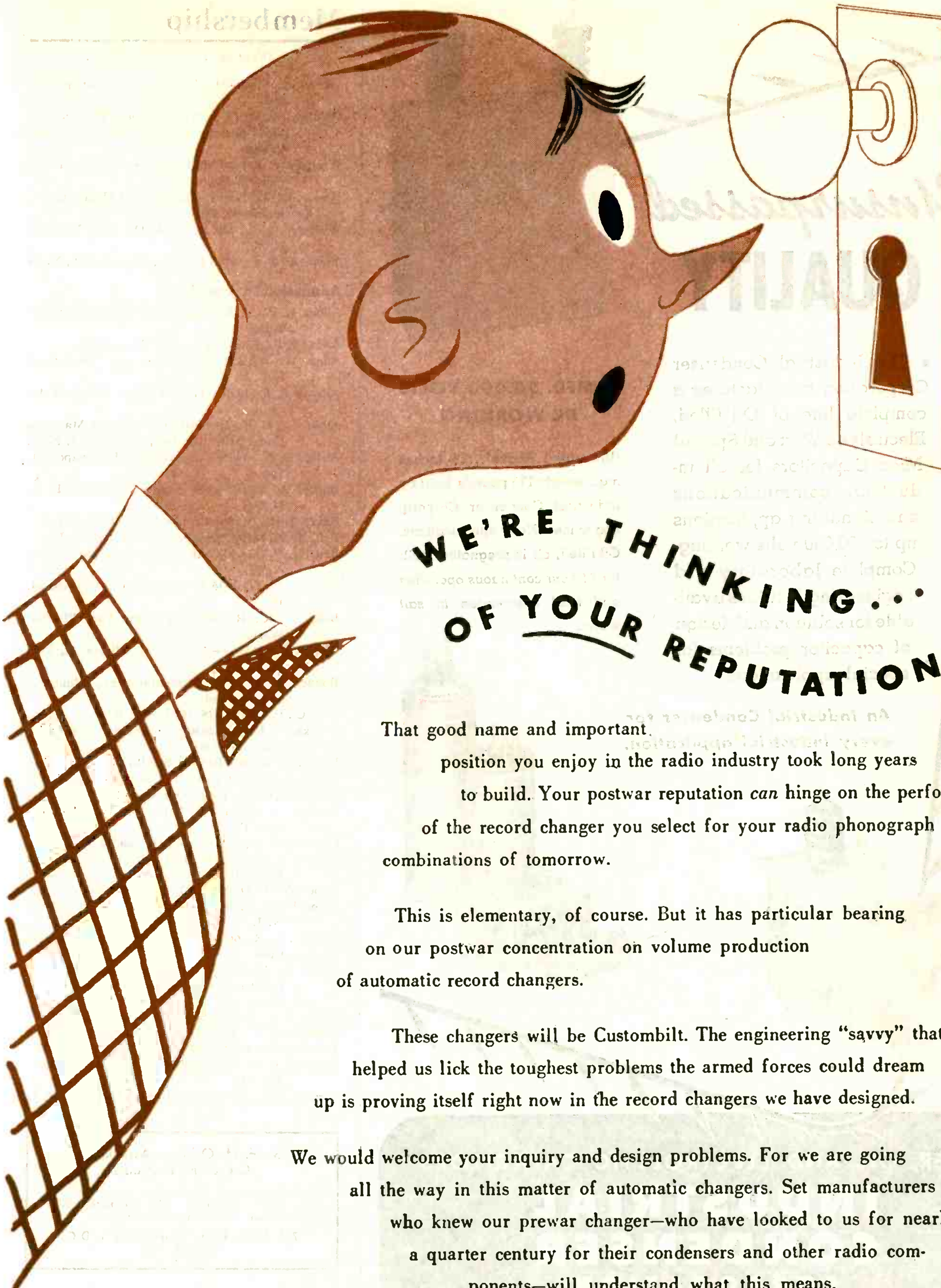
Other applications..........

SCOVILL MANUFACTURING COMPANY
Electronic Division
26 Mill Street, Waterbury 91, Connecticut

Name ....

Company ....

Address..........



WE'RE THINKING... OF YOUR REPUTATION!

That good name and important position you enjoy in the radio industry took long years to build. Your postwar reputation *can* hinge on the performance of the record changer you select for your radio phonograph combinations of tomorrow.

This is elementary, of course. But it has particular bearing on our postwar concentration on volume production of automatic record changers.

These changers will be Custombilt. The engineering "savvy" that helped us lick the toughest problems the armed forces could dream up is proving itself right now in the record changers we have designed.

We would welcome your inquiry and design problems. For we are going all the way in this matter of automatic changers. Set manufacturers who knew our prewar changer—who have looked to us for nearly a quarter century for their condensers and other radio components—will understand what this means.

GENERAL INSTRUMENT CORPORATION

The first in our industry to be so honored — ARMY E NAVY

829 NEWARK AVENUE • ELIZABETH 3, N. J.

Membership

(Continued from page 48A)

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Winchester, J. L., 6009 Edmondson Ave., Catonsville 28, Md.
Woods, O. R., The Upjohn Co., 301 Henrietta St., Kalamazoo 99, Mich.
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Yeomans, P. C., 1156 E. 40 St., Brooklyn 10, N. Y.

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Ambrosio, B. F., International Business Machines Corp., 310 Fifth Ave., New York 1, N. Y.
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Bloom, L., 115-63—229 St., St. Albans 11, L.I., N. Y.
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Burke, W. B., 907 Ruffner St., Birmingham, Mich.
Burns, L. F., P. O. Box 578, Chula Vista, Calif.
Campbell, W. A., Appin, Ont. Canada
Cassens, G. J., 612 W. Lafayette Ave., Jacksonville, Ill.
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Spielman, S. C., R. F. D., Huntingdon Valley, Pa.
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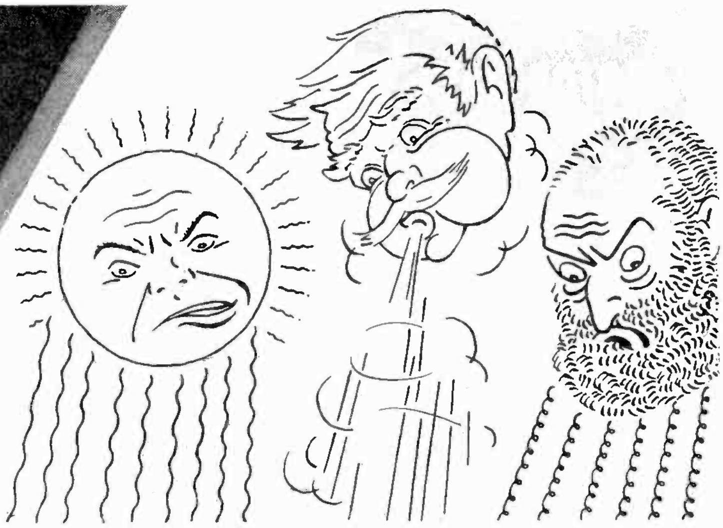

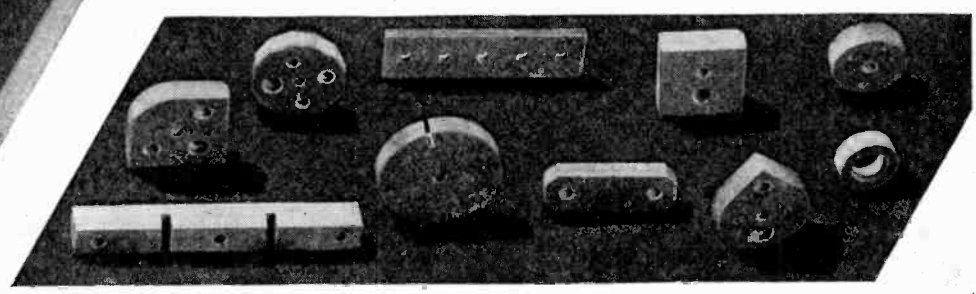

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Whether your needs call for close tolerances in unusual fabricated shapes or just stock sheets for your own machining we are equipped to serve you—PROMPTLY. **Details will be gladly furnished on request. A letter today will bring an immediate reply.**

Successor TURX ***to Pemque***

INTERNATIONAL PRODUCTS CORP.

TRADE MARK REG. 1944

PROPERTIES

ELECTRICAL	
Dielectric Constant	7.21
Power Factor	.002-.003
(At one Megacycle)	
(After 48 hours in distilled water at room temperature)	
Arc Resistance (Current and time to form conducting path)	
Milliamperes Average	45
Seconds Average	427
PHYSICAL	
Water Absorption	.009
Coefficient of Linear Expansion Per Degree C	10 x 10-6
Density—lbs. per cubic inch	.100
Specific Gravity	2.83
Color	Gray
Surface	(Hard - Smooth)
Porosity—After 6 hours in dye at 10,000 psi there was no visible penetration into the sample.	
MECHANICAL	
Tensile Strength—lbs. per sq. in.	8,500-10,000
Compressive Strength—lbs. per sq. in.	35,000-45,000
Flexure	17,000-18,500
Impact Strength (IZOd)	
Energy absorbed ft. lbs.	
Per inch—Width	(Aver.) 0.437
Per inch—Square	(Aver.) 2.25

TURX will not soften until it reaches a temperature of 800° to 900° F. It has, however, a permanent expansion as shown on the following table:

Permanent Expansion	15-Min. Cycle
750 F.	.05%
850 F.	.29%
950 F.	1.75%

INTERNATIONAL PRODUCTS CORPORATION

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BALTIMORE 18, MARYLAND

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DISPLAY ADVERTISERS

Without Exception

these molded, oil-paper capacitors meet the performance requirements of American War Standard C 75/221.

AVAILABLE IN STANDARD RATINGS		
CAPACITANCE MMFD.	VOLTAGE D-C WKG.	TYPE DESIGNATION
SIZE: 13/16 x 13/16 x 19/64 INCHES		
3000	800	CN35-302
6000	600	CN35-602
10000	600	CN35-103
20000	300	CN35-203
SIZE: 11/16 x 29/64 x 7/32 INCHES		
1000	400	CN20-102
2000	200	CN20-202
3000	200	CN20-302
6000	200	CN20-602
10000	120	CN20-103
Other capacitances from 1000 mmfd. to 50000 mmfd., available in Tobe DP style, conform to the same high quality standard.		

★ **MOISTURE SEAL** . . . adequate to ensure compliance with thermal cycle, immersion, and humidity requirements.

★ **SHUNT RESISTANCE** . . .
40,000 megohms at 25° C.
1,000 megohms at 85° C.

★ **WORKING TEMPERATURES** . . .
−55° C. to + 105° C.

★ **OPERATING FREQUENCIES** . . .
up to 40 megacycles.

★ **POWER FACTOR** . . . .
.004 to .006 at 1,000 cycles.

TOBE DEUTSCHMANN CORP.
TOBE
CANTON · MASSACHUSETTS

A SMALL PART IN VICTORY TODAY — A BIG PART IN INDUSTRY TOMORROW

"WE USE EIMAC TUBES EXCLUSIVELY IN ALL OUR LARGER GROUND STATIONS"

Says Robert F. Six

PRESIDENT, CONTINENTAL AIR LINES

CONTINENTAL AIR LINES, INC.
MUNICIPAL AIR TERMINAL
Denver 7, Colorado

January 9, 1945

Chief Engineer
Eitel-McCullough, Inc.
870 San Mateo Avenue
San Bruno, California

Dear Sir:

An airline must have a communication system which is absolutely dependable. For that reason, we scrutinize with great care the records we keep on the performance of the various components used in our transmitting and receiving equipment.

Included among these records are those on Eimac transmitting tubes—used exclusively in all of the larger ground stations operated by Continental Air Lines. I am pleased to tell you that these records show that your transmitting tubes are averaging well over 20,000 hours of service in our stations.

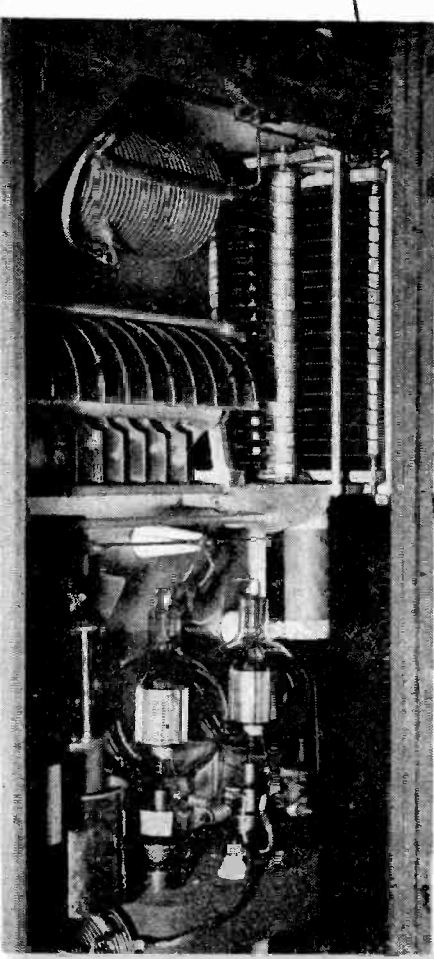
Sincerely yours,

Robert F. Six
President

RFS/lad

ROBERT F. SIX
President
Continental Air Lines

Below... a pair of Eimac 450-T tubes in the panel of Continental ground station transmitter built by Wilcox.



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