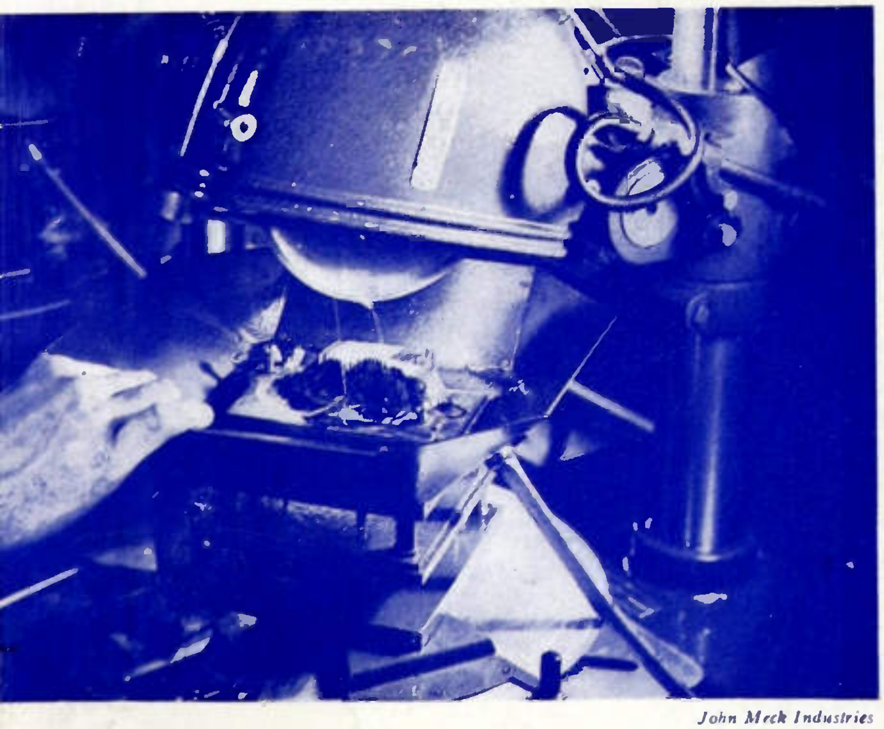
Proceedings of the I·R·E

SEPTEMBER, 1944

VOLUME 32 NUMBER 9



John Meck Industries

NATURE'S CRYSTALS BECOME RADIO'S CONTROLS
Brazilian quartz sawed into piezoelectric wafers

IMPORTANT NOTICE: A Group of Constitutional Amendments Will Be Voted on by the Membership in Late September. All Members Are Urged to Read and Study Carefully the Discussion and Correspondence Dealing with the Proposed Amendments on Pages 560 Through 568 of This Issue.

Institute of Radio Engineers

Proceedings *of the* I·R·E

Published Monthly by

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VOLUME 32 — *September, 1944* — NUMBER 9

Responsibility for the contents of papers published in the PROCEEDINGS rests upon the authors. Statements made in papers are not binding on the Institute or its members.

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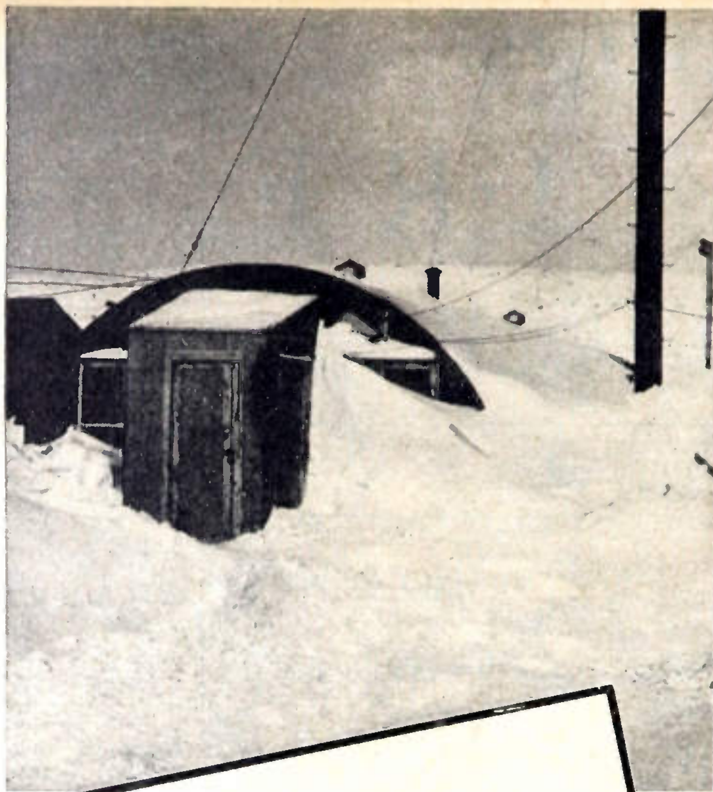
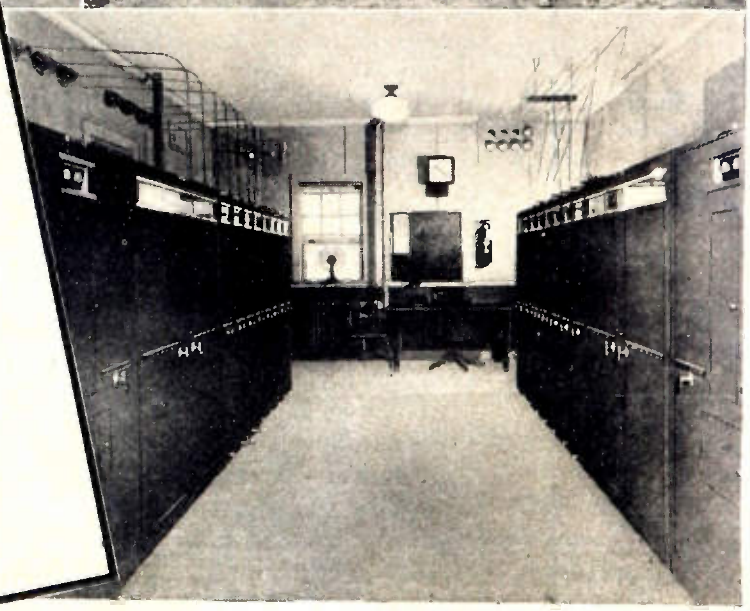


WHETHER ARCTIC OR JUNGLE . . .

FOR RADIO COMMUNICATIONS

Wilcox is there



Official United States Army Photographs

In the theaters of war and on the battlefronts, every precaution is taken against failure of communications. The performance of Wilcox radio equipment has proved its reliability under all conditions, in all parts of the world. Today, Wilcox manufacturing is fulfilling military needs and those of the commercial airlines of the nation.

WILCOX ELECTRIC COMPANY

Manufacturers of Radio Equipment

Fourteenth & Chestnut • Kansas City, Mo.

but Full Capacity Production at G. I.

All in all, industry did, and is still doing, a grand job — has rolled up a stupendous record of accomplishment in the past four years. But, looking back, we can see errors of procedure which made the going tough in spots, obstacles that retarded progress. These conditions were due to confusion and lack of experience in the drastic conversion from civilian to war production. Our industry can well profit by these mistakes as we make the transition back to peacetime activity.

We at G. I., anticipating WPB's recent Go-Ahead signal, have readied definite plans — plans which will enable us to swing into capacity execution of post-war assignments the instant our facilities are no longer wholly required for the supplying of military equipment.

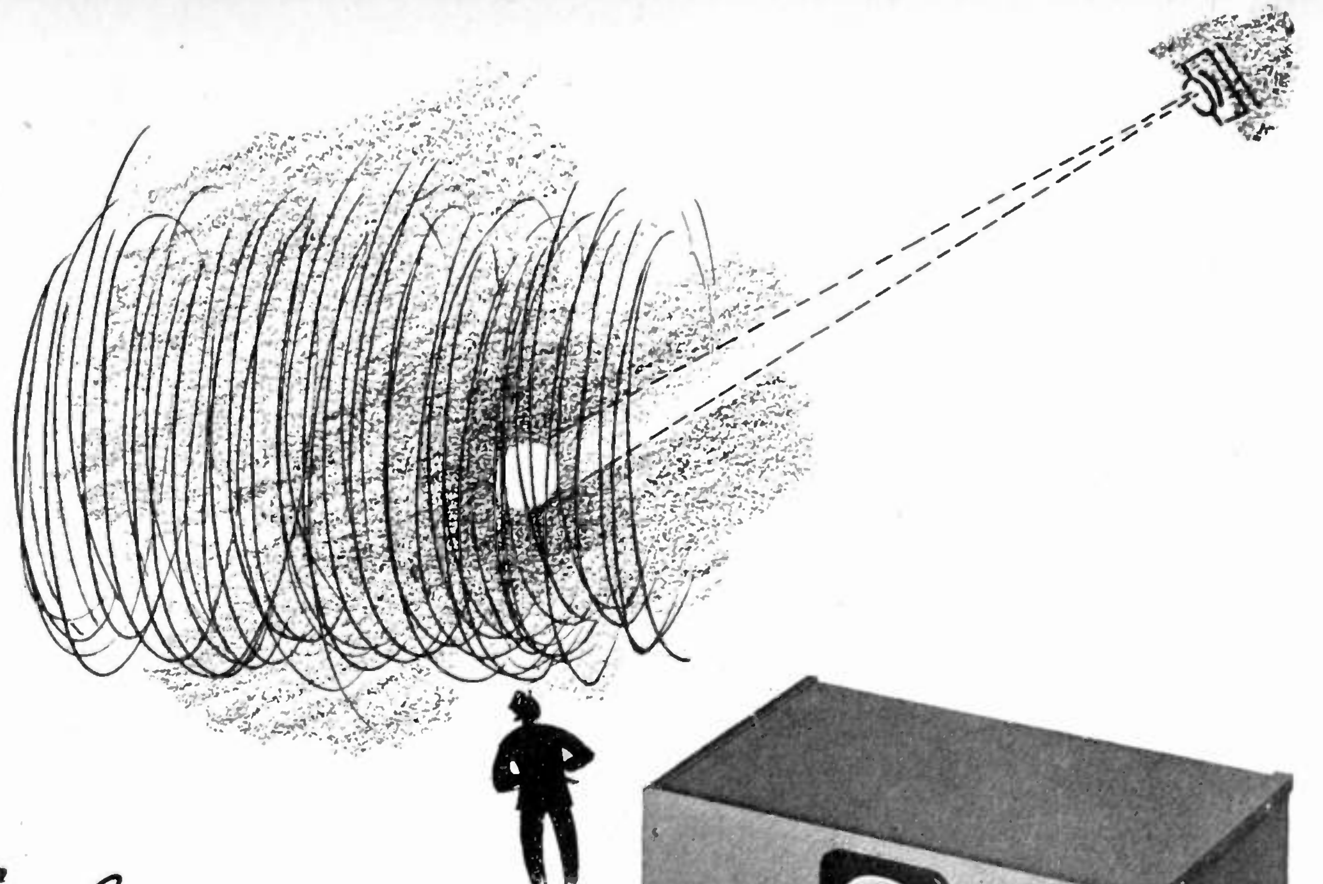
GENERAL INSTRUMENT CORP.

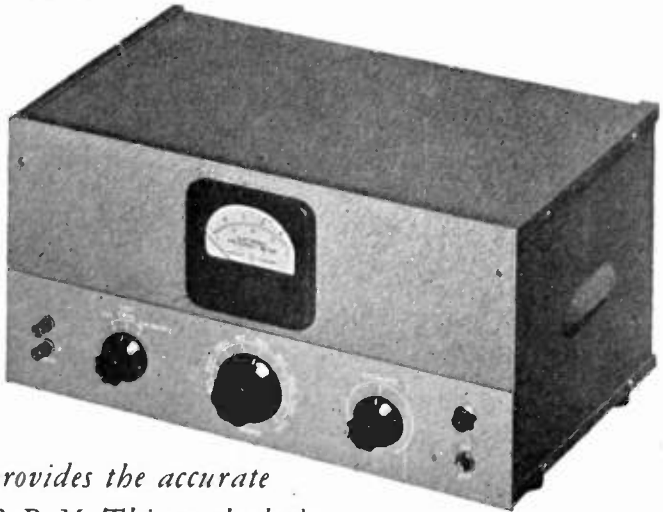
829 NEWARK AVENUE, ELIZABETH 3, N. J.

The first in our industry to be so honored

OUR WARTIME JOB has been the volume output of variable condensers, many with circuit applications never before possible, wired assemblies, automatic tuning mechanisms, etc.

OUR PEACETIME JOB will be to produce such precision instruments, featuring new designs, innovations and improvements, for civilian use in the fields of electronics and communications equipments.





QUICK-REFERENCE CHART
RCA MINIATURE TUBES

BASIC DATA FOR DESIGNERS ON RCA'S WIDE MINIATURE LINE

TYPE NO.	DESCRIPTION	APPLICATION DATA AND SUGGESTED USES	FILAMENT OR HEATER: VOLTS	FILAMENT OR HEATER: AMPERES	FILAMENT OR HEATER: TYPE	MAX. RATINGS: PLATE VOLTS	MAX. RATINGS: SCREEN VOLTS	MAX. RATINGS: TOT. CATH. MA.	TYPICAL PLATE MA.	TRANSCONDUCTANCE at max. plate volts (μmhos)	LIST PRICE
1A3*	H-F DIODE	For discriminator in FM receivers and in measuring equipment. Resonant freq., 1000 Mc.	1.4	0.15	H	330a	—	0.5g	—	—	$1.15
1L4*	R-F AMPLIFIER PENTODE	For use where sharp cut-off characteristic is required—no external bulb shield needed.	1.4	0.05	F	110	90	6.5	4.5c	1025c	1.15
1R5*	PENTAGRID CONVERTER	Has conversion transconductance of 300 micromhos at 90 volts on plate.	1.4	0.05	F	90	67.5	5.5	1.6	—	1.15
1S4	POWER AMPLIFIER PENTODE	Capable of handling audio power output of 270 milliwatts.	1.4	0.10	F	90	67.5	9	7.4	1575	1.15
1S5*	DIODE-PENTODE	Combined diode and a-f pentode providing high voltage gain.	1.4	0.05	F	90	90	4.5	1.6	625	0.95
1T4*	SUPER-CONTROL R-F AMPLIFIER PENTODE	Useful as r-f or i-f amplifier—no external bulb shield needed.	1.4	0.05	F	90	67.5	5.5	3.5	900	1.15
2D21	THYRATRON (Gas-Tetrode)	For relaying. Will operate directly from high-vacuum phototube.	6.3	0.6	H	1300a	—	100d,g	—	—	3.75
3A4*	POWER AMPLIFIER PENTODE	Can handle a-f output of 700 milliwatts, or r-f output of 1.2 watts at 10 Mc.	2.8s 1.4p	0.1 0.2	F	150	90	18	13.3	1900	0.75
3A5*	H-F TWIN TRIODE	Has Class C output of about 2 watts at 40 megacycles.	2.8s 1.4p	0.11 0.22	F	135	—	5 AF 30 RF	3.7c	1800c	1.30
3Q4	POWER AMPLIFIER PENTODE	Can handle relatively high audio output of 270 milliwatts.	2.8s 1.4p	0.05 0.10	F	90	90	12	9.5	2150	1.15
3S4*	POWER AMPLIFIER PENTODE	Similar to Type 1S4 but has filament arrangement for either series or parallel operation.	2.8s 1.4p	0.05 0.10	F	90	67.5	9	7.4	1575	1.15
6AG5*	R-F AMPLIFIER PENTODE	Has sharp cut-off characteristic and high transconductance—useful up to 400 Mc.	6.3	0.3	H	300	150	—	7.0e	5000e	2.15
6AK6	POWER AMPLIFIER PENTODE	Can handle a-f power output of 1.1 watts.	6.3	0.15	H	300	250	—	15f	2300f	1.10
6AL5*	TWIN DIODE	High-perveance detector for wide-band circuits. Tube drop, 10 volts at 60 ma. per diode.	6.3	0.3	H	420a	—	9b,g	—	—	0.75
6AQ6*	DUPLEX-DIODE HIGH-MU TRIODE	For use as a combined detector, amplifier and avc tube.	6.3	0.15	H	300	—	—	1.0e	1200e	1.50
6C4*	H-F POWER TRIODE	Has Class C output of about 5.5 watts at moderate frequencies and 2.5 watts at 150 Mc.	6.3	0.15	H	300	—	25 RF	10.5e AF	2200e	0.90
6J4*	U-H-F AMPLIFIER TRIODE	For use primarily as grounded-grid amplifier at frequencies up to about 500 Mc.	6.3	0.4	H	150	—	20	15	12000	8.35
6J6*	TWIN TRIODE	Useful as mixer at frequencies up to 600 megacycles. Also useful as oscillator.	6.3	0.45	H	300	—	30 RF	8.5b AF	5300b	1.85
9001*	DETECTOR AMPLIFIER PENTODE	A sharp cut-off pentode for use as an r-f amplifier or detector in u-h-f service.	6.3	0.15	H	250	100	—	2.0	1400	2.50
9002*	DETECTOR AMPLIFIER TRIODE	Has moderately high amplification factor. Useful as u-h-f detector, amplifier, oscillator.	6.3	0.15	H	250	—	—	6.3	2200	2.00
9003*	SUPER-CONTROL R-F AMPLIFIER PENTODE	Remote cut-off pentode useful as mixer or as r-f or i-f amplifier in u-h-f work.	6.3	0.15	H	250	100	—	6.7	1800	2.50
9006•	U-H-F DIODE	For u-h-f service as rectifier, detector, or measuring device. Resonant freq., 700 Mc.	6.3	0.15	H	750a	—	5g	—	—	1.50

a—Peak inverse volts
b—Per unit
c—At 90 volts on plate (and screen)
d—For an averaging period of 30 sec.
e—At 250 volts on plate
f—At 180 volts on plate and screen
g—D-C output Ma.
p—Filaments connected in parallel
s—Filaments connected in series

*Army/Navy Preferred Type.

HERE is a condensed story on the complete line of RCA miniatures. Miniatures—you will recall—were an RCA development back in 1940 when that famous quartet, the 1R5, 1S4, 1S5, and 1T4, put "personal" portables on the map. War demands have speeded the development of miniatures so that today 22 RCA types are available. Note that 18 of the 22 are on the Army/Navy Preferred Type List; of these 22 tubes, 21 were developed by RCA! When you have a tube application problem, turn to RCA engineers. *Remember, the Magic Brain of all electronic equipment is a Tube, and the fountain-head of modern Tube development is RCA.*

Copies of this advertisement for reference are available on request. Write to: RADIO CORPORATION OF AMERICA, 738 South Fifth Street, Harrison, N. J.

BUY MORE WAR BONDS

RCA

RADIO CORPORATION OF AMERICA

RCA VICTOR DIVISION • CAMDEN, N. J.

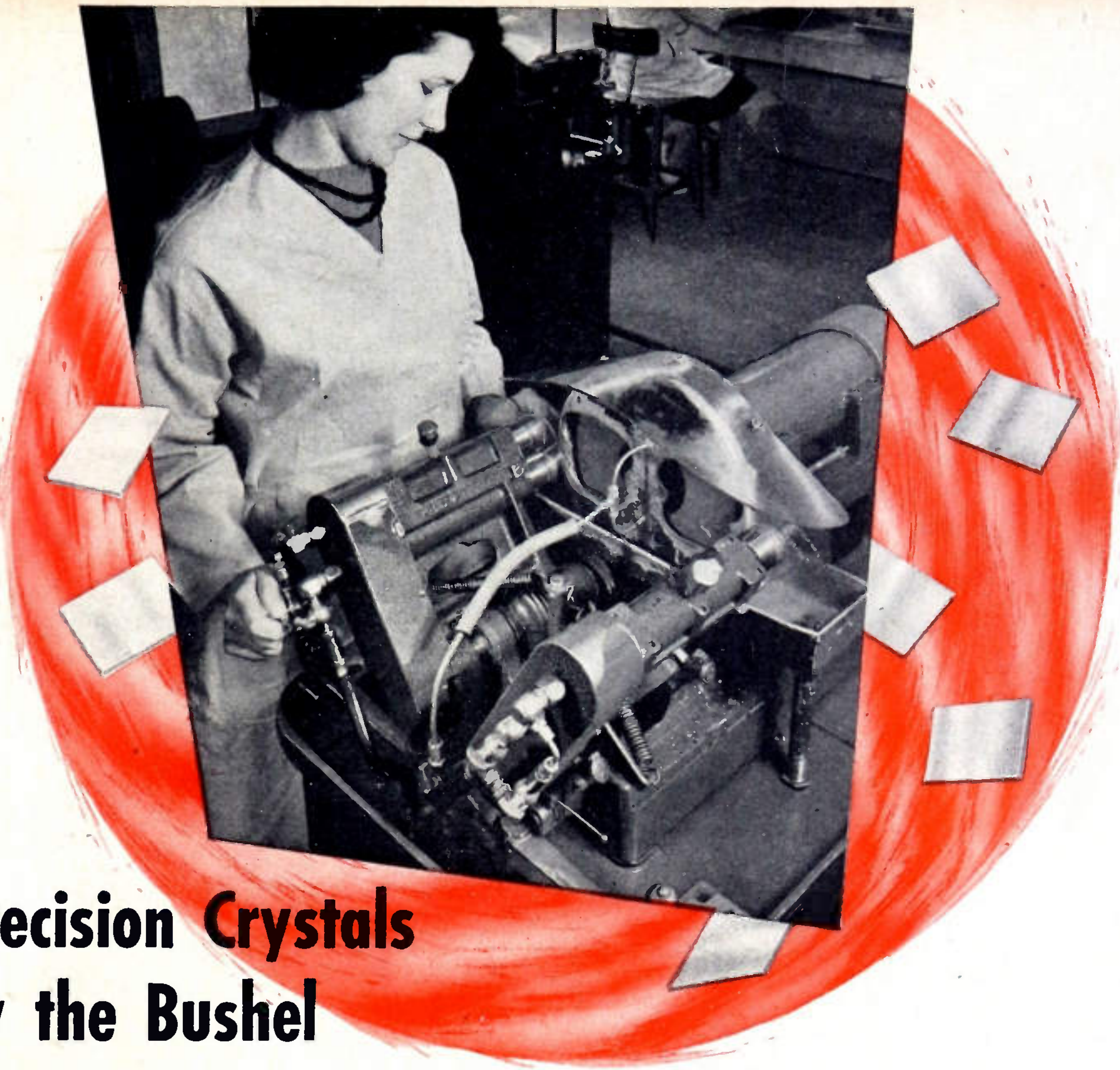
FOR SERVICES WELL RENDERED, I THANK THE MEN AND WOMEN WORKERS OF THE ELECTRO-VOICE MANUFACTURING COMPANY WHO HAVE BEEN AWARDED THE "E" BY THE ARMY AND NAVY OF THE UNITED STATES.

Albert Kahn

PRESIDENT, ELECTRO-VOICE MANUFACTURING CO., INC.

Electro-Voice MICROPHONES

ELECTRO-VOICE MANUFACTURING CO., INC. — 1239 SOUTH BEND AVENUE, SOUTH BEND 24, INDIANA



Precision Crystals by the Bushel

To meet the wartime demand for the mass production of quartz crystals having highly precise electrical characteristics, our engineers designed this special high-speed automatic lapping machine, known as the *Q-Lap.* Results: Fast rough grinding of single crystals up to ¼″ thick; parallel grinding of blanks with respect to reference surface to within .0002″; rapid grinding of special angle blanks to within 2 minutes of arc; excellent surface despite rapid grinding.

The Q-Lap and the X-ray Quartz Crystal Analysis Apparatus, both developments of North American Philips, are described in the booklet "How Quartz Crystals Are Manufactured." Write for it today.

Behind the North American Philips Company is a team of outstanding electronic engineers, headed by one of America's leading physicists, and coached by a group with world-wide experience resulting from fifty years of research and development. Today, we work for Victory; tomorrow, our aim will be to serve industry.

NORELCO PRODUCTS: Quartz Oscillator Plates; Amplifier, Transmitting, Rectifier and Cathode Ray Tubes; Searchray (X-ray) Apparatus, X-ray Diffraction Apparatus; Medical X-ray Equipment, Tubes and Accessories; Electronic Measuring Instruments; Direct Reading Frequency Meters; High Frequency Heating Equipment; Tungsten and Molybdenum products; Fine Wire; Diamond Dies. *When in New York, be sure to visit our Industrial Electronics Showroom.*

Send today for this *FREE* booklet!

Norelco ELECTRONIC PRODUCTS by
Reg. U. S. Pat. Off.
NORTH AMERICAN PHILIPS COMPANY, INC.

Executive Offices: 100 East 42nd Street, New York 17, N. Y.
Factories in Dobbs Ferry, N. Y.; Mount Vernon, N. Y. (Metalix Division); Lewiston, Maine (Elmet Division)

North American Philips Co., Inc.
100 East 42nd Street, New York 17, N. Y.
Gentlemen:
Kindly mail a free copy of the booklet, "How Quartz Crystals Are Manufactured" to:

Name ____________

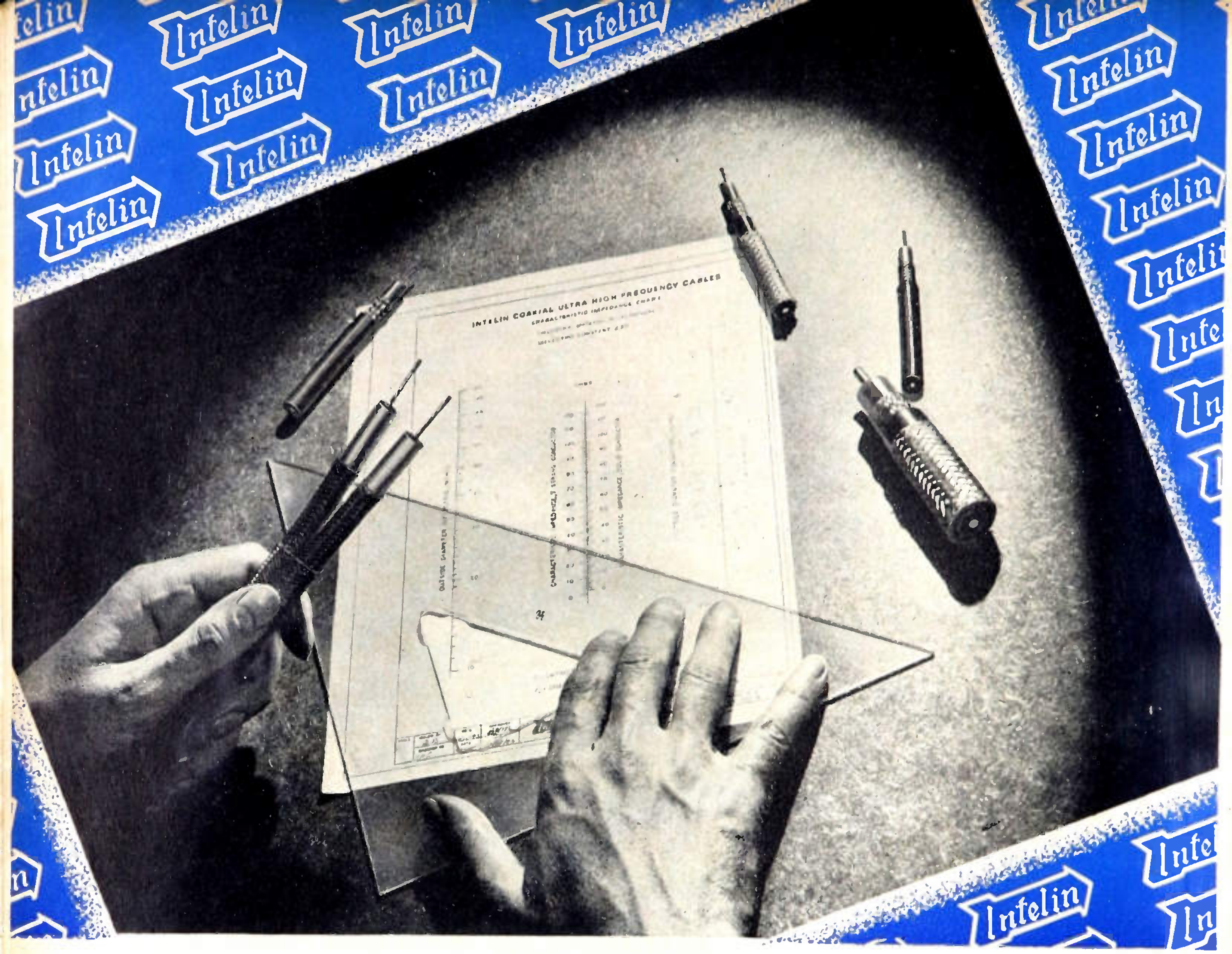
Title ____________

Company ____________

Address ____________

F-9

POWER SUPPLY
COMPONENTS
FOR WAR
UTC
The complex power supplies of war apparatus require components of maximum dependability. The unit illustrated is a typical power transformer for cathode ray application. In addition to the tapped primary, this unit provides a low voltage filament winding . . . a 5,000 volt anode supply winding . . . and a filament winding insulated for 15,000 volts peak inverse.
For hermetic sealing this unit employs an all metal enclosure . . . glass seal terminals . . . sealing compound which neither cracks nor flows from -55°C to + 130°C.
May we cooperate with you on design savings for your applications...war or postwar?
United Transformer Co.
150 VARICK STREET NEW YORK 13, N. Y.
EXPORT DIVISION: 13 EAST 40th STREET, NEW YORK 16, N. Y., CABLES: "ARLAB"



HOW BIG A CABLE?

The impedance characteristics of Ultra-High Frequency Cables are dependent on the physical dimensions — the size of center conductor and the inside diameter of the coaxial braid.

You can easily determine impedance by the use of this Intelin Chart. Apply a straight edge, with the crossover at the desired impedance on the center scale. The other two scales then indicate, for any scale position, the corresponding conductor size and dielectric size necessary for the desired impedance.

BUY MORE BONDS

Federal, long recognized as a manufacturer of better vacuum tubes, now leads with new production methods resulting in still greater tube efficiency and length of life. Everywhere, it's Federal tubes for superior transmitting and industrial power performance.

A full size copy of this chart is yours on request. Write for it today!

Remember, Intelin Cable is more than insulated wire — it is specialized transmission line — made with watchmaker accuracy.

In the Intelin Cable family there is a type to match your ultra-high-frequency problems, a cable balanced in all electrical properties to do your job.

INVEST IN THE FUTURE

Federal Telephone and Radio Corporation

AN IT&T ASSOCIATE

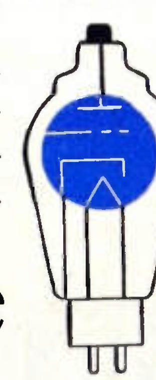
Newark 1, N. J.

Westinghouse Electronic Tubes . . . doing a job on every front, in every battle, in every war industry

WOULD GIVE THEIR EYE TEETH TO KNOW

Secret weapon of American war industry is surely the electronic tube. It has revolutionized industrial and manufacturing methods, brought about startling new production techniques . . . many of them well kept secrets that enemy agents would give their eye teeth to know. As a major supplier of electronic tubes, Westinghouse is proud to be sharing in this still secret, but tremendously vital "electronic revolution."

To meet the enormous demands for Westinghouse Electronic Tubes—from the armed forces as well as war industry, we've increased floor space 20 times, trained 28 new workers for each one formerly employed, multiplied output 30 times! And now we're not only meeting time and quality musts on all Government contracts—we're also continuing to supply the heavy demands of war industry. Your nearest Westinghouse Office or Distributor will be glad to receive your inquiries for Westinghouse Tubes. Westinghouse Electric & Manufacturing Company, Bloomfield, N. J.



Westinghouse

PLANTS IN 25 CITIES OFFICES EVERYWHERE

Electronic Tubes at Work

ATTENTION TO DETAIL ADDS UP TO DEPENDABLE PERFORMANCE

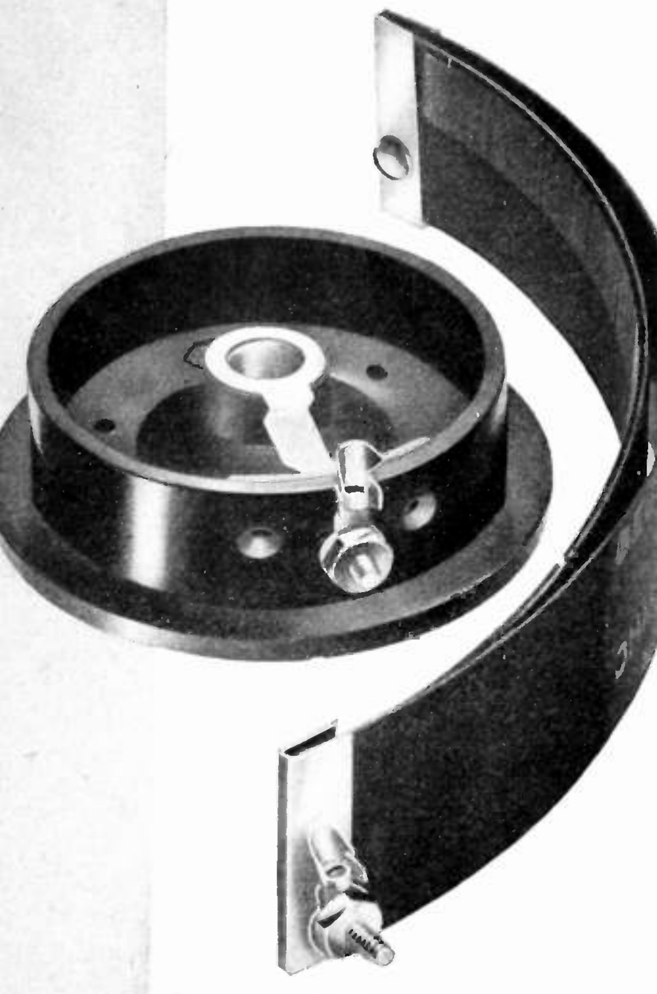
DeJUR U.S.A.

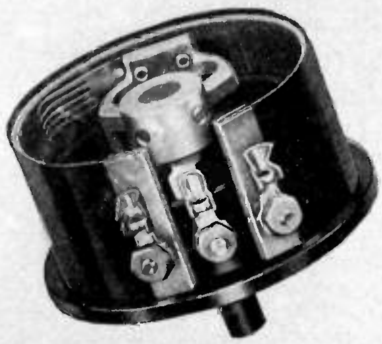
POTENTIOMETERS

TYPES 260, 275, 261, 276, 281, 291, 292, 296

Twenty-five years of experience in the precision electrical instrument field assure quality and dependability in DeJur potentiometers. We have created a wide variety of standard models for practically all applications. Special attention is paid to individual specifications.

- Winding strip is wound on a linen bakelite card which has been carefully sanded before winding.
- Windings are made of either Nichrome or Advance wire, depending upon the resistance of the card to be wound.
- The card, wrapped around a moulded phenolic base, is held in position by heavily plated brass nuts and bolts.
- The wiper, incorporating five contacts, is made of plated bronze, carefully buffed where electrical contact is made with the winding.
- Types 261, 276, 281, 292 and 296 incorporate an "edge" type wiper for closer tolerances.
- The shaft may be either bakelite, cold rolled steel suitably plated, or solid brass, depending on whether the instrument is to have a live or dead shaft.
- The bushing which supports the shaft is made of precision machined brass.
- For ease of wiring Installation, the selected terminal lugs are carefully tinned.
- In assembly, the cards are treated by dipping and baking to assure adhesion of the winding to the card; the entire unit is assembled to exacting specifications.





A DEJUR ENGINEER IS AVAILABLE FOR A DISCUSSION OF YOUR PRESENT OR POSTWAR APPLICATIONS

DeJur-Amsco Corporation

MANUFACTURERS OF DeJUR METERS, RHEOSTATS, POTENTIOMETERS AND OTHER PRECISION ELECTRONIC COMPONENTS

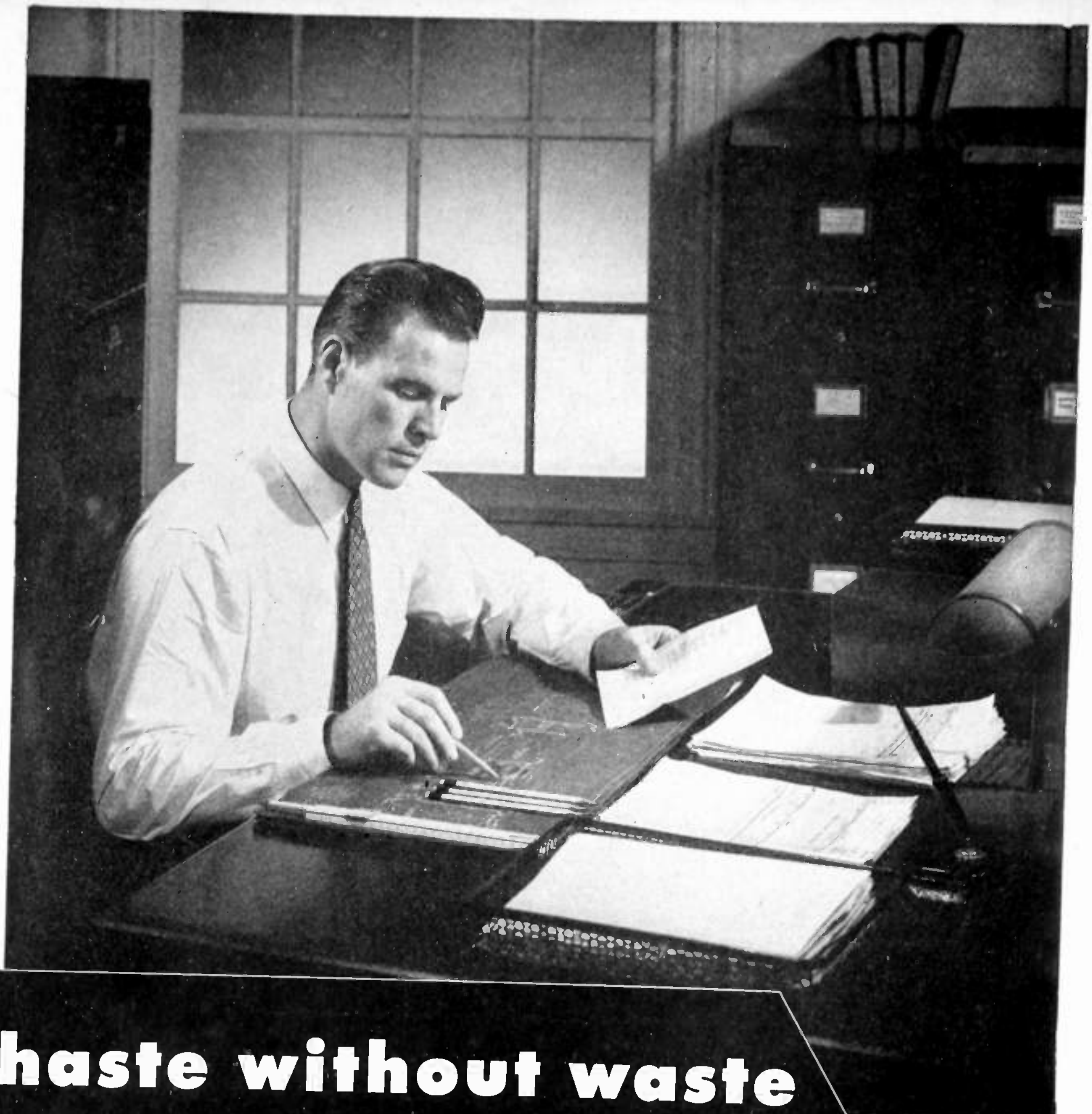
GENERAL OFFICE: NORTHERN BLVD. AT 45th ST., LONG ISLAND CITY 1, N. Y.

SHELTON FACTORY: Shelton, Conn. • CANADIAN SALES OFFICE: 560 King Street West, Toronto

BUY MORE THAN BEFORE . . . KEEP "HOARDING" WAR BONDS

ARMY E NAVY


JUST OUT!
SPRAGUE DRY ELECTROLYTIC CAPACITORS
SPRAGUE ELECTRIC COMPANY, NORTH ADAMS, MASS.



haste without waste

The electronic engineer has been doing a tremendous job. The increasing importance of advanced electronic equipment in modern warfare has multiplied his task a hundredfold. But, the special training and vitally important knowledge of the electronic engineer enables him to tackle each day's job regardless of its magnitude and get it out of the way. The electronic engineer is living proof that *haste without waste* is possible.

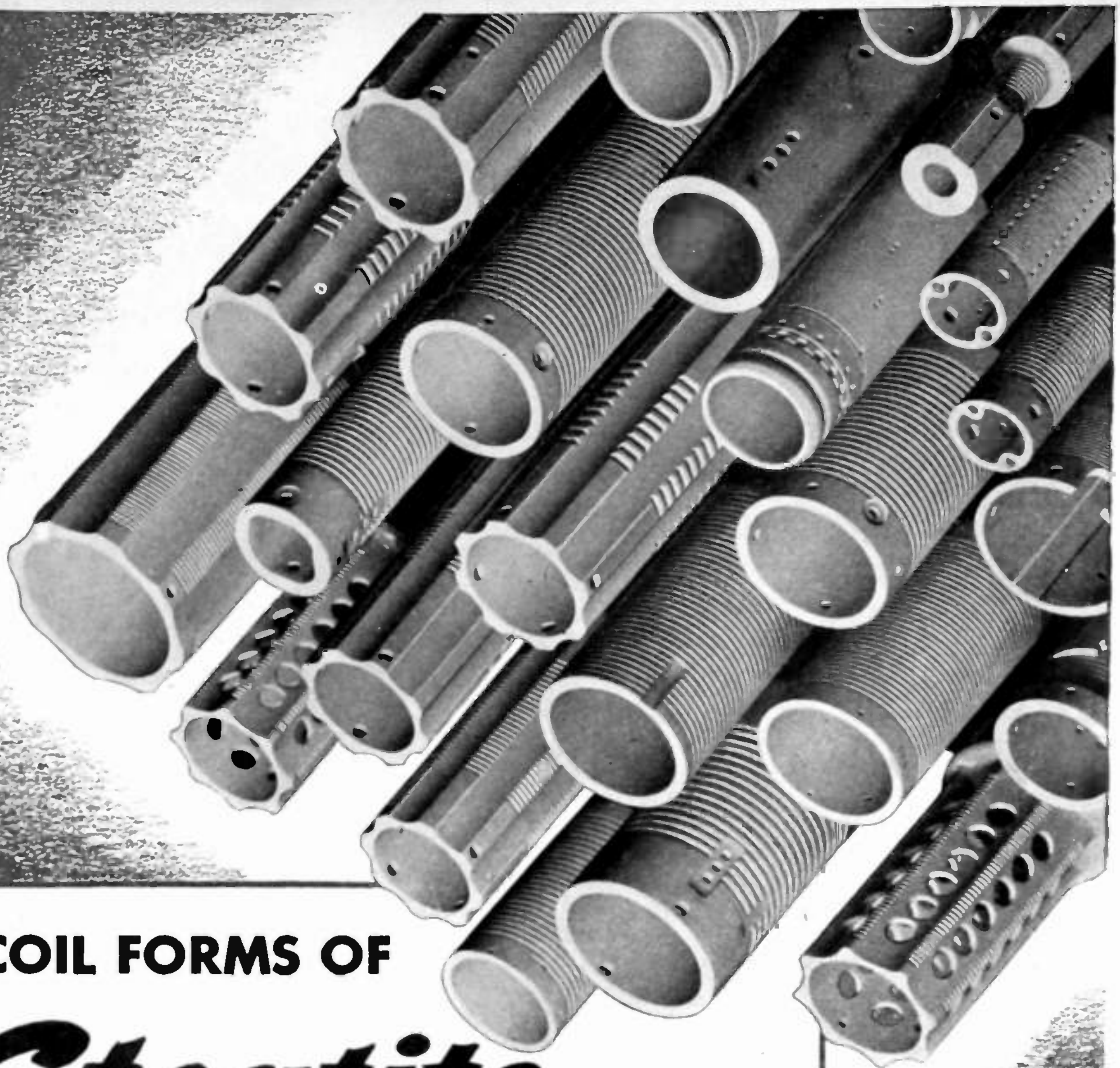
Advanced electronic tubes and equipment are playing a role of immeasurable importance in the Allied Nations' drive for Victory. When the war ends, the results of Raytheon's intensive research and manufacturing experience will be utilized to meet advanced electronic tube requirements.

ARMY-NAVY "E" WITH STARS
Awarded All Four Divisions of Raytheon
for Continued Excellence in Production

RAYTHEON

Raytheon Manufacturing Company
ELECTRICAL EQUIPMENT DIVISION
Waltham and Newton, Massachusetts

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



In anticipation of "the day," alert manufacturers recognize the importance of lining up sound sources for the component parts they will require.

Right now, as for many months past, IRC research engineers are busily engaged in war development work on many new types of resistances which will fit the pattern of post-war applications. In addition, special design problems have been undertaken in instances where the prospective volume warranted such course.

That IRC will have in its expanded line most of the resistance devices industry will need, is assured as a result of careful market surveys. These quality units will be offered at prices consistent with mass production methods made possible through operation of the world's largest resistor plants.

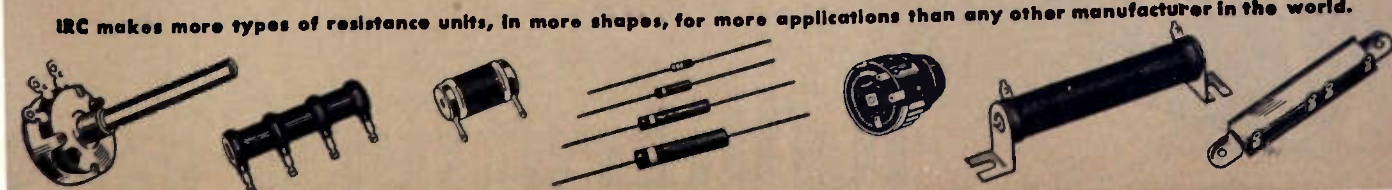
If resistances will play a part in your post-war products, why not get in touch with IRC now? No obligation is entailed.

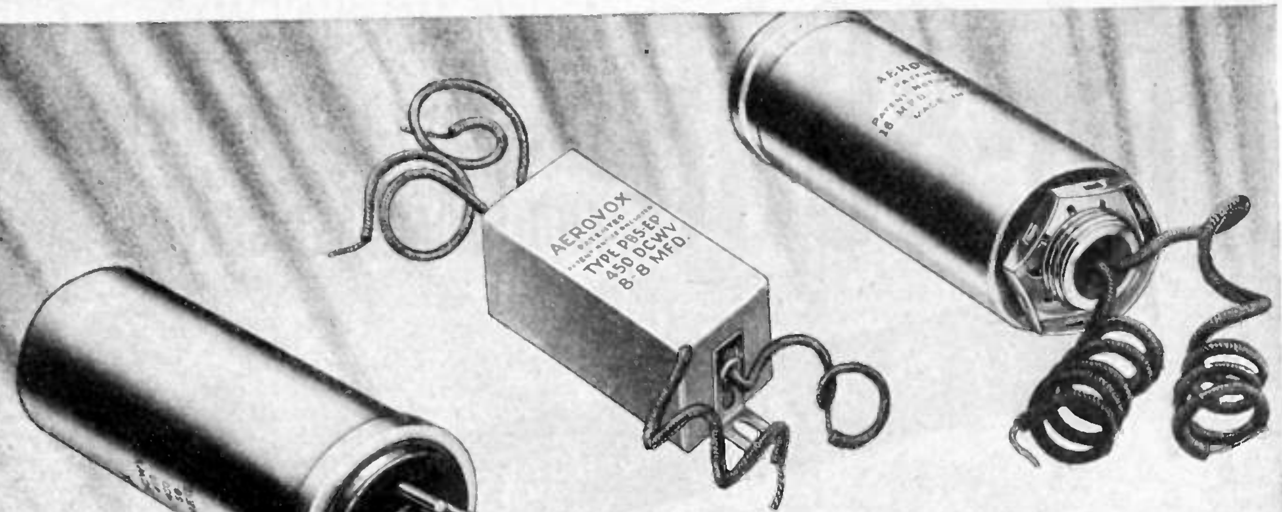
PREFERRED FOR PERFORMANCE · IRC · FIXED & VARIABLE RESISTORS

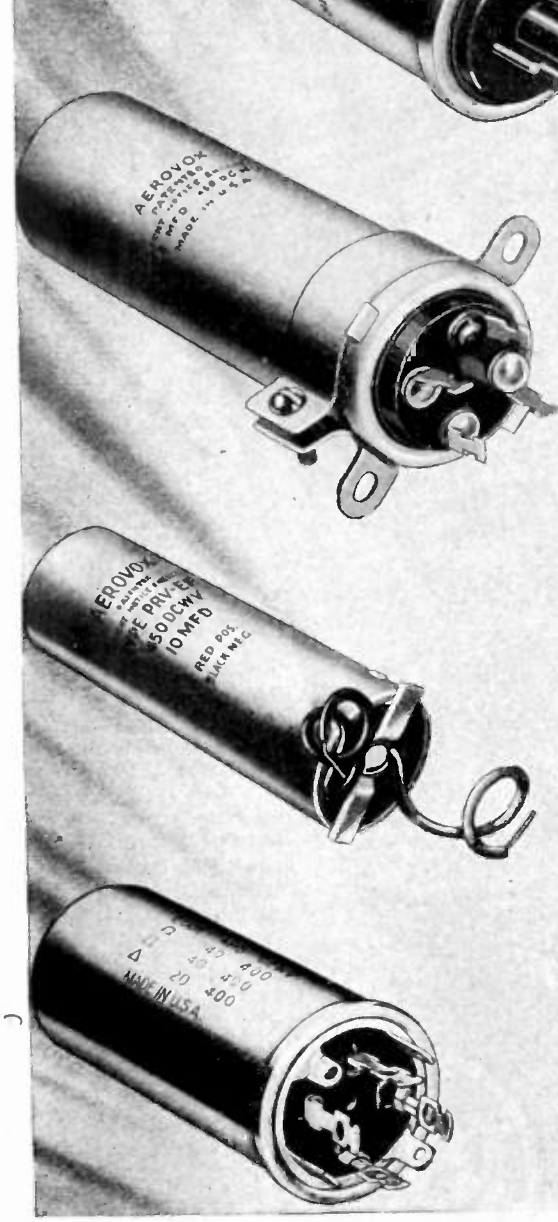
INTERNATIONAL RESISTANCE CO.

401 N. Broad St. Philadelphia 8, Pa.

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




AEROVOX
TYPE PBS-EP
450 DCWV
8-8 MFD.



THERE'S GOLD HERE!

another new letter contest

$200.00 in prizes every month

$100.00 first prize, $50.00 second prize, $25.00 third prize, $15.00 fourth prize, $10.00 fifth prize, plus $1.00 for every letter received.

Here we go again. Another great Hallicrafters letter contest for service men. Wherever you are, whenever you see this announcement, drop us a line. Write and tell us your first hand experience with *all* types of radio communications built by Hallicrafters, including the famous SCR-299.

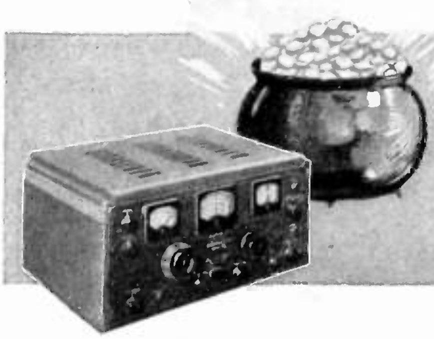
There is gold here! Write today to get your share. Tell us your story in your own way. You can't lose and you *can* win as high as $100.00.

Rules for the Contest

Hallicrafters will give $200.00 for the best letters received during each of the six months of September, October, November, December, 1944, January, and February, 1945. (Deadline: Your letter must be received by midnight, the last day of each month.)

For every serious letter received, Hallicrafters will send $1.00 so even if you do not win a big prize your time will not be in vain. Your letter will become the property of Hallicrafters and they will have the right to reproduce it in a Hallicrafters advertisement. Write as many letters as you wish. V-mail letters will do.

Open to servicemen around the world. Wherever you are, whenever you see this ad, drop us a line. Monthly winners will be notified immediately upon judging.



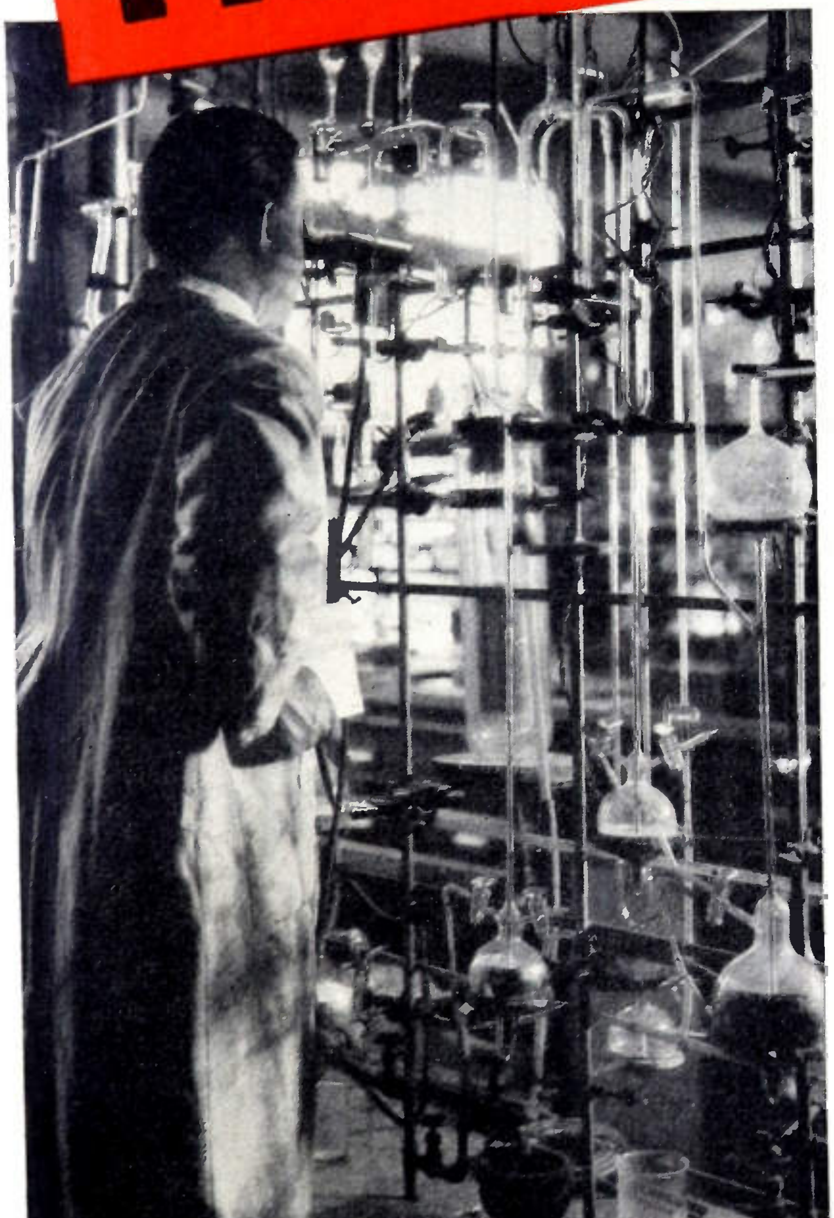
There's gold here at the end of the rainbow in Hallicrafters great letter contest—and there's a great and exciting future ahead for short wave enthusiasts. In peacetime Hallicrafters will continue to build "the radio man's radio" and that means the best that can be made. There will be a set for you in our postwar line.

BUY A WAR BOND TODAY!

hallicrafters RADIO

THE HALLICRAFTERS COMPANY, MANUFACTURERS OF RADIO AND ELECTRONIC EQUIPMENT, CHICAGO 16, U.S.A.

FREE { THE KEY TO THE WORLD'S BIGGEST GLASS RESEARCH LABORATORY!



WE mean it. The services of the world's largest glass research laboratory are yours for the asking. In its 75 years, Corning has developed more than 25,000 different glass formulae . . . a vast storehouse of glass-making research and skill ready and able to help you no matter what your problem.

At Corning, right now, more than 250 planners, researchers, engineers and production men are constantly at work to make better glass for the radio tubes, X-ray bulbs, cathode ray tubes, resistor tubes and other glassware you need in your business. As a result, it is difficult to find *any* electronic glassware in use today that did not get its start at Corning.

Actually, many of Corning's developments come properly under the head of "near miracles". It was only yesterday, for instance, that it became practical to solder metal to glass. But Corning Research did it. And today the Corning metallized bushing is performing an important job in the electronic equipment of the industry's leading manufacturers . . . a proven time and money saver. And we could quote a dozen other examples just as good.

If you'd like to know more about what Corning knows about electronic glassware, we have a suggestion. Write today for a new booklet, "There Will Be More Glass Parts in Postwar Electronic Products". Please address the Electronic Sales Dept. P-9 Bulb and Tubing Division, Corning Glass Works, Corning, New York.

CORNING *means* Research in Glass

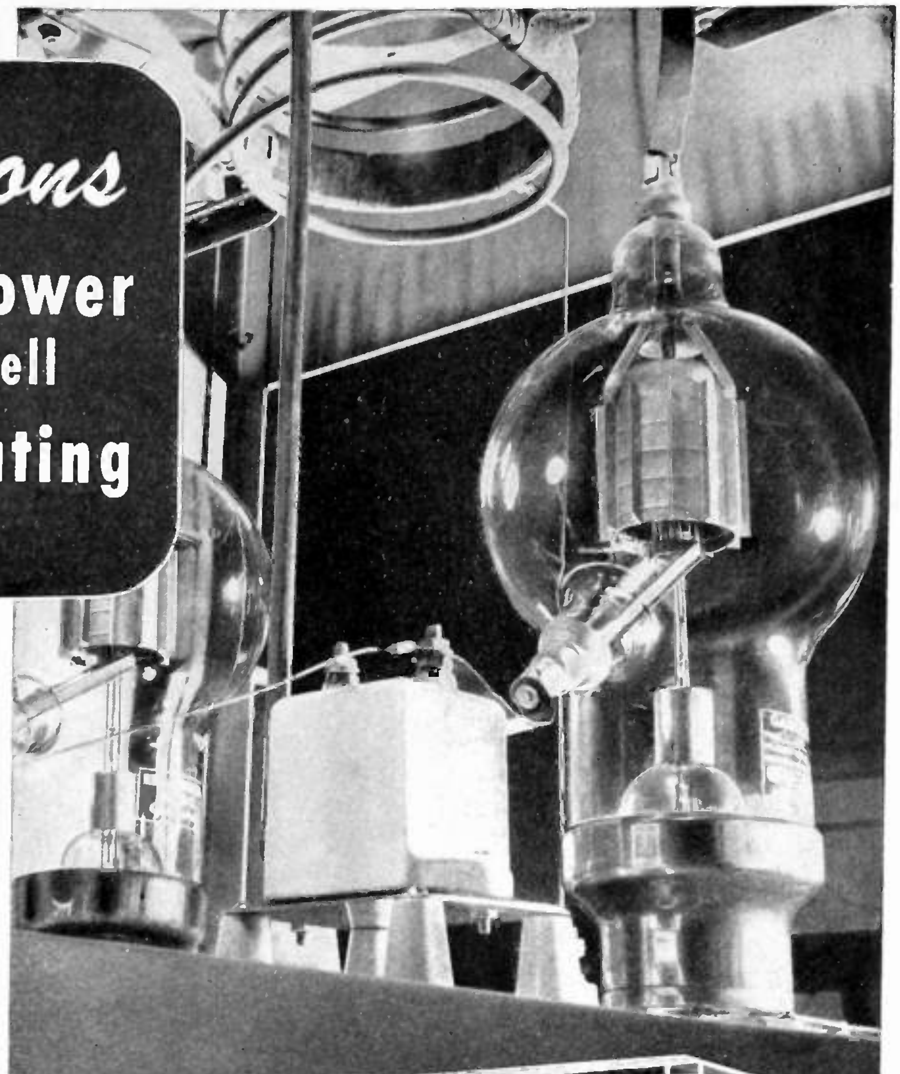
Electronic Glassware

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

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

"PYREX" and "CORNING" are registered trade-marks of Corning Glass Works

Gammatrons Provide R-F Power for Mann-Russell Dielectric Heating Generators



The pair of HK-1054 Gammatrons shown in the master oscillator of a Mann-Russell RF generator at upper right, provide a maximum of 13,300 BTUs per hour at 20 to 30 meters for dielectric heating applications.

10,000 BTU PER HOUR
FROM A PAIR OF HK-1054 TUBES

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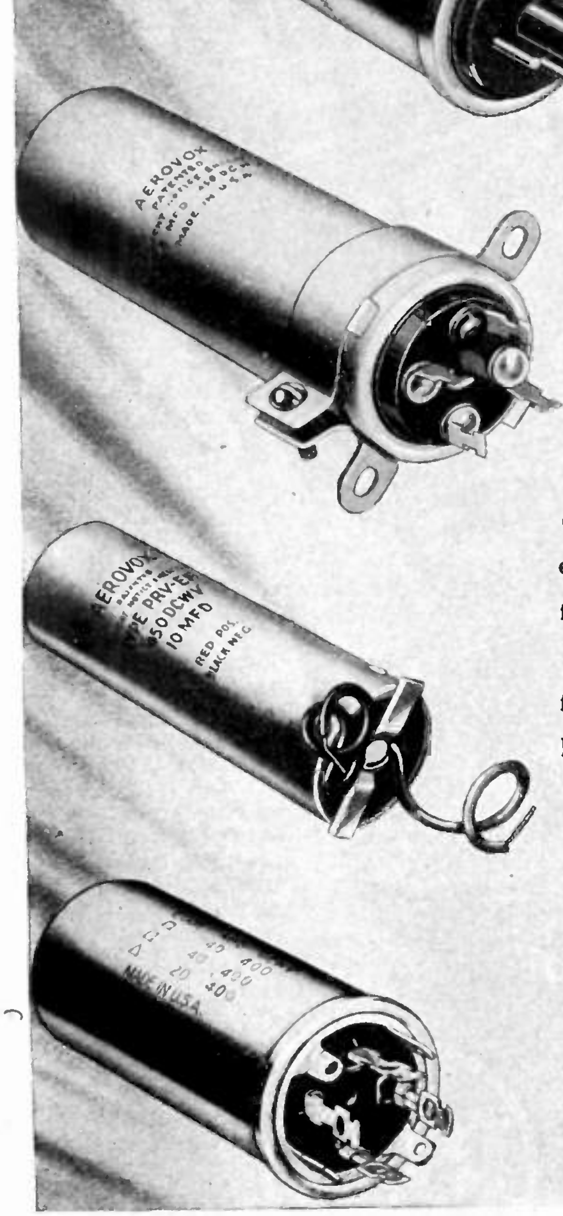

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To further such closeness of contact between engineers and major executives, there is here presented a guest editorial by the President of the National Broadcasting Company, based on his long and successful activities in the field of radio broadcasting.

The Editor

Of the Engineer and His Works

NILES TRAMMELL

Man's progress through the centuries has been measured by his ability to think, to wrest, one by one, her secrets from nature, and to fashion them to his own uses. All about him there have been wonderful things he could not see.

Since time immemorial living creatures have demonstrated to him flight through the air. For man's taking have been fuels for the fires to add to his comforts and provide the power for machines of transportation, communication, health, and security. At his finger tips have been the ingredients for the medicines to cure his disease and lengthen his span of life and health.

Scientists and engineers, trained to seek and to recognize the unknowns, to lift the veil which shrouds the age-old secrets of nature and to fashion of them a better way of life, are constantly contributing to our security, culture, and enjoyment.

Man's researches are conducted in many constantly expanding fields of activity. I, as a member of the National Broadcasting Company, am naturally most conversant with that of communication by radio.

It has been my good fortune during the past two decades to participate in a small way in the growth of a great new industry. It has been spawned from the fertile minds and tireless efforts of trained radio engineers and physicists, with many of whom it is my privilege to be friend and associate.

These workers produce new products of the laboratory and the shop in such abundance that at times our ability to view them in proper perspective becomes overtaxed. This condition is, to some degree, abetted by the matter-of-fact modesty with which the engineer himself views his works.

It is given to us to judge the future by the present and the past. The growth of radio communications is an intensely interesting story, which in a practical sense began on a bleak day only forty-two years ago at Signal Hill, Nova Scotia.

In an atmosphere tense with anxiety three young men listened breathlessly at crude radio instruments for a prearranged signal being transmitted from Cornwall, England. The clock hands crept by the appointed time. Twenty minutes passed. The atmosphere was heavy with agonized suspense. And then, as the needed adjustment was made, the tiny shack reverberated to the exultant cries of Marconi and his associates. History was made.

Twelve years later radio communication began to play its first role, and an important one, in a great armed conflict. It rapidly became an indispensable weapon of mechanized war.

In retrospect it is almost unbelievable that, despite the accelerated research and application in radio during that conflict, frequencies above approximately 1500 kilocycles were considered of little or no value in communication when the war ended in 1918. But such was the case. Our modern world has been profoundly changed during the last twenty years by the tremendous development of aviation and radio communications. The radio services which have wrought this change, which have brought us vastly improved international communication, television, high-frequency broadcasting, and many other benefits of peaceful living, have been gifts of the engineers and experimenters who delved into the unknown high frequencies above the World War I frontier of 1500 kilocycles.

The second great world conflict has demanded and received the bounteous fruits of research and engineering and to a degree which taxes the most fertile imagination. Only when peace returns and the absorbing story can be told shall we learn of the tremendous strides which have been made in fashioning weapons of war through the use of higher and still higher frequencies. Only then shall we know of all the contributions they will make to our normal pursuit of happiness and security.

One hesitates to make predictions because they imply a limit to engineering techniques and devices of the future.

I have unlimited confidence in the engineering profession and prefer to confine my writing about the future to the hope that civilization will adapt the fruits of their skill to beneficent uses and not to machines of destruction and devastation.

Raymond A. Heising

Treasurer, Institute of Radio Engineers

Raymond Alphonsus Heising was born on August 10, 1888, at Albert Lea, Minnesota. He received the E.E. degree in 1912 from the University of North Dakota. Two years were then spent as assistant in physics at the University of Wisconsin where he received a Master's degree in 1914.

In July, 1914, he joined the research department of the Western Electric Company. The project to which he was assigned was the application to radio transmission of the new high-vacuum thermionic tube that had just gone into service as a telephone amplifier. His first accomplishment was the development and laboratory demonstration of a two-channel two-way carrier system for wire communication that led to carrier transmission in the Bell System. Principles which he developed for that purpose he extended and applied to the design and construction of a radio transmitter. This was installed at Montauk, Long Island, and used in May, 1915, to demonstrate radiotelephony over a distance of 800 miles. Later in 1915 there followed the design and construction of a radiotelephone transmitter installed at the borrowed Navy radio station of Arlington, Virginia, that demonstrated the possibility of long-distance radiotelephony by transmission to San Francisco; Darien, Panama; Pearl Harbor, Hawaii; and Paris, France. This transmitter has the unique record of embodying 550 vacuum tubes in parallel in its final amplification stage. There followed radio research that led to his developing for World War I the radiotelephone transmitters of airplane radio SCR-68 and Naval radio CW-936. These equipments saw much service in 1918 and subsequently, for such sets were used even in broadcasting in its early days.

After the war, he had a responsible part in the Bell System development of radio for many purposes including the commercial transoceanic radiotelephone circuits, both long and short wave, in ship-shore telephone system, in short-wave transmission and, ultra-short-wave research. For almost 20 years the piezoelectric research of Bell Telephone Laboratories has been carried on under his supervision. From this work have come most of the low-temperature-coefficient quartz-crystal cuts known to the art.

Mr. Heising is probably best known to radio engineers for his invention of the constant-current modulation system which made possible the first practical radiotelephone in the days when there were few experts on vacuum tubes circuits. He has over 100 other United States patents to his credit covering other modulation systems, radio circuits, etc.

Mr. Heising joined the Institute of Radio Engineers as an Associate in 1920 and transferred to Fellow grade in 1923. He was awarded the Morris Liebmann Memorial Prize in 1921; he has served seven years as elected and appointed member of the Board of Directors, and was President of the Institute in 1939. At present he is serving as Treasurer, and as chairman of the Sections Committee, and Constitution and Laws Committee.

The Phoenix—A Challenge to Engineering Education*

W. L. EVERITT†, FELLOW, I.R.E.

FOREWORD

WALTER CAMPBELL

UNITED STATES SIGNAL CORPS

"The Phoenix—a Challenge to Engineering Education," a paper by Dr. W. L. Everitt, Chairman of the I.R.E. Committee on Education, lights a torch for a campaign that may affect man's life and history down through the years to come. It is an opening gun, calling all members of the engineering fraternity to the colors; it opens a long-period program on which *every* engineer and engineering educator has a vital part to play.

We of the present, have benefitted from the efforts of our predecessors. We have dedicated our lives to the progress of mankind, for that is the *primary goal* of engineering. It is our privilege and duty to consolidate our experience and education and apply these as a guide to the training and education of those members of our profession yet unborn. We must accept "The Challenge to Engineering Education" and unitedly assure "The Rising of the Phoenix."

Engineering is based on economy; economy of manpower, economy of resources, economy of time. We usually evaluate these factors in terms of money but the paramount criterion remains the value in terms of progress and benefits to mankind.

With an active unity of all engineers and engineering educators, we can establish a modernized and well-designed plan for engineering education. We can provide the future engineers with tools, by means of which they can achieve better and more extensive results.

The future curricula of our technical schools must be designed and developed with the same care and thought as goes into well-engineered equipment. The schools providing these curricula must be adequately directed by competent educators. A resulting level of experience and education must be appreciated by all, both the public and existing engineers if the profession is to be respected and supported.

The aims and results of the program to modernize and redesign the plan for engineering education will require much work and involve the consummation of many details. For example, it is anticipated that a *code of ethics* will be developed and established. This code will pertain not to a statement of benefits to be derived by the engineer but rather to his performance, his loyalty, his reliability, and his paramount objective in assisting the progress of mankind. It is also anticipated that the engineer at the time of graduation will take an oath, much as a medical student undertakes, by which he dedicates his life and abilities to the progress of mankind.

Summary—**Engineering education is presented with a unique opportunity for improvement due to the interruption caused by the war. This improvement can only be obtained by a clear determination of the fundamental goals of engineering education and the application to its curricula of the engineering design processes it claims to teach. A distinction should be drawn between the problems of Science, which are those of analysis, and the problems of engineering which are those of Synthesis. Engineering and nonengineering students both should be taught what engineering really is, its philosophy and what it can do. The importance of its humanistic aspect should be stressed. A program is proposed for participation in the discussion and design of engineering curricula by the Institute sections.**

ENGINEERING education is at a crossroads. In this critical period, when the manpower requirements of industry and the Armed Forces are, of necessity, draining current and potential students from our schools, we are presented with an opportunity never before available.

The development of engineering education has been an evolutionary process. To a large degree, it began to expand after the Morrill Land Grant Act of 1862. This Act provided for the foundation and maintenance of colleges "where the leading object was, without excluding other scientific and classical studies, to teach such branches of learning as are related to agriculture and the mechanic arts." Those who have followed the history of the beginning of the Land Grant colleges know that the conception of engineering as a profession was practically unknown at that time and there was much groping and experimentation in the teaching of the "Mechanical Arts."

While education in this field has been modified and

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expanded since that time, it is quite generally admitted that it has, in many cases, grown like Topsy, and has not itself been the subject of the engineering design processes which it claims to teach.

Many of our plans and procedures of Engineering Education are haphazard, without broad but definite objectives, and inadequate in scope and detail. Redefinition and modernization are required if mankind is to reap the tremendous benefits of sound engineering.

We find an inspiring concept in "the Phoenix" of Egyptian mythology, a bird consumed in fire by its own act, but which arose from the ashes in youthful freshness, more vigorous than ever. This concept implies that an essence of immortality is the ability to begin anew, combining the wisdom of age with the dynamic drive of youth.

Engineering education is now being burned by the fires of a technological war. Will it arise from the ashes, like the Phoenix of old, with a rejuvenation shown by its awareness of its opportunities, and the vigor to attack and solve its problems? Or will it simply continue on the path laid out by the old curricula and methods after a temporary recess? The choice is plain, and must be made by engineers and educators now, if a "Phoenix" is to be ready when the war is over.

The present interim is a golden opportunity for a real study of the basic problems of engineering education, and for the *design* of curricula. In peaceful years, there has been a resistance to marked change because of the difficulties of disturbing a going concern, and at times even because of the vested interests of departments and individuals who were teaching subjects in ways which they did not wish to see questioned. Furthermore changes in individual curricula would have reduced flexibility in the arranging of schedules of irregular students and transfers from institution to institution. But these and many other objections to a basic study of the problem and action thereon do not apply today. Most of the upper-class engineering students in school at the time of Pearl Harbor were allowed to complete their college courses. After the war, a new crop of freshmen will enter and be carried forward. Now is the time for the engineering design of curricula in the several branches of professional engineering. In fact, if this opportunity is passed by, we may never in our lifetime have another.

In order to carry on discussions on any problem, it is important that an agreement be reached among those concerned on the subject of their discussion. Definitions are needed. Unfortunately definitions are frequently given which require such elaboration that they confuse rather than clarify. The words Science and Engineering have so frequently been confused that it is believed essential that they should be distinguished, at least for the purpose of this discussion. Of late, there has been a particular tendency to imply that scientific and engineering education are one and the same thing. If this be so, then the engineering colleges have no justification for their existence and their duties should be absorbed by the appropriate basic-science departments. The writer believes there is a definite and important difference, and furthermore this difference has not been taken into account in the *evolutionary* development of engineering curricula.

Webster defines Science as "knowledge of principles or facts," or more specifically "accumulated and accepted knowledge which has been systematized and formulated with reference to the discovery of general truths or the operation of general laws."

Webster defines Engineering as the "art by which the properties of matter are made useful to man in structures and machines."

The most fundamental difference between Science and Engineering is the difference between Analysis and Synthesis. Science is interested primarily in learning what effects follow causes, in learning why and how nature, both physical and biological, behaves as it does, in other words in analyzing everything and finding out what to expect under a given set of conditions. Engineering, on the other hand, goes far beyond this. It is interested in assembling a combination of men and materials to produce a desired result or a reasonable facsimile thereof. This is the process of synthesis, of putting things together to accomplish a definite end.

The processes of synthesis can be accomplished only after a thorough grounding in the processes of analysis. One must know what results will follow from definite causes, both when they occur singly and in combinations. But the methods of synthesis go beyond those of analysis and must be learned as such. Certain of these methods can be taught, others involve judgment, the willingness to try, recognize failures, and try again repeatedly, and some involve intuition which inevitably differs among individuals. But their importance in engineering should be recognized and taken into account in the training of the engineer.

Synthesis inevitably requires more mature judgment than analysis. Childhood is the time for taking clocks apart to find what makes them tick, only the mentality of the adult can design an assembly of springs, cogs, etc., to keep time within acceptable limits.

In particular, engineering synthesis requires the use of a knowledge of more related elements while analysis can be broken down into isolated areas. The performance of a radio set can be analyzed without attention to economic factors; but the design of such a set without considering economics, or the human use to which the set is to be put, is no design at all.

It is not intended to imply that the work of the pure physicist is less important or less mature than that of the engineer. The pure physicist in his research designs many ingenious devices to assist him in his work of analyzing nature. The cyclotron is itself a monumental work of synthesis. As such, it is essentially an engineering product, designed by physicists. But it is important to realize that the synthetic processes which physicists apply in research are not, in general, taught in the science classes. Applied physics is a form of engineering upon which the comments of this paper bear fully.

In our engineering curricula, we have taught the student almost exclusively the methods of analysis and very little of the methods of synthesis. He attends classes and laboratories and learns what happens when certain forces and materials are brought together. Very seldom does he have the opportunity to assemble, either on paper or in physical being, from out of all the world of nature at his disposal, a combination to produce a desired result. In other words, engineering curricula have omitted instruction in "Engineering." As a result of this, our students go out as graduates, obtain a job, and then ask "Why wasn't I told about this thing called engineering before?" We have, it is true, trained engineers but we have not taught engineering. We have taught the engineer how his tools are put together, but we have not generally shown him how to use them.

Engineering is a way of life for those who pursue it, much more than a way of making a living. An engineer cannot be made by academic procedures alone, but these procedures should point the way from the beginning. Clear thinking should be an essential in an engineering education and yet we have not even been clear in explaining to him what engineering is. Engineering is a dynamic force, it requires *doing* in order to exist, it cannot be learned solely by passively studying what is already known. It never consists in working the problems in the book, or ones like them with only changed constants. An engineering problem always contains new elements, requires the production of a new result or device, or else it is not an engineering problem. It cannot be solved by routine application of rule-of-thumb methods. Although he depends greatly upon experience for his results, the engineer seldom repeats the work of the day before without modification.

A way of life must be inspired and cannot be taught by rote. Engineers, as a group, are generally recognized as having high ethical principles. However, we lose a golden opportunity in the engineering college if we do not point out to the student the need for high moral principles, and the inspiration which can be drawn in working both with people and the laws of nature. We need also to point out the danger of a Frankenstein which can result from the improper application of scientific principles. We must be more articulate in the expression of the engineer's creed. We should have the equivalent of the Hippocratic oath which has inspired medical students for centuries.

Many people who merely operate instruments or turn dials or do other repetitive work are called engineers. But such people are not engineers, even though they may have engineering degrees, and every effort should be made to make this clear to the public. In fact, engineering education should unfit a man for repetitive tasks, even though such tasks may require their performer to ***know*** a greal deal.

The definition of engineering given by Webster included the phrase "made useful to man." This is extremely important, as the engineer has not produced an engineering product unless it *is* useful to man. Consequently, the engineer should understand man as well as matter. He must learn how to recognize the needs of men, and how to interpret his material products to men so that men will use them. Therefore, the curricula should include instruction which will help the young engineer to speak and write fluently and clearly. He must be able to convey his ideas to others. He should also be taught open-mindedness and a survey of other fields of knowledge, present and past, so that he can understand and evaluate the thoughts of others. And he should be required to use these principles throughout his course in his class recitations and in his written reports. The motto should be "learn and apply," not "study and forget."

It has frequently been assumed that courses in an engineering curricula should be set up to teach *all* that the engineer should know about a given subject. But such an aim is futile, both because of lack of time and because the instructor himself does not know everything. Furthermore, at the time he is a student, the art itself does not possess what the engineer will need to know ten years later. Therefore, the fundamental problem is to make the student Literate in the subject. By the word "literate" is meant not only the *ability* to read and understand the literature and other available material on the subject, but also the *desire* to continue his reading or education in the field. Any educational course has *completely failed* if it does not so relate the material to the man's life that he will be stimulated to continue to acquire knowledge in the subject and in turn relate it to his actions and decisions. The mental impressions received in a course where the student has the feeling at the end "Well, thank God that's over," will fade so rapidly that the course might better have been omitted. These remarks, of course, simply mean that engineering education should produce an educated man. Attainment of these objectives require not only good teaching but also a definite recognition of the goal and the integration of the whole educational program.

The processes of engineering, and synthesis in general, normally require the use of approximations. It is very seldom that an engineering product can be made to fit perfectly all the desirable criteria. If we try to make it fit too perfectly the most desirable objective, it may cost too much or be too difficult to run or maintain. Therefore, one of the most important decisions to be made is "how good is good enough." The engineering graduate too frequently does not realize this. The design of a $15 radio will, in general, require better engineering than that of a $500 one because it requires more judgment in eliminating the nonessential and making the most of the essential elements. And the design of the $15 radio may also be more "useful to man" because of its greater distribution. The engineer must be taught the utility of the imperfect, and the importance of the attainable and practical. Someone has said that an engineer is a man who can draw correct conclusions from incomplete and frequently incorrect premises. Above all, he should be thoroughly indoctrinated in the economics of everyday life, and how it affects the work of the engineer.

In learning the importance of the practical, the engineer should be taught not to waste his efforts or those of his associates. If he is going to use resistors which are manufactured to tolerances ± 5 per cent, he should not make calculations to a large number of significant figures. On the other hand, if his answer depends upon the difference between two large numbers which are nearly equal, the calculations of the individual numbers must be very accurate in order to get a reasonable accuracy in their difference and he should recognize when this is necessary. In the curricula, a studied effort should be made to introduce repeatedly situations where judgment is needed, and the student should be graded on his performance and given advice.

Special situations should be given where the student can use the principles of synthesis, starting with simple cases and proceeding to the more difficult. He should be taught how in a particular problem he can select from the complete world of data which is at his disposal, those elements of importance to the problem. He should then be shown that synthesis in general uses the principle of educated guessing and checking of the results of the guess by analytical methods. The problem is somewhat similar to the mathematical one of integration, where the answer must be guessed (unless an old problem is recognized) and the analytical method of differentiation is available to find out whether the guess is correct.

Engineering schools should consider a greater use of the "case method" which has been adopted so widely for legal training. Certain types of problems can be used to illustrate the synthetic process. The author has found the design of an attenuation equalizer a good example. In this problem, a network is desired whose attenuation characteristic fits a particular curve. A table is consulted to find combinations of resistances, inductances, and capacitances which have the general type of curve desired. Several may be available. The more complicated will, in general, cost more, both in time to design and money to manufacture. So we may try the simplest first. It may have two independent variables. We therefore select two points we shall try to fit exactly. This may be done by setting up two simultaneous equations. After we have fitted these two points, we then *analyze* the resulting network by computing its curve over the frequency range of interest. It will not fit the desired curve exactly but will be an approximation thereof. The designer must decide whether it is good enough. If it isn't, he must try again, either by using two new points to fit or by selecting a more complicated network which has more independent variables and so can be fitted at more points. In the end, he may have several solutions of different degrees of approximation and complexity (cost) and a decision must be made whether the better article is worth the extra cost. The complete plan of operation has most of the elements of engineering synthesis.

The purpose and conduct of laboratory courses should be examined carefully. To a large extent, the apparent aim of most laboratory experiments has been to verify that all the important statements in the book are really so. The same techniques are applied first on one piece of apparatus and then another to obtain curves which are already published. It is true that we should instill in our students a questioning mind that will not always accept the printed word as the gospel, but it is believed that repetition in the methods of test may not always make the best use of the student's time. At least in the senior year, an opportunity should be given the student to design his own experiments, with only some general instruction such as "Find what the important characteristics of this machine are." Then he should be given some opportunity to design and assemble a working piece of apparatus to produce a desired result. Such a laboratory program would necessarily mean that he would not have the time to verify as many principles which have been taught but it would give him some experience in the engineering method of making tests and producing designs.

Training in the combination of analysis and synthesis required by the engineer necessarily takes an extended time. The completed education of the engineer involves both the period spent in the college and in industry. Certain things can be taught best in the college, other things can be learned best in industry. Inevitably the job of the college will tend more toward the analysis which must be taught and the synthesis will be learned in industry. However, it would be surprising if the distribution of time decided on for the engineering curricula seventy or more years ago were the ideal today. Frequent suggestions have been made that the engineering curricula should be extended beyond four years. These suggestions have not been adopted because the *burden of proof* has been upon the colleges to show that more than four years would be advantageous to the individual and to industry in the completed training of the engineer, and this proof has *never been given* except in the case of men who intend to enter research or teaching in certain fields. Proper design procedure in the development of the curricula, and a realistic recognition of aims and possibilities should lead to a more definite answer.

It may be felt that, because our existing curricula have trained men who have become good engineers, no change should be considered. But this is the philosophy of "what was good enough for father is good enough for me", which is the very antithesis of the engineer's creed. As a matter of fact, we had engineers long before we had engineering education and we shall have engineering even though we do not teach it, because men will work out their own problems if the schools do not assist them.

But, unless the educational process itself is considered a failure, it seems evident that a properly designed curriculum will produce a better product.

The cultural value of the engineering way of thinking should not be overlooked in our postwar educational planning. The engineer has a way of life, a mental directness and vigor, which is useful in the solution of many of mankind's problems. The social scientist, the physician, the lawyer, the politician, the preacher, and many others can learn from him as well as teach him. But when the nonengineering student of arts has asked what course or courses he might take to learn about engineers and engineering, we have offered him Elementary Surveying 301 or Direct-Current Machinery 426. Such courses can never convey any idea of what engineers are or what they can do. Is it any wonder our profession is misunderstood? We should give serious consideration to providing some such course as the "Philosophy and Methods of Engineering" for the cultural education of nonengineers. If our methods were known, workers in other fields could frequently frame their problems so they could be brought to engineers for solution and great additional good would result.

The design of proper engineering curricula should not be the job of educators alone, but should be participated in by practicing engineers of experience. In order to obtain such participation, an orderly procedure is desirable. It is proposed that the individual sections of The Institute of Radio Engineers devote one meeting in the near future to a discussion of these problems. The representatives of the Institute at the educational institutions in the immediate vicinity of each section might act as a nucleus or committee to open the discussions. A secretary should be appointed for each section to record the significant comments and these should then be sent to the Institute's Committee on Education for compilation. Then these assembled comments, the opinions of a representative group of engineers, could be made available to educators for consideration of any action which might be recommended.

The design of new curricula may require changes in methods of teaching, without which the desired results cannot be obtained. Serious study must be given to this problem as well as to the curricula content itself.

Conclusion

The design of individual curricula for civil, electrical, radio, and other engineering branches will differ and this article is not intended to suggest particular collections of courses. What is suggested is that engineering curricula should be *designed*. The engineering method of synthesis to produce the most desirable result from all the available material should be applied. It is further emphasized that this is a golden opportunity for educators and engineers to get together to discuss their mutual problems. It is suggested that during a time when the flow of scientific knowledge is restricted for security reasons, many Sections of engineering societies could profitably devote meetings to the methods and aims of engineering education, so that following its resurrection after the war, we may find it indeed a new and better agency for promoting the welfare of the profession and of mankind in general. Simultaneously, the educators should make use of the time available to consider the possibility of modifications in curricula which will more nearly approach the possibilities latent in a true engineering education, taking into account the comments of practicing engineers who are the ones who make use of their product.

The Amplidyne System of Control*

E. F. W. Alexanderson†, fellow, i.r.e., M. A. Edwards†, nonmember, i.r.e.
K. K. Bowman†, nonmember, i.r.e.

Summary—Some typical forms of amplidyne control are described and a method of analyzing their functional characteristics is given. It is shown how it is possible to predict the speed and accuracy of response of a follow-up control and how to avoid self-sustained oscillations. The problem is approached by the method of resolving irregular control functions into their equivalent sine-wave components. Several methods are described for suppressing oscillations due to feedback in follow-up controls and it is shown how anti-hunting systems may be worked out so as to result in a minimum impairment of the speed and accuracy of the control.

The amplidyne is an amplifier used for power control. It has found extensive use both in industry and in other places, and it has proved to be a very successful alternative to the electronic amplifier in those cases where it can be used. The best way to explain briefly how the amplidyne functions is to indicate some of the typical applications.

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Voltage Control

The amplidyne is used to regulate the field of a generator. The advantage over an ordinary exciter is that it forces the changes in field strength to take place in much shorter time and therefore it smoothly and swiftly corrects either wide load swings or small deviations. Fig. 1 shows diagrammatically the application of amplidyne induction control to an induction furnace.

† General Electric Company, Schenectady, N. Y.

Current Control

The current in a motor or generator circuit is held within close limits by the amplidyne. Thus machinery can be made to operate at peak performance without fear of overload or mechanical damage. Constant tension can be automatically held in a continuous process. Maximum rate of acceleration and deceleration can be assured.

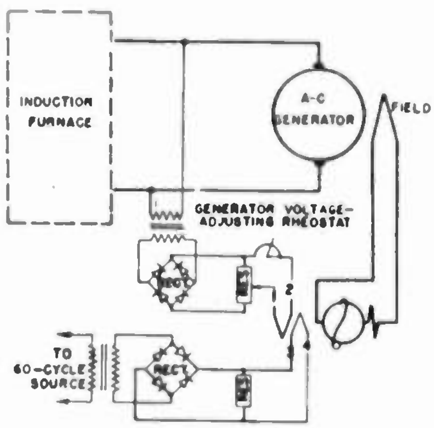

Fig. 1—Amplidyne reference field (3-4) is excited by constant-voltage power supply and opposes amplidyne control field (1-2), excited by main generator output voltage. The control field is connected in series with a voltage-adjusting rheostat. The amplidyne output excites the main generator. This same scheme (less small transformers and rectifiers) applies to direct-current generators.

Speed Control

Speed is translated into voltage by a tachometer generator and this indication is amplified so as to regulate and match speeds in industrial processes.

Positioning in Motion

Fig. 2 shows a typical position control in motion. A photoelectric device watches the moving paper edge.

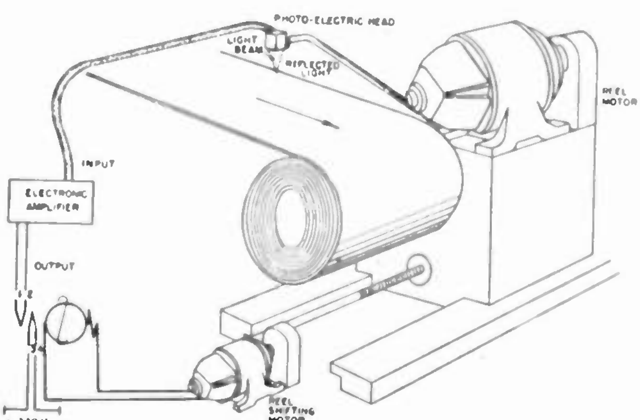

Fig. 2—Light variation in photoelectric device is electronically amplified and supplied to voltage field (1-2) where it is compared to reference field (3-4). Any difference causes the amplidyne to operate the reel-shift motor.

The intensity of the reflected light is converted into an electric signal which is then amplified in an electronic amplifier. Variations in this signal excite the amplidyne which then supplies the necessary power.

These typical applications show that the amplidyne is in all its uses essentially an amplifier. A high amplification with great accuracy and sensitivity is possible but the amplidyne is subject to the same limitations as the electronic amplifier so that the higher the amplification the greater is the tendency towards feedback, causing self-sustained oscillations which would make the process inoperative. The object of this paper is to give the application engineer a simple analysis so that he will be able to predict what accuracy of performance is obtainable and avoid instability and oscillations. The best approach to this has proved to be the point of view generally used in radio-and-electronic engineering. The changes in power flow used in industrial controls are not as fast as the changes when radio transmission is modulated by the human voice, but the principle of analysis is the same. We have found it convenient in radio to resolve the irregular voice modulation into its equivalent sideband of frequencies, and we are thus able to analyze the functioning of the amplifier into terms of

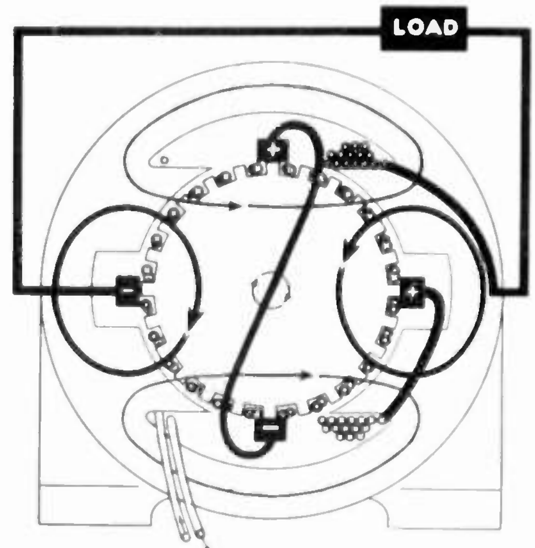

Fig. 3—Functional diagram of the amplidyne.

sine waves. This point of view will be applied to the amplidyne as a method of predicting its performance. Although the amplidyne is physically a direct-current generator we shall proceed to analyze it as if it were an alternating-current generator.

The Amplidyne Generator

The amplidyne is a two-stage amplifier incorporated in one dynamo electric generator. The first stage is from the control field to the short-circuit axis, the second from the short-circuit axis to the load axis, (Fig. 3). When we apply a voltage to the control field there is a time delay before the corresponding current appears in the control field, and then there is a second time delay before the voltage appears on the output terminals. The reason for this second time delay is the inductance in the winding which causes the short-circuit current to lag behind the induced electromotive force. Some machines respond faster than others and the laws which govern the rate of response will be discussed later.

Rate of Response

The rate of response is one of the essential characteristics of the amplidyne which must be chosen so that it is adapted to the purpose intended. In a typical machine the rate of response is defined as the voltage rise per second when a current is suddenly established in the control field which will give an ultimate voltage equal to the rated voltage. The rate of response according to this definition measures only the time delay in the second stage of amplification. In tests to determine this rate of response the delay in the first stage is reduced practically to zero by connecting high resistance in series with the control field. In a typical amplidyne the rate of response is 2000 volts per second. If the final voltage is 250 volts this gives a curve of response which will reach 200 volts measured on an oscillograph corresponding to a time constant of one tenth of a second (Fig. 4). The rate of response indicated in this way is an approximate measure of the capabilities of a certain machine.

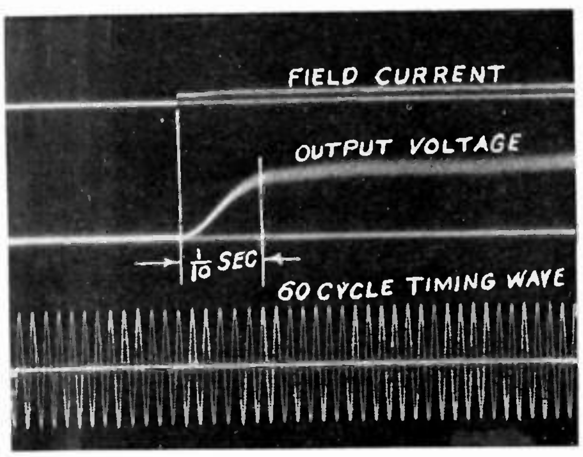

Fig. 4—Measurement of rate of response.

The rate of response in a control system depends on the combined characteristics of the amplidyne generator and associated circuits. The prediction of performance becomes very complicated if we look upon it as a single control transient passing through the amplidyne and a chain of circuits with degenerative feedback (Fig. 5). It is, on the other hand, important that such an analysis should be made because circuits of this sort are likely to be oscillatory. The designer must therefore foresee what measure must be taken to prevent such oscillations. He must also be able to design a system to meet the specified accuracy of control.

Analysis by Equivalent Sine Waves

For the purpose of predicting the results, the analysis of this complex problem can be greatly simplified by using the device commonly adopted in radio of resolving irregular transients into an equivalent sideband of sine waves. Thus the designer may say that the control functions which he is contemplating can be resolved into frequencies between zero and 2 cycles per second, just as the radio designer says that broadcast signals are resolved into frequencies up to 5000 cycles and television signals into frequencies up to 6,000,000 cycles. If the control changes which he is contemplating will take place in one tenth of a second he may say that the equivalent frequency band is 2 cycles wide. In such a case he may conclude that an amplidyne with a rate of response indicating a time constant of one tenth of a second will be suitable and he can proceed to analyze his complete circuit with time delays, phase changes, amplification ratios, and degenerative feedback effects at a frequency of 2 cycles. If he then concludes that his complete circuit at 2 cycles per second is nonoscillatory and meets the requirements for accuracy he may assume that he has a successful design. To be additionally sure he may make a similar analysis for 1 cycle per second and 3 cycles per second. This is illustrated by Fig. 6, which shows the transition from an oscillatory to a nonoscillatory state by a change in control.

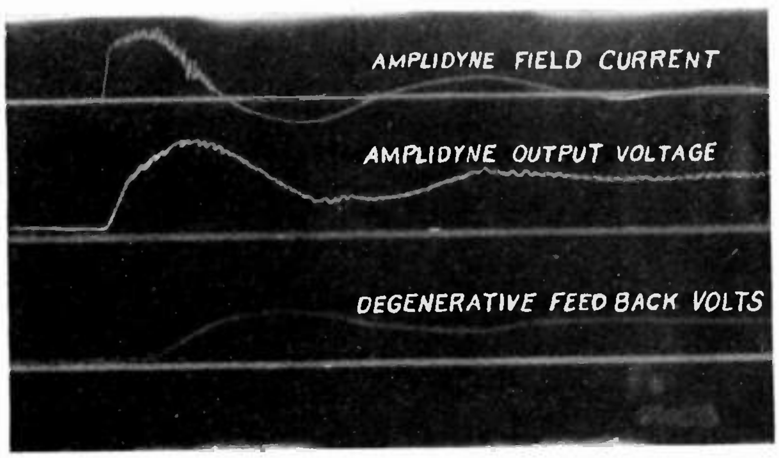

Fig. 5—Control transient with degenerative feedback and strong damping

One advantage in the analysis of alternating-current circuits compared with direct-current circuits, is that in an alternating-current circuit the currents and voltages are determined almost entirely by the reactance of the windings so that the resistance can be neglected. Thus it is possible to predict the performance of an alternating-current transmission system involving synchronous generators and induction motors so that the overload capacity and stability can be calculated. In doing so it is only necessary to assume the probable constants of typical generators and motors without having in mind any specific design. With alternating-current analysis the same method is applicable to the amplidyne.

Voltage Amplification

The typical machine on which the following tests have been made has a rotation frequency of 30 cycles. It has a rating of 8 amperes at 250 volts. This machine has a rate of response which makes it adaptable to control frequencies up to 2 cycles. Without knowing anything further about the design of the machine we can predict what amplification is to be expected at 2 cycles, or at any other frequency at which we wish to

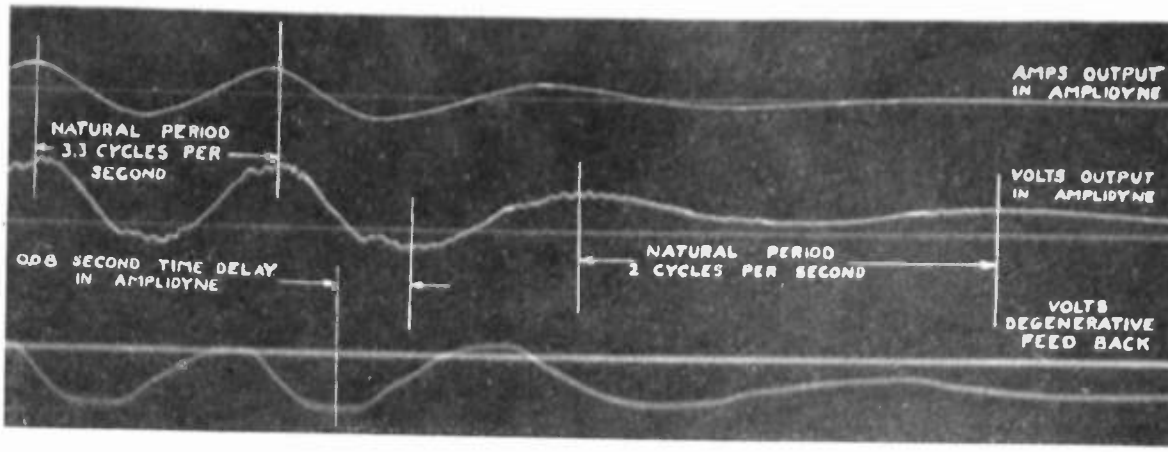

Fig. 6—Change from oscillatory to damped control.

operate it. For this purpose we will resolve the amplification into its two components: voltage amplification and current amplification. Of these, the voltage amplification is the more important. In estimating the voltage amplification we need only refer to the fundamental law that the voltage induced by a given flux is proportionate

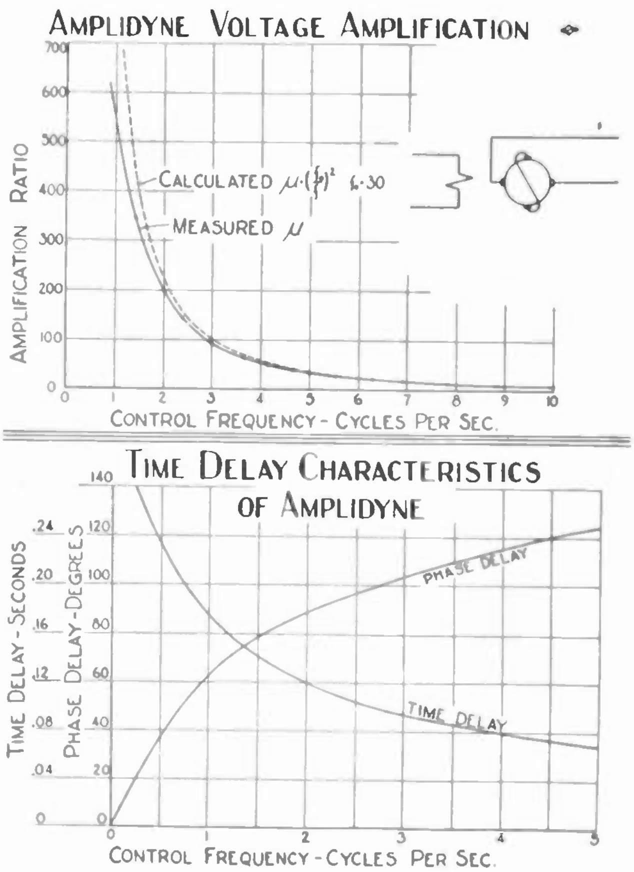

Fig. 7—Amplification and time delay at varying control frequency.

to the frequency. Thus the counter electromotive force in the control winding is proportionate to the control frequency which we assume to be 2 cycles. The voltage generated in the armature is however proportionate to the rotation frequency of the machine which in this case is 30 cycles. Therefore the voltage per turn induced in the armature winding is fifteen times as great as the voltage induced in the control windings. Thus the voltage amplification in the first stage is 15 to 1. This means that in a control winding with the same effective number of turns as the armature winding we need only to apply 1 volt in order to obtain an induction of 15 volts in the short-circuit axis. The voltage so generated is however short-circuited and consumed by the reactance in the armature winding. This reactance is equal to the reactance of the control winding. The short-circuit current is, therefore, fifteen times as great as the control current and the short-circuit flux fifteen times as great as the control flux. The second stage of generation will again multiply the voltage by fifteen so that the over-all voltage amplification is 15 times 15 or 225. This is an ideal voltage amplification which we should arrive at if we had windings without resistances. If we wish to estimate the ratio of voltages actually found on the terminals of the control winding and the armature winding we must make allowance for resistance of the windings and the brush contacts. The result of calculations and tests are shown in Fig. 7. In analogy with the practice of radio engineering the voltage amplification is designated by the Greek letter μ and it is significant that this amplification can be expressed by the simple formula $\mu = (f_0/f)^2$ where f_0 is the rotation frequency and f the control frequency.

Current Amplification

Having established the voltage amplification the designer will wish to estimate the impedance of the control winding so that he can match it with the impedance of associated circuits. The impedance in the steady state is of course the resistance of the winding but it is much more important to know the reactance of the winding at the representative control frequency. The reactance of a control winding with the same effective number of turns as the armature winding is equal to the reactance of that winding. The amplidyne is usually designed with a small air gap and distributed compensating winding so that it has a magnetic structure resembling the induction motor. In the practical design of such machines, it is found that the magnetizing ampere turns are of the same magnitude as the load ampere turns. It may therefore be assumed that the magnetizing impedance is about the same as the load impedance. The magnetizing impedance is measured at the rotation frequency. From this the inductance in henries may be calculated. This estimate of the inductance of the control winding is sufficiently accurate for the design of the associated circuits even if the detail design of the machine has not yet been established. If the control winding has a greater number of turns than the armature winding, the calculation of reactance must of course include the square of the turn ratio. In the typical machine used for this analysis the inductance of the control winding estimated by this method is 34 henries, whereas the measured inductance is 31 henries.

Oscillations

A regulating system usually can be described as a degenerative-feedback system. We may wish to regulate a voltage, a speed, a position, or a torque. In each case we provide means for measuring the result by electrical or mechanical means. Any departure from the desired result is then amplified and fed back into the control so as to correct the error. In the steady state it is therefore a negative feedback. There is, however, usually a time delay in this feedback circuit. At some frequency this time delay may amount to a phase displacement of 180 degrees. The feedback then becomes positive instead of negative and tends to create oscillations. Continuous oscillations will, however, not occur unless the amplification of the feedback energy is sufficient to repeat impulses of the same intensity as those preceding.

Oscillations must be avoided in a practical regulating system and in the design of such a system it is important to be able to predict whether oscillations will occur. The factors that must be examined are amplification and phase displacement. A practical procedure is to estimate from previous experience at what frequency oscillations are likely to occur. If such a frequency is 2 cycles per second we may estimate the phase displacement in each successive part of the circuit. If the sum of all those phase displacements is less than 180 degrees the system will not oscillate at 2 cycles. We may find however that the phase displacement will aggregate more than 180 degrees at $2\frac{1}{2}$ cycles. If in addition to this we find that the amplification at $2\frac{1}{2}$ cycles is sufficient to sustain oscillations we may conclude that the system will oscillate at that frequency.

Antihunting Systems

To avoid hunting the designer will choose some of the several methods of suppressing oscillations. These are usually known as antihunting systems. He may reduce the amplification or he may introduce corrections in the phase displacement. The first method is the easier and is usually resorted to if it is permissible. It must, however, be understood that when we reduce the amplification we also reduce the accuracy of regulation. A compromise may be resorted to whereby the amplification is reduced for frequencies around 2 cycles, whereas the steady-state amplification remains at full value. Such a measure leaves the steady-state regulation unimpaired but slows down the rate of response so that the accuracy is reduced during changes in the control.

When the requirements are such that close accuracy must be maintained during rapid changes it becomes necessary to resort to the second method of correcting the phase displacement. This can be done by use of additional feedback circuits and introduction of inductance-resistance-capacitance networks which produce the desired phase displacement. The design of circuits for specific practical purposes is an art rather than a science. As a general rule however it may be said that it is usually more practicable to construct circuits for lagging phase displacement and then get the effect of a resulting leading phase displacement by a reversal of polarity. There is a practical limit to the amount of correction that can be introduced in this way but it is found that a judicious use of phase displacement will result in substantially improved performance in speed of response and accuracy of regulation during control changes.

Position Controls

Among the many regulating systems for which the amplidyne is suitable the position control is in a class by itself. A position control is equivalent to a spring holding a weight. An error of position is amplified so that it produces a restoring force proportionate to the error. Thus the restoring force acts like a spring and the greater the amplification the stiffer is the spring. Like a spring with a weight, it has a natural period of oscillation. The designer of a position control should have in mind what natural period he wishes to establish because upon this depends the accuracy of control. If he is aiming at a high accuracy the system is likely to oscillate continuously. In this the position control differs from the spring with the weight which always oscillates with a decrement if it has received a shock. The phase displacement in the feedback circuit determines whether the position control will oscillate. This feedback circuit is partly mechanical and we find that this mechanical part of the feedback consumes the whole permissible 180 degrees so that no phase displacement whatever is permitted in the electrical circuit comprising the amplidyne and the driving motor. This is the reason why the position control places especially high requirements of rate of response on the amplidyne.

The nature of the feedback circuit is worth examining somewhat more in detail. Starting with the torque of the motor which moves the load, we have first a 90-degree phase displacement between torque and velocity. Then there is a 90-degree phase displacement between velocity and position. Thus there is 180-degree phase displacement between torque and position. The error of position is then translated into electrical quantities by a selsyn or a potentiometer and a corresponding voltage is applied to the amplidyne field. The amplidyne then generates a voltage which forces a current through the driving motor and produces a torque. If there is no phase displacement between the control impulse and torque delivered by the motor the system will act like a spring and will have a damped oscillation if it receives a shock. But if there is the least phase delay in the electrical circuit this will introduce an energy component which tends to sustain the oscillations. In practice we wish to have a strongly damped oscillation and therefore the phase displacement in the electrical circuit should preferably be leading but under no circumstances lagging.

Offhand it might seem that such a circuit would always oscillate because there is a definite lagging phase displacement in the amplidyne. This phase displacement may be corrected by antihunting circuits but this is, as a matter of fact, not always necessary, and the reason is worth explaining. The torque is produced by the current delivered by the amplidyne and this current is not necessarily in phase with the amplidyne voltage. It is usually in the nature of a leading current such as we get in a capacitive circuit and the leading phase displacement of the current is in many cases sufficient to more than compensate for the lagging phase displacement in the amplidyne. We usually think of the armature of a generator and a motor as an inductive circuit and we may wonder how we obtain the leading phase displacement. As a matter of fact we have the equivalent of an electrostatic capacitance in series with this circuit but this capacitance is of a nature with which we seldom have reason to deal. The armature of a direct-current motor with separate excitation is such a capacitance. We may assume that 100 amperes applied to the motor armature will produce a torque which causes it to accelerate in 1 second from standstill to a speed which generates 100 volts. We have thus a circuit in which 100 amperes causes a voltage rise of 100 volts per second. But this is the definition of the electrostatic capacitance of 1 farad. If we use a motor of the size indicated we must therefore include a series capacitor of 1 farad. If we now assume that the actual period of oscillation is 2 cycles per second we find that the series capacitance has an impedance of 0.08 ohm. The inductive impedance of the circuit at the same frequency may be less than that and then we have a circuit in which the capacitance is predominant and the current is definitely leading. If this leading phase displacement of the current more than offsets the lagging phase displacement in the amplidyne, we have a position control in which no further antihunting measures are necessary. In many cases it is, however, desired to increase the accuracy of control beyond this point. A higher amplification will then result in a higher natural period. The capacitive impedance in the motor circuit will decrease and the inductive impedance will increase until the two become equal. The point has then been reached where the motor current is no longer leading and a still greater amplification will cause it to become lagging. The antihunting effect of the leading current in the motor circuit has, therefore, been lost and the difficulty of artificial stabilization by antihunting circuits has been greatly increased. Fig. 8 shows how the equivalent capacitor effect of the motor armature produces a leading current at 1 cycle per second, whereas the inductance of the windings is in tune with the mechanical capacitor at $2\frac{1}{2}$ cycles, so that the current is in phase with the terminal voltage.

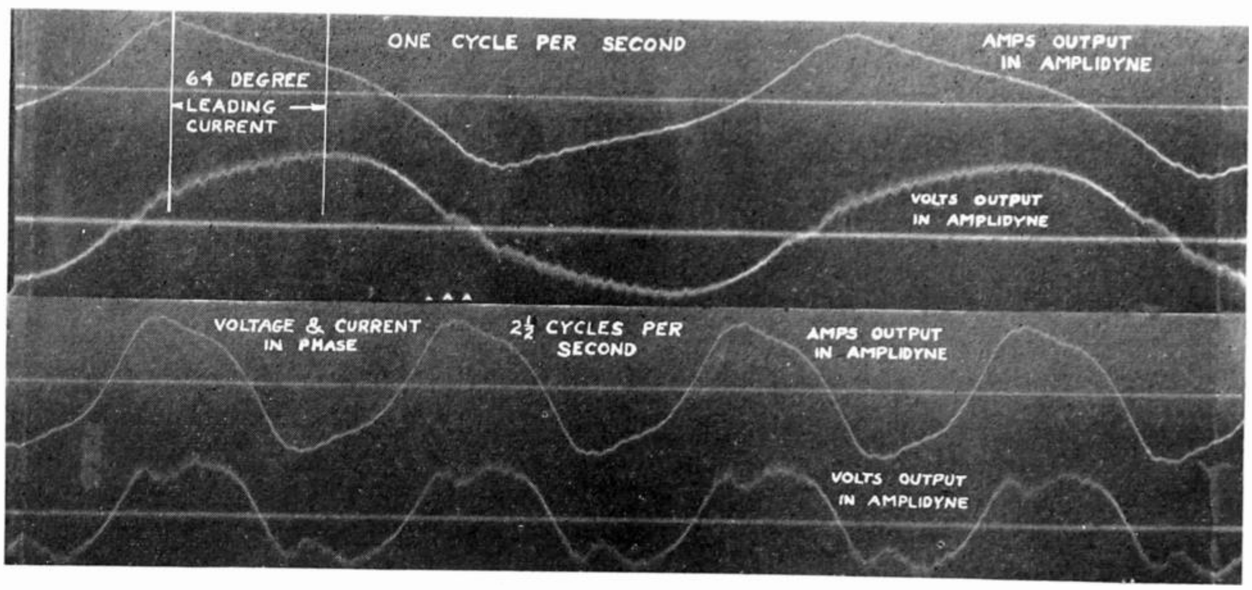

Fig. 8—Oscillogram showing leading current in output circuit.

Practical Limits of Accuracy

As a practical rule for the design of position controls, it may be stated that the limit of stiffness of the control circuit is reached when the corresponding natural period is a frequency where the capacitive impedance of the motor circuit is equal to the inductive impedance. This point of view also indicates to the designer how the best possible results may be obtained. The inertia attached to the motor shaft should be as low as possible. The motor design and the gearing should be selected accordingly. The inductance of the motor winding should also be made as low as possible by special care in the design of the windings. The designer will also choose an amplidyne with the highest possible rate of response. This means that he will choose one with a high rotational frequency as indicated by the formula given above for voltage amplification.

Characteristics for General Information

The relationship between the designer of the amplidyne generator and the application engineer is the same as between the manufacturer of vacuum tubes and the radio engineer. It is important that those two branches should mutually understand each other but they are distinctly different efforts. It is attempted here to give some of the basic information on amplidyne generators in such a form that it can be readily used by designers of amplidyne systems. As a sample of the kind of information that may be useful we are here giving some characteristic curves of typical machines. Fig. 7 shows the amplification at various control frequencies. The dotted curve is the ideal amplification that may be calculated if we disregard the resistance of the winding and the other is the measured amplification. It may be seen that these two curves approach each other closely at the higher frequencies and that the amplification as measured at the lower frequencies departs from the ideal curve just at the rate which should be expected because of winding resistances. Another curve of Fig. 7 shows the time delay and phase displacement between the voltage impressed upon the control field and the voltage generated at various frequencies. These two curve sheets represent the basic characteristics of the amplidyne without feedback circuits. They give the information on amplification and time delay from which various antihunting systems may be designed. Thus, feedback circuits may be introduced not only from the terminals of the amplidyne but also from currents or voltages that appear as later links in the chain of circuits. The procedure in each case must be adapted to the circumstances and the results will largely depend upon the skill of the engineer.

In order to serve as a sample for comparing theory and practice, a complete amplidyne regulating system is analyzed and the test results thereby given. An amplidyne is used to drive a motor-generator set and regulate its speed. The resulting system is designed to give the quickest possible response with the apparatus available. For this reason a high amplification is used in the regulating circuit. The result is that the system oscillates violently unless effective antihunting methods are used.

From a theoretical point of view the following may be observed:

The amplidyne has a rotation frequency of 30 cycles. Its amplification and phase characteristics are shown in Figs. 7 and 9. At a control frequency of 2 cycles its phase displacement is 90 degrees. This indicates that its usefulness is limited to about 2 cycles.

The inertia of the motor-generator set driven by the amplidyne is such that the equivalent capacitance of the direct-current driving motor is 0.2 farad. The inductance in the circuit including the amplidyne and the motor is 0.04 henry. The natural period determined by the inductance of the circuit and the inertia of the load is, therefore,

$$f = 1/2\pi\sqrt{LC} = 1/2\pi\sqrt{0.2 \times 0.04}$$
$$f = 1.75.$$

This is the critical frequency beyond which stabilization becomes difficult.

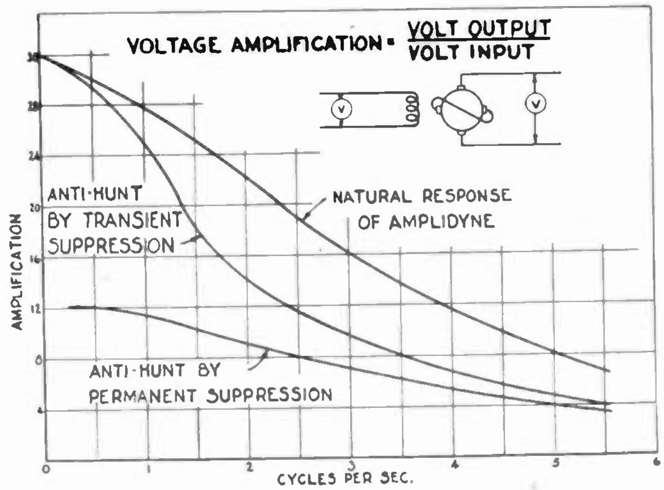

Fig. 9

This calculation is consistent with the oscillogram Fig. 8, which shows the current in phase with the terminal voltage of the amplidyne at $2\frac{1}{2}$ cycles. This means that the inductance of the motor alone is in tune with the mechanical capacitance at $2\frac{1}{2}$ cycles; whereas in the prediction of tendency to hunt we are interested in the tuning frequency of the circuit as a whole.

If we now examine the practical results we find that the system oscillates at 3 cycles. This is as would be expected. If the amplification is reduced the result is that the frequency of oscillation and its amplitude decrease until the oscillation stops at a frequency of about 2 cycles. This is shown on the oscillogram Fig. 5, where a continuous oscillation is changed into an oscillation with a sharp decrement.

Fig. 10 shows how this circuit responds to a sudden change of control. It should be noted that the quantity which is being controlled reaches its new steady-state value in a half cycle of an oscillation. The time interval is in this case one fifth of a second. To keep this time interval short is one of the objects in the design of a regulating system. The antihunting system used in this case is a suppression of amplification combined with a

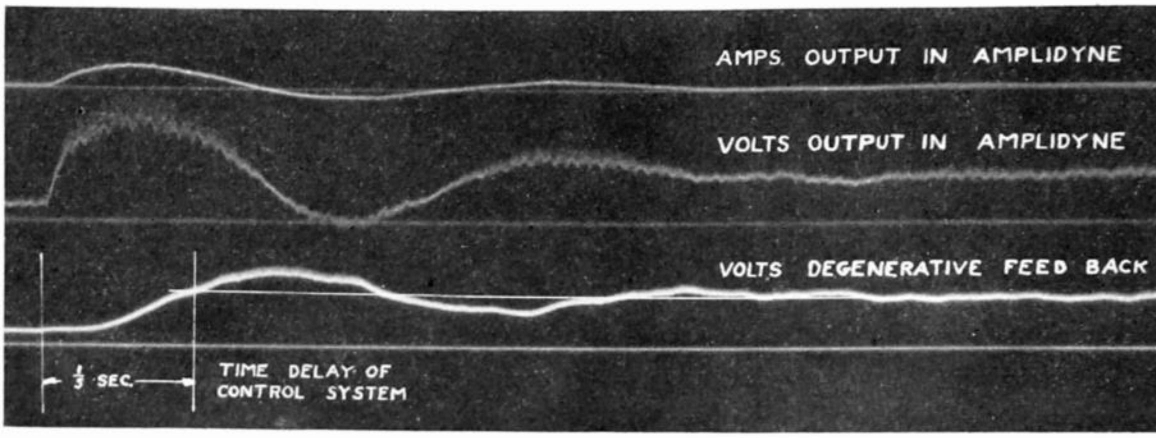

Fig. 10—Antihunt by permanent suppression of amplification.

reduction of phase displacement. The amplification response measured at different frequencies is shown on Fig. 9. The upper curve shows the natural response of the amplidyne and the lower curve the change which stopped the oscillation. The middle curve in Fig. 9 reduced to less than one half. The performance, however, demonstrates that an antihunting system by transient suppression can be so adjusted that it stops the oscillation without reducing either the accuracy or the quickness of response.

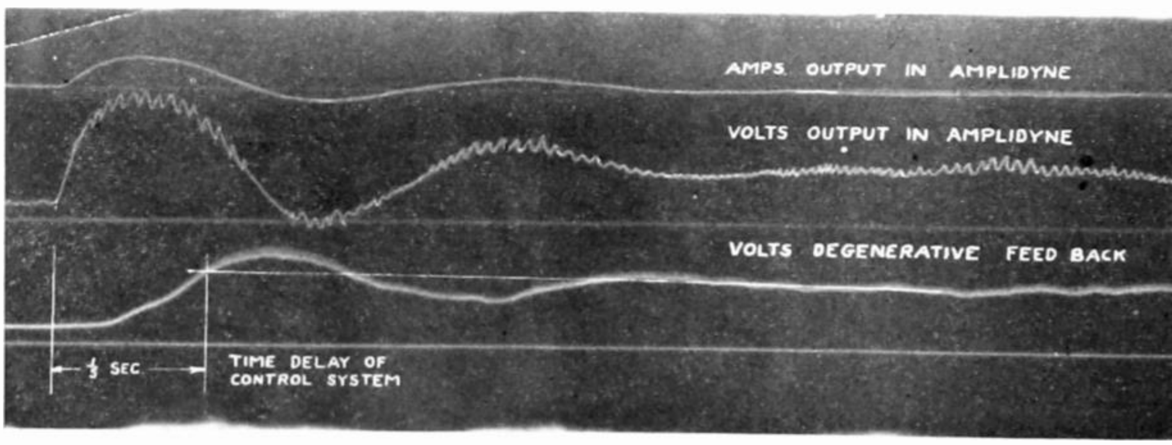

Fig. 11—Antihunt by transient suppression of amplification.

shows another method of changing the characteristics with substantially the same effect of damping the oscillation. This is illustrated by Fig. 11 which may be compared with Fig. 10. The amplification response is however quite different which may be seen by comparing the lower curve with the middle curve. In the second case the amplidyne at zero frequency has the full natural sensitivity whereas in the first case this sensitivity is

We hope that the method of analysis here given will be helpful to the application engineer. This control problem stated in terms of accuracy and speed of response may thus be translated into requirements for amplification and phase characteristics of the amplidyne at various control frequencies. He will thus be able to choose amplidyne generators suited for his purpose and predict the performance of a system before it is completed.

"Unitized" Radio-Chassis Design*

SHIRLOCK MORRISON†, NONMEMBER, I.R.E., JOHN NOWAK†, NONMEMBER, I.R.E., AND
G. B. GREEN†, NONMEMBER, I.R.E.

Summary—This paper is a description of the "unitized" principle of radio construction, written in the interest of historical records, since it is quite radical in design and has been developed to a high degree of refinement.

A receiver built of "unitized" parts will consist of a number of subunits which are assembled on two identical sheet-metal chassis, and all fall under three general classifications, namely, radio frequency, intermediate frequency, or audio cells. A detailed description of each cell type, as well as contingencies arising from their use in groups, is given.

While "unitized" construction is primarily a mechanical development, certainly no compromise in quality need be accepted in the electrical performance of the unit. Indeed, an electrical advance has been achieved in the improved use of shielding and unique arrangement of parts which "unitizing" permits.

"UNITIZING" is a unique construction in electronic equipment, which has resulted from an extensive research program conducted in the laboratories of the Harvey Machine Co., Inc.

"Unitized" equipment design is based upon four primary design premises: 1. Ease in maintenance; 2. Extreme mechanical strength; 3. Advantageous location of parts; and 4. Ease of manufacturing, particularly with respect to fabrication, assembly, and testing.

From the research data compiled, there evolved the design of a "unit" chassis, measuring $5\frac{1}{4}$ inches wide, $4\frac{1}{2}$ inches high, and $2\frac{1}{8}$ inches deep. These dimensions represent a compromise between overcompactness and excessive bulkiness.

There were three basic cells developed, viz., radio frequency, intermediate frequency, and audio. In all three types of cells it is characteristic that a vacuum tube is located in the upper surface, and grouped capacitors and resistors located in a recess along one edge. The majority of the remaining components are placed within the cell in such a way as to derive a maximum of the benefits of electrical shielding provided by the cell, and all the protection the cell can provide to the more fragile components, such as coils and intermediate-frequency transformers.

The radio-frequency cell is identical in outward appearance to the other two types of cells, but has a trunnion support welded in the rear face of the cell and acting as a radial bearing for a rotary turret-mounted coil assembly.

The coil assembly consists of four radio-frequency transformers wound on polystyrene-coil forms and provided with solid-silver contacts and negative-coefficient trimming condensers, accessible through a porthole provided in the skirt of the chassis. Four such transformers, covering four bands of radio-frequency operation, are secured to a turret shaft by means of machine screws and positioned by two molded register pins on the coil form.

The turret shaft is bored to fit its trunnion freely, but has an overhanging lip at one extremity which has been broached to fit a flattened band-changing shaft running the length of the radio-frequency section and resting in the bore of all the trunnions in that section. Manipulation of the band-changing shaft rotates all the coil assemblies in unison. Each turret shaft is provided with its own detent mechanism.

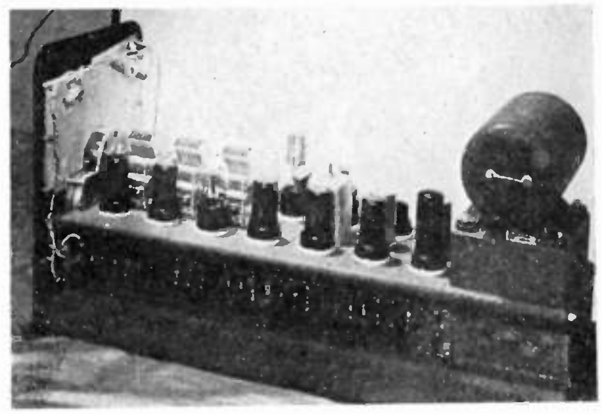

Fig. 1—Harvey HM-9 12-volt direct-current-operated "unitized" aircraft receiver.

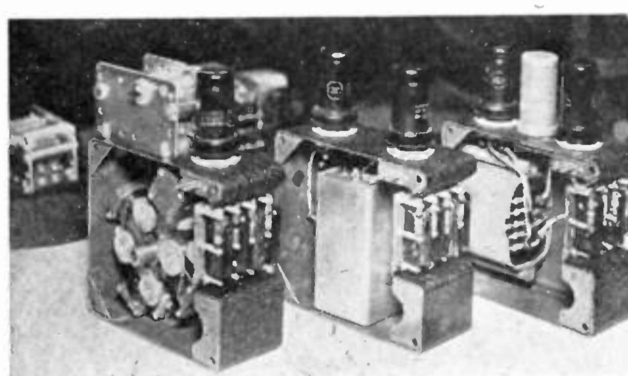

Fig. 2—Radio-frequency, intermediate-frequency, and audio cells.

A molded-bakelite coil-clip assembly is attached within the cell by means of machine screws. It is so placed as to engage the silver contacts of a single radio-frequency coil with its own solid-silver contactors supported by phosphor-bronze spring clips. All external wiring to the radio-frequency coil is made to solder lugs provided on the contact assembly.

A group of nine pin-jack fittings is held in place in the back of the cell by rivets, and each of the anode and filament connections within the cell is connected to the

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† Harvey Machine Co., Inc., Los Angeles, California.

proper pin-jack fitting, to be supplied, after assembly, with current from a corresponding group of demountable bus bars.

The tuning capacitors in the radio-frequency stages are single-gang, double-ended condensers mounted beside the tube on the upper surface of the cell, and are ganged together by means of concentric clamps. All de-

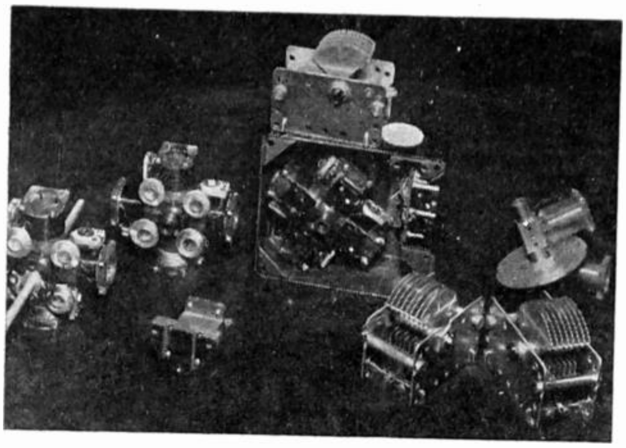

Fig. 3—Details of a radio-frequency stage, showing tuning capacitor details, turret-mounted-coil details, detent-plate details, and a coil-clip detail.

coupling resistors and by-pass condensers are ganged and mounted in a recess in the side of the cell.

Among the advantages springing from this construction in the radio-frequency section are exceptionally good shielding between stages, and minimized stray capacitance between various critical portions of the circuit, greatly enhancing the stability of a receiver so equipped.

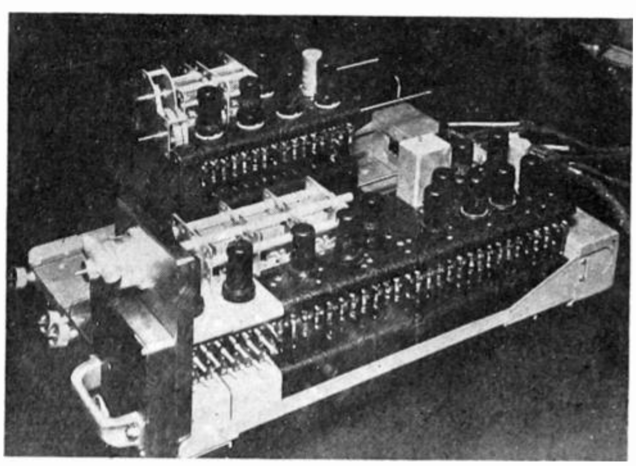

Fig. 4—An experimental automatic direction finder, in the foreground, and an experimental six-tube scout-car receiver in the background.

Another advantage is the reduced minimum-circuit capacitance achieved in this manner, for the minimum-circuit capacitance is numerically approximately equal to a single-band receiver with the same bandwidth ratio, and is materially below that value usually present in conventional band-switch arrangements. This reduced minimum-circuit capacitance provides higher input impedances, and improved radio-frequency selectivity and gain, since the inductance-to-capacitance ratios throughout the band are considerably higher.

The basic intermediate-frequency cell is outwardly identical to the radio-frequency cell, but the trunnion is omitted. The tube is mounted in a similar position to that in the radio-frequency unit; the by-pass condensers and decoupling resistors are grouped in the recess in the side of the chassis as before; the nine-gang pin-jack assembly is mounted in the back of the chassis and connected as before, but the intermediate-frequency transformer is attached by means of two machine screws to the chassis floor, its permeability adjustments being accessible through two portholes provided in the skirt of the cell. The fragile components, such as the intermediate-frequency transformer, the decoupling resistors, and by-pass condensers, are, therefore, well protected, contributing materially to the mechanical strength of this unit.

The shorter leads, due to the intermediate-frequency transformer's proximity to the tube sockets and to the

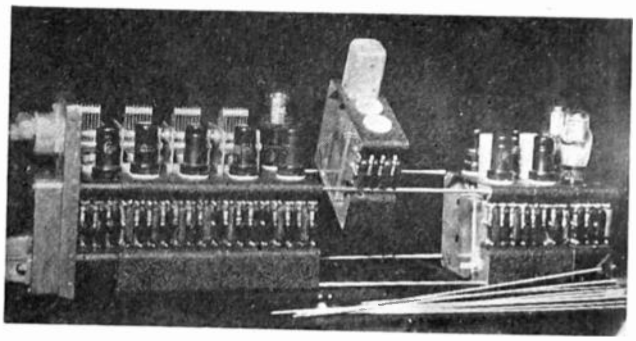

Fig. 5—Harvey automatic direction finder with second intermediate-frequency cell removed.

intermediate-frequency by-passes, reduce stray capacitance between critical portions of the intermediate-frequency circuit. Since, in the assembled unit, each of the intermediate-frequency transformers is located within the completely enclosed copper-plated sheet-metal cell in addition to its own drawn-aluminum shield, electromagnetic coupling from plate back to grid is practically eliminated, even though closer center distances between intermediate-frequency transformers are employed than is usually permissible, resulting in added compactness.

Variations have been taken from this basic radio-frequency cell to include, as optional equipment, a combination first-intermediate-frequency and voltage-regulator tube for controlling the anode potential at the oscillator plate, mixer screen, and beat-frequency-oscillator plate. Also, there is a combination second intermediate-frequency amplifier and beat-frequency-oscillator cell with the additional tube and beat-frequency-oscillator transformer mounted on the upper surface of the cell beside the second intermediate-frequency amplifier tube.

Another variation is a twin-diode, detector-peak limiter and first audio amplifier, as well as a detector-peak limiter and interchannel noise-suppressor combination. It is characteristic that all the detector combinations have the audio-gain potentiometer located within its cell and operated by an extension shaft, thereby reducing the stray capacitance to the low-level-audio leads and contributing to the quietness of the audio amplifier.

The basic audio amplifier contains a single output tube mounted upon a cell which is identical to the intermediate-frequency cell with by-pass condensers and decoupling resistors mounted in a recess in the side of the cell as before, and with a universal audio-output transformer mounted within the cell. The basic audio amplifier uses a single 6V6 tube, and is compensated for an audio bandwidth from 200 to 2000 cycles held level.

A variation from the basic audio cell is a cell with a combination first-and-final audio stage with the resistance-coupled first audio-amplifier tube located alongside the final amplifier tube. A low-voltage electrolytic condenser used as a cathode by-pass is also located on the top of the cell. This combination first-and-final cell is recommended in conjunction with the detector-noise limiter and interchannel noise suppressor tube, and is used only when interchannel-noise suppression is provided.

A combination first-and-final audio cell with 6V6's in push-pull along with the driver tube is used where more than 2½ watts of undistorted audio is desired.

This unit is very similar to the first-and-final audio combination, but with the additional 6V6 located beside

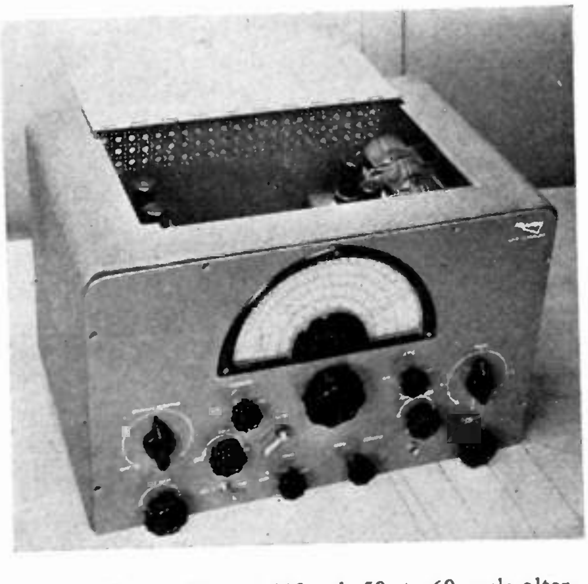

Fig. 6—Harvey HM-10 110-volt 50- to 60-cycle alternating-current-operated "unitized" aircraft receiver.

the other two tubes, and with the cathode by-pass condensers located within the cell.

Another type of cell, which has been developed, is a self-contained power-supply unit. This unit is available in a 50- to 60-cycle alternating-current 110-volt input or a 12- to 24-volt direct-current input employing either Genemotor or Vibrapack. All power-supply units are mounted upon a cell which is physically of the same dimensions as the other standard cells, excepting for depth which is expanded to 4¼ inches. The input transformer and rectifier tube of the alternating-current power supply are mounted upon the upper surface of the cell, while the radio-frequency and audio-frequency-filter components are located within the cell.

In the direct-current power supply, the Genemotor is provided with a subchassis containing all radio-frequency-filter parts, and is demountable, as a unit, from the remainder of the cell containing all audio-frequency-filter components.

In the final assembly, the various cells going into the set are assembled in a cascade fashion with the first radio frequency at one extremity, the power supply at the other, and the balance of the cells going into the assembly in their logical order.

Three-sixteenths-inch diameter steel-corner bolts are added to the assembly to become structural ties, or cap-strips, of a deep-box beam. These bolts engage plate nuts which are an integral part of a junction box whose cross-section shape is identical with the other cells, but whose depth is only ⅞ inch. This is used as a tuning-dial mounting bracket, as well as a junction box for all external connections.

After the structural assembly has been completed, the nine bus bars are inserted into nine rows of pin jacks, and engage a pin-jack fitting in the power supply corresponding to the potential desired at points of distribution in the various cells.

From a manufacturing aspect, it is obviously of great advantage to use a multiplicity of relatively smaller and simple chassis to gain a final chassis unit, inasmuch as high-production methods may be economically applied to its production. This is particularly true, since a standard chassis may be used in many current-production models without variation in the basic chassis design.

From the assembly point of view, many advantages also present themselves, in that, on the whole, a lower degree of skill is needed in the wiring, since a production line is confronted with only a one- or two-tube model, as production is economically run in a single stage at a time.

From the standpoint of satisfactory testing, it is for the first time really feasible to use a substitution method wherein one cell under test may be inserted into a set whose performance is thoroughly known. Other advantages lie in the fact that special test equipment might be built up on a standard-unit chassis and bolted into place, thereby reducing the variation that may prove troublesome due to such variables as test-load capacitance. Among the special test equipments that have been found useful are an intermediate-frequency crystal oscillator, vacuum-tube voltmeter as output meter, and a 100- and 1000-kilocycle crystal oscillator, which is very useful in aligning and tracking operations.

From the maintenance viewpoint, the entire novel expedient of inserting a new or factory-rebuilt stage into an existing receiver to replace a damaged or inoperative stage is possible with the "unitized" receiver construction.

Maintenance is further facilitated by the straightforward layout, in that each stage is located exactly as would be expected, and all decoupling resistors and by-pass condensers associated with a given tube are grouped beside that tube and in a consistent order. For example, there are four decoupling resistors and by-pass condensers in the recess of each cell. They are, from front to rear, plate-decoupling, screen-decoupling, cathode-biasing, and grid-decoupling resistors, respectively, with their associated by-passes alternating between them. With this arrangement, a wiring diagram is not at all necessary in order to find and remedy a breakdown.

Variations in design are handled in a very interesting manner in this construction. For example, if a very high-frequency, four-band receiver of a very small bandwidth is desired, the only changes from a low-frequency receiver with very wide bandwidths are in the coil assembly, which may be removed entirely without hand tools, and the tuning condenser, which may be removed and replaced with four machine screws. Therefore, the assembly line may operate on both radio-frequency cells simultaneously, as band characteristics are not assumed until after wiring has been completed.

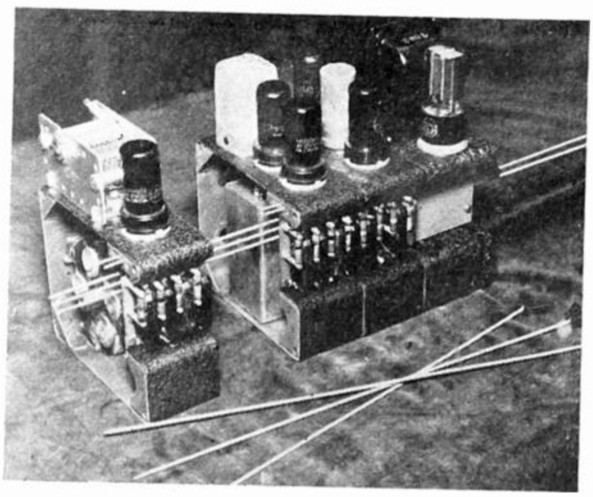

Fig. 7—An expanded view of the "unitized" construction. Of particular interest are the demountable-buss details, three of which are shown in place, and three lying at the side. These busses, which are 3/32-inch diameter silver-plated solid wire, extend the length of the assembled unit, and each buss engages a standard pin jack located in each individual cell.

Such variations as the number of stages in either the radio frequency, intermediate frequency, or audio, are elementary, in that the operation is identical except for gain and intermediate-frequency selectivity, whether or not the second intermediate-frequency amplifier is included in the assembly. Likewise, the operation is identical excepting for radio-frequency selectivity (image rejection) and radio-frequency gain, whether two or one or even no radio-frequency amplifiers are provided. By the same token, a tuned-radio-frequency receiver may be assembled from three radio-frequency cells working directly into the detector and audio amplifier with no changes necessary for the production of the elementary units going into the assembly.

The equipment built on the basis of "unitizing" is unusually stable, and has good gain characteristics over quite a wide range of frequencies. The spectrum between 100 kilocycles and 45 megacycles has been thoroughly explored with four adjacent overlapping bands at all portions of the spectrum.

With turret-coil construction, overlapping bands are no problem even without short-circuiting bars in the switching network, as a load is completely switched in or out of the circuit when a band-change operation is made. It is characteristic that high-impedance primaries are used, and are self-resonant on the lower extremity of their own bands, so that when the output capacitance plus wiring capacitance of a tube is added to the primary, it becomes resonant safely below the band. Yet, when not switched into the circuit, it will not interfere with adjacent bands, since it is self-resonant within its own band. This is found considerably less harmful to gain and selectivity characteristics of a coil in operation than the conventional short-circuiting bandswitch arrangement, since it is loosely coupled to nonresonant inoperative coils rather than to a number of short-circuited coils which must necessarily couple a considerable resistive load into the coil which is in operation. The fact that the coils are arranged in a radial position from a common center reduces the coupling between any one coil in operation and the three coils not in operation to where the reactance of the nonoperative coils coupled into the operative coil is easily negligible.

The principles of cascading units upon each other are readily extended to the field of industrial-control networks, such as, for example, sequence-controlling devices. The component cells would be identical for a single time-delay device or for an industrial-sequence control, such as is commonly used in electrical-resistance-welding, injection-molding, and die-casting equipment. In this application, a single coil containing a single trigger-tube network with a variable time-delay control represents a single operation in the sequence, and its triggering sets in motion the resistor-capacitance network in the grid of the subsequent-triggering network. Thus, a complete sequence control will consist of a power-supply unit, plus one cell for each operation in the sequence.

"Unitizing" has been extended experimentally to a 35-watt transmitter, and to various control devices, such as a recording-and-actuating thermometer, a recording-and-actuating humidistat, a gas calorimeter, a recording-and-actuating barometer, and a combustionable-gas analyzer, all of which have shown considerable promise and have taken advantage of the unique features of "unitized" construction.

In all of the above applications, 60-cycle alternating current is used, and the only difference between one experimental equipment and another is a single cell containing the actuating or sensitive elements. Its design has usually departed from the standard "unitized" cell to the extent of providing sample ducts and a forced-draft system in the cases where gases are dealt with.

"Unitized" cells also have been used in torque-amplifier applications, involving motor control up to 1/20 horsepower, with all the necessary networks for stabilizing motor speed incorporated.

Though "unitized" construction is primarily a mechanical development, certainly no compromise in quality need be accepted in the electrical performance of the unit. Indeed, an electrical advance has been scored in the improved use of shielding and unique arrangement of parts which "unitizing" permits. It may be said that "unitizing" is another way to arrive at a desired end.

A Remote-Controlled Radio-Frequency Booster for a Broadcast Station*

J. L. HOLLIS†, ASSOCIATE, I.R.E.

Summary—Adequate coverage of the business districts of major cities by medium- or low-powered transmitters operating in the high-frequency end of the broadcast band has always presented a big problem to the broadcast engineer. This paper describes an auxiliary transmitter installation which was installed as a means of overcoming this handicap in Cincinnati, Ohio, where WSAI on 1360 kilocycles is located 10 miles from the business district.

A special receiving antenna and a straight radio-frequency amplifier without detection is used to produce sufficient signal, after reradiation, to provide adequate service to the business area.

Introduction

ALTHOUGH the March 29, 1941, frequency reallocation for broadcast stations in the United States was the most obvious result of the Havana Conference of 1938, it was not the only result. Because of the definite understandings and decisions agreed upon at this conference, a number of broadcast stations in the United States found it possible to expand their facilities for a better utilization of their assigned frequencies.

WSAI, on 1360 kilocycles in Cincinnati, was one such station. In this particular case, the increased facility was a change from 5 kilowatts by day with 1 kilowatt at night to 5 kilowatts full time. A directional antenna was required to furnish protection to four other stations operating on the WSAI frequency. The particular field pattern and the minimum field strength required for adequate service in the business district limited the choice of transmitter location. Although 6 or 7 miles was the absolute maximum distance the transmitter site should be from the business district for adequate coverage, the nearest available site was 10 miles. The potentialities of the new site, as well as several other factors, were sufficient to warrant its use provided the business district could, in some way, be provided with the required service. Since no other section of the city presented any problem, it was felt that a supplementary source of radiation located in this business district would produce the desired result. Fig. 1 is the resultant

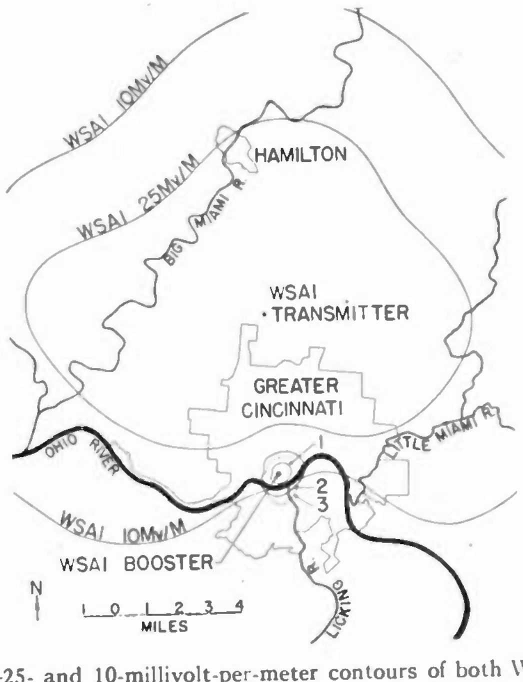

Fig. 1—25- and 10-millivolt-per-meter contours of both WSAI and the booster. The booster contours are (1) 25 millivolts per meter; (2) 10 millivolts per meter; and (3) line of equal intensity of the two signals. These contours were independently measured and superimposed on this map. The line of equal intensity (contour 3) was calculated for this map but tests have shown it to be very nearly correct.

daytime field pattern of the complete installation. Directional operation of the main transmitter without the booster is used at night. The idea for this type of installation was not new or original with the author as it was proposed in 1932 by Aiken[1] in a paper presented before the American Association for the Advancement of Science. Nor is this particular type of installation new, but to the author's knowledge, no details of other similar installations have appeared in the technical journals.

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† Development Engineer, Broadcast Branch, Crosley Corporation, Cincinnati 2, Ohio.

[1] Charles B. Aiken, "A study of reception from synchronized broadcast stations," Proc. I.R.E., vol. 21, pp. 1265–1302; September, 1933.

THE INSTALLATION

This paper describes the WSAI "booster" installation in detail and mentions a few of the problems of location and development that were encountered.

The first problem of any transmitter installation is to decide the general method of operation of the equipment to be installed. In this case, it was decided that the installation should consist of a good, noise-free antenna

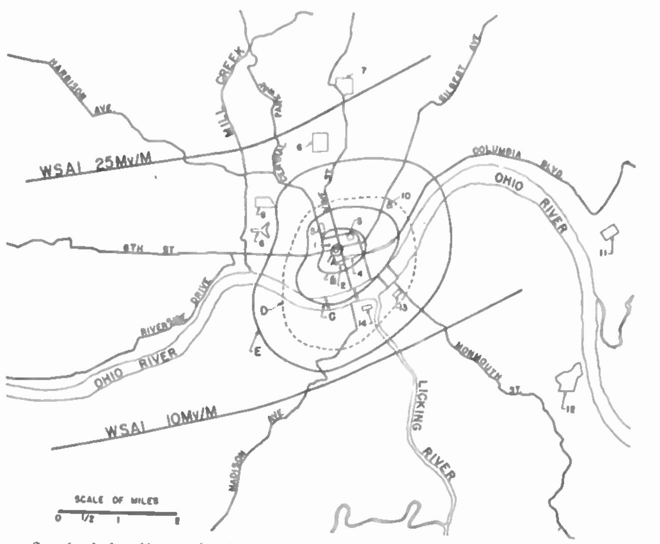

Fig. 2—Originally calculated 10- and 25-millivolt-per-meter contours based on field measurements from a test antenna and oscillator. The booster is located at the center of the concentric contour lines designated *A*, *B*, *C*, and *E* which are the 250-, 50-, 25-, and 10-millivolt-per-meter contours respectively. *D* is the line of equal intensity from the two transmitters. The downtown area of Cincinnati is centered around the figure composed of buildings 1, 2, 3, and 4. The buildings shown on this map are as follows: (1) Crosley Square, home of WLW and WSAI; (2) Carew Tower, Cincinnati's highest building (see Fig. 9); (3) Hamilton County Court House; (4) Fountain Square; (5) Music Hall; (6) University of Cincinnati; (7) Zoological Gardens; (8) Union Terminal; (9) Crosley Field (Ball Park); (10) Art Museum; (11) Lunken Airport; (12) Fort Thomas Military Reservation; (13) Court House (Newport, Ky.); (14) Court House (Covington, Ky.).

tuned to 1360 kilocycles, a series of voltage amplifiers, a power amplifier, and a radiating antenna. The radiated power should be sufficient to provide a signal of 25 millivolts per meter or better in the downtown area.

Before any such equipment could be installed, however, several critical details had to be worked out. Since this installation included both a receiving and a transmitting antenna, some provision was needed for keeping the reradiated energy out of the receiving antenna to prevent over-all oscillation. For this installation a shielded loop antenna oriented with its null in the direction of the reradiated signal was chosen.

The location of the loop had to be such that when the above condition was met, the induced voltage from the main transmitter field was as near maximum as possible. The first question to be answered then was "What order of discrimination can be expected from such a loop antenna?"

To find the answer to this question, a shielded loop antenna was set up in the field near one of the transmitter towers and the maximum induced voltage was measured. The loop was then oriented for minimum pickup and the voltage again measured. It was found that ratios of 1000 to 1 could easily be obtained and maintained and that 10,000 to 1 was not out of the question with precision adjustment of the loop. With this information it was thought possible to predict the required distance between the receiving and transmitting antennas of the booster. As will be pointed out later, this prediction was erroneous because of another very important factor.

There remained now the problem of selecting a suitable location downtown for a new transmitter. This proved to be much more difficult than it at first appeared.

The requirements for a suitable site for such an installation are as follows:

1. It must provide space for a suitable transmitting antenna.
2. The field from the antenna must cover the area without exceeding permissible limits of radiation in any direction.
3. There must be sufficient space for installation of the receiving antenna and transmitter.
4. The completed installation must comply with city building codes.

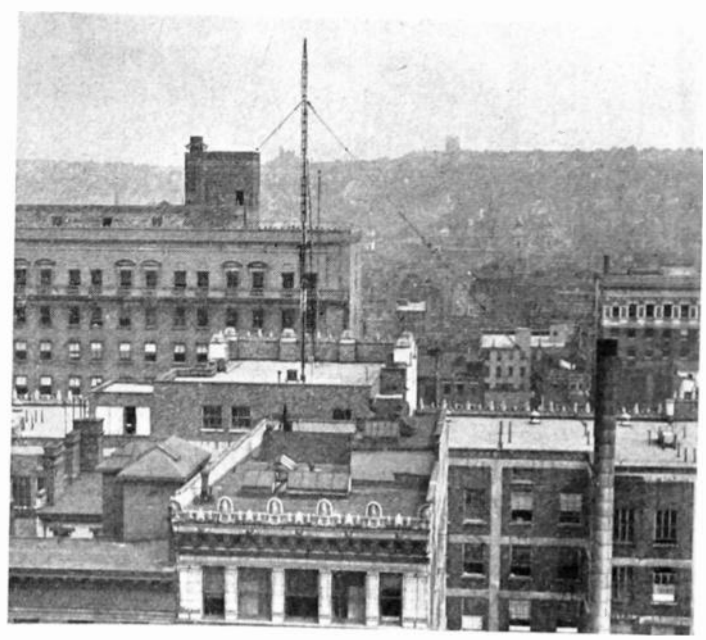

Fig. 3—The booster location as viewed from the south.

After several unsatisfactory trials, a site which complied with the above requirements was located. Fig. 2 shows the measured field, based on measurements made with 50 watts exciting a test antenna at this site. A 75-foot Wincharger, triangular cross-section guyed tower was selected and installed. The transmitter was moved in, the receiving antenna was set up, and the tests were begun.

The particular requirements of the transmitter are here considered since they are quite stringent. Aiken[1] pointed out a distortionless case. The two requirements for this case were practical identity of the radiated waves and small geographical separation.[2] The following explanation should make the reasons for these requirements quite evident:

Within a radius of several miles from the booster there are two sources of energy, both of which will affect the receiver. The fields from both transmitters add vectorially so that at any particular location the resultant field is the vector sum of both. As long as one field is considerably stronger than the other, there is little change in the predominant field, but when the amplitudes of the two fields are nearly equal the resultant becomes definitely and sensitively dependent on each. Obviously there will be a complete ring around the source of least energy where the two signal amplitudes are equal. On this line of equal intensity there can be resultant fields which vary from almost zero to double value depending on the phase relation of the two fields. It is in these points of almost zero intensity that the distortion introduced by the booster has a most profound effect. If the two signals were identical, equal in intensity, and 180 degrees out of phase—there would be complete cancellation. Now assume that the two signals differ slightly, for instance, one signal with more audio second harmonic than the other. The fundamental will cancel completely but there is nothing to cancel the second harmonic. This results in the reception of the second harmonic only. Though this harmonic may have been negligible by comparison to the fundamental, it is no longer negligible since there is no fundamental. Consequently, if the booster introduces any distortion at all, that distortion by itself is heard at this point of equal intensity and 180 degree displacement. Its effect will also be to increase the distortion in the areas near the points of complete carrier cancellation. More reference will be made to this effect later in the paper in the discussion of measurements and observations.

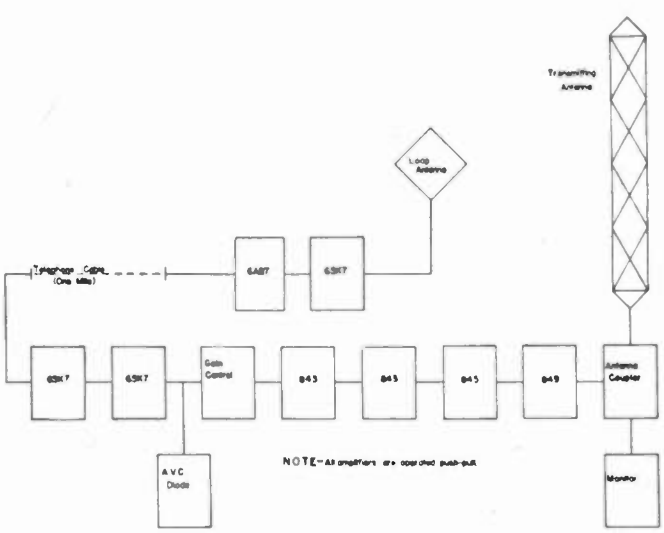

Fig. 4—Block diagram of the booster installation.

It is obvious now that in order to minimize this distortion band or so called "mush area" it is necessary to keep the booster transmitter distortion at an absolute minimum. The tube complement and circuit design of this transmitter were chosen with low distortion as a first consideration and long tube life and trouble-free operation as second.

[2] The exact separation in miles depends upon many local factors but Aiken suggests separation of from 10 to 25 miles as maximum.

Fig. 4 is a block diagram of the complete installation.

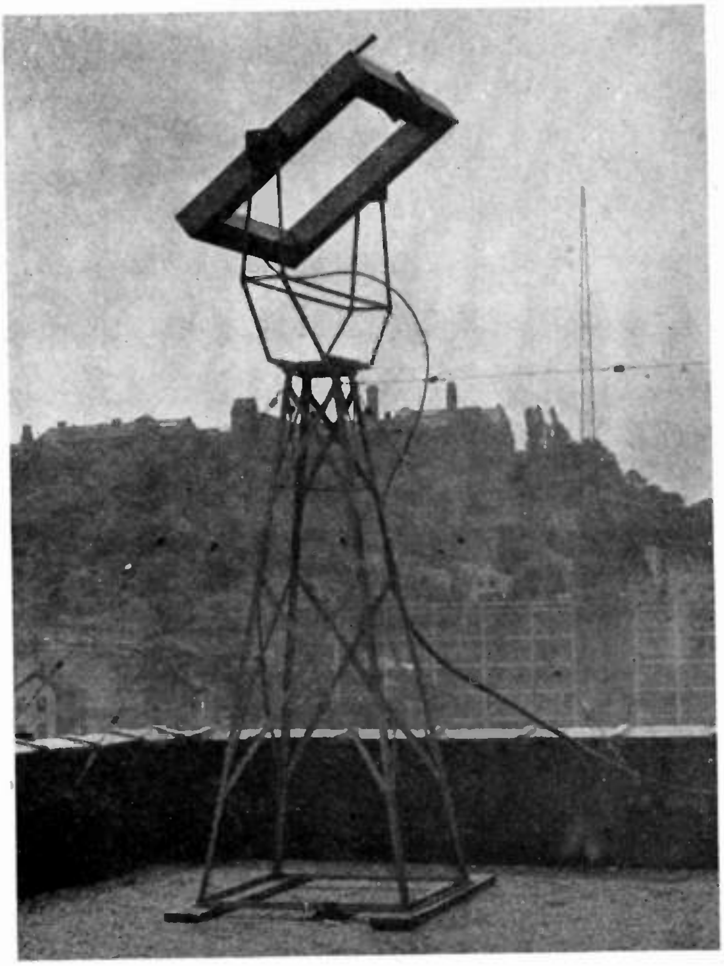

Fig. 5—The loop receiving antenna. (The antenna in the background has no connection with this installation.)

It will be noted from this diagram that this installation consists of a shielded, balanced loop antenna for receiving the signal, a two-stage amplifier to raise the signal level, a mile of telephone cable, five voltage-amplifier stages, a power-amplifier stage, and a radiating-antenna system.

For this type of installation, it is necessary that the input circuit be shielded or otherwise adjusted so that the induced voltage due to the booster radiating antenna system be not over, and preferably less than, 10 or 20 per cent of the induced voltage due to the signal from the main transmitter. This requirement was met, as will be pointed out later, by locating the loop approximately a mile from the transmitting antenna.

Another factor was now involved. This was a means of transferring the received signal from the receiving antenna to the transmitting equipment. The most apparent solution was to use a telephone circuit, especially since short telephone lines have proved practical even for television transmission. Tests were conducted which confirmed the feasibility of operating these lines at 1360 kilocycles.

Fig. 5 is a picture of this loop antenna after it was installed and oriented.

The telephone pair that was installed has had all long stubs removed and has been jumped from cable to cable, where necessary, to keep the line as short as possible. However, due to the high line loss, it was impossible to affect the input impedance by the termination impedance. Input- and output-power measure-matic-volume-control circuits incorporated. This, as well as the input amplifier at the loop, is a band-pass amplifier designed to pass a 20-kilocycle band. Following these amplifiers is the gain control, then two more stages of class A neutralized-triode, voltage amplifiers. The triode stages have loading on all tuned circuits to produce the required bandwidth. Next is a class A, neutralized-triode, driver stage with its tuned circuits also loaded by resistance. The final amplifier stage is likewise a neutralized triode. This stage is operated as a

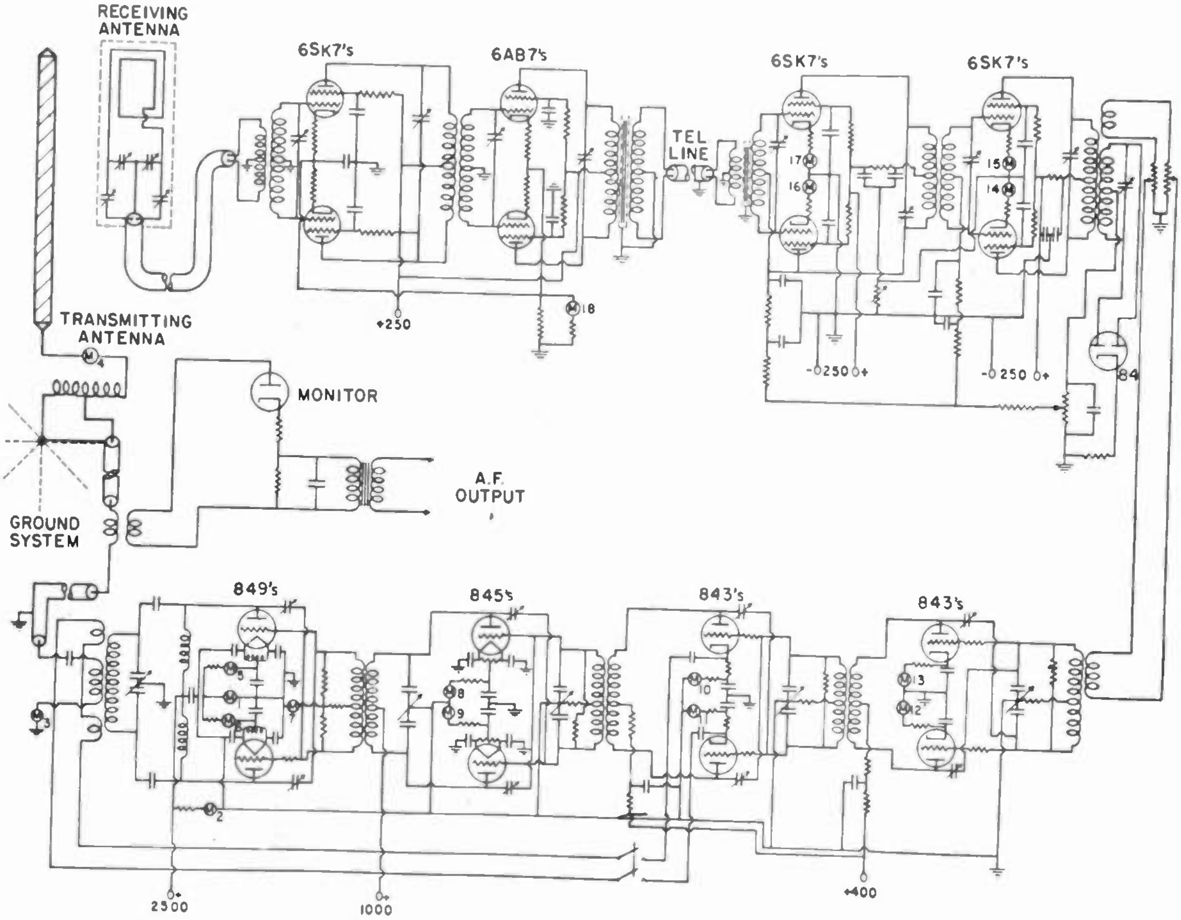

Fig. 6—Schematic diagram of the installation.

ments indicated a loss of 40 decibels on this 1 mile of cable. Further tests were made to determine the minimum input voltage required to maintain a good signal-to-noise ratio. It was found that the same order of power was required at radio frequency as is required in audio work. An input of 0.1 volt was fair but 1 volt or approximately 0.012 watt was excellent. No measurements of actual noise were made.

In order to overcome the line loss, a two-stage double-tuned transformer-coupled amplifier was installed at the input end of this cable. This amplifier is continuously operated and remotely metered.

Fig. 6 is the complete schematic circuit of the installation. It will be noted that all stages are push-pull. This was done for two reasons—low distortion and continuity of service. In the transmitter proper are two stages of double-tuned transformer-coupled amplifiers with auto-class AB amplifier operating with a 220-degree plate-current pulse for 100 watts output.

It will be noted that all stages that are handling any appreciable voltage swing are, with the exception of the final stage, class A operated triodes. These tube types were chosen because of the low distortion possible by their use. The final amplifier which must deliver a maximum output of 250 watts could not be economically operated as a class A amplifier, therefore class AB was chosen[3]. In order further to reduce the distortion due to the final amplifier, a radio-frequency feedback circuit was incorporated around the final amplifier and the two previous stages. Ten decibels of feedback were found to be very effective and not too difficult to obtain. It should be pointed out that in order to tune a radio-frequency

[3] Although this transmitter is now operating at 100 watts output, it was designed as a 250-watt transmitter.

amplifier with feedback around it, the feedback must be disconnected. A switch is installed in the feedback circuit for this purpose.

The booster antenna is a straightforward vertical antenna, coupled in a conventional manner by means of a coaxial line.

Mention has been made of the band-pass characteristics of the equipment. Since both frequency and amplitude distortions can occur in a tuned-radio-frequency amplifier, it is important that the system have essentially constant gain throughout the audio range. Anyone familiar with receiver design will realize the numerous considerations involved in this problem. It is well known that for the best signal-to-noise ratio and greatest discrimination against unwanted signals, a narrow band pass is desirable. This system must have a good signal-to-noise ratio, good discrimination, and at the same time the equipment must pass high audio frequencies. The only solution is to try to attain, as nearly as possible, an ideal band-pass characteristic, i.e., uniform response up to 10 kilocycles off the carrier and infinite rejection from there on. The over-all characteristics of this equipment approach the ideal to a very practical extent. At 10 kilocycles off the carrier frequency, the gain is down approximately $\frac{1}{2}$ decibel while at 20 kilocycles off it is down over 20 decibels. It was realized that there is a potential source of interference from carriers only 10 kilocycles removed. However, as long as no nonlinearity exists in the amplifiers to produce cross modulation, any received signal within the pass band would be merely amplified by the equipment and reradiated at its identical place in the band. It is still possible for the receiver to discriminate against unwanted signals. This condition has been noted during nighttime tests when the sky-wave signal of a station on 1350 kilocycles has become sufficiently strong. It was necessary, however, to tune a receiver, coupled to the amplifier output, to 1350 kilocycles to hear the station.

The amplitude-distortion characteristics of this booster were measured before installation and do not include the effect of the loop and loop amplifier nor the transmitting antenna. At 50 per cent modulation, the root-mean-square distortion was less than 0.3 per cent and at 100 per cent modulation it was approximately 0.8 per cent. These measurements were made at a modulation frequency of 1000 cycles with the transmitter developing 250 watts.

To date a few measurements have been made on the completed installation but no satisfactory method of making distortion measurements accurately has been devised.

Oscillation Tendency

Although this system can be made to oscillate by raising the gain sufficiently, there is a safety factor when operating with normal gain. Since the receiving antenna is so far removed from the booster transmitting antenna and because of the disturbance which necessitated this spacing, it would be expected that this installation would be quite free from continuous oscillation tendency. Any oscillation which would occur would be of an erratic nature and of short duration because of the nature of the disturbance. Tests made on the installation by measuring the automatic-volume-control voltage and calculating the change in gain with the WSAI carrier on and off have indicated a safety factor of 14 for 100 watts and 9 for 250 watts output.

Remote Operation

The last phase of this installation was a provision for operating convenience. Since this equipment was to operate concurrently with the main transmitter it was decided that, if at all possible, a duplication of operating personnel should be avoided.

This required some method of remote operation that was capable of carrying out every necessary operation that a local operator himself could accomplish. This operation, of course, would be supplemented by daily or weekly inspection by a qualified technician.

It was desirable that the main transmitter operator handle the remote operation. Due to the cost of long multiple telephone circuits between the two transmitters, it was desirable that remote operation be accomplished with only one circuit if possible.[4] Fig. 7 is the diagram of the remote-control equipment used on this transmitter. The requirement of single-line operation has been met by using a standard telephone dial and a 50-position step-selector switch. In the control unit are three components—the dial, a push button, and a meter. The dial operates from one side of the line to ground, the push button from the other side of the line to the ground and the meter across the line. The function of these controls is as follows:

Operation of the dial steps the selector to the desired position and pushing the push button performs the operation which has been selected. A second operation of the push button causes the selector to return to its number 1 or "home" position ready for any subsequent dial selection.

The operations that can be performed by this circuit are as follows:

(1) Turn on filaments and low voltages.
(2) Meter low-voltage circuit.
(3) Turn on high voltage.
(4) Meter high voltage.
(5) Meter antenna current.
(6) Turn off complete transmitter.
(7) Raise or lower transmitter gain.
(8) Meter cathode currents of all tubes individually.

[4] Although the circuit described herein has proved satisfactory over a period of several months, in compliance with the recommendations of the Federal Communications Commission, a second telephone line has been installed for the purpose of continuously metering the antenna current. This second telephone pair made possible a positive interlock in case of telephone-line failure. Alternating-current power is fed from the main transmitter end of the line to operate a relay with its contacts in series with hold-on circuit of the booster. Thus, in case of any line failure which would prevent remote control the booster will automatically shut down.

For metering purposes the telephone line and 0- to 1-milliampere meter constitute a 0- to 5-volt voltmeter which can be calibrated at any time by means of a permanently installed battery at the transmitter and an adjustable calibrating resistor at the meter. It is then merely necessary that each circuit to be metered shall develop approximately 2 volts to ground when operating with normal current. To facilitate easy reading, all metering circuits except the antenna ammeter are adjusted to read 2 volts with normal currents. For reading antenna current the audio monitoring diode is used. A portion of the diode load resistance is utilized to produce the necessary voltage to make the reading on an auxiliary scale of the remote meter identical with the ammeter at the base of the transmitting antenna. Each metering circuit contains an adjustable resistor for the purpose of setting these meter readings.

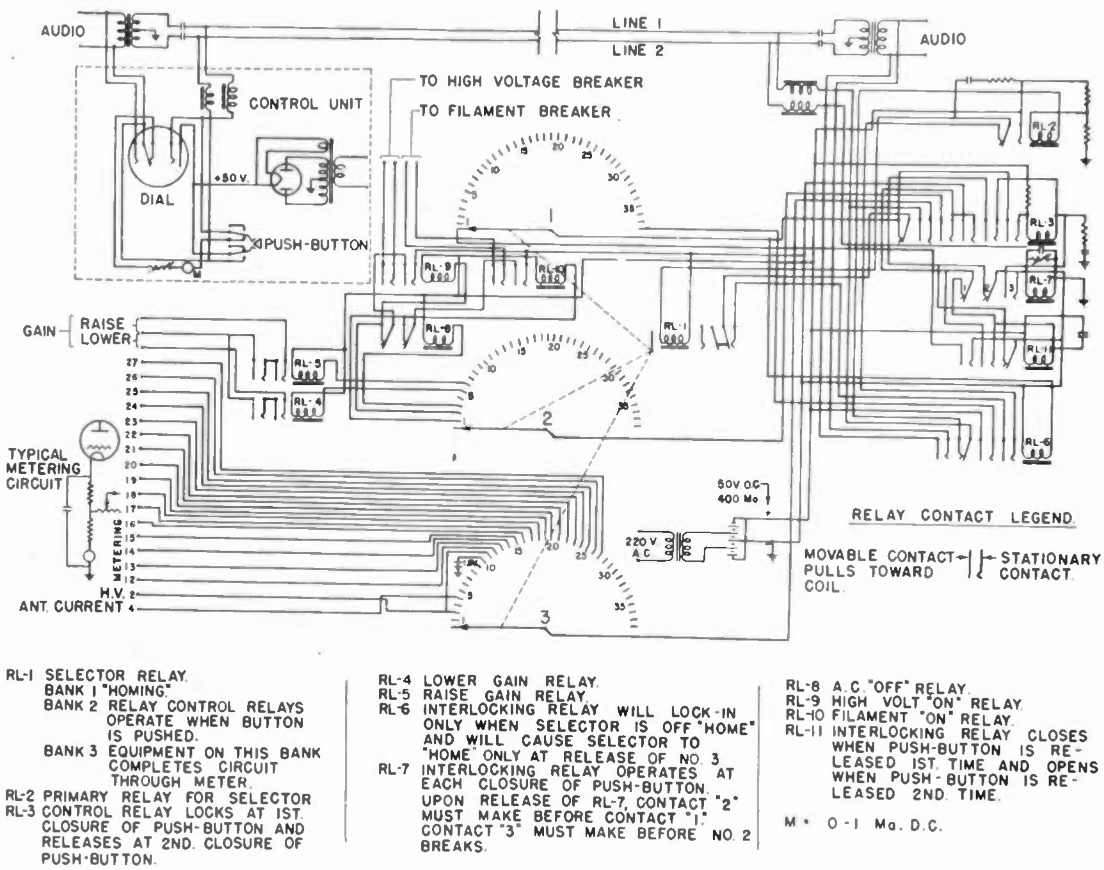

Fig. 7—Remote-control circuit.

A provision for continuous audio monitoring is also included so that the operator at the main transmitter can monitor the booster. In case of a failure in the system the operator can quickly locate the source by means of a switch which shifts his monitor from the booster to the main transmitter or the studio line. All of the control equipment is isolated from the telephone lines by audio chokes so that the line is kept free for audio-frequency use at any time.

In order to prevent simultaneous operation of control circuits and monitoring circuits the monitor is cut off whenever the dial is operated or the line selector is off "home." This was a necessary feature to prevent simultaneous operation of metering and audio circuits and has the added feature of giving the operator an audible indication when the selector has returned "home" and is ready for another operation.

Identical control units are also installed in the master control room at the studios and at the booster transmitter. The unit at the booster is for the purpose of adjusting relays and checking operation while the unit at the master control room is for use in an emergency such as line failure between the WSAI transmitter and master control room.

Measurements and Observations in Area of Equal Signal Intensity

Measurements and observations from a moving car have been made at various places along the line of equal signal intensity from the two transmitters.

Observations have been made with three different methods, two of which were listening tests. The equipment used was a standard automobile receiver, a field-intensity meter set on its linear position, and the field-intensity meter connected for logarithmic recordings. From these observations it is possible to draw some very interesting conclusions regarding the loss of service in this area.

In the first listening tests using a standard receiver, it has been found quite difficult to locate the equal-intensity points throughout most of the area. Only by driving quite slowly through the area can they be found at all. If the street, on which the observations are made, intersects the line of equal intensity at angles of from 45 to 90 degrees there are from 3 to 5 points, separated from 400 to 600 feet, at which the effect can be noted. If, however, the street is nearly parallel with this equal-intensity line, many points can be found.

It has been observed that over a range of about 100 feet a critical listener can detect a slight change in the audio-frequency characteristics and that for about 15 to 20 feet in the center of that 100-foot range, distortion accompanied by a noticeable increase in background noise can be detected. Speech transmission in this 15- to 20-foot area is about equally impaired by distortion and noise. While driving this distance of approximately two car lengths, conditions are noted which closely resemble the characteristics of cross modulation generally found along the highways near any broadcast transmitter. The noticeable distortion in the center of the area is associated with only one or two out of the three to five points that can be found. Fifty feet or more from these points of distortion not even the most critical listener is aware of their existence. Since the test receiver was equipped with automatic volume control, the output from the speaker remained essentially constant when this area was driven through. However, there was a very noticeable rise in background noise in the 15 or 20 feet previously mentioned. The noise level in this case was as high as the signal level indicating that the two signals were almost completely canceled.

Listening tests were made in the same area, using the field-intensity meter set on its linear position. This time the points of equal intensity were marked by an almost complete dropping out of the signal. Since most present-day receivers have automatic volume control, this test was of no particular value except in verifying the observations made previously.

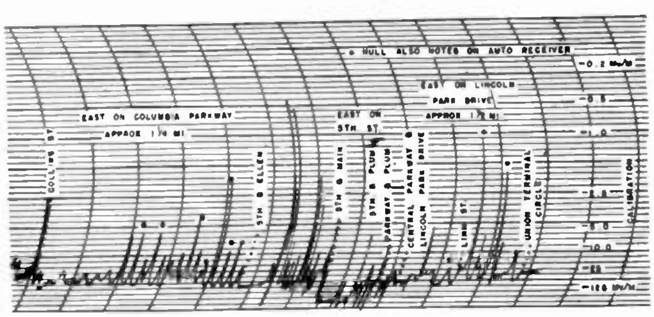

Fig. 8—Field-intensity recordings taken mostly through areas of equal intensity. The center of the chart indicated field strengths in the center of the business district from Fifth and Plum to Fifth and Main. The high signal intensity through this area is due to reflection and reradiation from Carew Tower.

A third test was a series of field-strength recordings made in an automobile moving at a constant speed through and also nearly parallel to the line of equal intensity. These recordings were made with a field-intensity meter using a vertical antenna mounted on the car. The equipment was set for approximately logarithmic recording. Measurements made on a street which had been previously used for a number of listening tests, and which was at approximately right angles to the line, showed the following: (see Fig. 8, section marked "East on Lincoln Park Drive"). The average field is approximately 30 millivolts per meter with maximum field peaks of approximately 65 millivolt per meter. There were four nulls recorded, approximately 700 feet apart. The first and last dropped to about 15 millivolts per meter, while the second dropped to 2 millivolts per meter and the third to 1 millivolt per meter. It was in this third null that the best previous listening-test observations have been made. The two nulls that dropped below 10 millivolts per meter were below that value for approximately 80 feet and below 5 millivolts per meter for only 40 feet.

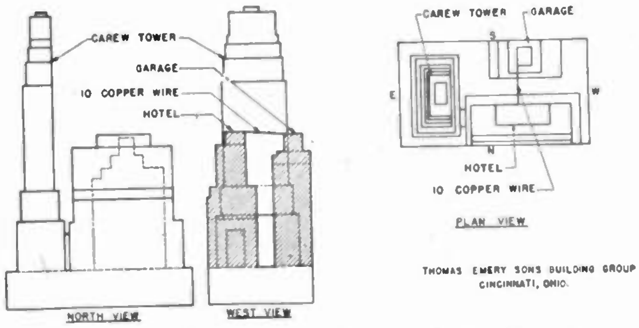

Fig. 9—Building group used as experimental antenna.

The second set of measurements were made on Columbia Parkway while driving east. This street runs nearly parallel to the line of equal intensity and, as was expected, there were a number of noticeable nulls. Fig. 8 shows that nulls were found approximately every 350 feet for a mile. The average level is about 40 to 50 millivolts per meter with maximum levels of 65 to 70 millivolts per meter and minimum levels of 2 to 12 millivolts per meter. Only a few of these nulls could be located by listening with an auto receiver.

As a result of these observations and measurements, it was concluded that, although a number of equal-intensity points can be found, the area over which they are noticeable is so limited that the loss of service is almost negligible. This is undoubtedly due to the low distortion introduced by the booster transmitter.

Problems Encountered in Choosing Location and in Installation

Earlier in this paper, mention was made of several sites that were checked and found unsuitable. One of these was a group of buildings which were used as the radiating antenna. These buildings were the Carew Tower and an adjacent hotel and parking garage, which are located in the very center of the downtown business district.

Fig. 9 is an outline drawing of the Carew Tower and the two other buildings included in this group.

Carew Tower is 570 feet high or approximately ⅜ of a wavelength at this frequency, has steel-beam construction, and provides plenty of space for equipment.

Several methods of exciting the tower as an antenna were devised and checked. The results were not too encouraging—efficiency was low and the shape of the field pattern wrong. However, by exciting the hotel and parking garage to the south of it as a loop antenna, and not directly exciting the tower, a suitable field pattern could be produced. The disadvantage was the extremely low radiation efficiency which was between 3 and 5 per cent. Even with this low efficiency, it would be possible to produce satisfactory service downtown with a 250-watt transmitter feeding this system. Fig. 10 shows the field pattern which would result from a 250-watt transmitter utilizing this radiator.

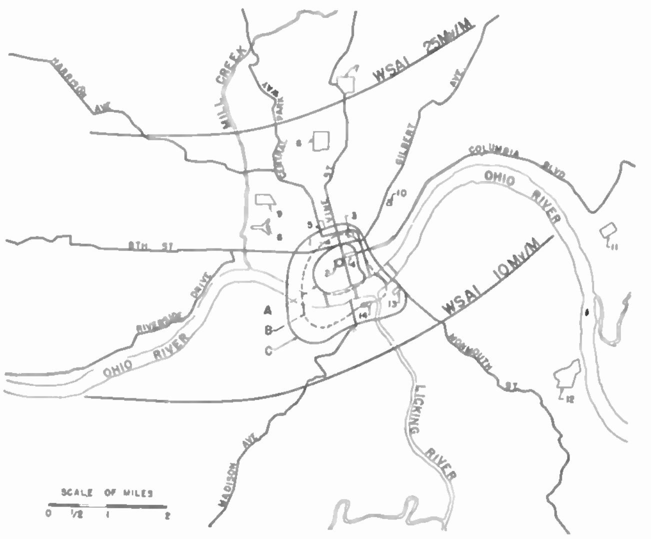

Fig. 10—Calculated field contours based on measurements of the radiation from the building group shown in Fig. 9. Contours *A* and *C* are the 25- and 10-millivolt-per-meter contours respectively while contour *B* is the line of equal intensity. The buildings shown are the same as those in Fig. 2.

Several additional sites were checked with a 60-foot vertical test antenna before the present location was selected. In general these sites also revealed efficiencies much too low to be caused by the shortness of the test antenna or the inadequacy of the ground system.

Selection of the Loop Location

It was pointed out previously that a ratio of maximum to minimum induced voltage of 1000 to 1 was entirely practicable and 10,000 to 1 could be obtained. This means that if the loop is to operate satisfactorily in a main transmitter field of 5 millivolts per meter, it must be so located that the field due to the reradiated signal is not greater than 5 volts per meter. For maximum induced voltage from the main transmitter field the loop must also be located at a point where the main transmitter field and the booster fields are essentially at right angles. From these observations, it was concluded that it would be possible to operate both the receiving and the booster radiating antenna on one building provided the above-mentioned conditions were met, and provided further that the field from the radiating antenna was essentially constant in its propagation direction at the receiving antenna.

It was found that the conditions of essentially right-angle fields of less than 1000-to-1 ratio could be met on the roof of the building selected. During the search for a suitable location on the roof for the loop, it was discovered that on the roof of a building such as this, placing the antenna well above the roof and in the clear is not the solution to the problem. After several attempts to balance the loop had failed, it was decided to make a thorough survey of the propagation direction and the normal to the wave front actually existing on the roof. Since the field to be received was vertically polarized, the loop must be located only at points where the wave front normal was approximately horizontal. It was found that points could be located on the roof where the propagation direction and wave front normal were almost anything, but that in general the points near the edge of the roof and back a few feet suffered the least distortion. On the average, as long as the loop was 6 feet or more above the roof, the signal appeared to arrive from somewhere down in the building itself. The wave front normal was almost vertical at 15 feet above the roof. The reason for this becomes obvious since the equipotential plane near a vertical antenna is hemispherical. Only at points near the edge of the roof did the normal become horizontal. This effective change in the wave front is not limited to propagation near the transmitter antenna as a similar effect was noted on the field from the main transmitter. The normal to the wave front from the main transmitter was checked on a number of buildings, and almost without exception was found to be nearly vertical at all points on the building roof except near the edge closest to the transmitter. This extreme wave tilt is due apparently to the high attenuation of the signal, produced by the building. The high attenuation produced by buildings explains the adverse attenuation noted in all field surveys over the downtown section and probably explains the low efficiency of all the test antennas tried in the downtown area.

As a result of all these observations, the loop antenna was mounted about three feet above the roof near one corner of the building. From the standpoint of the factors so far mentioned, this location was very satisfactory, but there was one other factor that made the location unsatisfactory. Although it was easily possible to get more than sufficient discrimination, it could not be maintained. It appeared that either the loop was shifting position slightly or the field was changing direction. The first possibility was eliminated by a very solid mounting but the trouble still existed. The problem then was to find the source of the field shift and eliminate it if possible. Every imaginable thing associated with the building was checked—wiring, pipes, elevators, etc., and nothing tied in with the observed shift. Streetcar and other traffic movements on the streets near the building did not seem to tie in nor did anything else that could be observed or checked from the building. Finally a recording meter was connected to the output of the loop and the transmitting antenna excited with 100 watts from a crystal-controlled transmitter. The meter then recorded the reduce the required loop discrimination to some value considerably less than 1000 to 1. With this in mind, tests were conducted on various buildings in downtown Cincinnati in an effort to find a location such that the maximum change in resultant field from the booster antenna resulted in an induced voltage in the loop of not more than 20 per cent of that due to the field from

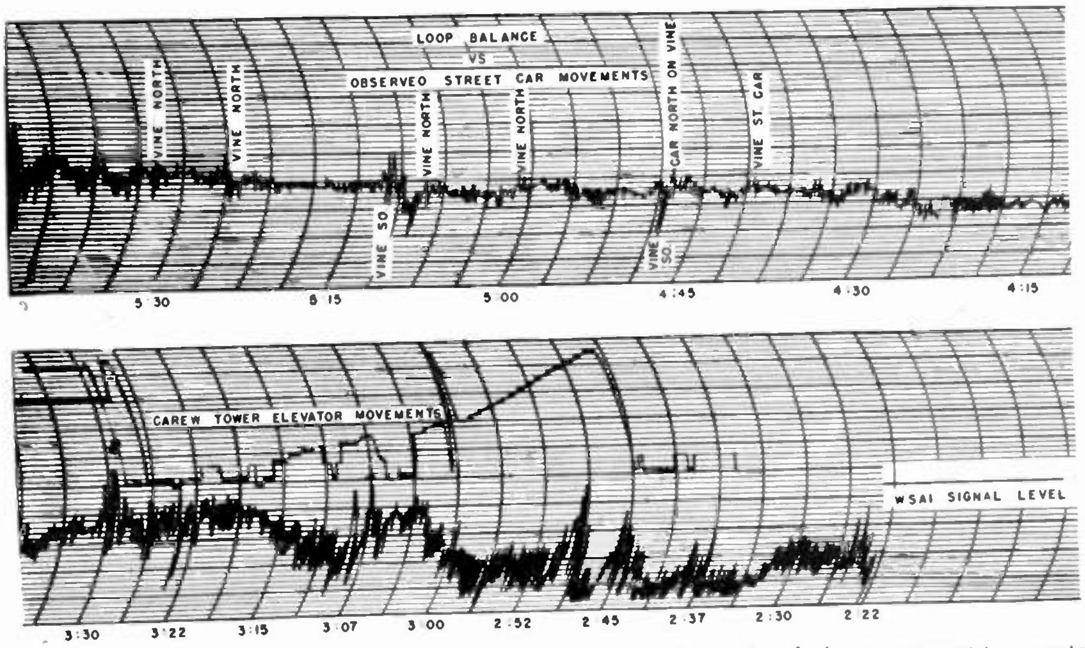

Fig. 11—Recording meter charts of apparent loop-balance variations taken during an attempt to operate the loop approximately 100 feet from the transmitting antenna. The upper chart has had streetcar movements in the downtown area listed at the appropriate places to show the association between car movements and loop balance. The lower chart shows elevator movements in Carew Tower versus loop balance and proves that there was no definite association here.

loop-balance variations against time. It was found that although there were numerous small variations, the main shift recurred at irregular intervals but lasted for a rather regular time suggesting the possibility of elevator or streetcar movements. Fig. 11 shows meter charts for two different nights. The nature of the disturbance is clearly shown on these charts. The source of trouble was found only after several nights of patient timing, and checking against the meter chart, of elevator movements in a number of the downtown buildings and finally a couple of nights plotting streetcar movements from the observation roof of Carew Tower. The streetcar movements showed a very close correspondence to field variations. The double trolley wires used in Cincinnati are a very effective transmission line of extremely complex nature at broadcast frequencies. The streetcars traveling along provide the tuning as they act like short-circuiting bars. Due to the complex nature of the system, car movements almost anywhere downtown would change the standing-wave pattern on the trolley wires and cause a resultant change in field at the loop. Naturally, the previous conclusion that streetcars were not affecting the field was wrong because it was based on observations of car movements in the immediate vicinity of the building.

Obviously it was impracticable to attempt to eliminate this source of interference. The only solution was to the main transmitter. These observations indicated that it was necessary to operate the receiving loop at a point where the field ratio was not greater than 5 to 1. This proved to be approximately a mile removed from the transmitting antenna.

Fig. 12—The remote-control unit. This unit contains the remote equipment and is capable of complete operation of the transmitter. The two small doors can be closed when not in use thus making a very neat appearance on the main transmitter speech-equipment racks. On the back side of the left door is an abbreviated set of operating instructions while the directory of operations is on the back of the right door.

Acknowledgment

In conclusion the author would like to acknowledge the helpful suggestions, criticisms, and co-operation of Mr. R. J. Rockwell, Technical Director of Broadcasting, Mr. G. F. Leydorf, and the entire engineering personnel of the broadcast branch of the Crosley Corporation.

Circular Loop Antennas at Ultra-High Frequencies*

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Summary—**The radiation characteristics of single-turn circular loops are investigated at wavelengths of the order of loop dimensions. Expressions are obtained for the distant field intensity in the plane of the loop and on the axis. Radiation patterns are shown for loops of various dimensions.**

I. Introduction

The directional properties of loop antennas are well known under the condition of uniform current distribution, that is, when operated at wavelengths long in comparison with the dimensions of the loop.[1] Under such conditions, radiation (or reception) is a uniform maximum in the plane of the loop, and is zero perpendicular to that plane, regardless of the shape of the loop. The characteristics of single-turn rectangular loops at frequencies for which the dimensions approach the wavelength were investigated by Williams,[2]

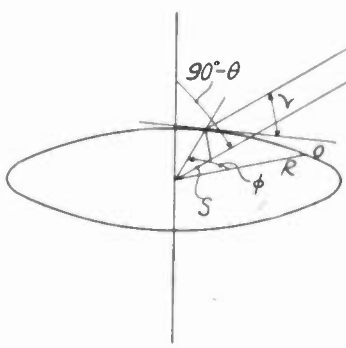

Fig. 1—Circular loop referred to spherical co-ordinates.

especially in the frequency range in which nonuniform current first appears. This paper also discussed the previous use by radio amateurs of short-wave loops for transmission and reception;[3] in particular, loops of perimeter equal to a half wavelength, which display unidirectional effects due to phase differences in various portions of the loop. Williams found that these unidirectional properties were not marked unless loading was added to the loop in the form of suitably disposed reactances to obtain more favorable current amplitude and phase distribution.

Rectangular loops with sides of the order of one-eighth wavelength have been investigated in detail in connection with the development of antennas for aircraft ranges and receiving equipment.[4]

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† Electrical Engineering Department, The Cooper Union, New York, N. Y.

[1] A. Hund, "Phenomena in High Frequency Systems," McGraw-Hill Book Company, New York 18, N. Y., 1936, chapter 12.

[2] Everard M. Williams, "Radiating characteristics of short-wave loop aerials," Proc. I.R.E., vol. 28, pp. 480–484; October, 1940.

[3] J. L. Reinartz, "Half-wave loop antennas," *QST*, vol. 21, pp. 27–29; October, 1937.

[4] Andrew Alford and A. G. Kandoian, "Ultra-high frequency loop antennas," *Trans. A.I.E.E.*, vol. 59, pp. 843–848; 1940. Also, related patents to Alford.

The present paper considers the directional characteristics of single-turn circular loops having circumference equal to an integral number of wavelengths. Sinusoidal-current distribution is assumed, which gives ideal characteristics from which those of various actual loops may be expected to depart, according to existing attenuation and phase shift.

II. Formulation and Solution of the Field Integral

The problem will be formulated in spherical co-ordinates. It is shown in Fig. 1 that the loop is placed in the ϕ plane and the generator is located at O. The loop will first be considered closed at the point opposite O.

The distant electric-field intensity is obtained by evaluating the integral

$$E = \frac{60\pi}{\lambda d}\int_0^{2\pi} (\sin\gamma)(I\cos\beta R\phi)\epsilon^{j\beta S} R\,d\phi \tag{1}$$

where

E = field intensity in volts per meter at point P
I = crest value of current in the loop in amperes
λ = wavelength in meters
d = distance to point P in meters
γ = angle between a tangent to the loop and the line from the point of tangency to point P (Fig. 1)
$\beta = 2\pi/\lambda$, phase constant
R = radius of loop in meters
S = difference between the distance from P to the origin and to a point on the loop (Fig. 1)

It is evident that both γ and S are functions of ϕ. From Fig. 1 it is found that

$$\gamma = \sin^{-1}\sqrt{1-\cos^2\theta\sin^2\alpha} \tag{2}$$

and

$$S = R\cos\theta\cos\alpha \tag{3}$$

where α is an angle obtained by projection onto the plane of the loop (Fig. 2). Thus (1) becomes

$$E = \frac{60\pi IR}{\lambda d}\int_0^{2\pi}\sqrt{1-\cos^2\theta\sin^2\alpha}\,(\cos\beta R\phi)\epsilon^{j\beta R\cos\theta\cos\alpha}d\phi. \tag{4}$$

This is intractable because α is a function of ϕ, but the integration can be performed for the cases of principal interest, that is, for the field in the plane of the loop and perpendicular to that plane.

In the plane of the loop, that is, for $\theta = 0$ (Fig. 2), we have from (4)

$$E = \frac{60\pi IR}{\lambda d}\int_0^{2\pi}(\cos\alpha)(\cos H\phi)\epsilon^{jH\cos\alpha}d\phi \tag{5}$$

where $H = \beta R$, and is the (integral) number of wavelengths in the circumference of the loop. It may be noted that the factor $\cos\alpha$ changes sign so as always to show changes in direction of the conductor relative to the distant point. From Fig. 2,

$$\phi = \alpha + A \tag{6}$$

where A is the particular angle, measured from the generator, at which E is desired. Placing (6) in (5) and expanding the sum,

$$E = K \int_0^{2\pi} (\cos \alpha)(\cos HA \cdot \cos H\alpha - \sin HA \cdot \sin H\alpha)\epsilon^{jH \cos \alpha} d\alpha. \tag{7}$$

The change of limits involved in the change of variable is not written because the value of the integral is unaffected by the addition of a constant to the limits. Expanding the products, we obtain

$$E = \frac{K \cos HA}{2}\left\{\int_0^{2\pi} (\cos a\alpha)\epsilon^{jH \cos \alpha} d\alpha + \int_0^{2\pi} (\cos b\alpha)\epsilon^{jH \cos \alpha} d\alpha\right\} - \frac{K \sin HA}{2}\left\{\int_0^{2\pi} (\sin a\alpha)\epsilon^{jH \cos \alpha} d\alpha + \int_0^{2\pi} (\sin b\alpha)\epsilon^{jH \cos \alpha} d\alpha\right\} \tag{8}$$

in which

$$a = \beta R + 1 \tag{9a}$$

$$b = \beta R - 1. \tag{9b}$$

The integral

$$X = \int_0^{2\pi} (\cos n\alpha)\epsilon^{jH \cos \alpha} d\alpha \tag{10}$$

can be evaluated by expanding the exponential in the series[5]

$$\epsilon^{jH \cos \alpha} = J_0(H) + 2\sum_{n=1}^{\infty} j^n J_n(H) \cos n\alpha \tag{11}$$

where $J_0(H)$ and $J_n(H)$ are Bessel functions of the first kind. On carrying out the expansion, multiplying each term by $\cos n\alpha$, and integrating, it is found that all the circular functions vanish. The result is

$$X = 2\pi j^n J_n(H). \tag{12}$$

By the same process, the integral

$$Y = \int_0^{2\pi} (\sin n\alpha)\epsilon^{jH \cos \alpha} d\alpha \tag{13}$$

is found to be equal to zero.

Applying the above results to (8), it is seen that the third and fourth integrals vanish. The result is

$$E = \frac{60\pi^2 IRj^a}{\lambda d} \cos HA\left[J_a(H) - J_b(H)\right]. \tag{14}$$

III. Reduction to Low-Frequency Case

Equation (14) can be made to yield the usual expression for the distant low-frequency field in the plane of the loop. As the frequency is reduced for a given loop (or the radius decreased for a given frequency), $H \rightarrow 0$. The magnitude of E as $H \rightarrow 0$ becomes

$$E_1 = 60\pi^2 IR/\lambda d\left[J_1(H) - J_{-1}(H)\right] \tag{15}$$

or, since $J_{-1}(H) = -J_1(H)$,

$$E_1 = (120\pi^2 IR/\lambda d)J_1(H). \tag{16}$$

The leading term in the series expansion[6] of $J_1(H)$ is $H/2$, from which it is seen that as $H \rightarrow 0$, $J_1(H) \rightarrow H/2$. Placing this in (16),

$$E_1 = 120\pi^3 IR^2/\lambda^2 d \tag{17}$$

which is the usual solution, obtained directly when the loop is initially considered to have uniform current distribution.[7]

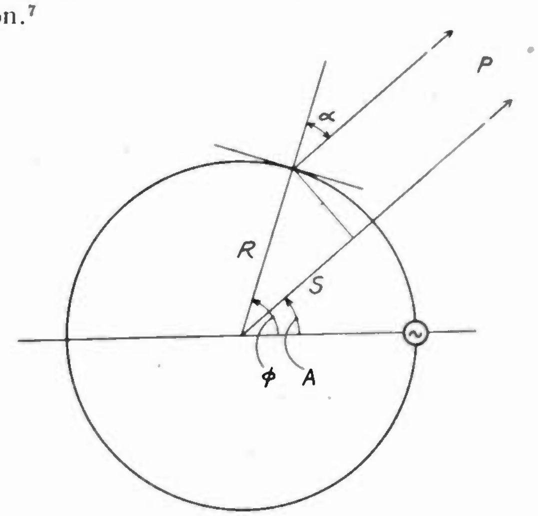

Fig. 2—Pertaining to ϕ plane.

IV. Effect of Open-Circuiting the Loop

The loop may be open instead of closed at the point opposite the generator. In this case (5) becomes

$$E = \frac{60\pi IR}{\lambda d}\int_0^{2\pi} (\cos \alpha)(\sin H\phi)\epsilon^{jH \cos \alpha} d\phi. \tag{18}$$

Carrying out the same operations as performed on (5), we obtain

$$E = (60\pi^2 IRj^a/\lambda d) \sin HA\left[J_a(H) - J_b(H)\right]. \tag{19}$$

Thus it is seen that opening the closed loop has the effect of interchanging the maxima and nulls of the radiation pattern, as might be predicted from the change in current distribution. Hence a bidirectional pattern is rotated through 90 degrees, etc. (This does not necessarily mean that practical shifting of the pattern can be obtained by only opening or closing the loop, since the input impedance of the loop changes.)

V. Radiation Patterns

Figs. 3, 4, and 5 show the radiation patterns in the plane of the loop, for closed loops of circumference λ, 2λ, and 3λ, respectively. For open loops, the maxima and nulls are interchanged. The loop is fed in each case at $A = 0$, as in Fig. 2.

[5] N. W. McLachlan, "Bessel Functions for Engineers," Oxford University Press, Oxford, England, 1934, chapter 3.

[6] See page 20 of footnote reference 5.

[7] William R. Smythe, "Static and Dynamic Electricity," McGraw-Hill Book Company, New York 18, N. Y., 1939, p. 478.

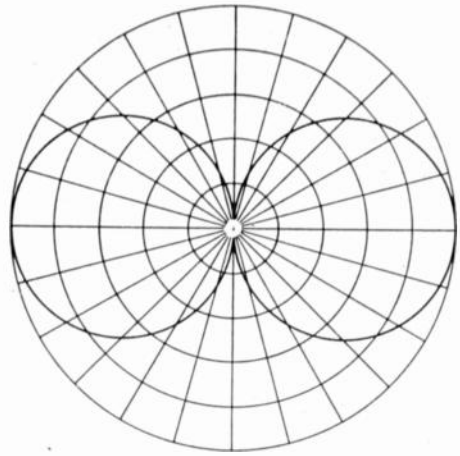

Fig. 3—Relative field intensity in plane of closed loop; circumference = 1λ.

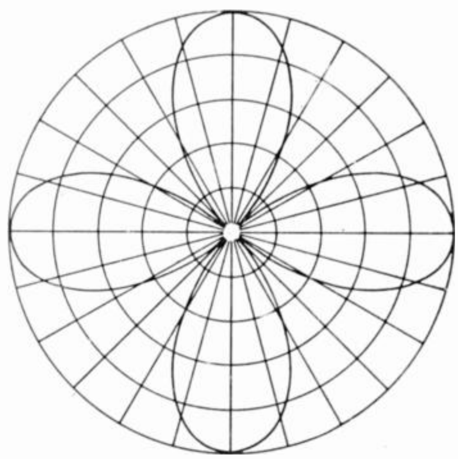

Fig. 4—Relative field intensity in plane of closed loop; circumference = 2λ.

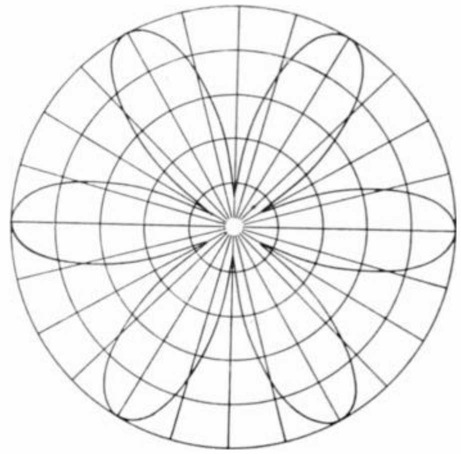

Fig. 5—Relative field intensity in plane of closed loop; circumference = 3λ.

VI. Field on the Axis of the Loop

The remote field on the axis of a circular loop may be considered from Figs. 6, 7, and 8. In Fig. 6, a closed loop of 1 wavelength circumference has been divided into half-wave portions. The arrows show relative direction of current flow for the assumed cosine distribution. It is evident that the two portions are effectively in parallel with respect to radiation in the direction of the axis, and the electric polarization is as indicated. The field is very simply evaluated; in the integrand of (4) the phase angle is zero and the radical goes to unity.

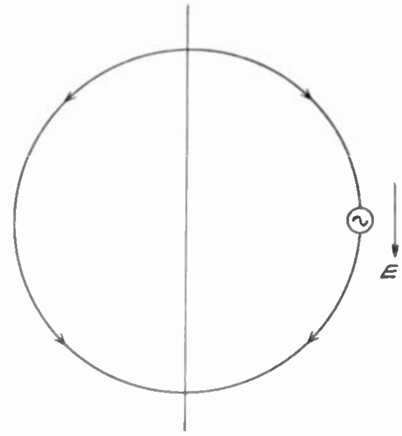

Fig. 6—Currents in 1λ loop and field vector on axis.

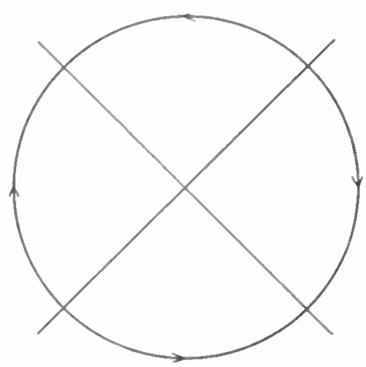

Fig. 7—Currents in 2λ loop.

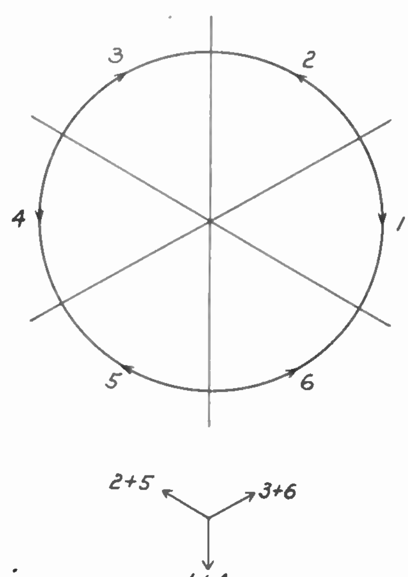

Fig. 8—Currents in 3λ loop and field vectors on axis.

Selecting proper limits, we have

$$E' = \frac{60\pi IR}{\lambda d} \cdot 2 \int_{-\pi/2}^{\pi/2} \cos \phi d\phi$$
$$= 120I/d. \tag{20}$$

From (14) the field in the plane of a 1-wavelength loop in the direction of a maximum is

$$\begin{aligned} E'' &= -(30\pi I/d)[J_2(1) - J_0(1)] \\ &= -(30\pi I/d)[0.115 - 0.765] \\ &= 19.5\pi I/d. \end{aligned} \tag{21}$$

The ratio of (20) to (21) is

$$E''/E' = 120/19.5\pi = 1.96$$

that is, the distant field intensity on the axis of the loop is nearly twice the maximum intensity in the plane of the loop.

Fig. 7 shows a 2-wavelength loop divided into half-wave portions with arrows as before to show relative current direction. It is seen that each segment bears current in opposite direction to that of an equally weighted segment, so far as radiation along the axis is concerned. The field intensity is therefore zero. The same argument holds for all loops whose circumference contains an even number of wavelengths.

It is readily shown that the radiation along the axis is zero also for all loops of an odd number of wavelengths other than unity. In Fig. 8, a 3-wave loop has been divided into half-wave segments. The segments pair to produce the symmetrically disposed vectors shown, the resultant field thus being zero. The same argument applies to all loops whose circumference contains an odd number of wavelengths other than unity.

VII. Experimental Results

The preceding results and conclusions have been checked qualitatively by the use of loops of circumference λ, 2λ, and 3λ, in connection with an oscillator operating at a fixed wavelength of 150 centimeters. This was found convenient for the wide range involved as neither the oscillator nor the field-strength meter required frequency adjustment.

Due to phase differences, a 1-wave loop of No. 12 copper wire was found to have its two lobes of appreciably different magnitude; these were approximately in the ratio of 3/2. The field on the axis was found to be about twice that of the average of the two lobes in the plane of the loop, with polarization as predicted. On a 2-wave loop, all four lobes were found to have approximately the same magnitude. A 3-wave loop showed appreciable differences among its six lobes. In the two latter cases, the field on the axis was small in comparison with the maxima in the plane of the loop. That it was not zero is due presumably to the same phase differences which cause the lobes to be of different amplitude.

Lack of a suitable reflection-free area limited these observations to data of a qualitative nature.

The author is glad to acknowledge the assistance of Mr. H. J. DiGiovanni of this staff in this experimental work.

VIII. A Circular Nonresonant Antenna

An interesting problem, mentioned here because its solution is of the same form as that of the resonant loop, concerns the radiation from an isolated nonresonant wire which is bent into a circular loop and terminated close to the generator. This is similar to the isolated straight wire discussed by Terman,[8] which may be imagined to be curved in a circular path so that its end is near the generator; in neither case is the return circuit taken into account.

In the plane of this loop, assuming an integral number of wavelengths in the circumference, and assuming an unattenuated traveling wave, we have

$$E = \frac{60\pi IR}{\lambda d}\int_0^{2\pi}(\cos\alpha)\epsilon^{jH(\cos\alpha-\phi)}d\phi. \tag{22}$$

On expansion this yields integrals of the same form as those of (8). The solution is

$$E = 60\pi^2 IRj^a\epsilon^{-jHA}/\lambda d[J_a(H) - J_b(H)]. \tag{23}$$

This antenna is omnidirectional in the plane of the loop. Of course, an isolated terminated wire, whether in straight or circular path, is rather hypothetical, except that it may represent a portion of an actual structure.

[8] F. E. Terman, "Radio Engineering," second edition, McGraw-Hill Book Company, New York 18, N. Y., 1937, pp. 662–663.

Additional Reference

Eugene Jahnke and Fritz Emde, "Tables of Functions," Dover Publications, New York, N. Y., 1943.

The Application of Filter Theory to the Design of Reactance Networks*

AUSTIN V. EASTMAN†, FELLOW, I.R.E.

Summary—**The design of electrical networks does not necessarily require the development of any special method of attack since a direct application of Ohm's and Kirchhoff's laws is always possible. Nevertheless such designs may be simplified and the selection of a suitable type of network for a particular application expedited by developing special methods of attack. It is the purpose of this paper to present one of these special methods; namely, the application of low-pass and high-pass filter theory to the design of reactance networks. While this method of attack probably offers no simplification unless one is already familiar with filter theory, such theory is now so well known to most radio engineers that its application to the design of reactance networks should appreciably simplify the procedure. Two specific applications of the method of attack are given; namely, (1) the design of impedance-matching networks such as might be used between a radio-frequency transmission line and an antenna and (2), the design of coupling units for video amplifiers. No doubt other applications will occur to the reader.**

Filter Theory

Filter theory is thoroughly covered in a number of textbooks[1,2] and it therefore seems desirable merely to review briefly the essential points. For simplicity, low-pass filters only will be considered, a similar discussion applying to high-pass filters.

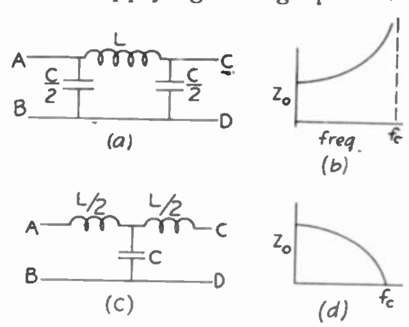

Fig. 1—Low-pass filter sections and their characteristic impedance.

Fig. 1(a) shows a single pi-section, low-pass filter. If the reactance elements are without loss the characteristic impedance will be purely *resistive* and will vary throughout the pass band according to the curves of Fig. 1(b), where f_c is the cutoff frequency. The equation of this impedance is

$$Z_{0\pi} = \frac{L/C}{\sqrt{L/C - (\omega^2 L^2)/4}}. \qquad (1)$$

If, on the other hand, the inductance is split in half and the elements are rearranged into the T section of Fig. 1(c), the characteristic impedance will follow the curve of Fig. 1(d) given by the equation[3]

$$Z_{0T} = \sqrt{L/C - (\omega^2 L^2)/4}. \qquad (2)$$

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† Electrical Engineering Department, University of Washington, Seattle, 3, Washington.

[1] W. L. Everitt, "Communication Engineering," second edition, chapter VI, McGraw-Hill Book Company, New York, 18, N. Y., 1937.

[2] L. A. Ware and H. R. Reed, "Communication Circuits," chapters IX and X, John Wiley and Sons, New York, N. Y., 1942.

If a half section is considered, as shown in Fig. 2(b), it will be seen to look like the T section of Fig. 1(c) when looking into the AB terminals, and like the pi section of Fig. 1(a) when looking into the CD terminals.

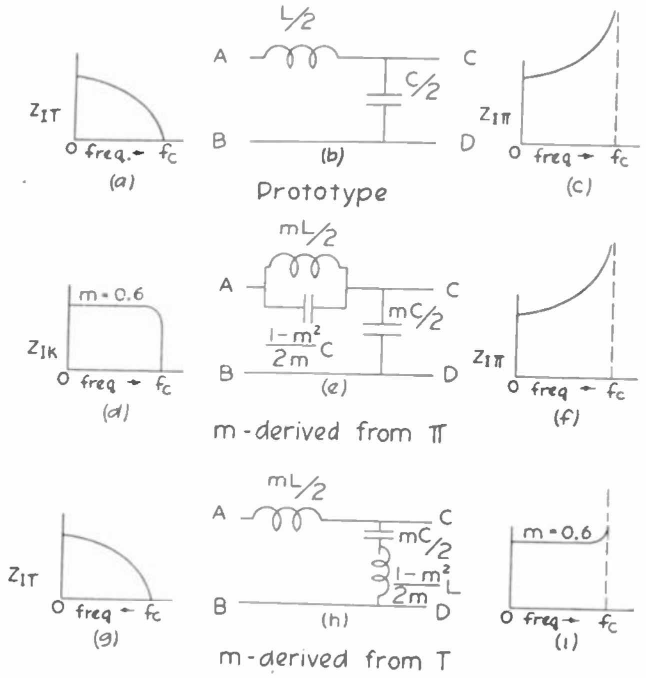

Fig. 2—The three fundamental low-pass filter half sections together with the curves of image impedance as seen from either pair of terminals.

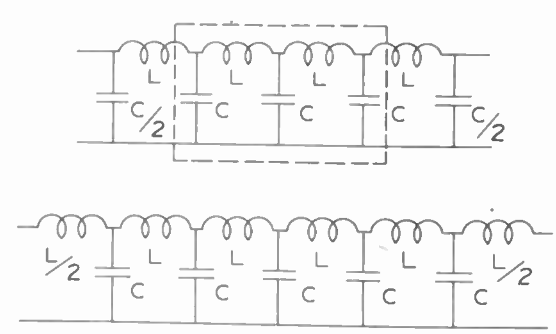

Fig. 3—Illustrating the similarity between a filter made up of a series of pi sections and one consisting of a series of T sections. (a) (upper) is a series of pi sections while (b) (lower) is a series of T sections.

The image impedance of this half section, looking into the AB terminals, is the same as the characteristic impedance of the T section, and is shown in Fig. 2(a). Similarly, the image impedance looking into the CD terminals is the same as the characteristic impedance of the pi-section, and is shown in Fig. 2(c).

To illustrate the value of working with half sections, consider the multisection filter of Fig. 3(a). If only that

[3] For a more extensive discussion of half sections see T. E. Shea, "Transmission Networks and Wave Filters," McGraw-Hill Book Company, New York 18, N. Y., 1929.

region enclosed in the dotted lines is observable there is no possible way of determining whether the filter consists of a series of pi or T sections. It is only by observing the terminating half sections that any distinction is found, in this case showing the filter of Fig. 3(a) to consist of a series of pi sections. If a half section similar to Fig. 2(b) is connected at each end of the filter of Fig. 3(a) with the *CD* terminals connected to the filter, the result will be as in Fig. 3(b) and the filter now consists of a series of T sections. Evidently then the only difference between a series of pi and of T sections lies in the type of terminating half sections used. Since the input impedance of Fig. 3(a) is given by the curve of Fig. 1(b) while that of Fig. 3(b) is given by the curve of Fig. 1(d) it is evident that the half section of Fig. 2(b) is an impedance-matching network, matching an impedance which follows the curve of Fig. 1(d) (across the terminals *AB* of Fig. 2(b)) to an impedance which follows the curve of Fig. 1(b) (across the terminals *CD*). Figs. 2(a) and 2(c) therefore indicate the two impedances which may be matched by the impedance-matching network of Fig. 2(b).

Another common type of filter section may be derived from the prototype sections of Fig. 1. Fig. 4(a) shows one such section derived from the pi section of Fig. 1(a) in which m may have any value from 0 to 1. Its characteristic impedance, Fig. 4(b), follows the same curve as its prototype, Fig. 1(b), for all values of m between 0 and 1. If this section is now split in half as in Fig. 2(e) it will be found that the image impedance as seen looking into the *CD* terminals will be exactly like the characteristic impedance of Fig. 4(b) and is shown in Fig. 2(f). On the other hand, the image impedance seen looking into the terminals *AB* varies with m, being exactly like the characteristic impedance of the T section of Fig. 1(d) when $m=1$, and approaching that of the pi section, Fig. 1(b), as m approaches zero. If $m=0.6$ the image impedance is nearly independent of the frequency throughout the pass band as shown in

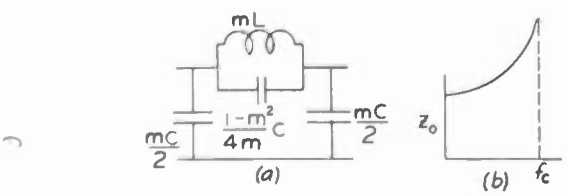

Fig. 4—Low-pass filter section derived from the pi section of Fig. 1(a) together with its characteristic impedance curve.

Fig. 2(d). This half section may therefore be considered, with a fair degree of exactness, as an impedance-matching network between a constant resistance and a resistance varying as in Fig. 2(f) for all frequencies less than f_c. Fig. 2(h) shows a half section derived in a similar manner from the T section of Fig. 1(c) which, when $m=0.6$, is an impedance-matching network between the characteristic impedance of the T section and a constant resistance over most of the pass band, as indicated in Fig. 2(g) and Fig. 2(i).

The three half sections of Fig. 2 cover the principal forms used for low-pass filters since two half sections like Fig. 2(b) may be put together to form a full prototype section, either T or pi, while two half sections like Fig. 2(e) or like Fig. 2(h) may be combined to form a full m-derived section. Furthermore, any one of these

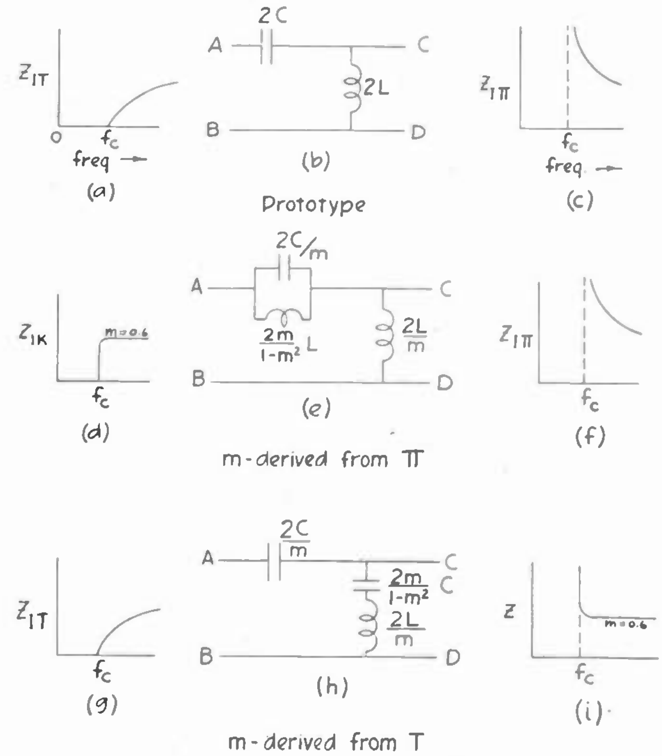

Fig. 5—The three fundamental high-pass filter half sections together with the curves of image impedance as seen from either pair of terminals.

half sections may be combined with any other provided the terminals to be joined together present the same image impedance throughout the frequency range to be used. Thus the *CD* terminals of Fig. 2(b) and 2(e) may be joined together provided the two impedances are equal at all frequencies in the useful range. This will be true if the m-derived section is derived from the prototype to which it is joined. It is further evident that the *CD* terminals, Fig. 2(b), can never be joined to the *AB* terminals of Fig. 2(e) or to either pair of terminals of Fig. 2(h) since their image impedances follow entirely different curves.

A similar analysis may be made of the high-pass filter, resulting in Fig. 5, similar to Fig. 2. The equation for the image impedance looking into the *CD* terminals of Fig. 5(b) is

$$Z_{0\pi} = \frac{L/C}{\sqrt{L/C - 1/(4\omega^2C^2)}} \quad (3)$$

and looking into the *AB* terminals

$$Z_{0T} = \sqrt{L/C - 1/(4\omega^2C^2)}. \quad (4)$$

Design of Radio-Frequency Impedance-Matching Units

One application of filter theory is in the design of impedance-matching networks for use at radio frequencies. Such circuits are used for example, in coupling transmission lines to antennas or to the output of radio transmitters. When coupling a transmission line to an antenna, the antenna may first be tuned to resonance by a suitable reactance, so that it will appear as a pure resistance R_a. The characteristic impedance of a radio-frequency transmission line is also nearly a pure resistance R_t. From Figs. 2 and 5 it will be seen that a prototype low-pass or high-pass half section may be used to match these resistances provided the image im-

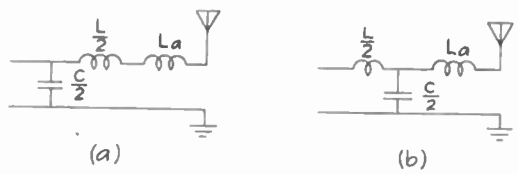

Fig. 6—Circuits for coupling a transmission line to an antenna by means of a low-pass half section. (a) should be used when the impedance of the transmission line is greater than the resistance of the antenna. (b) should be used when the antenna resistance is greater than the characteristic impedance of the transmission line.

pedances, at the frequency at which the antenna is to be operated, are respectively equal to R_a and R_t. It is also obvious that the CD terminals must be connected to the larger of the two resistances. Let R_1 represent the smaller of these two resistances and R_2 the larger (e.g., if $R_t>R_a$, $R_t=R_2$ and $R_a=R_1$, whereas if $R_t<R_a$, $R_t=R_1$ and $R_a=R_2$). If a low-pass unit is to be used we may write from (1)

$$R_2 = \frac{L/C}{\sqrt{L/C-(\omega^2L^2)/4}} \tag{5}$$

and from (2)

$$R_1 = \sqrt{L/C-(\omega^2L^2)/4}. \tag{6}$$

Multiplying (5) and (6) gives

$$R_1R_2 = L/C \tag{7}$$

and dividing (6) by (5) gives

$$R_1/R_2 = 1-(\omega^2LC)/4. \tag{8}$$

When these two equations are solved simultaneously for $L/2$ and $C/2$ the results are

$$L/2 = (R_1/\omega)\sqrt{(R_2-R_1)/R_1} \tag{9}$$

$$C/2 = (1/\omega R_2)\sqrt{(R_2-R_1)/R_1}. \tag{10}$$

Fig. 6(a) shows the circuit used if $R_t>R_a$ in which L_a represents the reactance required to tune the antenna to resonance. This may, of course, be combined with $L/2$ into a single coil which is either larger or smaller than $L/2$ depending on whether inductive reactance or capacitive reactance is required to tune the antenna to resonance.

If $R_t<R_a$, the circuit is that of Fig. 6(b).

The phase shift of an impedance-matching network is often of importance, as where two or more radiators are used to provide a directional radiation pattern. It may readily be shown[4] that the phase shift β in one full section of a low-pass prototype filter section, either Fig. 1(a) or Fig. 1(c), is given by

$$\cos\beta = 1-(\omega^2LC)/2. \tag{11}$$

[4] See page 128 of footnote reference 2.

Since we are dealing with half-sections the phase shift for the circuit of Fig. 2(b) would be $\beta/2$, and using the trigonometric relationship

$$\cos\beta/2 = \sqrt{(1/2)(1+\cos\beta)} \tag{12}$$

we may write

$$\cos\beta/2 = \sqrt{1-(\omega^2LC)/4} = \sqrt{R_1/R_2}. \tag{13}$$

The phase shift in a low-pass filter section is such that the voltage across the output lags the voltage across the input by the angle $\beta/2$. This is true whether the CD terminals or the AB terminals are used as the output. Evidently, too, the phase shift will be zero when R_1 and R_2 are equal to each other and will approach 90 degrees as the ratio of R_1 to R_2 approaches zero.

While a low-pass unit is usually preferred to a high-pass because of the resulting attenuation of harmonic frequencies, there are times when the latter is of value because its phase shift is opposite to that of the low-pass unit, or for other reasons. Equations for $2L$ and $2C$ for a high-pass unit may be obtained in the same manner as were $L/2$ and $C/2$ for the low-pass unit by starting with (3) and (4), giving

$$2L = (R_2/\omega)\sqrt{R_1/(R_2-R_1)} \tag{14}$$

$$2C = (1/\omega R_1)\sqrt{R_1/(R_2-R_1)}. \tag{15}$$

Equations for the phase shift in a high-pass filter may be obtained in a manner similar to those in a low-pass filter except that

$$\cos\beta = 1-1/(2\omega^2LC).$$

This gives

$$\cos\beta/2 = \sqrt{R_1/R_2}. \tag{16}$$

It will be seen that this is exactly the same equation as for the low-pass filter but in this case the output voltage will lead the input voltage.

Impedance-matching networks are sometimes built with three reactance elements forming a full pi or T section. One use for such a network is found when R_1 and R_2 are nearly equal, since (9), (10), (14), and (15) show that L and C will then be nearly zero in low-pass coupling units and nearly infinite in high-pass units.

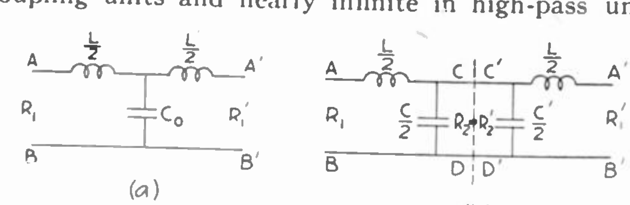

Fig. 7—Illustrating the use of two dissimilar half sections to form a single T-section filter for matching two unequal resistances.

The use of two half sections in tandem to form one full section will permit impedance match between two nearly equal resistances with constants which are of a more practical size. Fig. 7(a) shows a full-section, low-pass unit, matching a resistance R_1 to a resistance R_1'. This may be considered the equivalent of two half sections in tandem as indicated in Fig. 7(b). Here the first section is an impedance-matching network between R_1 and R_2, and the second section, between R_2' and R_1', where R_2 and R_2' must be larger than R_1 and R_1'.

R_2 and R_2' must evidently be equal to each other in order to maintain impedance match at the mid-point. C_o of Fig. 7(a) is evidently equal to $C/2+C'/2$.

The usual procedure in designing a 3-element network is to assume a value for one of the three elements and compute the other two to give the desired impedance match. Exactly the same procedure may be followed in using filter theory. In Fig. 7(b), $L/2$, $L'/2$, $C/2$, $C'/2$, or R_2 may be chosen at will and the remaining elements of the network designed by the procedure above outlined for the design of half-section, impedance-matching networks. It is usually desirable to select either $L/2$ or $L'/2$. If $L/2$ is chosen R_2 may be determined by solving (9) for R_2 giving

$$R_2 = (\omega^2/R_1)(L/2)^2 + R_1.$$

$C/2$ may be found from (10). $L'/2$ and $C'2$ may then be determined from the same equations to match R_2' (equal to R_2) to R_1'. By proper selection of $L/2$ it is thus possible to design the network with constants of the most desirable order of magnitude.

The phase shift in this unit obviously will be the sum of the phase shifts in the two half sections.

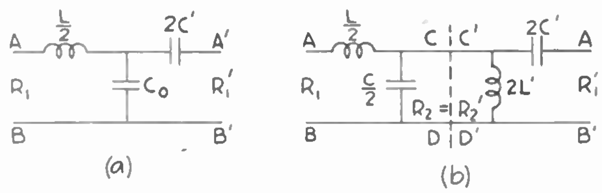

Fig. 8—Illustrating the use of a low-pass and a high-pass half section to form a single T-section filter to match two unequal resistances.

Where less phase shift is desired one of the networks may be a high-pass type as in Fig. 8(b). Since the voltage at CD lags the voltage at AB while the voltage at $A'B'$ leads the voltage at $C'D'$ the total phase shift will be the difference of the two. Fig. 8(a) shows the actual circuit used in which C_o has a reactance equal to the reactance of $C/2$ and $2L'$ in parallel, assuming that the reactance of $C/2$ is less than that of $2L'$. If this is not so an inductance must be used as the shunt element. Evidently the use of a condenser as the shunt element will more effectively suppress harmonics. The necessary condition for this reactance to be capacitive is for R_1' to be greater than R_1, whereas it will be inductive if R_1 is greater than R_1'.

Pi sections may also be designed, such as the low-pass filter shown in Fig. 9. The procedure should be obvious. It is also possible to combine two high-pass half sections into either a T or a pi section or to combine a low-pass half section and a high-pass half section to form a single pi. The design procedure and the performance of each type of network should be obvious from the foregoing analysis.

It was stated in a preceding paragraph that the use of low-pass rather than high-pass filter sections for impedance matching reduces the magnitude of any harmonics which may be present. However, this will only be true provided the cutoff frequency is less than the frequency of the harmonic to be suppressed.

The cutoff frequency of a filter may be found by noting from Fig. 2(a) that the image impedance looking into the T terminals is zero at the cutoff frequency. Making Z_{0T} in (2) equal to zero gives

$$L/C = \omega_c^2L^2/4$$

or

$$\omega_c = \frac{2}{\sqrt{LC}} = \frac{1}{\sqrt{(L/2)(C/2)}} \tag{17}$$

where ω_c is 2π times the cutoff frequency. Substituting

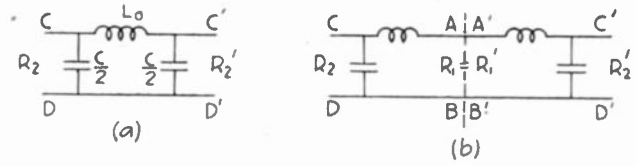

Fig. 9—Illustrating the use of two dissimilar half sections to form a single pi-section filter for matching two unequal resistances.

for $L/2$ and $C/2$ from (9) and (10) gives

$$\omega_c = \omega\sqrt{R_2/(R_2 - R_1)}. \tag{18}$$

Substitution of the numerical values of R_2 and R_1 in (18) will show whether or not attenuation is present at the frequency of any harmonic which is of interest.

Since the second harmonic is not only lower in frequency than any other but is usually larger in magnitude, it will be interesting to investigate the range of R_2/R_1 throughout which attenuation of the second harmonic will be present. Attenuation will always be present if $\omega_c<2\omega$, and will be greater as ω_c is made increasingly less than 2ω. Considering the limiting conditions of $\omega_c=2\omega$ we may rewrite (18)

$$2\omega = \omega\sqrt{R_2/(R_2 - R_1)} \tag{19}$$

from which

$$R_2/R_1 = 4/3. \tag{20}$$

Equation (20) indicates that attenuation of the second harmonic will be present whenever $R_2/R_1>1.33$, and for appreciable attenuation it should be several times this minimum value. If the ratio of these two resistances is less than 1.33 or is only slightly greater, it may be desirable to use two half sections in tandem as described in a preceding paragraph, making R_2/R_1 and R_2'/R_1' each considerably greater than 1.33.

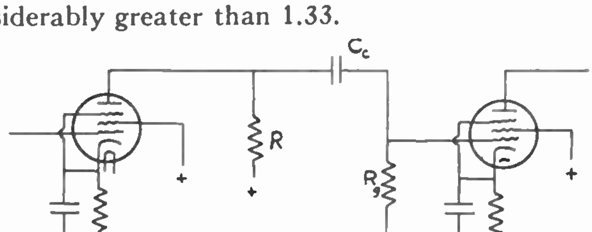

Fig. 10—A resistance-coupled audio-frequency amplifier which is also the basic form of the video amplifier.

Design of Coupling Units for Video Amplifiers

The simplest form of video amplifier is the resistance-coupled, audio-frequency amplifier, Fig. 10, in which the frequency range has been extended by suitable changes in circuit constants and by the use of low-capacitance tubes. Electrically this circuit may be represented by the equivalent circuit of Fig. 11(a), in which the "load" represents the network coupling the output of the first tube to the input of the second tube, including tube and wiring capacitances. Since low-pass filter units may be used in video amplifiers to improve the high-frequency response only (having no effect upon low-frequency

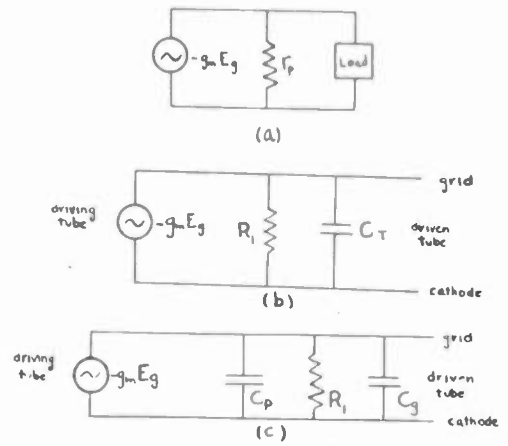

Fig. 11—Equivalent circuit of Fig. 10.

response) the performance of the amplifier will be studied only at high frequencies and the effect of the coupling condenser C_c may be neglected. Under such circumstances the load circuit consists of resistances R_1 and R_g in parallel and of the output capacitance of the driving tube, input capacitance of the driven tube, and the wiring capacitance to ground, all in parallel. In a video amplifier R_1 is of the order of a few thousand ohms, whereas R_g is of the order of 100,000 to 500,000 ohms. Therefore these two resistances in parallel are virtually equal to R_1 alone. It will be seen from Fig. 11(a) that R_1 is effectively in parallel with r_p which is of the order of one million ohms in the pentode tubes normally used in these amplifiers. The net result is that the equivalent circuit for the higher frequencies of a video amplifier is as shown in Fig. 11(b), in which R_1 is the coupling resistance of Fig. 10 and C_T is the total shunt capacitance, being the sum of the two tube capacitances and the wiring capacitance. It may be shown that the high-frequency gain of this circuit is[6]

$$A_h = (g_m R_1)/\sqrt{1 + \omega^2 C_T^2 R_1^2}. \tag{21}$$

Equation (21) may be solved for ω from which it will be seen that the maximum frequency of response, if the drop in the gain from the mid-frequency value ($g_m R_1$) is not to exceed 3 decibels, becomes

$$f_m = 1/(2\pi R_1 C_T). \tag{22}$$

If this equation is now solved for the coupling resistance the result will be

$$R_1 = 1/(\omega_m C_T) \tag{23}$$

where ω_m is $2\pi f_m$ and f_m is the maximum frequency of response for a drop in gain of not to exceed 3 decibels. If the value of C_T usually experienced in a normal resistance-coupled amplifier using pentode tubes is inserted into (23) it will be verified that R_1 for a video-frequency amplifier must be of the order of only a few thousand ohms. Since the mid-frequency gain (actually the gain of the amplifier throughout the entire frequency spectrum except at very low and very high frequencies) is

$$A_m = g_m R_1 \tag{24}$$

it is evident that the gain of such an amplifier will be extremely low. It is true that special high-g_m tubes have been developed for this service in an effort to raise this gain but even with $g_m = 9{,}000$, the maximum gain of the amplifier is only about 25 to 30.

In order to increase the gain further, low-pass filters are now widely used as coupling units, since the shunt capacitance C_T may then be used as a part of the filter circuit. The capacitance C_T of the equivalent high-frequency circuit of a video amplifier (Fig. 11(b)) is made up of two principal parts, the output capacitance of the driving tube C_p and the input capacitance of the driven tube C_g. The stray capacitances Cw due to wiring, tube sockets, etc., may be grouped with either C_p or C_g depending upon their location. The circuit of Fig. 11(b), therefore, may be shown as in Fig. 11(c) where C_p and C_g include the wiring capacitances. Evidently, if a filter circuit is to be successfully employed as a coupling circuit, the capacitances C_p and C_g must be part of the filter. A prototype pi section is therefore indicated giving the equivalent circuit of Fig. 12(a) and the actual circuit of Fig. 12(b). In the actual circuit C_p and C_g do not show since they represent the internal capacitances of the tubes plus the wiring capacitance. On the other hand, C_c and R_g do not show in the equivalent circuit since their effect is negligible at high frequencies. Such a circuit, when properly designed by means of equations presented in a later part of this paper, will be found to offer some improvement over the simple circuit of Fig. 10.

Inspection of Fig. 2(a), (b), and (c) will show that the circuit of Fig. 12(a) is made up of two prototype half sections the image impedances of which are designed to match each other (making a full pi section) but that R_1 cannot terminate this filter in its image impedance at

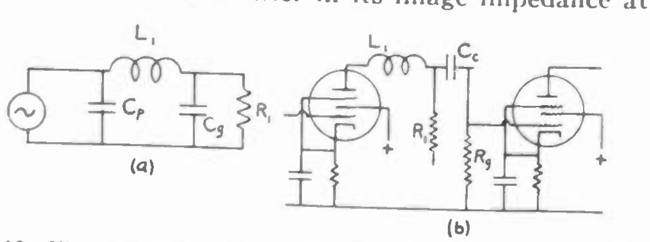

Fig. 12—Illustrating the use of a prototype low-pass filter pi section as a coupling impedance in the amplifier of Fig. 10.

all frequencies. To terminate this filter correctly it is necessary to insert the half section of Fig. 2(e) between C_g and R_1, producing the equivalent circuit of Fig. 13. (Here the capacitance C_g evidently must include the capacitance $C/2$ of Fig. 2(b) and $mC/2$ of Fig. 2(e).) Since Figs. 2(d) and (f) show that the half section of Fig. 2(e) will match the impedance $Z_{I\pi}$ to a constant resistance, the filter is now (for all practical purposes)

[6] A. V. Eastman, "Fundamentals of Vacuum Tubes," second edition, p. 260. McGraw-Hill Book Company, New York, N. Y., 1941.

correctly terminated at all frequencies up to the cutoff frequency f_c of the filter and the voltage across the driven tube at CD will be exactly equal to the voltage impressed across EF by the driving tube within this frequency range (neglecting the small effect of resistance in the coils).

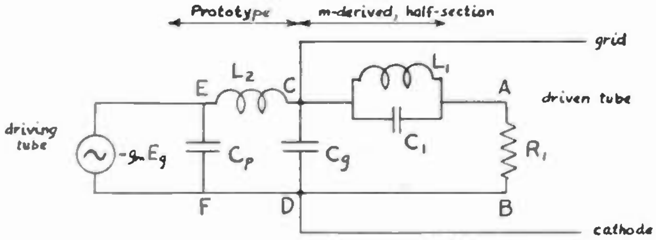

Fig. 13—Equivalent circuit of a video amplifier using a load impedance as a prototype low-pass pi section terminated by an m-derived half section.

Unfortunately, the impedance across points EF varies with frequency as shown in Fig. 2(c) and the voltage set up across EF by the driving tube will therefore vary with frequency. This might be avoided by inserting another m-derived half section across the points EF as shown in Fig. 14, except that the constant-impedance points are GH and AB, whereas the tube capacitances must be at the points CD and EF. These two conditions are obviously incompatible since the inductance L_3 and the capacitance C_3 cannot be inserted between the tube capacitance and the equivalent generator of Fig. 13.

Wheeler[6] has shown that placing a condenser C_n having a capacitance $C/2$ across the input terminals of the coupling units of Fig. 13, as indicated in Fig. 15, will produce an input impedance which is constant in magnitude although varying in phase. This may be demonstrated by noting that the input impedance Z_i is equal to the impedance of the added condenser in parallel with the characteristic impedance of a T-section, low-pass filter, since the input impedance of the filter in

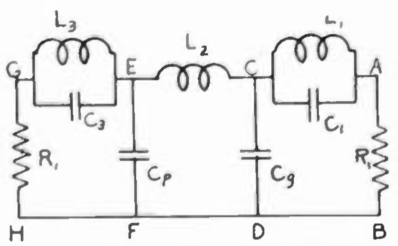

Fig. 14—Illustrating the ideal method of terminating a prototype pi section to give constant impedance in either direction.

Fig. 13 is equal to the characteristic impedance. Therefore, we may write

$$Z_i = \frac{1}{i\omega\frac{C}{2} + \frac{\sqrt{L/C - (\omega^2L^2)/4}}{L/C}} = \sqrt{\frac{L}{C} - \frac{\omega^2L^2}{4}} - j\omega\frac{L}{2} \qquad (25)$$

or, in polar co-ordinates,

$$Z_i = \sqrt{L/C}\ \underline{/-\cos^{-1}\sqrt{1-(\omega^2LC)/4}}. \qquad (26)$$

This equation shows that the input impedance is constant in magnitude throughout the pass band of the filter, being equal to the zero-frequency impedance of the prototype filter section. Since the driving tube is essentially a constant-current generator (as shown in Fig. 11) the use of this constant-impedance circuit will result in constant voltage being impressed across the

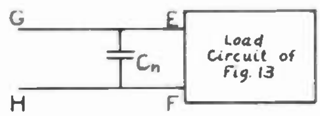

Fig. 15—Illustrating the use of a capacitor across the terminals EF of Fig. 13 to produce a constant impedance input.

terminals GH of Fig. 15, although the phase of this voltage will evidently shift with frequency, a point of considerable importance which will be discussed in a later section of this paper.

We now see that the circuit shown in Fig. 13 will maintain constant impedance at EF and will, therefore, maintain constant gain in the driving tube from zero frequency up to the cutoff frequency of the filter provided that it be so designed that C_p is the equivalent of both $C/2$ of the conventional filter and C_n. (This is more fully demonstrated in the actual design procedure set forth in a subsequent section.) The grid-cathode circuit of the driven tube must be placed across CD since EF and CD are equal impedance points and the voltages at these two points must therefore be equal for all frequencies less than the cutoff frequency of the filter.

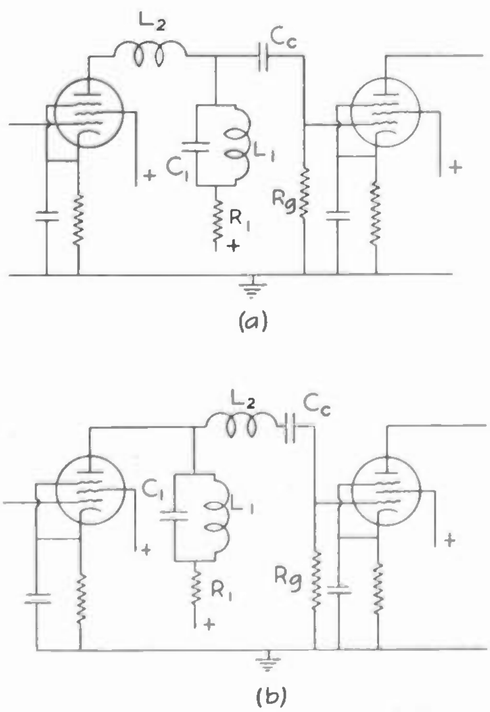

Fig. 16—Actual circuit using the coupling unit of Fig. 13. Terminals EF and CD are interchanged in Fig. (b).

Evidently, too, by applying the reciprocity theorem it is possible to interchange the connections to the driving and driven tubes. Since the capacitance required between C and D to satisfy the filter equations is different

[6] Harold A. Wheeler, "Wide-band amplifiers for television," Proc. I.R.E., vol. 27, pp. 429–438; July, 1939.

from that between E and F, the best selection of the points to which the driving and driven tubes are connected is dependent upon the relative output capacitance of the driving tube and input capacitance of the driven tube. The capacitances between C and D and between E and F are those of the tubes and the external circuit elements, and the actual circuit of a video amplifier, using the coupling unit of Fig. 13, would therefore appear as in Fig. 16(a) or, if the driving and driven tubes are interchanged, Fig. 16(b).

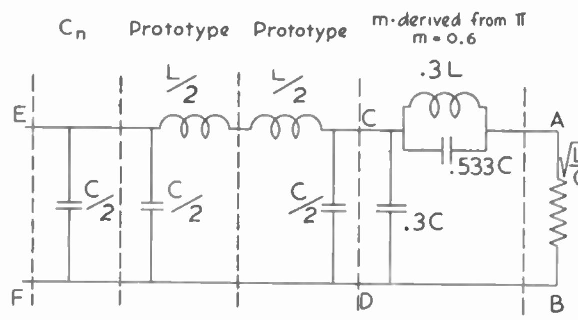

Fig. 17—Showing the component parts of the circuit of Fig. 13.

Design of Low-Pass Filters as Coupling Units

Computation of the numerical values of the inductances and capacitances in the circuit of Fig. 13 may readily be carried out by means of the design equations for a low-pass filter. First the circuit must be broken down into its equivalent half sections and other parts as in Fig. 17. These parts consist of the condenser C_n of Fig. 15, two prototype half sections, an m-derived pi half section, and the terminating resistance.[7] Inspection of Fig. 2 shows that all these half sections may be correctly matched in impedance by proper design. To insure proper match throughout, L and C of Fig. 17 must be evaluated from the low-pass filter equations which are presented in this section.

Comparison of the circuits of Figs. 13 and 17 show that the following relationships are true.

$$L_1 = 0.3L \qquad R_1 = \sqrt{L/C}$$
$$C_1 = 0.533C \qquad C_p = C \qquad (27)$$
$$L_2 = L \qquad C_g = 0.8C$$

where C_p is the output capacitance of the driving tube plus any wiring capacitance to ground between the plate of this tube and the coil L_2; while C_g is the input capacitance of the driven tube plus any wiring capacitance to ground between L_2 and the grid of that tube. From Fig. 2(c) it is seen that $Z_{I\pi}$ is infinite at cutoff and solving (1) for f where $Z_{I\pi} = \infty$ gives

$$f_c = 1/(\pi\sqrt{LC}). \qquad (28)$$

From (28) we may solve for L giving

$$L = 1/(\pi^2 f_c^2 C). \qquad (29)$$

We may, therefore, write

$$R_1 = \sqrt{L/C} = 1/(\pi f_c C). \qquad (30)$$

[7] The terminating resistance is shown as $\sqrt{L/C}$ since inspection of (1) and Fig. 2(d) shows that the nearly constant value of the image impedance across the AB terminals of Fig. 2(e) is equal to the zero-frequency impedance $\sqrt{L/C}$.

In this case the cutoff frequency f_c is the maximum frequency to be amplified, or $f_c = f_m$. The capacitances C_p and C_g are known and according to (27) should be in the ratio of 10 to 8. Since it is improbable that the actual capacitances will be in any predetermined ratio it is best to write $C_p + C_g = C_T = C + 0.8C = 1.8C$ from which C is equal to $C_T/1.8$. From these two relationships R_1, L_1, and L_2 may be computed by (29) and (30) to give

$$R_1 = 1.8/(\pi f_m C_T) \qquad (31)$$
$$L_2 = 1.8/(\pi^2 f_m^2 C_T) \qquad (32)$$
$$L_1 = 0.54/(\pi^2 f_m^2 C_T). \qquad (33)$$

C_1 may next be obtained by substitution in (27) to give $C_1 = 0.296 C_T$. By the foregoing procedure, therefore, the circuit may be designed for any given maximum frequency f_m, as soon as the tubes are selected so that C_T is known.

If C_p is larger than C_g the actual circuit should be that of Fig. 16(a) where $C_p = C_n + C/2$ and $C_g = C/2 + mC/2$, i.e., $C_p/C_g = 1/0.8$. If C_g is greater than C_p the circuit should be that of Fig. 16(b) where $C_p/C_g = 0.8/1$. If these theoretical ratios are not exactly realized the results will fall somewhat below the ideal. It is of course possible to secure the exact ratio desired by introducing a suitable external capacitance in parallel with C_p or C_g as required but this will reduce the gain for a given f_m and will normally do more harm than good.

Other Circuits

It is possible to secure reasonably satisfactory results with somewhat simpler circuits than that of Fig. 13. For example, the terminating m-derived half section was omitted in the circuit of Fig. 12. Fig. 18 shows this

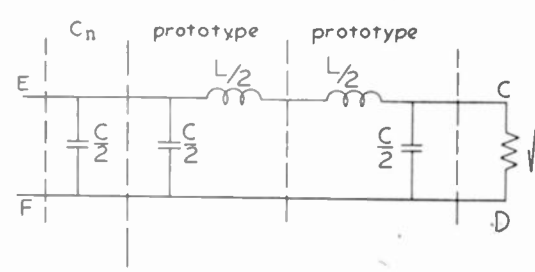

Fig. 18—The component parts of the circuit of Fig. 12.

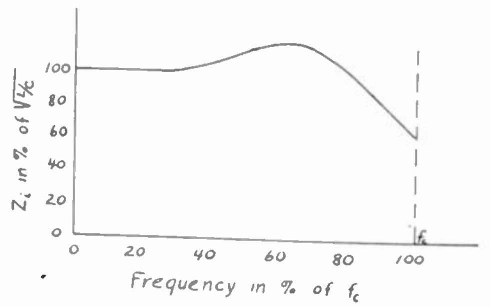

Fig. 19—Curve of impedance between terminals E and F of Fig. 18.

circuit broken down into its equivalent parts. In this circuit the prototype pi section is not properly terminated and the impedance curve instead of being constant throughout virtually all of the pass-band, as in the circuit of Fig. 13, follows the curve of Fig. 19. It may be seen that the deviation is not excessive up to a frequency of about one half the cutoff frequency of the filter.[8]

Comparing the circuit of Fig. 12 to that of Fig. 18 it is seen that the following relations are true.

$$L_1 = L \qquad C_g = C/2$$
$$C_p = C \qquad R_1 = \sqrt{L/C}. \tag{34}$$

Again C_p and C_g are known and we may write $C_p+C_g = C_T = C+C/2 = 1.5C$, from which C is equal to two thirds C_T. Also, from Fig. 19, $f_m = f_c/2$ due to the mismatch of impedances. From these relations we can solve for L_1 and R_1 in terms of f_m and C_T with the aid of (29) and (30). This gives

$$R_1 = 3/(4\pi f_m C_T) \tag{35}$$
$$L_1 = 3/(8\pi^2 f_m^2 C_T). \tag{36}$$

In general it may be said that $f_m = f_c$ when an m-derived section is used to produce impedance match to R_1 and $f_m = (1/2)f_c$ when this type of section is not used.

Improvement in Gain

Since the mid-frequency gain of the amplifier is $g_m R_1$, the improvement in gain due to any circuit is proportional to the permissible increase in R_1. R_1 for the circuit of Fig. 12 is given by (34) while (23) gives R_1 for the ordinary resistance-coupled amplifier of Fig. 10. The ratio of R_1 in Fig. 12 to R_1 in Fig. 10 for the same maximum frequency of response is therefore

$$\frac{R_1 \text{ in Fig. 12}}{R_1 \text{ in Fig. 10}} = \frac{3/(4\pi f_m C_T)}{1/(2\pi f_m C_T)} = \frac{3}{2}. \tag{37}$$

The gain of the circuit of Fig. 12 is therefore 50 per cent greater than that of Fig. 10 for the same frequency range.

The ratio of R_1 of Fig. 16 to that of Fig. 10 is given by the ratio of (31) to (23) which shows that the gain of the circuit of Fig. 16 is 3.6 times as great as that of Fig. 10 for the same frequency range.

Effect of Phase Shift

Evidently video amplifiers must reproduce the impressed wave shape without change. This means that not only must the gain of the amplifier be the same at all frequencies through the band to be amplified but that each component of the impressed signal, no matter what its frequency, must maintain the same phase relationship to all other components as it passes through the amplifier. This requirement will be met either if the amplifier has no time delay or if the time delay is the same for all components. The first condition is impossible of attainment in a practical amplifier but the second will be realized if the phase shift is proportional to the frequency.

Let us consider the circuit of Fig. 16(a), the equivalent circuit of which was shown in Fig. 13. Since the driving tube may be considered as a constant-current generator (Fig. 11) it is evident that the phase shift between the voltage across EF (Fig. 13) and the grid voltage E_g will be that of the load impedance. This was given in (26) so that the phase shift is given by

$$\cos\theta = \sqrt{1-(\omega^2 LC)/4}. \tag{38}$$

This angle is plotted against frequency in Fig. 20 where it will be seen that the phase shift is reasonably proportional to frequency over 90 per cent of the pass band of the filter.

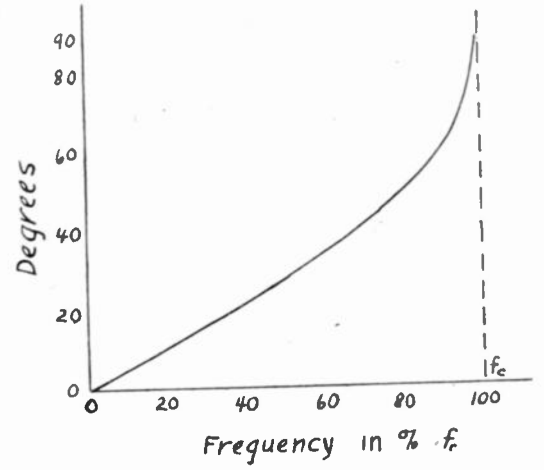

Fig. 20—Curve of phase shift between the terminals E and F of Fig. 13.

The phase shift between EF and CD of Fig. 13 may be found by breaking down the coupling unit into its component parts as in Fig. 17. The phase shift in each half of the prototype section of this figure is given by the first part of (13) or

$$\cos\beta/2 = \sqrt{1-(\omega^2 LC)/4}. \tag{39}$$

This equation is seen to be exactly the same as (38). Therefore the total phase shift in this amplifier will be 3θ and will be nearly proportional to frequency over most of the pass band, thus meeting the requirements of a satisfactory video amplifier to a reasonable degree.

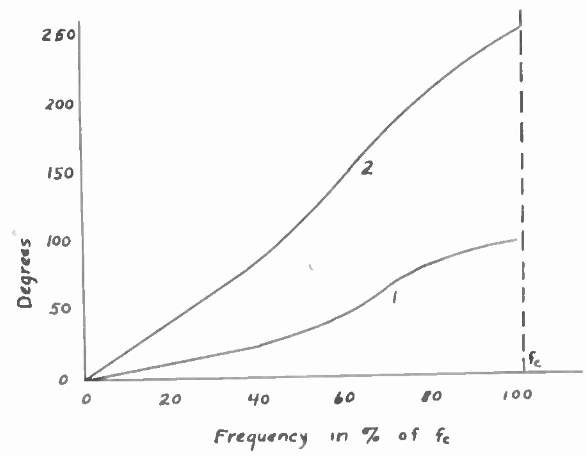

Fig. 21—Curves of phase shift between terminals E and F of Fig. 18 (curve 1), and total phase shift between the voltage across CD and the grid voltage of the driving tube (curve 2).

The equations for the phase shift in the circuit of Fig. 12 (the component parts of which are shown in Fig. 18) are rather complex. However, if the phase of

[8] As will be shown in a later section the phase-shift characteristics also become unsatisfactory at frequencies above half cutoff.

the impedance between terminals E and F, Fig. 18, is computed for various frequencies it will be found to vary as in curve 1 of Fig. 21. Curve 2, Fig. 21, is the total phase shift in the amplifier, equal to the sum of the phase shift between EF and CD, Fig. 18, and the phase angle of curve 1, Fig. 21. These curves are seen to be quite linear up to a frequency of half cutoff which is the useful upper limit of frequency for this circuit.

Optical Constants of a Magnetic-Type Electron Microscope*

L. MARTON†, NONMEMBER, I.R.E., AND R. G. E. HUTTER†, NONMEMBER, I.R.E.

Summary—**The majority of transmission-type electron microscopes use magnetic electron lenses because of their superiority with respect to resolving power as compared with that of electrostatic lenses. The axial field distribution of magnetic lenses customarily in use can be approximated very closely by the analytical expression $H(z)=H_0/[1+(z/a)^2]$. $H(z)$ is the field strength along the optical axis z. H_0 is the maximum field strength at the point $z=0$. 2_a is the so-called half width of the field curve, i.e., $H(\pm a)=H_0/2$. The paraxial-ray differential equation can be rigorously solved for such a field. On the basis of this solution, it is possible to calculate accurately all optical constants which are of interest in the design and performance of a microscope. Previous measurements and calculations are summarized and extended to give a complete description of the behavior of this type of electron microscope.**

I. The Field Form of Common Magnetic Lenses

It has been shown[1] that a field of rotational symmetry is known everywhere in space if the field distribution along the axis of rotation, the optical axis, is given. In the case of a magnetic lens it is therefore necessary to measure the field strength $H(z)$ only along this axis. The co-ordinate of this axis is z.

A magnetic lens, as used in practice, consists of a coil whose axis is made to coincide with the optical axis of the microscope. The coil is encased in iron with an air gap between pole pieces of various shapes. (Figs. 1 and 2). The magnetic-field strength is varied by variation of the direct current through the windings of the coil.

The measurements of the field distribution along the axis are difficult because the field is made to vary strongly over a very short distance, since the space between the pole pieces is very small. Due to saturation of the iron, it is not possible to make measurements on a large-scale model; they have to be made on the lens itself.

Such measurements were carried out in 1938 by one of the authors[2] using the ballistic method for determining the magnetic-field strength. A small test coil, of about 1 cubic millimeter volume, is placed on the optical axis, and the current produced in it by the reversal of the lens current is recorded with a ballistic galvanometer. The connection to the coil is a coaxial cable. The results of these measurements are reproduced in Figs. 2a, b, c, and d.

Slightly different methods were used by A. Kohaut[3] and by R. H. Cole.[4] Their apparatus consists essentially

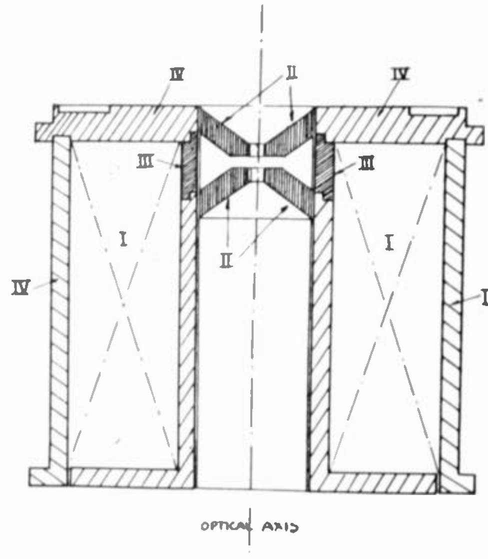

Fig. 1—Lens coil with pole pieces. I coil space, II pole pieces, III nonmagnetic spacers, IV iron enclosure of coil.

of a very small coil on the end of a long shaft, driven by a synchronous motor. The induced voltage is a direct measure of the field strength at the location of the armature coil. Such a method introduces errors caused by the variable resistance of brush contacts on the slip rings and commutators, and requires the introduction of the search coil perpendicularly to the axis of the lens, which is very often impossible to accomplish.

O. Klemperer[5] developed an oscillating search coil for similar measurements. The necessity of including gears and flexible conductors at the close vicinity of the search coil makes it relatively cumbersome to measure the

* Decimal classification: 621.375.1. Original manuscript received by the Institute, January 17, 1944; revised manuscript received, May 26, 1944.

† Division of Electron Optics, Stanford University, California.

[1] E. Brüche and O. Scherzer, "Geometrische Elektronenoptik," Julius Springer, Berlin, Germany, 1934.

[2] L. Marton, Field measurements and possible correction of aberrations for magnetic electron lenses." (Abstract). *Phys. Rev.*, vol. 55, p. 672; April, 1939.

[3] A. Kohaut, "Ein Messgerät für magnetische Felder," *Zeit. für tech. Phys.*, vol. 18, pp. 198–199; July, 1937.

[4] R. H. Cole, "A magnetic field meter," *Rev. Sci. Instr.*, vol. 9, pp. 215–217; July, 1938.

[5] O. Klemperer, "Search coil oscillator for measuring fields of magnetic electron lenses," *Jour. Sci. Instr.*, vol. 26, pp. 121–123; April, 1939.

fields produced between the pole pieces of very small diameter. Another objection to this method is the possibility of induced voltage caused by the oscillation of the connections to the search coil which might introduce quite considerable errors.

The best measurements to date have been published by Dosse[6] using the same method as Marton. His search coil is even smaller, containing about one hundred turns of wire in a volume of 0.05 cubic millimeter. Dosse claims an accuracy sufficiently high to determine also the first- and second-order derivatives of the field function $H(z)$. Dosse's measurements are reproduced in Figs. 3, 4, and 5.

The shape of the field function is determined by the form of the pole pieces for currents below the saturation limit of the iron. Beyond this limit the effect of saturation begins to influence this shape, tending to make an unsymmetrical field more symmetrical.

A symmetrical bell-shaped field can be approximated very closely by the mathematical expression

$$H(z) = \frac{H_0}{1 + (z/a)^2} \tag{1}$$

where H_0 is the maximum field strength, at $z=0$, and a is that co-ordinate where $H(z)$ drops to $H_0/2$. $2a$ therefore may be called the half width of the field curve.

In order to represent an unsymmetrical field distribution mathematically, two functions of the type given by (1) can be used in the following manner:

$$H_1(z) = \frac{H_0}{1 + (z/a_1)^2} \quad \text{for} \quad z \leq 0$$

$$H_2(z) = \frac{H_0}{1 + (z/a_2)^2} \quad \text{for} \quad z \geq 0 \tag{2}$$

where a_1 and a_2 are the two values of z where the two branches of the field curve are equal to $H_0/2$.

The close approximation of actual field distributions by these expressions justifies the application of the results of a theory developed on the basis of these functions.

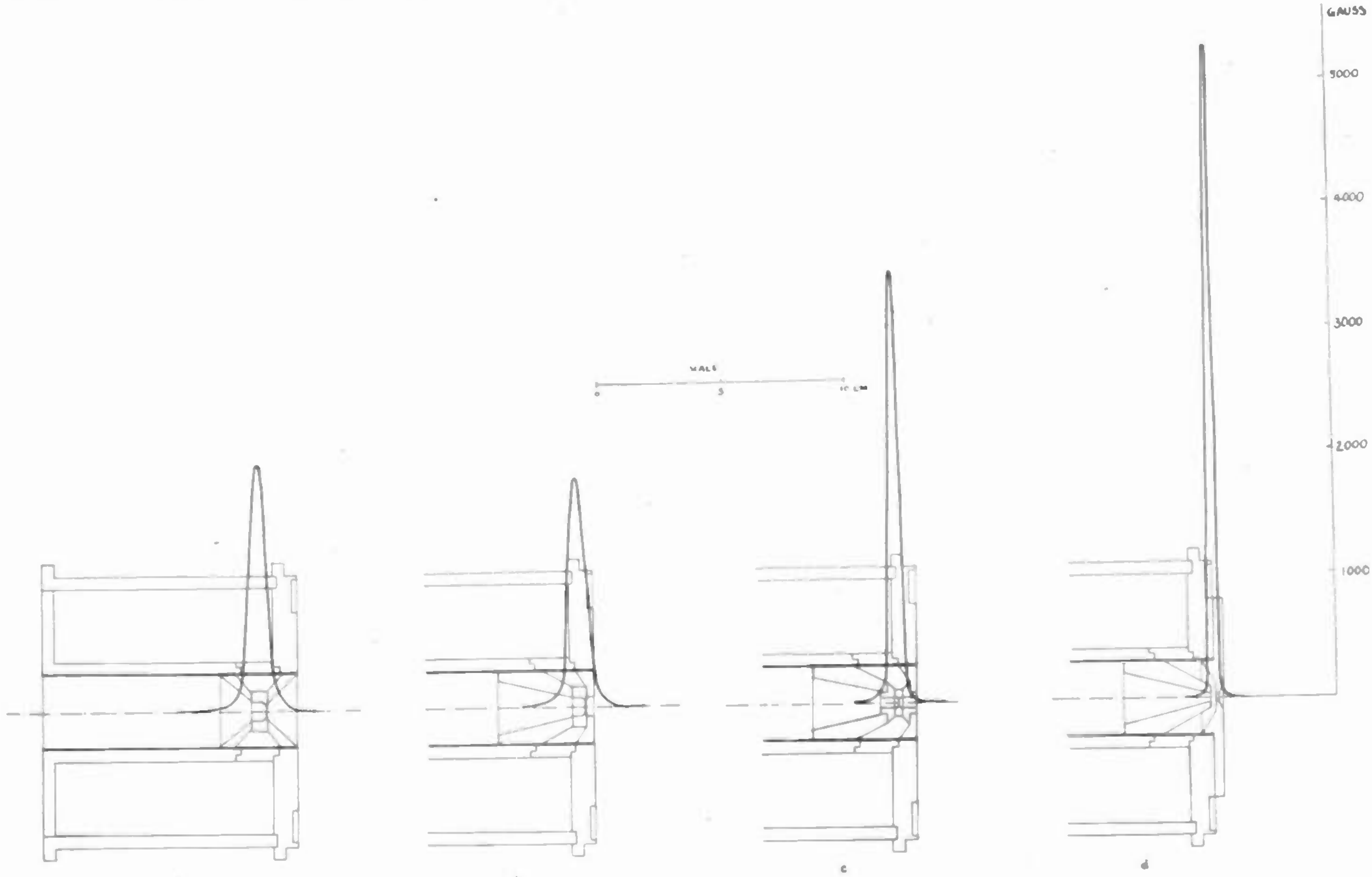

Fig. 2—Magnetic-field-strength distribution along the optical axis for various forms of the pole pieces (measured by L. Marton).

II. The Paraxial-Ray Equation

The paraxial-ray differential equation for a magnetic field of rotational symmetry is

$$d^2r(z)/dz^2 + (e/8mV)H^2(z)r(z) = 0 \tag{3}$$

where $r=r(z)$ is the equation for the paraxial-ray path of an electron in the magnetic field whose axial field distribution is given by $H(z)$. e/m is the specific charge of an electron and V is the accelerating potential.

If (2) is substituted in (3) it follows that

$$\frac{d^2r(z)}{dz^2} + \frac{eH_0^2}{8mV}\,\frac{1}{[1 + (z/a)^2]^2}\,r(z) = 0. \tag{4}$$

The general solution of this equation was given by Glaser.[7] It is

[6] J. Dosse, "Zur Ausmessung des Feldes magnetischer Elektronenlinsen," *Zeit. für Phys.*, vol. 117, pp. 437–443; 1941.

$$r(z) = a\sqrt{1+(z/a)^2}\{C_1 \sin[\sqrt{1+k^2}\,\mathrm{arc\,cotg}\,(z/a)] + C_2 \cos[\sqrt{1+k^2}\,\mathrm{arc\,cotg}\,(z/a)]\} \quad (5)$$

where C_1 and C_2 are two arbitrary constants of integration and $k^2 = eH_0^2a^2/8mV$ is a parameter characterizing

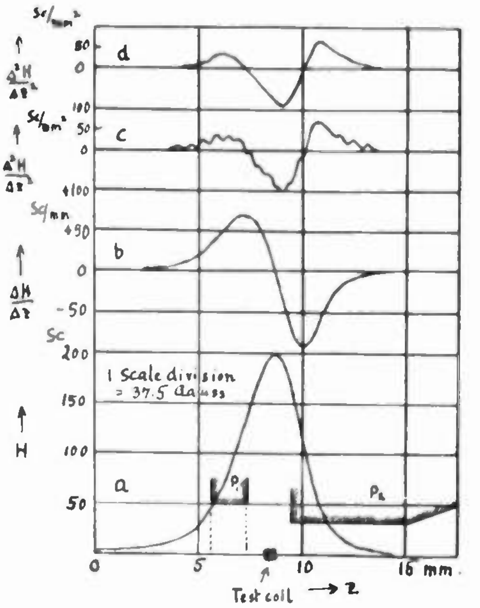

Fig. 3—Magnetic-field-strength distribution along the axis of a strong lens. a) Distribution of the magnetic field strength along the optical z axis. P_1 and P_2 are the two pole pieces and M is the test coil, drawn to scale of z axis. b) and c) give the first and second differences as calculated by the method of the least squares.

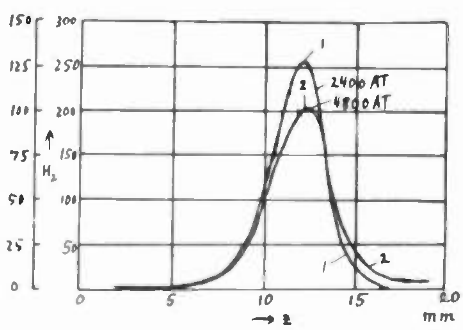

Fig. 4—Field curves of a magnetic lens for two values of ampere turns.

the lens strength. C_1 and C_2 can be determined so that the path satisfies any initial or boundary conditions.

III. Optical Constants

Knowing the general solution of (4), it is easy to determine the location of focal points, principal planes, and to give rigorous expressions for the focal lengths, magnification, and the relation between object and image distances. The focal points, for instance, can be determined in the following manner: C_1 and C_2 are chosen so that $r(z)$ is finite at $z=+\infty$ and $dr/dz=0$ for $z=+\infty$ (i.e., a parallel ray enters the lens, which begins at $z=+\infty$). The focal points are located at all values of z for which the solution $r=r(z)$ has roots.

Glaser[7] gives the following formulas:

$$\left.\begin{aligned} z_{F_0} &= a \,\mathrm{cotg}\, n(\pi/\omega) \\ z_{F_i} &= -a \,\mathrm{cotg}\, n(\pi/\omega) \end{aligned}\right\} \text{ for the location of the focal points } F_0 \text{ and } F_i \quad (6)$$

$$\left.\begin{aligned} f_0 &= \frac{a}{\sin n(\pi/\omega)} \\ f_i &= -\frac{a}{\sin n(\pi/\omega)} \end{aligned}\right\} \text{ for the focal distances } f_0 \text{ and } f_i \quad (7)$$

where

$$\omega = \sqrt{1+k^2} \quad (8)$$

Either ω^2 or k^2 can be used to characterize the lens strength.

If z_0 and z_i are the co-ordinates of object and image

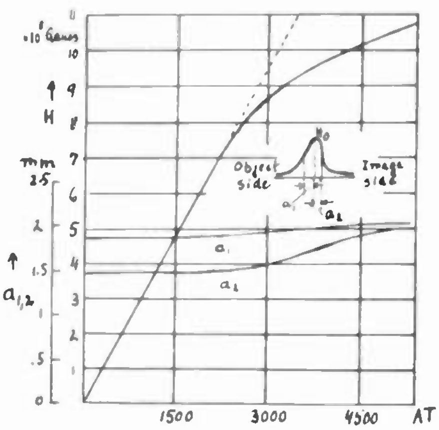

Fig. 5—Maximum of the field strength and half value of the half widths a_1 and a_2 as a function of the number of ampere turns for a lens with the pole pieces indicated in Fig. 3.

position respectively, the following relations, well known from geometrical light optics, are satisfied:

Lens equation

$$(z_0 - z_{F_0})(z_i - z_{F_i}) = f_0 f_i \quad (9)$$

Magnification formula

$$M = (-1)^{n-1} f_0/(z_0 - z_{F_0}) = (-1)^{n-1}(z_i - z_{F_i})/f_i. \quad (10)$$

As (9) and (10) are valid, it is possible to use the elementary-image construction of light optics although object and image are located within the lens.

If ω has a value such that $N<\omega<N+1$ where N, $N+1$ are successive integers, the lens characterized by ω will have N focal points. Consequently

$$0 < eH_0^2a^2/8mV < 3 \quad \text{or} \quad 1 < \omega < 2 \quad (11)$$

is the condition that single images exist, a condition usually realized in practice. In this case $n=1$ in (6) to (10).

Glaser[7] further shows that the Busch formula for the focal length, commonly used in design work,

$$\frac{1}{f} = \frac{e}{8mV}\int_{-\infty}^{+\infty} H^2(z)dz \quad (12)$$

yields values which differ from those obtained by the exact formula, equation (7), by as much as 300 per cent. Equation (12) holds for weak lenses only and gives too large values for strong lenses, such as are used in electron microscopes. Fig. 6 shows the refractive power calculated according to (12) and (7).

[7] W. Glaser, "Strenge Berechnung magnetischer Linsen der Feldform $H=H_0/1+(z/a)^2$," *Zeit. für Phys.*, vol. 117, pp. 285–315; 1941.

IV. Lens Aberrations

Knowing the field distribution $H(z)$ and the paraxial-ray path $r(z)$ it is possible to determine exactly the magnitude of all lens aberrations making use of the definite integrals contained in (29) and of (33) of a paper previously published by the authors.[8] The two main lens

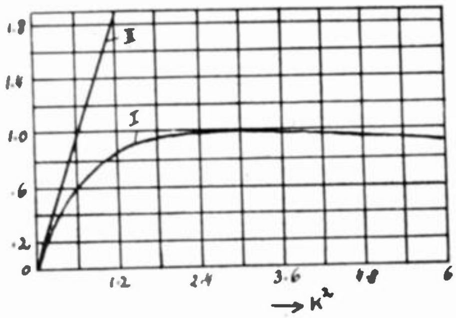

Fig. 6—The refractive power a/f of a magnetic lens of the field form $H(z) = H_0/1+(z/a)^2$. I calculated from equation (7). II calculated from equation (12) (Busch's approximate formula).

defects are chromatic and spherical aberration. The expressions for the resolving power, if only one of the defects is present at a time, are for chromatic aberration:

$$\delta_{Chr} = \alpha\frac{\Delta V}{V}\int_{z_0}^{z_i} y'^2 dz = \alpha\frac{\Delta V}{V}C_{Chr} \tag{13}$$

for spherical aberration:

$$\delta_{Sp} = \alpha^3\frac{e}{96mV}\int_{+z_0}^{z_i}\left(\frac{2e}{mV}H^4 + 5H'^2 - HH''\right)y^4 dz$$
$$= \alpha^3 C_{Sp} \tag{14}$$

where $y(z)$ is that path for which $y(z_0)=0$ and $y'(z_0)=1$ (the primes indicate derivation with respect to z) and α is the angular aperture.

The aberration constants C_{Chr} and C_{Sp}, as determined by the lens characteristics only, can be calculated as functions of the lens parameter k^2 and the object position z_0. The resulting expressions are

$$\frac{C_{Chr}}{a} = \frac{\pi k^2}{2(k^2+1)^{3/2}}\cdot\frac{1}{\sin^2[\text{arc cotg}(z_0/a)]}$$
$$= \frac{\pi k^2}{2(k^2+1)^{3/2}}\cdot\frac{a^2+z_0^2}{a^2} \tag{15}$$

for the chromatic aberration.

If the object is very near the focal point, as is practically the case for the objective lens of a microscope, in order to realize high magnification, (15) combined with (6) gives

$$\frac{C_{Chr}}{a} = \frac{\pi k^2}{2(k^2+1)^{3/2}}\cdot\frac{1}{\sin^2\pi/\sqrt{1+k^2}} \tag{16}$$

for high magnifications.

The formulas for the spherical aberration constants are

$$\frac{C_{Sp}}{a} = \frac{\pi k^2}{4(k^2+1)^{3/2}}\cdot\frac{(a^2+z_0^2)^2}{a^4} - \frac{1}{4}\,\frac{4k^2-3a^2+z_0^2}{4k^2+3a^2+z_F^2}$$
$$\cdot\frac{z_0^2 z_F + a^2(2z_0 - z_F)}{a^3} \tag{17}$$

and if $z_0 = z_F$,

$$\frac{C_{Sp}}{a} = \frac{\pi k^2}{4(k^2+1)^{3/2}}\cdot\frac{(a^2+z_0^2)^2}{a^4} - \frac{1}{4}\,\frac{4k^2-3}{4k^2+3}$$
$$\cdot\frac{(a^2+z_F^2)z_F}{a^3} \tag{18}$$

for high magnification.

V. Minimum Conditions and Resolving Power

For practical design purposes, it is better to use the formulas which were derived by Dosse.[9] For high magnifications the object is very near the focal point and the aberration constants are therefore given by (16) and (18). The quantities C_{Sp} and C_{Chr} and the focal length f are functions of a and k^2 where $k^2 = eH_0^2a^2/8mV$. If, therefore, H_0 and V are kept constant C_{Sp}, C_{Chr}, and f become functions of a alone. It is then possible to determine the optimum value of $a = a_{opt}$ for which each of these quantities reaches its minimum value. According to Dosse, the following expressions result:

Focal length:

for

$$\left.\begin{aligned} f_{min} &= (\sqrt{V}/H_0)85\,[\text{gauss millimeters/volt}] \\ \text{for}\quad a_{opt} &= (\sqrt{V}/H_0)60\,[\text{gauss millimeters/volt}] \end{aligned}\right\} \tag{19}$$

Spherical aberration:

$$\left.\begin{aligned} C_{Sp\,min} &= (\sqrt{V}/H_0)35\,[\text{gauss millimeters/volt}] \\ \text{for}\quad a_{opt} &= (\sqrt{V}/H_0)108\,[\text{gauss millimeters/volt}] \end{aligned}\right\} \tag{20}$$

Chromatic aberration:

$$\left.\begin{aligned} C_{Chr} &= (\sqrt{V}/H_0)59\,[\text{gauss millimeters/volt}] \\ \text{for}\quad a_{opt} &= (\sqrt{V}/H_0)67\,[\text{gauss millimeters/volt}] \end{aligned}\right\}. \tag{21}$$

All three conditions can be achieved approximately for a mean value of a_{opt} since the individual values a_{opt} do not differ appreciably.

If the less serious chromatic defect is neglected and only diffraction defect and spherical aberration are assumed to limit the resolving power, an expression for minimum resolution can be obtained in the following manner:

The expression for the diffraction defect is

$$\delta_0 = \lambda/\alpha_0 \tag{22}$$

where λ is the electron wavelength and α_0 is the effective aperture angle.

The spherical aberration is given by

$$\delta_{Sp} = C_{Sp}\alpha_0^3. \tag{23}$$

If quadratic superposition of both defects is assumed, i.e.,

$$\delta = \sqrt{\delta_0^2 + \delta_{Sp}^2} = \sqrt{(\lambda^2/\alpha_0^2) + \alpha_0^6 C_{Sp}^2}, \tag{24}$$

then a minimum ($d\delta/d\alpha_0 = 0$) can be obtained for

$$\alpha_{0\,opt} = 0.872\lambda^{1/4}C_{Sp}^{-1/4} \tag{25}$$

[8] L. Marton and R. G. E. Hutter, "The transmission type of electron microscope and its optics," Proc. I.R.E., vol. 32, pp. 3–12; January, 1944.

[9] J. Dosse, "Über optische Kenngrössen starker Elektronenlinsen," Zeit. für Phys., vol. 117, pp. 722–753; 1941.

δ_{min} is given by

$$\delta_{min} = 1.32\lambda^{3/4}C_{Sp}^{1/4}. \tag{26}$$

The wavelength of the electrons is related to their speed, as expressed in volts, by

$$\lambda = 1.23 \cdot 10^{-6} V^{-1/2} \text{ [millimeter]}. \tag{27}$$

Combining (25) and (26) with (27) and (20) gives

$$\delta_{min} = (120/\sqrt[4]{VH_0})10^{-6} \text{ [millimeter]} \tag{28}$$

for

$$\alpha_{0\ opt} = 1.2 \cdot 10^{-2} \sqrt[4]{H_0/V} \tag{29}$$

where v is in volts and H_0 is in gauss.

VI. Unsymmetrical Fields

If the two pole pieces of magnetic lenses are not identical in shape, asymmetry of the field along the axis will result. A mathematical treatment of such a field is possible by combining two bell-shaped field forms of different half widths a_1, a_2 and equal maximum field strength H_0.

A path equation is then obtained by matching two solutions for the two fields $H_1(z)$ and $H_2(z)$ at the point $z=0$ so that $r_1(0)=r_2(0)$ and $dr_1(0)/dz=dr_2(0)/dz$. $r_1(z)$ describes the path on one side of $z=0$ and $r_2(z)$ that on the other side of the lens center.

The "image equation," i.e., the equation relating object and image coordinates, is in this case given by

$$\tan \omega_2((\pi/2) - \phi_i) = (a_1/a_2)(\omega_2/\omega_1) \tan \omega_1((\pi/2) - \phi_0) \tag{30}$$

$$\left.\begin{aligned} &\text{where} && z_0 = a_1 \operatorname{cotg} \phi_0 \quad \text{for} \quad z \leqq 0 \\ &\text{and} && \omega_1 = \sqrt{k_1^2+1} = \sqrt{1 + eH_0^2a_1^2/8mv} \\ &\text{and} && z_i = a_2 \operatorname{cotg} \phi_i \quad \text{for} \quad z \geqq 0 \\ &\text{and} && \omega_2 = \sqrt{k_2^2+1} = \sqrt{1 + eH_0^2a_2^2/8mv} \end{aligned}\right\}. \tag{31}$$

Equation (30) becomes identical to (9) if $\omega_1=\omega_2=\omega$.

The magnification is given by

$$M = \frac{k_2}{k_1}\sqrt{\frac{k_1^2+1}{k_2^2+1}}\frac{\sin\phi_i}{\sin\phi_0} \cdot \frac{\sin\left[\sqrt{1+k_1^2}(\phi_i - \pi/2)\right]}{\sin\left[\sqrt{1+k_2^2}(\phi_0 - \pi/2)\right]}. \tag{32}$$

The focal points are given by

$$\left.\begin{aligned} &\tan\left[\sqrt{1+k_2^2}\left(\frac{\pi}{2} - \phi_{F_i}\right)\right] \\ &\qquad = -\frac{k_1}{k_2}\sqrt{\frac{k_2^2+1}{k_1^2+1}} \tan\sqrt{k_1^2+1}\,\frac{\pi}{2} \\ &\tan\left[\sqrt{1+k_1^2}\left(\frac{\pi}{2} - \phi_{F_0}\right)\right] \\ &\qquad = +\frac{k_2}{k_1}\sqrt{\frac{k_1^2+1}{k_2^2+1}} \tan\sqrt{k_2^2+1}\,\frac{\pi}{2} \end{aligned}\right\}. \tag{33}$$

Glaser and Dosse[7] investigated the influence of the asymmetry on the chromatic and spherical aberrations. This analysis shows that the steeper the side of the field on which the object is located, the more both lens aberrations increase. In case of a practically constant and homogeneous magnetic field on the object side, both quantities converge rapidly to limits whose values are maller than those for symmetrical lenses.

VII. Aperture Considerations

It has been shown that the highest resolving power can be achieved only if the numerical aperture has the proper value. This angle α_0 is the sum of the angles α_C and α_D where α_C is the largest angle between electron rays through the center of the object, and α_D the angle of the electron rays in the direction of the first diffraction maximum. (See Fig. 7.)

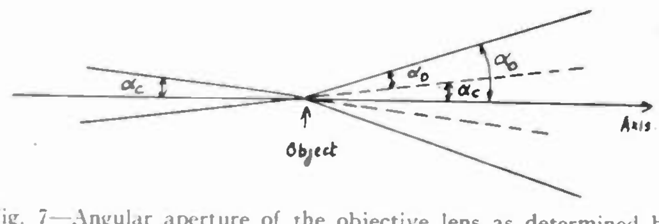

Fig. 7—Angular aperture of the objective lens as determined by aperture of the incoming beam and the diffraction effect.

The angle α_C can be adjusted to the correct value by varying the condenser-lens strength. Due to the fact that the object is well within the objective lens, the value of α_C is not determined by the focusing action of the condenser lens alone. In microscopical work it has previously been assumed that the field of the objective lens, which extends beyond the specimen into the region between it and the condenser lens, is not strong enough to exert an appreciable converging effect on the illuminating beam of electrons.[10] For high magnifications the specimen is very near the focal point, which for strong lenses is close to the lens center ($k^2=3$, $z_{F_0}=z_{F_i}=0$). This means that the electrons coming from the condenser lens have to traverse half of the objective lens before reaching the object. The converging effect on the illuminating beam thus is far from negligible.[11]

If it is assumed that the field forms of objective and condenser lens are of the same type described by (1) and, furthermore, that a change in lens current does not alter the half width of the field curve but varies only the maximum field strength H_0, α_C can be calculated in such a manner that the converging effect of the objective-lens fragment is included.

If the distance between the condenser and the objective lens is large compared with the half widths of the field curves, an almost field-free plane can be assumed to exist midway between the two lenses. This assumption makes it possible to compose the electron path through both lenses, using two separate solutions for each lens, and matching them in the field-free plane so that both their distance from the axis and their slopes are identical. (Fig. 8.)

C is the image of the cathode formed by the Wehnelt

[10] B. von Borries and R. Ruska, "Versuche, Rechnungen und Ergebnisse zur Frage des Auflösungsvermögens beim Übermikroskop," *Zeit. für tech. Phys.*, vol. 20, pp. 225–235; August, 1939.

[11] L. Marton and R. G. E. Hutter, "On apertures of transmission type electron microscopes using magnetic lenses, *Phys., Rev.* vol. 65, pp. 161–167; March, 1944.

ynder. This image is the virtual source of the electro-optical system. Electrons leave this source at various angles and pass through the condenser-lens aperture of radius R_c. These electrons will intersect the optical axis at the center of the object forming various angles α. α_C is the maximum value of all the angles α. α_C

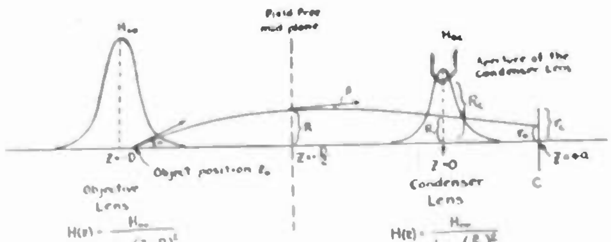

Fig. 8—Path of an electron through the condenser- and the objective-lens fields.

been calculated as a function of the focal length of the condenser lens for the special conditions: $z_0=0$ (object of center of the objective lens)

$D = 420$ mm $\quad a = 250$ mm $\quad a_c = 3$ mm $\quad a_0 = 1.5$ mm
$r_c = 0.05$ mm $\quad R_c = 0.4$ mm $\quad \omega_0 = 1.5$ mm

α_C is plotted in Fig. 9 as a function of $1/f$. For comparison the values of α_C calculated on the basis of formulas given previously by Borries and Ruska[10] are also plotted.

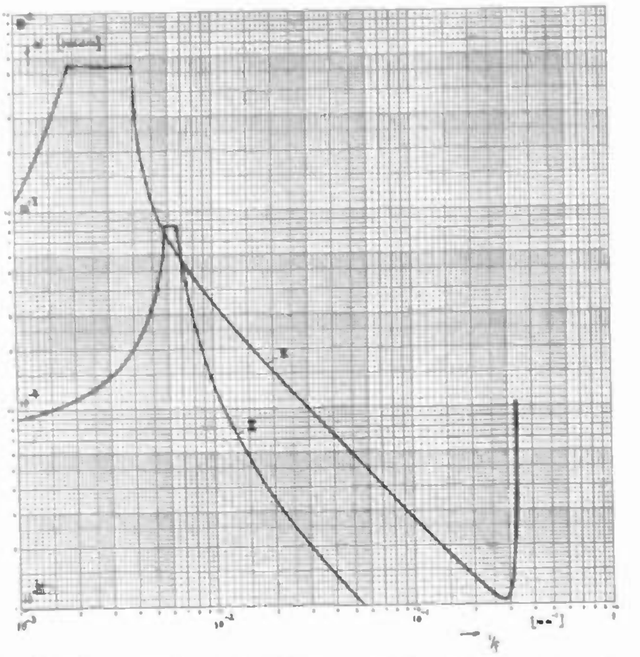

Fig. 9—Angular aperture of the incoming beam as a function of the refracting power of the condenser lens for the following conditions: $z_0=-D$ (the object is located at the center of the objective lens) $D=420$ mm, $a=250$ mm, $a_c=3$ mm, $a_0=1.5$ mm, $r_c=0.05$ mm, $R_c=0.4$ mm, $\omega_0=1.5$ (for meaning of $D, a, a_c, a_0, r_c, R_c, \omega_0$, see Fig. 8).

It can be seen that it is not possible to decrease α_C below any prescribed limit by increasing the refractive power of the condenser lens. A definite minimum for α_C exists, and it is noteworthy that this is in accord with experimental results.

The physical aperture of the objective lens has to be of such a size as to allow only those rays to pass which leave the center of the object forming an angle smaller or equal to α_0. The calculations of this aperture diameter were based on the assumptions that the electron paths are straight lines to the aperture edges, that the object is very near the focal point (high magnification) and that the aperture position is at the center of the lens. Apertures determined by this method do not have at all the intended ray-limiting effect. Optimum apertures can be obtained in the following manner (see Fig. 10). The

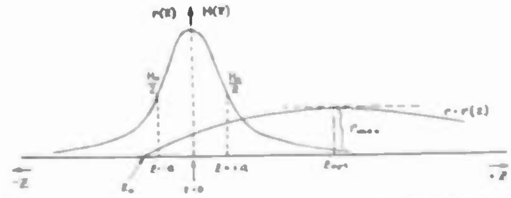

Fig. 10—Optimum conditions for the location of a ray-limiting aperture.

electron path (equation (5)) reaches its maximum at some distance z_{opt} from the center of the lens. This distance is given by

$$\text{arc cotg}\,(z_0/a) = \text{arc cotg}\,(z_{opt}/a) + \pi/\omega - (1/\omega)\,\text{arc cotg}\,(z_{opt}/a\omega) \qquad (34)$$

as a function of z_0, the object position and the lens parameters a and ω. Combining (34) with the formula for the magnification equation (10) (for $n=1$) it follows that

$$M = \frac{\sin\{\text{arc cotg}\,(z_{opt}/a) + \pi/\omega}{\sin\{(1/\omega)\,\text{arc cotg}\,(z_{opt}/a\omega) - (1/\omega)\,\text{arc cotg}\,(z_{opt}/a\omega)\} - \text{arc cotg}\,(z_{opt}/a)\}} \qquad (35)$$

Equation (35) is plotted in Fig. 11. z_{opt} can be determined from this plot for various M, a, and ω.

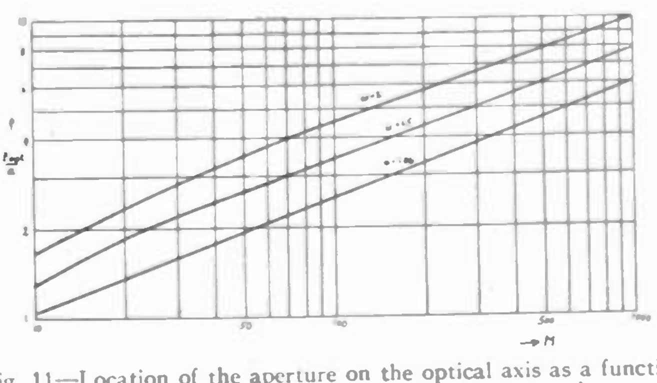

Fig. 11—Location of the aperture on the optical axis as a function of the magnification and the lens parameters a and ω.

An aperture placed at that point on the optical axis where the maximum occurs therefore can be made larger than an aperture at the center of the lens and still have the same ray-limiting effect.

The size of an aperture at z_{opt} can easily be determined; it is given by

$$\frac{r_A}{a \tan\alpha} = a\sqrt{\frac{(1+(z_{opt}/a)^2)(1+(z_0/a)^2)}{\omega^2+(z_{opt}/a)^2}} \quad D_A = 2r_A. \qquad (36)$$

It can be shown that the distance z_{opt} from the lens center increases with increasing lens strength and that the ratio D_A to D_0 (see Figs. 11 and 12) increases rapidly with the strength of the objective lens.

Fig. 12 shows the ratio of the diameters of the two apertures, one at the optimum position, and the other at the center, for the same ray-limiting effect. Fig. 13 allows the determination of the optimum aperture size, D_A, for any given α, M, ω, and a.

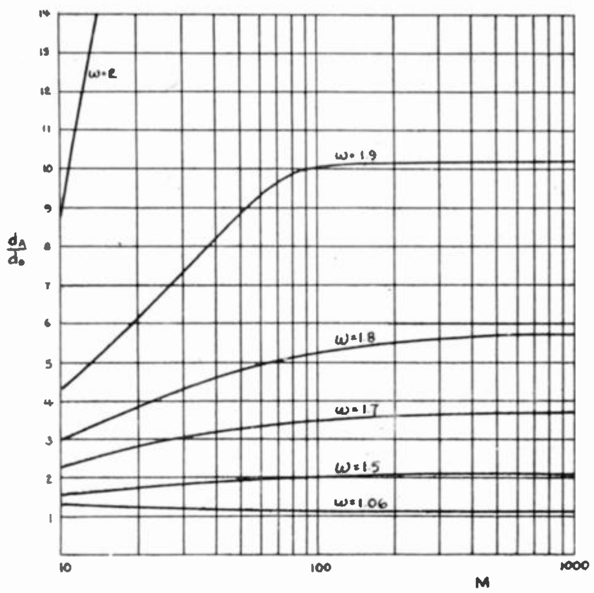

Fig. 12—Ratio of aperture sizes of two equivalent apertures, one located at optimum position (diameter d_A) and the other, one located at the center of the lens (diameter d_0).

VIII. Stability of the Power Sources

Chromatic aberrations, caused by the variation of the field strength of the lenses and the fluctuations of the accelerating potential can be reduced to such an extent that they no longer impair the resolving power. This can be achieved by the use of highly regulated power supplies. Exact values for the stability of the accelerating potential V and the lens currents I can be obtained from the formulas for the chromatic aberration (13) and (16). Taking into account both voltage and current fluctuations of the relative amounts $\Delta V/V$ and $\Delta I/I$, equations (13) and (16) combined are

$$\delta_{\mathrm{Chr}} = \alpha\left(\frac{\Delta V}{V} - 2\,\frac{\Delta H_0}{H_0}\right)\frac{a\pi k^2}{2(k^2+1)^{3/2}}\cdot\frac{1}{\sin^2 \pi/\sqrt{1+k^2}}. \quad (37)$$

Here $\Delta H_0/H_0 = \Delta I/I$ before saturation of the pole pieces occurs. $\Delta V/V - 2\Delta H_0/H_0$ can be calculated for a given lens and a required resolving power.

IX. Numerical Example

In order to convey an idea of the dimensions of some of the quantities involved, a numerical example is given.

For the objective lens, let $H_0 = 10{,}000$ gauss and $V = 70{,}000$ volts. From (20) the optimum value for half of the half width of the field curve follows: $a_{\mathrm{opt}} = 2.86$ millimeters. Equations (29) and (28) yield $\alpha_{0\mathrm{opt}} = 7.38 \times 10^{-3}$ and $\delta_{\min} = 0.737 \times 10^{-6}$ millimeter or 7.37 angstrom units. (The best values for the least resolvable distance achieved so far are about three times higher than this theoretical value.) Furthermore, $k^2 = 2.57$ and $\omega = 1.89$. The focal length becomes: $F = 2.875$ millimeter. For an assumed magnification of $M = 100$ the optimum position for the objective aperture is at $z_{\mathrm{opt}} = 12.3$ millimeters from the lens center towards the side of the image. The size of this aperture is $D_A = 19.5 \times 10^{-3}$ millimeter (compared with 2.2×10^{-3} millimeter for an aperture at the center of the lens).

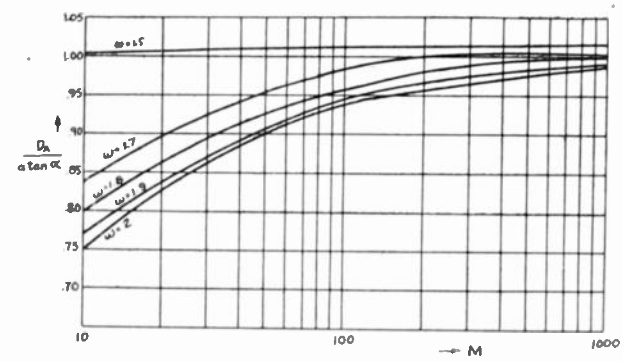

Fig. 13—Reduced aperture size as a function of the magnification for various lens strengths parameters ω.

The constancy of the high voltage has to be better than 0.0039 per cent (i.e., if $V = 70{,}000$ volts, ΔV must be smaller than 2.7 volts) and the constancy of the current of the objective-lens coil must be better than 0.00195 per cent.

The Quarter-Wave Step-Up Transformer*

H. SALINGER†, ASSOCIATE, I.R.E.

Summary—**In the arrangement of Fig. 1, the load Z_L is assumed to have a high impedance and a capacitive phase. Formulas and graphs are presented for determining the correct length and tapping point on the line. If the step-up ratio is high, a simple formula (equation (12)) can be derived for the bandwidth of the system.**

THE use of a quarter-wave transmission line as a step-up transformer in short-wave work is well known. The case which will be examined in detail in this paper is the one represented by Fig. 1. An

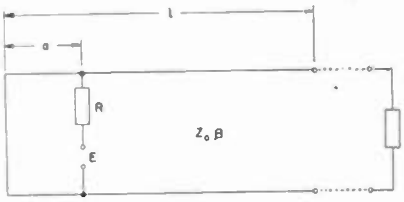

Fig. 1—A quarter-wave transformer.

electromotive force E is acting in series with a resistance R, and excites a load impedance Z_L through a line (coaxial or two-wire) of characteristic impedance Z_0 and phase constant β.

In a commonly used application of this circuit, Z_L is the input impedance of a tube grid. It will have a relatively high value but may have a capacitive component. We shall, however, regard Z_0, β, and R as real.

To design such a circuit properly, the following questions have to be answered. By how much is the length l different from a quarter wavelength? How should the line be tapped; i.e., what is the length of a in Fig. 1? How high a step-up ratio can be secured if the bandwidth is prescribed?

The fundamental equations of this circuit are, of course, quite straightforward, and have been extensively discussed;[1–4] yet the solution of the problems just mentioned is rather involved. The discussion and graphs presented herewith may, therefore, be found useful.

The inverse problem (step-down transformer) arises if Z_L is a power amplifier of which the line forms the tank circuit, with the load R connected to a tap point. This case will not be discussed here, although the same method would be applicable.

I. Basic Formulas

Let us represent Z_L as composed of a reactance in parallel to a resistance, as in Fig. 2. Let g be the con-

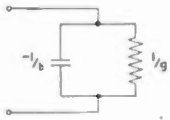

Fig. 2—Representation of the load Z_L.

ductance and b the susceptance of these two arms. g and b will depend on frequency, but in most cases they will vary only slowly, so that for the narrow range of frequencies for which the quarter-wave transformer is used they may be considered as constant.

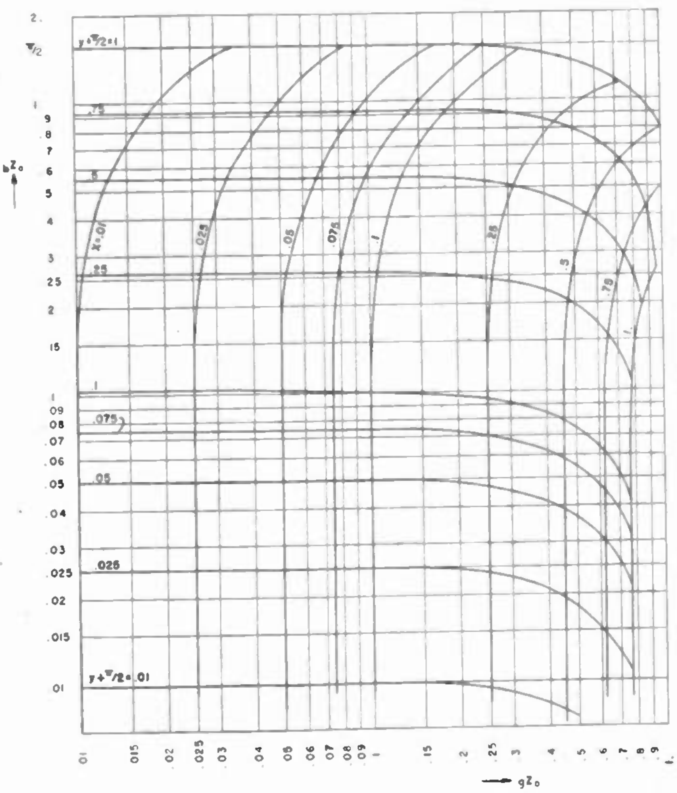

Fig. 3—Tanh $(x+jy)=[(g+jb)Z_0]^{-1}$ in logarithmic representation.

The formulas take their simplest shape if g and b are considered as the real and imaginary part of a hyperbolic tangens function.[3,5–7] More specifically, we put

$$Z_L/Z_0 = 1/(g+jb)Z_0 = \tanh z, \text{ where } z = x+jy. \quad (1)$$

As $\tanh z = \tanh (z \pm j\pi)$, y may be taken to lie between $-\pi/2$ and $\pi/2$. We shall restrict our attention to large values of Z_L, say $(g+jb) \cdot Z_0 < 1$, because there is no

* Decimal classification: R116. Original manuscript received by the Institute, February 21, 1944; revised manuscript received, April 21, 1944.

† Farnsworth Television and Radio Corporation, Fort Wayne, Indiana.

[1] P. S. Carter, "Charts for transmission line measurements and computations," *RCA Rev.*, vol. 3, pp. 355–368; January, 1939.

[2] J. G. Brainerd, G. Koehler, H. J. Reich, and L. F. Woodruff, "Ultra-high-frequency techniques," D. Van Nostrand Company, New York, N. Y., 1942, p. 362.

[3] J. C. Slater, "Microwave transmission," McGraw-Hill Book Company, New York, N. Y., 1942, pp. 38 and 39.

[4] R. I. Sarbacher and W. A. Edson, "Hyper and ultra-high frequency engineering," John Wiley and Sons, New York, N. Y., 1943, p. 352, 354.

[5] This method which dates back to Kennelly, has been exposed by F. Emde, "Sinusrelief und Tangensrelief in der Elektrotechnik," F. Vieweg, Braunschweig, Germany, 1924.

[6] G. C. Dahl, "Electric circuits, theory and application," vol. 1, McGraw-Hill Book Company, New York, N. Y., 1928, p. 182.

[7] E. A. Guillemin, "Communication networks," vol. 2, John Wiley and Sons, New York, N. Y., 1935, p. 52.

δ_{min} is given by

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Combining (25) and (26) with (27) and (20) gives

$$\delta_{min} = (120/\sqrt[4]{VH_0})10^{-6} \text{ [millimeter]} \tag{28}$$

for

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where v is in volts and H_0 is in gauss.

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If the two pole pieces of magnetic lenses are not identical in shape, asymmetry of the field along the axis will result. A mathematical treatment of such a field is possible by combining two bell-shaped field forms of different half widths a_1, a_2 and equal maximum field strength H_0.

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The "image equation," i.e., the equation relating object and image coordinates, is in this case given by

$$\tan \omega_2((\pi/2) - \phi_i) = (a_1/a_2)(\omega_2/\omega_1) \tan \omega_1((\pi/2) - \phi_0) \tag{30}$$

$$\left.\begin{array}{ll} \text{where} & z_0 = a_1 \operatorname{cotg} \phi_0 \quad \text{for} \quad z \leqq 0 \\ \text{and} & \omega_1 = \sqrt{k_1^2 + 1} = \sqrt{1 + eH_0^2 a_1^2/8mv} \\ \text{and} & z_i = a_2 \operatorname{cotg} \phi_i \quad \text{for} \quad z \geqq 0 \\ \text{and} & \omega_2 = \sqrt{k_2^2 + 1} = \sqrt{1 + eH_0^2 a_2^2/8mv} \end{array}\right\}. \tag{31}$$

Equation (30) becomes identical to (9) if $\omega_1 = \omega_2 = \omega$.

The magnification is given by

$$M = \frac{k_2}{k_1}\sqrt{\frac{k_1^2+1}{k_2^2+1}} \frac{\sin \phi_i}{\sin \phi_0} \cdot \frac{\sin\left[\sqrt{1+k_1^2}\,(\phi_i - \pi/2)\right]}{\sin\left[\sqrt{1+k_2^2}\,(\phi_0 - \pi/2)\right]}. \tag{32}$$

The focal points are given by

$$\left.\begin{array}{l} \tan\left[\sqrt{1+k_2^2}\left(\dfrac{\pi}{2} - \phi_{F_i}\right)\right] \\ \quad = -\dfrac{k_1}{k_2}\sqrt{\dfrac{k_2^2+1}{k_1^2+1}} \tan \sqrt{k_1^2+1}\,\dfrac{\pi}{2} \\ \tan\left[\sqrt{1+k_1^2}\left(\dfrac{\pi}{2} - \phi_{F_0}\right)\right] \\ \quad = +\dfrac{k_2}{k_1}\sqrt{\dfrac{k_1^2+1}{k_2^2+1}} \tan \sqrt{k_2^2+1}\,\dfrac{\pi}{2} \end{array}\right\}. \tag{33}$$

Glaser and Dosse[7] investigated the influence of the asymmetry on the chromatic and spherical aberrations. This analysis shows that the steeper the side of the field on which the object is located, the more both lens aberrations increase. In case of a practically constant and homogeneous magnetic field on the object side, both quantities converge rapidly to limits whose values are maller than those for symmetrical lenses.

VII. Aperture Considerations

It has been shown that the highest resolving power can be achieved only if the numerical aperture has the proper value. This angle α_0 is the sum of the angles α_C and α_D where α_C is the largest angle between electron rays through the center of the object, and α_D the angle of the electron rays in the direction of the first diffraction maximum. (See Fig. 7.)

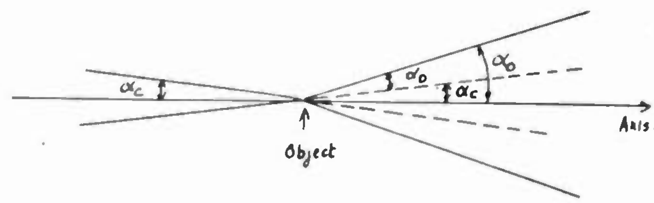

Fig. 7—Angular aperture of the objective lens as determined by aperture of the incoming beam and the diffraction effect.

The angle α_C can be adjusted to the correct value by varying the condenser-lens strength. Due to the fact that the object is well within the objective lens, the value of α_C is not determined by the focusing action of the condenser lens alone. In microscopical work it has previously been assumed that the field of the objective lens, which extends beyond the specimen into the region between it and the condenser lens, is not strong enough to exert an appreciable converging effect on the illuminating beam of electrons.[10] For high magnifications the specimen is very near the focal point, which for strong lenses is close to the lens center ($k^2=3$, $z_{F_0}=z_{F_i}=0$). This means that the electrons coming from the condenser lens have to traverse half of the objective lens before reaching the object. The converging effect on the illuminating beam thus is far from negligible.[11]

If it is assumed that the field forms of objective and condenser lens are of the same type described by (1) and, furthermore, that a change in lens current does not alter the half width of the field curve but varies only the maximum field strength H_0, α_C can be calculated in such a manner that the converging effect of the objective-lens fragment is included.

If the distance between the condenser and the objective lens is large compared with the half widths of the field curves, an almost field-free plane can be assumed to exist midway between the two lenses. This assumption makes it possible to compose the electron path through both lenses, using two separate solutions for each lens, and matching them in the field-free plane so that both their distance from the axis and their slopes are identical. (Fig. 8.)

C is the image of the cathode formed by the Wehnelt

[10] B. von Borries and R. Ruska, "Versuche, Rechnungen und Ergebnisse zur Frage des Auflösungsvermögens beim Übermikroskop," *Zeit. für tech. Phys.*, vol. 20, pp. 225–235; August, 1939.

[11] L. Marton and R. G. E. Hutter, "On apertures of transmission type electron microscopes using magnetic lenses, *Phys., Rev.* vol. 65, pp. 161–167; March, 1944.

cylinder. This image is the virtual source of the electron-optical system. Electrons leave this source at various angles and pass through the condenser-lens aperture of radius R_c. These electrons will intersect the optical axis at the center of the object forming various angles α. α_C is the maximum value of all the angles α. α_C

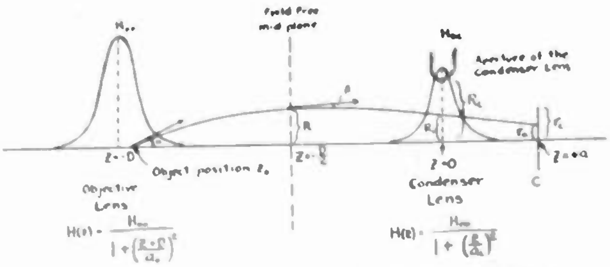

Fig. 8—Path of an electron through the condenser- and the objective-lens fields.

has been calculated as a function of the focal length of the condenser lens for the special conditions: $z_0=0$ (object of center of the objective lens)

$D = 420$ mm $a = 250$ mm $a_c = 3$ mm $a_0 = 1.5$ mm
$r_c = 0.05$ mm $R_c = 0.4$ mm $\omega_0 = 1.5$ mm

α_C is plotted in Fig. 9 as a function of $1/f$. For comparison the values of α_C calculated on the basis of formulas given previously by Borries and Ruska[10] are also plotted.

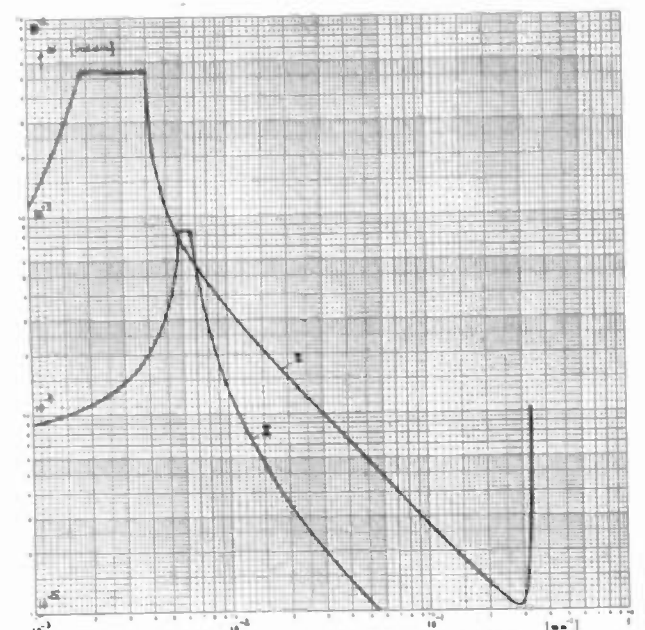

Fig. 9—Angular aperture of the incoming beam as a function of the refracting power of the condenser lens for the following conditions: $z_0=-D$ (the object is located at the center of the objective lens) $D=420$ mm, $a=250$ mm, $a_c=3$ mm, $a_0=1.5$ mm, $r_c=0.05$ mm, $R_c=0.4$ mm, $\omega_0=1.5$ (for meaning of D, a, a_c, a_0, r_c, R_c, ω_0, see Fig. 8).

It can be seen that it is not possible to decrease α_C below any prescribed limit by increasing the refractive power of the condenser lens. A definite minimum for α_C exists, and it is noteworthy that this is in accord with experimental results.

The physical aperture of the objective lens has to be of such a size as to allow only those rays to pass which leave the center of the object forming an angle smaller or equal to α_0. The calculations of this aperture diameter were based on the assumptions that the electron paths are straight lines to the aperture edges, that the object is very near the focal point (high magnification) and that the aperture position is at the center of the lens. Apertures determined by this method do not have at all the intended ray-limiting effect. Optimum apertures can be obtained in the following manner (see Fig. 10). The

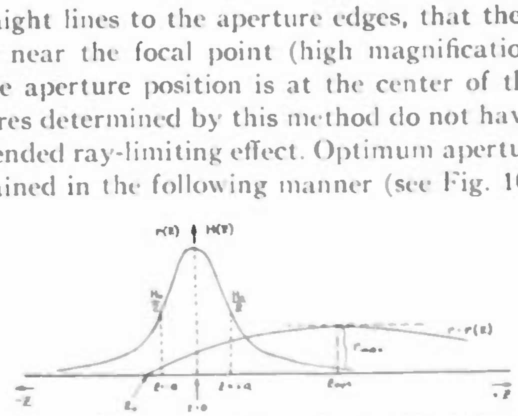

Fig. 10—Optimum conditions for the location of a ray-limiting aperture.

electron path (equation (5)) reaches its maximum at some distance z_{opt} from the center of the lens. This distance is given by

$$\text{arc cotg}\,(z_0/a) = \text{arc cotg}\,(z_{opt}/a) + \pi/\omega - (1/\omega)\,\text{arc cotg}\,(z_{opt}/a\omega) \qquad (34)$$

as a function of z_0, the object position and the lens parameters a and ω. Combining (34) with the formula for the magnification equation (10) (for $n=1$) it follows that

$$M = \frac{\sin\left\{\text{arc cotg}\,(z_{opt}/a) + \pi/\omega - (1/\omega)\,\text{arc cotg}\,(z_{opt}/a\omega)\right\}}{\sin\left\{(1/\omega)\,\text{arc cotg}\,(z_{opt}/a\omega) - \text{arc cotg}\,(z_{opt}/a)\right\}} \qquad (35)$$

Equation (35) is plotted in Fig. 11. z_{opt} can be determined from this plot for various M, a, and ω.

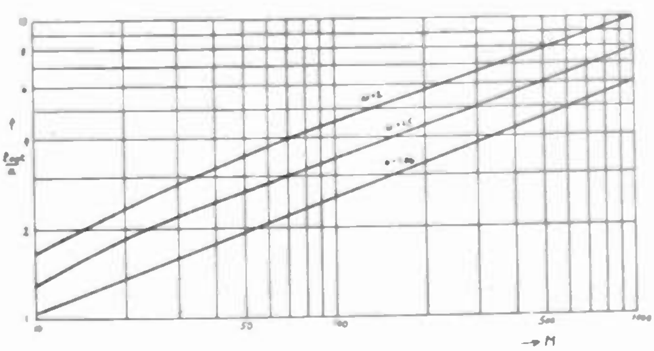

Fig. 11—Location of the aperture on the optical axis as a function of the magnification and the lens parameters a and ω.

An aperture placed at that point on the optical axis where the maximum occurs therefore can be made larger than an aperture at the center of the lens and still have the same ray-limiting effect.

The size of an aperture at z_{opt} can easily be determined; it is given by

$$\frac{r_A}{a \tan\alpha} = a\sqrt{\frac{(1+(z_{opt}/a)^2)(1+(z_0/a)^2)}{\omega^2+(z_{opt}/a)^2}} \quad D_A = 2r_A. \qquad (36)$$

It can be shown that the distance z_{opt} from the lens center increases with increasing lens strength and that the ratio D_A to D_0 (see Figs. 11 and 12) increases rapidly with the strength of the objective lens.

Fig. 12 shows the ratio of the diameters of the two apertures, one at the optimum position, and the other at the center, for the same ray-limiting effect. Fig. 13 allows the determination of the optimum aperture size, D_A, for any given α, M, ω, and a.

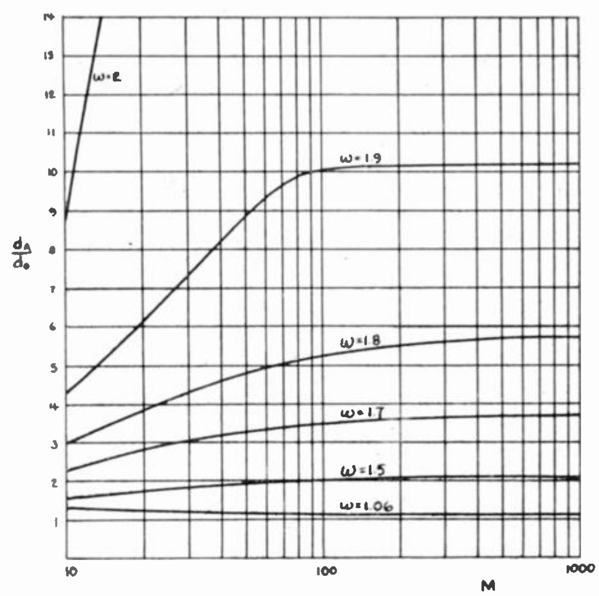

Fig. 12—Ratio of aperture sizes of two equivalent apertures, one located at optimum position (diameter d_A) and the other one located at the center of the lens (diameter d_0).

VIII. Stability of the Power Sources

Chromatic aberrations, caused by the variation of the field strength of the lenses and the fluctuations of the accelerating potential can be reduced to such an extent that they no longer impair the resolving power. This can be achieved by the use of highly regulated power supplies. Exact values for the stability of the accelerating potential V and the lens currents I can be obtained from the formulas for the chromatic aberration (13) and (16). Taking into account both voltage and current fluctuations of the relative amounts $\Delta V/V$ and $\Delta I/I$, equations (13) and (16) combined are

$$\delta_{\mathrm{Chr}} = \alpha\left(\frac{\Delta V}{V} - 2\frac{\Delta H_0}{H_0}\right)\frac{a\pi k^2}{2(k^2+1)^{3/2}}\cdot\frac{1}{\sin^2 \pi/\sqrt{1+k^2}}. \quad (37)$$

Here $\Delta H_0/H_0 = \Delta I/I$ before saturation of the pole pieces occurs. $\Delta V/V - 2\Delta H_0/H_0$ can be calculated for a given lens and a required resolving power.

IX. Numerical Example

In order to convey an idea of the dimensions of some of the quantities involved, a numerical example is given.

For the objective lens, let $H_0 = 10{,}000$ gauss and $V = 70{,}000$ volts. From (20) the optimum value for half of the half width of the field curve follows: $a_{\mathrm{opt}} = 2.86$ millimeters. Equations (29) and (28) yield $\alpha_{0\mathrm{opt}} = 7.38 \times 10^{-3}$ and $\delta_{\min} = 0.737 \times 10^{-6}$ millimeter or 7.37 angstrom units. (The best values for the least resolvable distance achieved so far are about three times higher than this theoretical value.) Furthermore, $k^2 = 2.57$ and $\omega = 1.89$. The focal length becomes: $F = 2.875$ millimeter. For an assumed magnification of $M = 100$ the optimum position for the objective aperture is at $z_{\mathrm{opt}} = 12.3$ millimeters from the lens center towards the side of the image. The size of this aperture is $D_A = 19.5 \times 10^{-3}$ millimeter (compared with 2.2×10^{-3} millimeter for an aperture at the center of the lens).

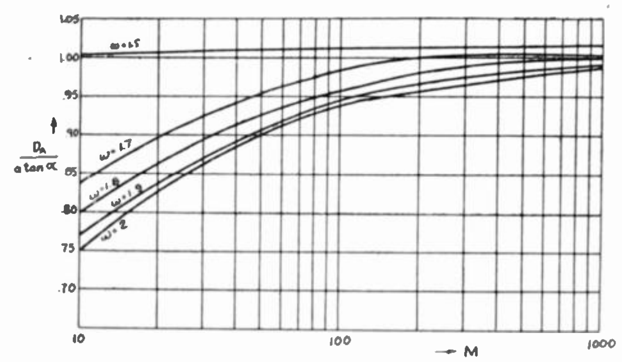

Fig. 13—Reduced aperture size as a function of the magnification for various lens strengths parameters ω.

The constancy of the high voltage has to be better than 0.0039 per cent (i.e., if $V = 70{,}000$ volts, ΔV must be smaller than 2.7 volts) and the constancy of the current of the objective-lens coil must be better than 0.00195 per cent.

The Quarter-Wave Step-Up Transformer*

H. SALINGER†, ASSOCIATE, I.R.E.

Summary—**In the arrangement of Fig. 1, the load Z_L is assumed to have a high impedance and a capacitive phase. Formulas and graphs are presented for determining the correct length and tapping point on the line. If the step-up ratio is high, a simple formula (equation (12)) can be derived for the bandwidth of the system.**

THE use of a quarter-wave transmission line as a step-up transformer in short-wave work is well known. The case which will be examined in detail in this paper is the one represented by Fig. 1. An

Fig. 1—A quarter-wave transformer.

electromotive force E is acting in series with a resistance R, and excites a load impedance Z_L through a line (coaxial or two-wire) of characteristic impedance Z_0 and phase constant β.

In a commonly used application of this circuit, Z_L is the input impedance of a tube grid. It will have a relatively high value but may have a capacitive component. We shall, however, regard Z_0, β, and R as real.

To design such a circuit properly, the following questions have to be answered. By how much is the length l different from a quarter wavelength? How should the line be tapped; i.e., what is the length of a in Fig. 1? How high a step-up ratio can be secured if the bandwidth is prescribed?

The fundamental equations of this circuit are, of course, quite straightforward, and have been extensively discussed;[1–4] yet the solution of the problems just mentioned is rather involved. The discussion and graphs presented herewith may, therefore, be found useful.

The inverse problem (step-down transformer) arises if Z_L is a power amplifier of which the line forms the tanh circuit, with the load R connected to a tap point. This case will not be discussed here, although the same method would be applicable.

I. Basic Formulas

Let us represent Z_L as composed of a reactance in parallel to a resistance, as in Fig. 2. Let g be the con-

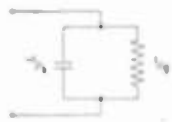

Fig. 2—Representation of the load Z_L.

ductance and b the susceptance of these two arms. g and b will depend on frequency, but in most cases they will vary only slowly, so that for the narrow range of frequencies for which the quarter-wave transformer is used they may be considered as constant.

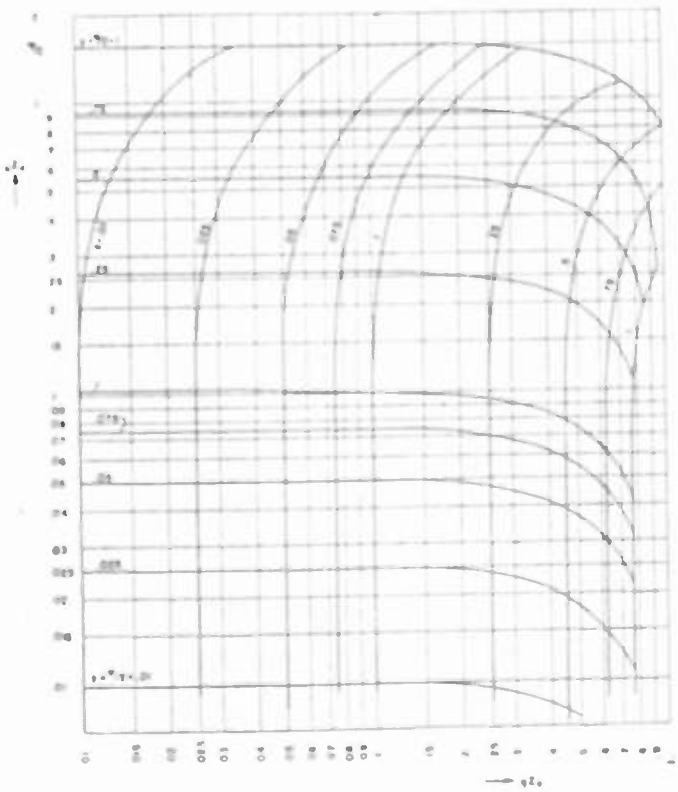

Fig. 3—Tanh $(x+jy)=[(g+jb)Z_0]^{-1}$ in logarithmic representation.

The formulas take their simplest shape if g and b are considered as the real and imaginary part of a hyperbolic tangens function.[5,6–7] More specifically, we put

$$Z_L/Z_0 = 1/(g+jb)Z_0 = \tanh z, \text{ where } z = x+jy. \qquad (1)$$

As $\tanh z = \tanh(z \pm j\pi)$, y may be taken to lie between $-\pi/2$ and $\pi/2$. We shall restrict our attention to large values of Z_L, say $(g+jb)\cdot Z_0<1$, because there is no

* Decimal classification: R116. Original manuscript received by the Institute, February 21, 1944; revised manuscript received, April 21, 1944.

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[1] P. S. Carter, "Charts for transmission line measurements and computations," *RCA Rev.*, vol. 3, pp. 355–368; January, 1939.

[2] J. G. Brainerd, G. Koehler, H. J. Reich, and L. F. Woodruff, "Ultra-high-frequency techniques," D. Van Nostrand Company, New York, N. Y., 1942, p. 362.

[3] J. C. Slater, "Microwave transmission," McGraw-Hill Book Company, New York, N. Y., 1942, pp. 38 and 39.

[4] R. I. Sarbacher and W. A. Edson, "Hyper and ultra-high frequency engineering," John Wiley and Sons, New York, N. Y., 1943, p. 352, 354.

[5] This method which dates back to Kennelly, has been exposed by F. Emde, "Sinusrelief und Tangensrelief in der Elektrotechnik," F. Vieweg, Braunschweig, Germany, 1924.

[6] G. C. Dahl, "Electric circuits, theory and application," vol. 1, McGraw-Hill Book Company, New York, N. Y., 1928, p. 182.

[7] E. A. Guillemin, "Communication networks," vol. 2, John Wiley and Sons, New York, N. Y., 1935, p. 52.

point in using a step-up transformer if Z_L is small. If the load is capacitive, b is positive and y then turns out to lie in the range $-\pi/2 < y < 0$. The relation between x, y and g, b is then given by Fig. 3. If $|g+jb| \cdot Z_0 \ll 1$, the series expansion for the function $\tanh^{-1} z$ may be used, giving

$$x = gZ_0 + [(g^3 - 3gb^2)/3]Z_0^3 + \cdots$$
$$y = -(\pi/2) + bZ_0 + [(3g^2b - b^3)/3]Z_0^3 + \cdots. \quad (2)$$

If gZ_0 and bZ_0 are both smaller than 0.1, the cubical terms in (2) may be neglected, as is evident from Fig. 3.

With the aid of (1), the impedance as seen from the points 1, 1′ in Fig. 1 toward the right can then be expressed as $Z_0 \tanh (z+j\beta(l-a))$, while to the left of these points we have $Z_0 \tanh j\beta a$. The entire load connected at the points 1, 1′ will be called $W = Z_0 w$; it is then

$$w = \frac{W}{Z_0} = \frac{\tanh j\beta a \cdot \tanh (z + j\beta(l-a))}{\tanh j\beta a + \tanh (z + j\beta(l-a))}. \quad (3)$$

By applying well-known transformation formulas for complex hyperbolic functions, (3) can be expressed in the following form:

$$w = \coth (x + j(\beta l + y)) \sin^2 \beta a + j \sin \beta a \cos \beta a. \quad (3a)$$

Here the coth factor can be resolved into its real and imaginary part:

$$\coth (x + j(\beta l + y)) = \frac{\sinh 2x - j \sin 2(\beta l + y)}{\cosh 2x - \cos 2(\beta l + y)}. \quad (4)$$

II. Conditions for Optimum Power Transfer

W as given by (3) is the apparent impedance connected to points 1, 1′. As the line is assumed to be nondissipative, the power delivered to W will reappear in Z_L. Thus we get maximum power if $W = R$, or $w = r$, where $r = R/Z_0$. From (3a) and (4) this resolves itself into two conditions

$$\frac{R}{Z_0} = r = \frac{\sin^2 \beta a \sinh 2x}{\cosh 2x - \cos 2(\beta l + y)} \quad (5)$$

$$\tan \beta a = \frac{\cosh 2x - \cos 2(\beta l + y)}{\sin 2(\beta l + y)}. \quad (6)$$

We consider r, x, y as given; then (5) and (6) determine βl and βa, i.e., the tuning length of the line and the tapping ratio.

To solve for the unknowns, we write

$$\sin^2 \beta a = \tan^2 \beta a / (1 + \tan^2 \beta a)$$

in (5) and then eliminate $\tan \beta a$ by (6). We then obtain

$$\frac{\cos 2(\beta l + y)}{\cosh 2x} = 1 - \frac{r \tanh^2 2x}{2r - \tanh 2x}. \quad (7)$$

We note that βl depends on x, y, and r, but $\beta l + y$ depends only on two variables. Accordingly, $\beta l + y$ is plotted in Fig. 4. It would, of course, be possible to express βl directly in terms of the given quantities g, b, and r, but the graphs would become more complicated and difficult to read; that is why we have preferred to plot $\beta l + y$ in terms of x and r, where x and y have to be determined from Fig. 3 or from (2).

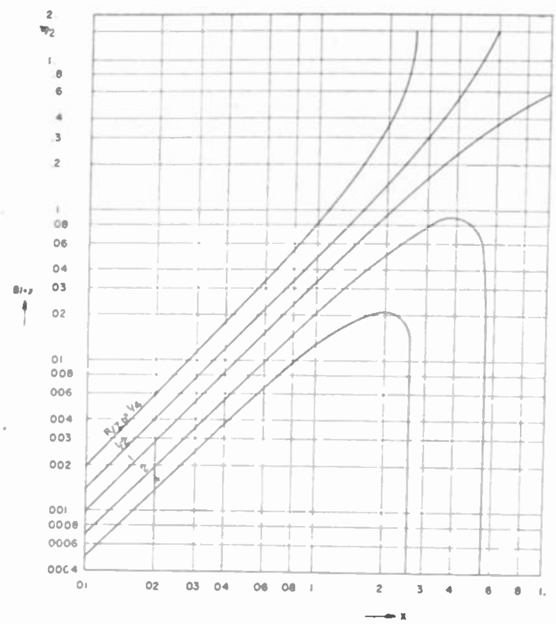

Fig. 4—Tuning angle βl in function of x, y, and R.

Equation (7) may fail to give a solution if the cosine turns out to be >1. This means that for given x and R it may not be possible to adjust the line so that the maximum power is obtained from the source. A necessary, but not sufficient condition that has to be fulfilled is $2r > \tanh 2x$, as can be seen immediately from (7).

In Fig. 4, the curves are drawn as far as there exists a solution, except for $r = 1$, where there is no limitation.

If no solution exists, it means that for the given values of x and r the line cannot be adjusted to present a resistance R as seen from terminals 1, 1′.

For small x (i.e., high transformation ratios), $\beta l + y$ is very small, and it is then better to use a series expansion into ascending powers of x.

$$\beta l + y = \sqrt{(1/r)}\, x^{3/2}[1 + 1/2(1/r - r)x + (3/8(1/r - r)^2 - r^2/2)x^2 + (5/16(1/r - r)^3 - 7r/12 + r^2/4)x^3 + \cdots]. \quad (8)$$

For $x \leq 0.1$, this formula has been used in computing Fig. 4.

To explain the meaning of the curves in Fig. 4, assume that there is no reactive component to the terminal load, i.e., $b = 0$. Fig. 3 then gives $y = -\pi/2$. Let $x = 0.1$, $r = 1$; then we read $\beta l + y = 0.0315$ from Fig. 4. Thus $\beta l = \pi/2 + 0.0315$, or the line has to be very slightly longer than a quarter wavelength. But if there is a small capacitive component, say $bZ_0 = 0.05$, then we would, for the same values of x and r as above, have $y = -\pi/2 + 0.05$, $\beta l = \pi/2 + 0.0315 - 0.05 = \pi/2 - 0.0185$, showing that now the line has to be slightly shorter than $\lambda/4$.

Other examples will be given immediately.

If $\beta l + y$ is known, (6) gives βa. The result is shown in Fig. 5. For small values of x, series expansions had to be used. We give the result in two forms:

$$\tan \beta a = \sqrt{rx}\,[1 + Ax + (3A^2/2 - 2/3)x^2 + A\,(5A^2/2 - 2)x^3 + \cdots] \quad (9a)$$

where $2A = r + 1/r$;

$$\text{or} \quad \beta a = \sqrt{rx}\,[1 + (1/2r + r/6)x + (3/8r^2 - 5/12 + 3r^2/40)x^2 + (5/16r^3 - 11/16r - 7r/48 + 5r^3/112)x^3 + \cdots]. \quad (9b)$$

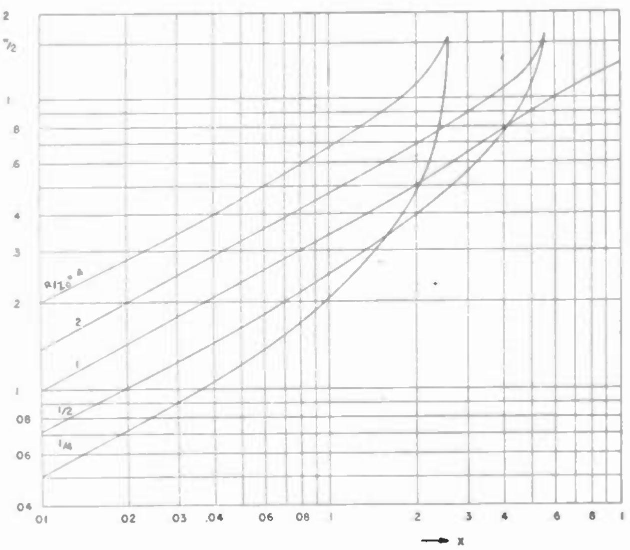

Fig. 5—Tapping angle βa in function of x and R.

Examples

1. Let a line of $Z_0 = 70$ ohms be terminated at 300 megacycles by 300 ohms, shunted by 2 micromicrofarads. We then find

$$g = 1/300, \qquad b = \omega C = 3.77 \times 10^{-3}$$
$$gZ_0 = 0.233, \qquad bZ_0 = 0.264.$$

Fig. 3 then gives

$$x = 0.22, \text{ and } y = -(\pi/2) + 0.272.$$

Let the source resistance be $R = 50$ ohms, or $r = 0.715$. Fig. 4 then gives $\beta l + y = 0.147$, $\beta l = \pi/2 - 0.125$ $(= 0.230\lambda)$, while Fig. 5 shows that $\beta a = 0.49$ approximately. Thus the line should be tapped at $\beta a/\beta l = 0.339$ of its length.

2. If we again let $R = 50$, $Z_0 = 70$ ohms, $f = 300$ megacycles, but with 1500 ohms at the far end, shunted by 0.4 micromicrofarad, we shall have $gZ_0 = 0.047$, $bZ_0 = 0.053$. A glance at Fig. 3 shows that we may now take $gZ_0 = x$, $bZ_0 = \pi/2 + y$. From Fig. 4 we see that $\beta l + y = 0.012$, or $\beta l = \pi/2 - 0.041$ $(= 0.243\lambda)$, and Fig. 5 gives $\beta a = 0.19$; thus $a/l = 0.124$. In this case, the initial terms of (8) and (9a) might be simplified to

$$\beta l = -\pi/2 - bZ_0 + \sqrt{(gZ_0)^3/r}, \quad \beta a = \sqrt{gZ_0 r} \quad (10)$$

and would be accurate enough.

III. Bandwidth Requirements

If we adjust the line for maximum power output and then change the frequency f by δf, the power P will decrease. We may write

$$P = P_0 + 1/2(\delta f)^2 \partial^2 P/\partial f^2 + \cdots \quad (11)$$

and define the relative bandwidth Δ as the relative frequency difference between the half-power points. This calculation has been carried out in the Appendix and leads to the formulas (21), where the abbreviations $u = \beta a$, $v_1 = \beta l + y$ have been used.

It appears that Δ depends on r, x, and y. However, if the formulas are worked out numerically, rather large values of Δ are found unless x is small. This was to be expected, as for $gZ_0 = 1$, $bZ_0 = 0$ the line loses its resonance properties. In such cases, (11), which contains only two terms of a Taylor expansion, may give a poor approximation; at the same time, the bandwidth is hardly of interest if it is larger than 30 per cent. We are, therefore, concerned with small values of x, for which formulas are given in (22) in the Appendix.

Now Fig. 3 shows that y will always lie between $-\pi/2$ and -0.5. The terms in β and γ in (21) and (22) may then be neglected, and the bandwidth formula simplifies to

$$\Delta = 2\sqrt{2}\,(x/|y|) = \frac{2\sqrt{2}\,gZ_0}{(\pi/2) - bZ_0} \quad (12)$$

as in these cases x and y can be reduced to the initial terms of (2). Even the term bZ_0 in the denominator may be omitted in some cases.

Thus Δ, in this approximation, is independent of R and only slightly dependent on y (or b). The formula is valid for $x \leqq 0.1$; in order to give an idea of the degree of approximation, table I gives Δ for a few values of x inside and outside this range as computed from (12) and (21).

TABLE I

x	y	Δ from (12)	Δ from (21)		
			$r=4$	$r=1$	$r=1/4$
0.05	−0.5 −1 −1.5	0.285 0.142 0.095	0.276 0.141 0.095	0.267 0.139 0.094	0.257 0.136 0.0925
0.1	−0.5 −1 −1.5	0.566 0.283 0.189	0.532 0.277 0.184	0.513 0.272 0.185	0.473 0.256 0.176
0.2	−0.5 −1 −1.5	1.13 0.57 0.38	1.10 0.58 0.39	0.82 0.50 0.35	0.86 0.49 0.35

In the two examples given at the end of Section II, (12) would give $\Delta = 47$ per cent and $\Delta = 8.65$ per cent. The latter of these values means, at 300 megacycles, that the band extends from 287 to 313 megacycles.

If the bandwidth is prescribed, formula (12) gives an easy means to compute the maximum x, and therefore the highest step-up ratio that can be secured.

Appendix

Derivation of the Bandwidth Formula

If we abbreviate $R/Z_0 = r$, $W/Z_0 = w = s + jt$, we obtain from (3), (3a), (4)

$$s = \frac{\sinh 2x \sin^2 \beta a}{\cosh 2x - \cos 2(\beta l + y)},$$

$$t = -\frac{\sin 2(\beta l + y) \sin^2 \beta a}{\cosh 2x - \cos 2(\beta l + y)} + \sin \beta a \cos \beta a \quad (13)$$

and the power delivered to the load will be given by

$$P = \frac{E^2}{Z_0} \cdot \frac{s}{(s+r)^2 + t^2}. \tag{14}$$

If the line is adjusted for maximum power, that is, if βl and βa have the values given in Figs. 4 and 5, we shall have $s=r$, $t=0$, and

$$P_0 = E^2/4Z_0 r = E^2/4R.$$

For a slight change in frequency, s and t will depart from these values by δs, and δt and we may expand P in the neighborhood of its maximum as follows:

$$P = P_0 + 1/2\{\delta s(\partial/\partial s) + \delta t(\partial/\partial t)\}^2 P + \cdots \tag{15}$$

where the expression in brackets {} is symbolical, $(\partial/\partial s)^2$ being replaced by $\partial^2/\partial s^2$, etc,[8] and the optimum values of s and t have to be substituted after performing the differentiations.

Now

$$\frac{\partial P}{\partial s} = \frac{E^2}{Z_0} \frac{r^2 - s^2 + t^2}{[(s+r)^2 + t^2]^2}, \quad \frac{\partial P}{\partial t} = \frac{E^2}{Z_0} \frac{(-2ts)}{[(s+r)^2 + t^2]^2}.$$

As expected, both these expressions vanish at $s=r$, $t=0$. As we have to insert these values after the second differentiation, we need only to differentiate the factors $r^2 - s^2$ and t, as the other terms in $\partial^2 P/\partial s^2$, etc., will ultimately vanish anyway. That is

$$\left(\frac{\partial^2 P}{\partial s^2}\right)_{\substack{s=r\\t=0}} = \frac{E^2}{Z_0} \cdot \frac{(-2s)}{[(s+r)^2 + t^2]^2} = -\frac{1}{8r^3}\frac{E^2}{Z_0},$$

$$\left(\frac{\partial^2 P}{\partial t^2}\right)_{\substack{s=r\\t=0}} = -\frac{1}{8r^3}\frac{E^2}{Z_0}, \qquad \left(\frac{\partial^2 P}{\partial s \partial t}\right)_{\substack{s=r\\t=0}} = 0.$$

Thus (15) becomes

$$P = P_0 - \frac{1}{16r^3}\frac{E^2}{Z_0}[(\delta s)^2 + (\delta t)^2]$$

$$= P_0 - \frac{1}{16r^3}\frac{E^2}{Z_0}|\delta w|^2, \quad \text{since} \quad w = s + jt. \tag{15a}$$

We define the relative bandwidth as the relative frequency difference between the half-power points. At these points

$$|\delta w|^2 = 8r^3 P_0(Z_0/E^2) = 2r^2. \tag{16}$$

The frequency f is proportional to β and enters w only in the combinations βa and βl; let us write $\beta a = u$, $\beta l = v$ for shortness.

Then

$$\partial f/f = \delta\beta/\beta = \delta u/u = \delta v/v, \tag{17}$$

as we want to find the influence of a change in frequency while a and l remain constant. Consequently

$$\delta w = \delta u(\partial w/\partial u) + \delta v(\partial w/\partial v)$$
$$= \delta f/f(u(\partial w/\partial u) + v(\partial w/\partial v)). \tag{18}$$

In order to perform these differentiations, it is best to take the expression (3a) for w, writing it now

$$w - j\sin u \cos u = \coth[x + j(v+y)]\sin^2 u.$$

We then find

$$\partial w/\partial u = 2w \cot u - j$$
$$\partial w/\partial v = j[\sin^2 u - (1/\sin^2 u)(w - j\sin u\cos u)^2], \tag{19}$$

and now we have to substitute the optimum values for u and v, which implies $w=r$.

If (18) and (19) are introduced into (16), there results

$$(\delta f/f)^2\{[2r(u-v)\cot u]^2 + [v(1-(r^2/\sin^2 u)) - u]^2\} = 2r^2. \tag{20}$$

The relative bandwidth Δ, as defined above, is then $2\delta f/f$, and (20) gives it as a function of u, v, and r. As Figs. 4 and 5 give u and $v+y$ as functions of x and r, we better introduce $v+y=v_1$ and arrive at the final formula:

$$\Delta = (\alpha y^2 - \beta y + \gamma)^{-1/2} \quad \text{with}$$
$$\alpha = 1/2[\cot^2 u + 1/4(1/r - r/\sin^2 u)^2]$$
$$\beta = (u - v_1)\cot^2 u + 1/4((v_1 - u)/r - r/\sin^2 u)(1/r - r/\sin^2 u), \tag{21}$$
$$\gamma = 1/2[(u-v_1)^2\cot^2 u + 1/4((v_1-u)/r - rv_1/\sin^2 u)^2].$$

These formulas have, for small values of u and v, (that is, of x) to be supplemented by expressions which can be worked out from (8), (9a), and (9b):

$$8x^2\alpha = 1 - 4x^2 + \cdots,$$
$$2\sqrt{rx}\beta = [1 - ((11r/6) + 1/2r)x + \cdots]$$
$$2\gamma = 1 - (1/r + 2r/3)x + \cdots. \tag{22}$$

These formulas are discussed in Section III of this paper.

[8] See I. S. and E. S. Sokolnikoff, "Higher Mathematics for Engineers and Physicists," McGraw-Hill Book Company, New York, N. Y., 1941, p. 156.

Discussion on

"The Principle of Reciprocity in Antenna Theory"*

M. S. Neiman

Dwight O. North:[1] I should like to direct the attention of readers of Dr. Neiman's interesting article to a paper[2] read before the Institute in January, 1942. In this paper, and starting with the reciprocity principle, the open-circuit voltage e appearing at the terminals of a receiving antenna was formulated in practical units as follows:

$$e^2 = \frac{\lambda^2}{2\pi}\frac{R_a}{120\pi}D^2(\Omega,\phi)E^2(\Omega,\phi)$$

where λ is the wavelength, R_a the radiation resistance in ohms as seen at the terminals in question, E the electric-field strength of a signal Poynting vector $S(\Omega, \phi)$

* Proc. I.R.E., vol. 31, pp. 666–671; December, 1943.

[1] RCA Laboratories, Princeton, New Jersey.

[2] D. O. North, "The absolute sensitivity of radio receivers," *RCA Rev.*, vol. 6, pp. 332–343; January, 1942: subsequently reviewed in "Some aspects of radio reception at ultra-high frequency, Part I," by E. W. Herold, Proc. I.R.E., vol. 31, pp. 423–438; August, 1943.

plane-polarized in azimuth ϕ and progressing in direction Ω (Ω symbolizing two numbers such as direction cosines, necessary to define a direction), and $D^2(\Omega, \phi)$ is the power-directivity function for the antenna, describing its relative susceptibility to Poynting vectors of arbitrary direction and polarization azimuth, and defined so that when averaged over all Ω and ϕ, $\overline{D^2(\Omega, \phi)} \equiv 1$.

Except for a difference in the definition of directivity (an unstandardized term which is discussed below), and the trivial difference that Dr. Neiman has formulated short-circuit current rather than open-circuit voltage, equation (3) which he develops, and upon which he bases his article, is identical with that quoted above.

The objects of the paper referred to were twofold. First, I proposed a term "noise factor" as a useful comparative measure of the internal noisiness of receivers. Noise factor N was defined as the ratio of actual noise power presented to the detector of a receiver fed from a dummy antenna at room temperature T_0 to the noise power that would be presented were the receiver ideal in the sense that it possessed no source of noise other than thermal agitation in the dummy antenna. Second, I proposed a term "absolute sensitivity" which I tentatively defined as that signal field strength E which produces at the detector of the receiver a signal power equal to the total noise power at that point, including that due to local noise fields at the antenna,[3] and showed that, assuming $T_0 = 300$ degrees Kelvin, the absolute sensitivity E, expressed in microvolts per meter, is given by

$$\overline{E^2} = \frac{39\Delta f}{\lambda^2 D^2(\Omega, \phi)}\left[N + \frac{T_a}{T_0} - 1\right]$$

where Δf is the noise bandwidth in megacycles, λ the wavelength in meters, and T_a is a fictitious temperature of local space, a convenient though succinct measure of local noise field strength.

Dr. Neiman's conclusions regarding the relative importance to receiving systems of high directivity, high antenna efficiency, and a high value for its "coefficient of exploitation," in the instances of both high and low local noise field strength, are in agreement with deductions which were drawn from the above formulation of absolute sensitivity, with one important exception. The maximum of his coefficient of exploitation corresponds to maximum power transfer from antenna to receiver proper. However, it has been emphasized that this does *not* necessarily coincide with the condition of minimum noise factor, hence minimum absolute sensitivity. A comprehensive discussion of the point will be found in the reference cited.[4]

The desire to consider quantitatively the directional properties of receiving antennas leads soon to the realization that there is no standard nomenclature, as I noted above. Perhaps the adoption of a name and definition of that function which describes directional properties has been retarded by the justifiable view that no other definition is so good as one which is applicable to both transmission and reception. At least a partial search of the literature reveals the following:

"The directional pattern of a transmitting antenna is the polar characteristic which indicates the intensity of the radiation field at a fixed distance in different directions in space. Similarly, the directional pattern of a receiving antenna is the polar characteristic which indicates the response of the antenna to unit field intensity from different directions. For a given antenna the two characteristics are identical in shape.

This characteristic depends upon such factors as the physical dimensions and configuration of the antenna, the frequency, the current distribution along the antenna, the position of the antenna with respect to ground, and the constants of the ground in the neighborhood of the antenna."[5]

And from another source: "The properties of an antenna, when used to abstract energy from a passing radio wave, are similar in nearly all respects to the corresponding properties of the same antenna when acting as a radiator. Thus the relative response of the antenna to waves arriving from different directions is exactly the same as the relative radiation in different directions from the same antenna when excited as a transmitting antenna. Also like the antenna directivity, the effective height, and the impedance of the antenna are the same in reception as in transmission. These reciprocal relations between transmission and reception properties make it possible to deduce the merits of a receiving antenna from transmission tests, and vice versa."[6]

Now, while these statements of correlation between the radiation field of an antenna and its response to passing Poynting vectors are perfectly true in a world which contains only the antenna in question and another (sufficiently remote) to permit measurement, a little mental reflection shows that a little terrestrial reflection can vitiate the proposition altogether. For the addition of any further material to the so-called "free space," even so simple an addition as a perfectly reflecting flat earth (mirror), while conceivably not affecting the response "to waves arriving from different directions" in the slightest, can distort the radiation pattern beyond all hopes of a correlation, altering the course of the radiation, introducing oscillating Poynting vectors at points where wave fronts intersect, forcing the radiation pattern into dependence on the distance, and in the worst cases (typified by an earth with finite conductivity) altering the degree of ellipticity of the wave polarization.

Of course, the reciprocity principle is not at all affected. An exploring instrument records the same

[3] It should be noted that neither of these terms possesses comprehensive utility in application to receivers which contain significant sources of noise following the detector. However, such receivers are rarely encountered nowadays.

[4] E. W. Herold, "An analysis of the signal-to-noise ratio of ultra-high-frequency receivers," *RCA Rev.*, vol. 6, pp. 302–331; January, 1942.

[5] I.R.E., "Standards on Transmitters and Antennas," 1938, p. 30.

[6] F. E. Terman, "Radio Engineers' Handbook," McGraw-Hill Book Company, New York, N. Y., 1943, p. 786.

relative directional reception data as are recorded at the antenna under study when, instead, the exploring instrument is made to transmit. While an exploration of this kind is a common and valuable engineering procedure, nevertheless, since the phenomena of wave propagation through encumbered space may be inseparably woven into the data, no generally useful characteristic of the antenna alone is necessarily recorded or even necessarily derivable from the record.

It follows, therefore, that a fundamental function useful in connection with both the transmitting and receiving properties of an antenna is its "free-space directivity," the concepts related to wave propagation through cluttered space being excised and put into a separate compartment. This is hardly a novel idea, but in need of emphasis. Whenever this function is known for a structure it will always be possible, at least in theory, to calculate directly the radiation and reception characteristics in an *encumbered* space, with one exception: should the structure be brought so close to an encumbrance that there is mutual impedance between the two (i.e., a redistribution of current in the structure), or should the encumbrance of necessity be an integral and sufficiently enormous part of the structure (e.g., an earthed antenna), the free-space directivity has either no obvious utility or no meaning. That these instances cannot be embraced is annoying but should not be allowed to hamper the adoption of a concept pertinent to the great majority of short- and ultra-short-wave structures.

While alternatives are possible, within my knowledge, receiving antennas are designed for the reception of plane-polarized waves. On the other hand, the design of many practical structures is such that they radiate elliptically polarized waves in nonoptimum directions, while in other structures this property is fully suppresed only with the greatest difficulty. It follows that, in order to be useful comprehensively in connection with reception, free-space directivity must be a description of the field directivity and not simply the power-per-unit solid angle. The difficulties encountered in attempting to use a function of the latter variety are seen in Dr. Neiman's adoption and extension of such a definition,[7] advanced in 1931, which constrains the sense of his equation (3) to those spatial directions for which the receiving antenna is not elliptically polarized.

I therefore propose that the name "free-space directivity" be associated with the function $D^2(\Omega, \phi)$ which is defined above, and that the term "gain" (without allusion to the reference antenna) be applied to its maximum value, it being obvious from the condition $\overline{D^2(\Omega, \phi)}^{\Omega,\phi} = 1$ that the gain in question is the power gain over a hypothetical structure radiating circularly polarized waves uniformly in all directions. Once a standard of *some* sort is adopted one is forevermore relieved of the necessity for stating parenthetically what the gain reference is. (The use of D^2 rather than D will, perhaps, be questioned, but is suggested as an eliminator of $\sqrt{\quad}$ in root-mean-square descriptions.)

To illustrate with the simplest structure, an electric doublet, $D^2 = 3 \sin^2\theta \cos^2\phi$, where θ is the angle between the Poynting vector and the doublet axis, and ϕ is the angle between the electric vector and its projection on a plane containing the axis and the Poynting vector. For this antenna, gain $= 3$. In the same notation, the gain of a half-wave dipole is approximately 3.3.

In the most general case, and provided the origin of ϕ is made to coincide with the direction of one of the axes of the polarization ellipse,

$$D^2 = 2\frac{A(\Omega)\cos^2\phi + B(\Omega)\sin^2\phi}{\overline{A} + \overline{B}}$$

and if the direction, $\phi = 0$, coincides with the major axis,

$$\text{gain} = \frac{2A_{max}}{\overline{A} + \overline{B}}$$

while if, for reasons not presently apparent, one *does* want a description of the distribution of radiated power-per-unit solid angle, it is

$$\overline{D^2}^{\phi} = \frac{A(\Omega) + B(\Omega)}{\overline{A} + \overline{B}} = 1/2\left[D^2(\Omega, \phi) + D^2(\Omega, \phi + \pi/2)\right].$$

M. S. Neiman:[8] I should like to express my agreement with the valuable remarks made by Dr. North in connection with my article.

His introduction of the additional condition of the minimum noise factor is a point which should be taken into consideration, when the optimum for the coefficient of exploitation is being determined, in cases where the local noise at the antenna becomes an important factor.

Dr. North's remarks as to the definition of the directivity factor is important, when elliptically polarized waves are radiated or received. It should be noted, however, that actually in most cases, the transmitting antennas radiate plane-polarized waves in the main direction which is most important for practical calculations.

I should like to mention also, that the definition of the directivity factor is useful for practical purposes in most cases, also for earthed antennas, as is the case in the long-wave range. Therefore, in my opinion, the calculations based on the directivity factor, if properly handled, are useful, not necessarily for antennas located in the "free-space" only.

In my article, which was written in 1935, and was first published in Russian in the August issue of the *Journal of Weak Currents Industry* in 1935, the additional considerations advanced later by Dr. North could not be used. However, I am in full agreement with his remarks, as to the usefulness of a more general definition for the directivity factor, embracing the case of elliptically polarized waves.

[7] P. S. Carter, C. W. Hansell, and N. E. Lindenblad, "Development of directive transmitting antennas by R.C.A. Communications, Inc.," PROC. I.R.E., vol. 19, p. 1802; October, 1931.

[8] 1610 Park Rd., N.W., Washington, D. C.

THE INSTITUTE OF RADIO ENGINEERS

INCORPORATED

SECTION MEETINGS

ATLANTA	CHICAGO	CLEVELAND	DETROIT	LOS ANGELES
October 20	October 20	September 28	October 20	October 17
NEW YORK	**PHILADELPHIA**	**PITTSBURGH**	**PORTLAND**	**WASHINGTON**
October 4	October 5	October 9	October 9	October 9

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BALTIMORE—Chairman, W. L. Webb; Secretary, H. L. Spencer, Box 6760, Towson 4, Md.

BOSTON—Chairman, R. F. Field; Secretary, Corwin Crosby, 16 Chauncy St., Cambridge, Mass.

BUENOS AIRES—Chairman, L. C. Simpson; Secretary, I. C. Grant, Venezuela 613, Buenos Aires, Argentina.

BUFFALO-NIAGARA—Chairman, A. J. Dybowski; Secretary, H. G. Korts, 51 Kinsey Ave., Kenmore, N. Y.

CHICAGO—Chairman, W. O. Swinyard; Secretary, A. W. Graf, 4 Midway Ct., Hammond, Ind.

CINCINNATI—Chairman, J. L. Hollis; Secretary, R. S. Butts, Box 1403, Cincinnati 2, Ohio.

CLEVELAND—Chairman, A. S. Nace; Secretary, Lester L. Stoffel, 1095 Kenneth Dr., Lakewood, Ohio

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DALLAS-FORT WORTH—Chairman, D. J. Tucker; Secretary, P. C. Barnes, WFAA-WBAP, Grapevine, Texas.

DAYTON— Chairman, I. H. Gerks; Secretary, Joseph General, 1319 Superior Ave., Dayton, 7, Ohio.

DETROIT—Chairman, R. A. Powers; Secretary, R. R. Barnes, 1411 Harvard Ave., Berkley, Mich.

EMPORIUM—Chairman, H. D. Johnson; Secretary, A. Dolnick, Sylvania Electric Products, Inc., Emporium, Pa.

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KANSAS CITY—Chairman, A. P. Stuhrman; Secretary, R. N. White, 4800 Jefferson St., Kansas City, Mo.

LOS ANGELES—Chairman, L. W. Howard; Secretary, Frederick Ireland, 1000 N. Seward St., Hollywood, 38, Calif.

MONTREAL—Chairman, F. S. Howes; Secretary, J. A. Campbell, Northern Electric Co., Ltd., 1261 Shearer St. Montreal, Que., Canada.

NEW YORK—Chairman, Lloyd Espenschied; Secretary, J. E. Shepherd, 111 Courtenay Rd., Hempstead, L. I., N. Y.

PHILADELPHIA—Chairman, T. A. Smith; Secretary, S. Gubin, RCA Victor Division, Radio Corporation of America Bldg. 8-10, Camden, N. J.

PITTSBURGH—Chairman, T. C. Kenny; Secretary, R. K. Crooks, Box 2038, Pittsburgh 30, Pa.

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SEATTLE—Chairman, F. B. Mossman; Secretary, E. H. Smith, Apt. K, 1620—14 Ave., Seattle, 22, Wash.

TORONTO—Chairman, E. O. Swan; Secretary, Alexander Bow, Wire Products, Ltd., 137 Roncesballes Ave, Toronto, Ont., Canada.

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Institute News and Radio Notes

Constitutional Amendment Section

In the June, July, and August issues of the PROCEEDINGS there were published in this section proposed amendments to the Institute Constitution on grade names and dues, and reasons for their proposal. A number of other amendments are being proposed at the same time largely to assist in management of Institute affairs. The purposes of these amendments will be given herewith. Their wording may be found in the August issue of the PROCEEDINGS under Board of Directors activities.

Article I, Section 2, is to be modified to make it clear that the Institute is scientific, literary, and educational in character thereby conforming to the Institute Charter as amended January 27, 1944.

Article IX is to be modified to enable the Board to set up special technical and other groups, including a Canadian Council to represent Canadian members in their relations with their government.

Article X, Section 2, is to be modified to delineate a method of balloting upon Constitutional amendments like that provided for the election of officers.

Article VII, Section 1, is to be modified so that the time limit for the arrival of petitions and ballots at the Institute office shall fall in working hours on a working day.

Article II, Section 1e, is to be modified by dropping the word PROCEEDINGS from the Constitution inasmuch as that is the only reference to it in the Constitution.

No rights or privileges are affected by any of these amendments except possibly in the last-mentioned above, and that is only a technicality. The Board by its past practices guarantees no change.

The ballots will be mailed to the voting membership about the middle of September. The marked ballots must reach the Institute Office on or before November 22 to be counted.

By Order of the Board of Directors
R. A. Heising, *Chairman*
Constitution and Laws Committee
July, 1944

Comments and Criticism on the Proposed Increase in Dues

The Institute Office is in receipt of a number of letters from the membership commenting upon the proposed increase in dues. The scope of the letters covers the range from inquiry to suggestion, and the opinions have bases that range from conjecture to business experience. The Board finds some of the suggestions and opinions of great merit and will attempt to work them into the management plan to whatever extent is possible. However, from a study of the letters, one arrives at the conclusion that there are quite a number of points upon which the membership desires further enlightenment.

It was the original intention of the Board to publish in the PROCEEDINGS a number of the expected letters to cover the principal points brought up. The number of these points, however, is larger than expected so that to publish the letters in full and then discuss them would lead to the use of too much space in the PROCEEDINGS. It is felt that the same result can be secured by grouping and listing the points from the various letters, and then providing a single discussion for all. This plan, therefore, will be followed.

The points of interest brought up are:

1. That the dues increase proposed is too great. Specific suggestions typifying the ideas are $15, 12, 8, 6, 4, and $12, 12, 8–10, 6–8, 3–6 per year for grades as listed in the Constitution; hyphenated pairs mean an automatic dues increase in that grade after a certain number of years.

Comment—The dues increase proposed by the Board should increase the Institute income coming from dues by about 32 per cent allowing for about 30 per cent shift into the Member grade, and 5 to 10 per cent dropouts in lower grades. The increase in income needs to be sufficient to cover three things (1) the inadequacy in income before the war, (2) the rise in salary, price, and rent levels during the war, and (3) the provision of added services which are being asked. A smaller percentage increase than that mentioned may be insufficient.

The suggested lower dues embody in one case different dues for Fellows and Senior Members. The Board decided some years ago that the Fellow grade should be strictly an honor award without any related financial aspect attached to it. Therefore, dues for that grade should not be greater than for Senior Member.

The Board feels Fellows and Senior members can stand an equal or greater increase in dues than the lower grades and therefore prefers $15 and 15, to 12 and 12 suggested in the other case.

The Board has not favored raising Student member dues above $3. Any loss is the Institute's contribution to their education. Besides, the period during which one is in Student grade is relatively short in most cases. The small loss is overbalanced by the encouragement to remain a member after student days end.

One suggestion embodies an automatic dues jump for both Member and Associate grades. The suggested figures are slightly lower than those to be voted on. The Board believes a Member does not require a period of membership at an "encouragement rate." He should have an income justifying a supporting rate.

2. That a loss in membership will result either immediately or after the war that will cancel the expected increase in income.

Comment—It is believed there will be some loss in membership with any increase in dues. After the war, there may be a membership drop. It is not believed as much of such membership drop can be attributed to increased dues as to changing to other occupations. This is, however, only opinion.

3. That the dues should not be increased until increased service to the membership is given.

Comment—This opinion was probably expressed without giving it sufficiently detailed thought. It implies that the Institute is an organization trying to sell something to an outsider, and should demonstrate its goods before asking an increased "price." Members are part of the Institute and the I.R.E. is *their* Institute. The Board, as servant of the membership, is telling the members they need to provide more money if they wish to give themselves a greater service. The Board can see no way by which the Institute (as a membership organization) can provide the services before the membership provides the necessary funds.

4. That the dues should be reduced to maintain the membership at present levels.

Comment—From the policy standpoint, a large membership is not a primary aim of the Institute but greater service to its members is. Large membership is advantageous only if it contributes to the greater service. Too much effort toward increasing or maintaining membership, or lowering dues for the same purposes, will leave reduced funds for service to the membership.

5. That increased income be secured by promoting wider membership among technical servicemen, etc.

Comment—A society such as ours must choose a field in which it wishes to serve. It happens that technical servicemen are outside the field which the Institute can most effectively serve at this time. The Institute would also have to change its publishing policy radically to be of aid to most servicemen. Research, development, and engineering papers would have to be sacrificed for papers useful to servicemen. The Institute wishes to remain in its present field until such time as a change or expansion can be carried out without sacrifice of its current services. Technical servicemen who believe that they are helped by becoming members of the Institute are invited to join. The Institute could not honestly, however, promote a membership campaign outside what it considers its chosen field under existing conditions.

6. That the Institute should receive its increase in support from advertising, by increased advertising promotion, and increase in rates.

Comment—The Board is actively promoting advertising to supplement the income from dues. The Board believes it would be an unsound fiscal policy to depend solely upon advertising income for the major portion of the Institute's income. It sees the field of technical publishing as one of considerable difficulty and active competition, so far as advertising is concerned. The Board would have an undue responsibility thrust upon it if it were required to maintain the Institute largely by income from the field of advertising. It is questionable whether the Institute with such a policy could induce certain competent engineers to serve on its Board of Directors.

The Board intends to supplement its income from dues by whatever increased advertising promotion or rate increases appear to be good business. It cannot, however, unduly stress the interest of the Institute in advertising. Institute engineering activities and the technical part of the PROCEEDINGS necessarily come first.

The Board is asking the membership to vote for an increase in their dues in the face of the greatest surplus in the Institute's history, a surplus which has come from advertising. However, the great business activity resulting from other possibly transient factors may in some measure be responsible for the large advertising which is now secured. With the termination of the war and relaxation on paper rationing, more periodicals may appear in the publishing field. The Board must plan a course for the Institute that envisages advertising as a competitive field, and does not disproportionately stress its long-term contributions to Institute finances.

7. That the Institute should obtain its increase in support from publication of booklets, handbooks, data, charts, etc., and should promote radio courses charging nonmembers larger fees than members.

Comment—Publication of booklets, handbooks, data, charts, etc., and promotion of radio courses are highly speculative ways of securing added income. If such methods were certain of producing income, they would already be utilized by private businessmen as bases for enterprises. Of course the prestige of the Institute connected with such activities would provide an appeal to users, but it is questionable whether it would provide a sufficiently more effective appeal than others now secure when using the name of some famous engineer or professor in associations with such products. Such a policy would, as mentioned previously in connection with advertising, place a heavy responsibility upon the Board of Directors in requiring that they carry on specialized activities to support the Institute. The Board is desirous of doing some of these things as a service to the membership at cost, or near to it, but cannot plan upon any major income from them to support other Institute activities.

8. That dues higher than those proposed would be welcome if benefits such as mentioned in the prospective plan can be provided.

Comment—The Board prefers to take a moderate step.

9. That the increase in dues be delayed for at least another year giving time to observe if advertising income remains up, and to ascertain the magnitude of some of the increased expenses.

Comment—It is believed the same suggestion could be made next year if the increasing of the dues were delayed the year. It would be necessary to wait until after the war to get full answers. It takes the major part of a year to put through a constitutional amendment, and if a dues' increase campaign is not started until a deficit impends, the deficit may materialize first. Also, the Board hesitates to inaugurate new plans until the means for carrying them through are in sight. The contemplated improvements would therefore develop much more slowly if at all.

10. That the dues for all grades except Student should attain a uniform level to encourage membership in the highest grade commensurate with qualifications. By leaving present Senior Member and Fellow dues as is, and making the dues for Member and Associate increase with time ultimately reaching the same level as Senior Member, uniformity would be attained, and a larger income received then from the proposed dues.

Comment—The Board does not know how well such a system would be received, since graduated scales of dues are most common in professional societies.

General Discussion

The ten points discussed above were contained in the letters received by the Institute office and have at one time or another been discussed by the Board. As mentioned, many conflict with the Institute policy as established. At least two are suggestions the Board will try to adopt to some extent for whatever they can contribute, but not as a substitute for an increase in dues.

The Board is very grateful to the various members who have written in and expressed themselves. It is only by such expressions that the Board can become cognizant of their opinions, or of the fact that the picture of the need for the increase in dues as presented so far has been incomplete. The undersigned has attempted to make the discussion as presented here as straightforward and as free from critical tone as have been the letters received, and hopes that no one who has sent in any suggestion will feel that any attempt has been made to belittle his ideas. Similar ideas must have occurred to others, and it is very helpful to have had some bring them up for discussion.

By Order of the Board of Directors
R. A. Heising, *Chairman*
Constitution and Laws Committee
July, 1944

Constitutional Amendment Petition

To the Board of Directors

"It is respectfully requested that you bring to the attention of the Board of Directors of the Institute of Radio Engineers that:

In accordance with Article X (Amendments) of the Constitution of the Institute of Radio Engineers, the voting members whose signatures appear below do hereby petition that the following proposed addition to Article VII, 'Nomination and Election, etc.', be submitted to the membership for approval in accordance with the appropriate sections of the Constitution:

No person shall be eligible for appointment by the Board as Director, Secretary, Treasurer, or Editor after having accepted five such appointments to any or several of these offices."

(The names of the signers are arranged in the order of arrival at the Institute headquarters.)

Page 1—Received May 31, 1944

H. N. Houck	Mountain Lakes, N. J.
Jerry Minter	Boonton, N. J.

Page 2—Received May 31, 1944

Arthur V. Baldwin	Emporium, Pa.
H. E. Ackman	Emporium. Pa.
E. E. Overmier	Emporium, Pa.
G. H. Klinestiver	Emporium, Pa.
J. R. Steen	Emporium, Pa.
N. L. Kiser	Emporium, Pa.
B. S. Ellefson	Emporium, Pa.
R. E. Palmateer	Emporium, Pa.
Herman Melzer	Emporium, Pa.
M. I. Kahl	Emporium, Pa.
W. H. Ottemiller	Emporium, Pa.
R. K. Gessford	Emporium, Pa.
W. A. Dickinson	Emporium, Pa.
W. L. Krahl	Emporium, Pa.
George W. Brunner	Emporium, Pa.
H. K. Ishler	Emporium, Pa.
Walter R. Jones	Emporium, Pa.
V. D. Goodwin	Emporium, Pa.
Walter Dehlinger	Emporium, Pa.
Raymond K. Zelt	Emporium, Pa.
E. J. Schneider	Emporium, Pa.

Page 3—Received June 1, 1944

J. F. Gaffney	Woburn, Mass.
Ben Kievit	Emporium, Pa.
George N. Mahaffey	Emporium, Pa.

Page 4—Received June 1, 1944

Harry E. Smithgall, Jr.	Williamsport, Pa.
Sidney Margolis	Montoursville, Pa.
Myron O. Schilling	Williamsport, Pa.

Ernest S. Vena	Williamsport, Pa.
Ron. G. Petts	Williamsport, Pa.
L. E. West	Emporium, Pa.
James G. Miles	Williamsport, Pa.
L. I. Knudson	Montoursville, Pa.
Joseph J. Willendorf	Williamsport, Pa.
O. Bruce Goldsmith	Williamsport, Pa.
Harry L. Ratchford	Williamsport, Pa.
R. N. Palmer	Emporium, Pa.
C. B. Eckel	Williamsport, Pa.

Page 5—Received June 1, 1944

Allan W. Keen	Emporium, Pa.
George T. Gunnell	Emporium, Pa.

Page 6—Received June 1, 1944

F. A. Lidbury	Niagara Falls, N. Y.
H. W. Parker	Toronto, Canada
Marcus A. Achesen	Emporium, Pa.
R. M. Bowie	Manhasset, L. I., N. Y.

Page 7—Received June 1, 1944

Walter C. Freeman, Jr.	Williamsport, Pa.
Franklin L. Burroughs	Williamsport, Pa.
Wm. P. Mueller	Emporium, Pa.

Page 8—Received June 5, 1944

Conan A. Priest	Syracuse, N. Y.
Irvin Reed Weir	Syracuse, N. Y.
Henry P. Thomas	Fayetteville, N. Y.
Raymond H. Williamson	Syracuse, N. Y.
Robert E. Moe	Bridgeport, Conn.
A. G. Manke	Schenectady, N. Y.

Correspondence Dealing with Proposed Constitutional Amendment Limiting Appointments

The following letter from Mr. Virgil M. Graham commenting upon the discussions of the Constitutional Amendments by Mr. R. A. Heising, and on "A Message from the President,"[1] particularly requests that a "Correction Message" from the President be published in the Proceedings.

SYLVANIA

Radio Division Williamsport, Penna.
July 14, 1944

Professor H. M. Turner, President
Institute of Radio Engineers
330 West 42 Street
New York, New York

Dear Professor Turner:

As a member of the Constitution and Laws Committee of the Institute, I was interested in reading the discussion of the several proposed amendments to the Constitution recently circulated, as well as the preprint of your message of which the Chairman of the Williamsport Section sent me a copy. Personally, I do not feel very strongly about these amendments but on reading the above-mentioned literature there are a couple of questions and comments that come to my mind.

First, it seems quite marked that Mr. Heising's discussion, by the order of the Board, published in the pamphlet, regards only those amendments proposed by the Board as being for the good of the Institute while those proposed by others are not.

Second, in your message you state that the proposed amendment on limitation of number of appointive terms would limit tenure of some of those offices to two years for any incumbent on the basis that the Secretary, Treasurer, and the Editor are holding two offices concurrently. My copy of the Constitution does not so read. It says, Article V:

Sec. 1—The governing body of the Institute shall be the Board of Directors and shall consist of the President, Vice-President, Secretary, Treasurer, Editor, nine elected Directors, five appointed Directors, and the two most recent past Presidents.

Sec. 2—Except for the elected Directors, the terms of all officers shall be for one year each.

and Article VII

Sec. 2—The five appointed Directors, Secretary, Treasurer, and Editor shall be appointed by the Board of Directors at its annual meeting to serve until the next annual meeting.

This does not seem to mean, and it never has been so interpreted to my knowledge, that the Secretary, Treasurer, and Editor have to be appointed from the group of five appointed Directors. Certainly this has not been the practice within my recollection. The Constitution, as indicated above, does not say that these officers are directors either elected or appointed but that they are members of the Board by virtue of appointment to those offices.

I feel therefore that point 2 in your message is serious misinformation to the membership as no interpretation that I can see for this amendment and the Constitution, would limit an individual to less than five terms in one of the offices or a total of five terms split among several. I would guess that, on the average, terms have not been much longer than this and five years is a reasonable time for the Institute to put heavy obligations on anyone. I believe also that there are more qualified men willing and able to serve than is implied, if opportunity to serve were given.

[1] Proc. I.R.E., vol. 32, pp. 496–497; August, 1944.

I suggest that a "Correction Message" from the President be sent to those receiving the first message and that correction be made in the August* issue of the "PROCEEDINGS."

Very truly yours,

(signed) VIRGIL M. GRAHAM, Manager
VMG:HB Industrial Apparatus Plant

* This communication was received too late for the August issue of the PROCEEDINGS and is, accordingly, here included.

—Reply—

A careful reading of Mr. Heising's discussion fails to disclose any statement that could be interpreted as suggesting that "only those amendments proposed by the Board as being for the good of the Institute while those proposed by others are not." I am sure that neither Mr. Heising nor the Board entertains any such thought, and it is my personal opinion that the source is absolutely immaterial.

Any amendment should be in the interest of the Institute. It will be recalled that a year ago, I opposed the Board-sponsored amendment changing the membership structure, and I am still of the opinion that the change was a mistake and that the adoption of the Montreal Amendment would be to the interest of the Institute, despite the fact that it would cause the office some temporary inconvenience.

With reference to the second point, had an error been made I should have been most happy to correct it but the language of the proposed amendment, which is quoted, appears perfectly clear on this point: "No person shall be eligible for appointment by the Board as Director, Secretary, Treasurer, or Editor after having accepted five such appointments to any or several of these offices." Mr. Graham is quite correct in assuming that the administrative officers do not have to be appointed from the group of five elected directors, but my interpretation, as a layman, was and is that no one becomes a member of the Board without appointment and the fact that the Secretary, Treasurer, and Editor become Board members by virtue of their office constitutes an appointment; that is, one act legalizes the two appointments. However, since the question has been raised, legal counsel was requested to submit an opinion so as to clarify the matter. I quote:

HAROLD R. ZEAMANS
Counselor At Law
103 Park Avenue, New York 17

July 27, 1944

Prof. H. M. Turner, President,
The Institute of Radio Engineers,
330 West 42nd Street,
New York, N. Y.

Dear Professor Turner:

In respect to the proposed amendment to the bylaws, limiting the term of any appointed Director, Editor, Secretary, or Treasurer, or any of such officers, I have read the proposed amendment carefully.

It seems to me that when a man is appointed to an office such as Secretary, Treasurer, or Editor, which automatically makes him a director, it might well be construed that such appointment is an appointment to both offices.

In effect, an appointment as Secretary makes a man a member of the Board under the Constitution, with all the rights of board members, and hence, such appointment makes him both Secretary and a member of the board. Under the limitation contained in the proposed amendment, that a man can only hold five of any or all of such offices, it might well be that only two years can be served by an appointed individual.

To substantiate this construction of the proposed amendment, consider the possibility of one man being appointed both Secretary and Treasurer. There will be no doubt then of the fact that the proposed amendment would limit such appointment to two years. In any event, in looking at the proposed amendment, it would be the duty of the officers of the Institute, to look at it from the standpoint of the broadest construction that can be put on it, in considering voting for such amendment.

You would also have to take into consideration that the authority of an officer such as Secretary or Treasurer, is sometimes passed upon by other institutions, who act on their authority, and they would naturally want to be certain that any such officer was duly and legally appointed and serving, before accepting his signature.

I feel, therefore, that your original communication stating that under the proposed amendment a man's term of office might be limited to two years, is a correct assumption.

Very truly yours,

(signed) HAROLD R. ZEAMANS

HRZ/msg
cc: Prof. H. M. Turner
c/o Yale University
New Haven, Conn.

While I have not been informed of the intent of the petitioners, I do know that in dealing with bankers and others there must be no question regarding the legality of the appointment of an officer of the Institute who signs financial and other legal papers.

I want to thank Mr. Graham for raising these questions and for giving me an opportunity to explain my point of view.

HUBERT M. TURNER, President, I.R.E.
August 2, 1944

MEASUREMENTS CORPORATION
BOONTON, NEW JERSEY

July 18, 1944

Secretary
Institute of Radio Engineers
330 West 42nd Street
New York, N. Y.

Gentlemen:

With regard to the petition to amend Article VII: let me say that the Institute has long neglected vital responsibilities to its members and the industry. To be specific, one such task: that of collecting and submitting to the membership for *approval* effective standards for the industry in a manner similar to the well known and efficiently operated Society of Automotive Engineers.

The radio and electronic industries are coming into their own. To survive as a real engineering society, the I.R.E. must assert its key position on top of the world's new major industry—electronics—and discharge its responsibilities accordingly.

Basically the trouble with the I.R.E. is that the wrong people are running it. Given new and *experienced* engineering guidance, much good can be done and war standards kept in line with sound engineering experience. Just what has the I.R.E. itself as an organization done to win the war? Think it over. Replace the few stale politicians by new and experienced blood. Five years is long enough in a democratic country.

Yours very truly,
(signed) JERRY MINTER—V.A.

Communication from the Secretary of the Institute

To the Members of the Institute

Mr. Jerry Minter's letter of July 18 criticizes the I.R.E. for laxity in making contributions to the war effort and ascribes such alleged deficiency to certain individuals who he thinks have controlled Institute policies for more than five years.

I feel that readers of Mr. Minter's letter should have before them some pertinent facts that are available in the records of the Institute many of which have already been given individual attention at one time or another in the pages of the PROCEEDINGS, so that they may make appraisals of the situations he discusses in the light of the record.

If special and diligent organized effort had not been initiated and suitably implemented, your PROCEEDINGS would have declined greatly in size and degenerated in content due to the scarcity of suitable technical papers shortly after the advent of the war. Later, drastic cuts due to the paper-limitation order were avoided after repeated pleas, or suitably documented and personally presented appeals, had been made to the Government. The vast technical effort of the radio engineering profession on war problems must have been enhanced through this maintenance of the flow of technical information. At the same time all papers published had to be very carefully scrutinized in order to exclude any material that might give aid or comfort to the enemy, a by no means simple task.

Exceptional efforts were necessary to organize and hold special technical meetings and I think that the attendance records at our recent I.R.E.-sponsored Winter Technical Meetings, and the Rochester Fall Meetings, as well as the war aspects of their programs, speak for their success. I.R.E. has also actively sponsored the forthcoming National Electronics Conference.

I.R.E. has had a representative serving on a Consultative Committee of the War Man Power Commission, which Committee dealt primarily with problems concerning professional and technical personnel. I.R.E. gave its support, through this committee, to programs that resulted in the adoption of special considerations for technical students in reorganized institutions of learning.

From the beginning of the war effort, I.R.E. rendered assistance to the National Roster, with regard to its valuable compilations concerning specialized and technical personnel to be used to prosecute the war effort. From time to time special committees of the Institute met with representatives of the Roster (now a part of the United States Employment Service).

The Institute has issued new tentative facsimile standards, reissued certain old standards for which there was a wartime demand, is preparing still other standards, has published a large group of tutorial papers on subjects of timely interest related to war activities, and has prepared and delivered certain other material of direct wartime value which because of security rules cannot be enumerated. Usefulness to the war effort was the primary guiding motive attached to the action taken on these items.

Your Institute appointed a representative to the War Committee on Radio, which operated by direction of the War Production Board, under the secretariat of the American Standards Association. This appointee also took the Chairmanship of the Subcommittee on Insulating Material Specifications for the military services. In addition the Institute lent the time and efforts of its then Secretary to assist the A.S.A. in this work, to the temporary detriment of our office activities. The results of this work cover some 361 pages of a published book, the bulk of which has been officially adopted by one or both military services, and many of which have been approved as Canadian War Standards by the Canadian Engineering Standards Association. Of these, 132 pages cover standards prepared under the Chairmanship of the I.R.E. representative. Much unfinished work started by the Committee has been taken over by the government and will issue later as specifications of the joint Army-Navy Electronics Standards Agency.

An examination of the personnel of the Boards of Directors at the beginning and end of the five-year period 1939–1944 inclusive, indicates that of the twenty-one members only eight who served in 1939 are serving in 1944, or 38 per cent. However only three of these are on an appointed basis in 1944 or about 14 per cent. Since the Constitution vests the control of policies and the management of Institute affairs in the Board of Directors it seems that these carry-over individuals representing a very distinct minority of the total membership, could control nothing.

Since Mr. Minter feels that the I.R.E. as an organization has slighted activities helpful to the war you should know that recently he was asked to take the Chairmanship of the Instrumentation Group of our Papers Procurement Committee. This Committee is a key one in the effort to maintain a flow of suitable technical material during the war. Mr. Minter declined because of demands of the War on his time. I know of a number of Institute members who carry very heavy wartime duties who have found opportunity also to participate in the Institute's contribution toward victory.

HARADEN PRATT
Secretary

A LETTER FROM A GROUP OF ELECTED DIRECTORS TO THE MEMBERS OF THE INSTITUTE, WITH REFERENCE TO THE PROPOSED AMENDMENT LIMITING TO FIVE YEARS THE TERMS OF CERTAIN APPOINTEES

A petition, duly presented by a group of members, has placed before you for your election a constitutional amendment which would limit to five years the total length of service of any one man in all the offices of Secretary, Treasurer, Editor and one-year Directors, all of which are appointed annually by the Directors who are elected for three-year terms. This plan leaves no room for the Directors or your membership to retain in these offices any selected individual for any more than five one-year terms. There is no such limitation on the length of service as elected Director, and you have selected some individuals for many years as your representatives on the Board.

The present proposal, whose motives were not stated by its proponents, would secure rotation in office, which is a laudable aim in any democratic organization and has been the aim of the Board of Directors as far as consistent with the welfare of the Institute. More specifically, it would dictate the immediate replacement (at the end of 1944) of several of your most faithful and energetic and qualified appointees who have been most generous in devoting their time and attention in these offices. This abrupt change in the administrative staff would disrupt the normal operation of the Institute office and PROCEEDINGS, and the Board would find it difficult, if not impossible, to replace some of these appointees with equally willing and competent servants. This is especially true during the war when so many of the members have had to withdraw from any regular activities in the Institute.

The proposal is also an attack on the performance of those incumbents whose reappointment would be blocked beyond the control of the Board. We urge that you should not sanction the proposal without hearing from its proponents just what is their dissatisfaction and why it could be cured by their five-year plan.

The present Editor is the individual who has served the Institute the longest and most energetically of all its members. The fact that he has done this willingly has added to the value of his services. With the growth of the PROCEEDINGS, this job has come to demand about one third of the working hours of himself and his secretarial staff, all without monetary compensation from the Institute. The Editor is the only one available to pass on the entire content of the PROCEEDINGS, and to edit the entire text. In one year, this has covered 120 submitted technical papers, of which 85 were published. These and the supplemental material total about 800 pages of text, and the advertising is another 800 pages to be reviewed. The Editor has to attend 22 afternoon meetings of the Board and the Executive Committee per year, and handles many hundreds of letters relative to his functions.

The Secretary and Treasurer also have to attend the monthly meetings of the Board and Executive Committee, in addition to their special obligations. The Secretary is constantly in touch with the Assistant Secretary who is directly in charge of the Institute office, and passes on all questions of policy as well as many administrative details. The Treasurer automatically is chairman of the Investments Committee. Both men are now devoting nearly a month per year to this work.

These administrative officers are men who have the interests of the Institute at heart and who, therefore, accept many other responsibilities beyond those of their offices. For example, the present Treasurer is chairman of three very active major committees unrelated to his office.

The fact that so much work is done by a few capable members is good for efficient administration but the Board recognizes that rotation in office is a better objective, with distribution of the work among the members. This objective can be obtained only with the aid of an enlarged staff of paid administrative workers to carry the burden of the work and to provide the necessary continuity of management. The proposed increase in dues is partly intended to support this staff. In the meantime, most of this work will have to be carried on by the few willing servants who are located in New York and who have been in close contact with Institute affairs.

Until the initiative of managing the Institute can be distributed among a larger number of volunteer workers with rotation in office, the present system should be retained. We oppose the adoption of the five-year amendment.

July 19, 1944

W. L. BARROW
A. B. CHAMBERLAIN
W. L. EVERITT
R. F. GUY
F. B. LLEWELLYN
H. A. WHEELER
W. C. WHITE

(Elected Members, Board of Directors)

Communication from Mr. Harold P. Westman

To the Editor:

Under date of June, 1944, there was distributed by order of the Board of Directors a leaflet on "Constitutional Amendments." It discusses several proposals to amend the Institute Constitution; two of these concern membership dues and grades.

Sections Committee Meeting. This document omits mention of certain actions taken by the Sections Committee at its Annual Meeting on January 27, 1944. Twenty-one of our twenty-seven Sections were represented at this meeting and six Directors and Officers of the Institute were present. The following two quotations are from the minutes of the meeting.

> In two motions, each passed with three dissenting votes, it was recommended to the Board of Directors that dues be increased by a moderate amount to cover the advances in costs and to provide for additional services to the membership and that dues for all grades be equalized with the exception that lower dues be paid by Students and for a reasonable period by new Associates.
>
> The amended motion requesting the Board of Directors to submit to the membership another revision of the Constitution changing the membership structure to Fellow, Member, Associate, Affiliate, and Student and to withhold until action is taken thereon all future transfers from Associate to Member, was approved with one dissenting vote.

The following views are in support of the recommendations of the Sections Committee; they are my personal observations based on numerous discussions with members of the Institute over a long period of years.

Dues. There is no difference in the expense to the Institute in serving the members of the various grades and all receive substantially the same services. What reasons might exist for asking one member to pay higher dues than another?

A few Fellows may aspire to the Presidency and the Vice-Presidency, and some Senior Members may serve on certain committees for which all grades of members are not eligible, but this is hardly justification for making all Fellows and Senior Members pay higher dues.

Another argument is that a higher-grade member is advanced further in his profession and hence should contribute more to his society because of its services to the field and their effect on his personal position in it. Carrying this to a logical conclusion, can we say that a member of lower grade is not being similarly aided by *his* society or is getting much less (say only 60 per cent) of the effects that benefit the higher-grade member, even though that society annually collects $46,332 from 7722 members of lower grade and only $10,710 from 1071 higher-grade members.

Still another reason stated is that the higher-grade man is able to absorb more of the services supplied by the Institute than those in lower grades. The fallacy of this view becomes evident if one were to try to sell an engineering textbook at a price adjusted to the ability of the purchaser to understand its contents. A high-school student might then purchase for $1.00 a book on advanced mathematics for which a college professor would be charged $10.00. Or, perhaps, one might attempt to justify higher tuition fees for bright college students than for their less favored brethren.

Even the argument that the higher-grade member is collecting more money for his services is unsound if we compare the financial status of the government employee and the educator with that of the industrial radio engineer.

It is easy to understand how a Board of Directors comprised of higher-grade members would be bashful about proposing a dues schedule in which all the increases hit the other grades. However, the Sections Committee has released the Board of any such criticism. At the very least, the Board should include its proposal on the ballot as an alternate dues schedule. If the Board insists that the Sections Committee bring in a formal petition to have its proposal placed on the ballot, it is assuming the responsibility of knowingly ignoring the "voice of the people."

It is true that the Sections Committee did not name the figure at which dues might be equalized. However, the Board has set $10.00 for the lower grades. On the bases of the membership data given, retaining this figure for the higher grades also would make the theoretical maximum dues receipts about $5000 less than for the Board's proposed schedule. There would still result an increase of more than $30,000 or over 50 per cent.

R. A. Heising, who is also chairman of the Section Committee, proposed[1] to the Board a schedule in which dues are equalized for all grades but would differ with the ages of the members. No reasons are given for using age as a factor in computing dues. In presenting this, he drew to the attention of the Board the actions of the Sections Committee. It may be inferred that this proposal was rejected by the Board.

It would not be amiss for the Board to agree that if the dues' increases are granted by the membership, the rebates to Sections would be doubled, at least. Our Sections have always struggled along and are unable to take their proper places among Sections of other National engineering societies, particularly in regard to membership in local engineering societies. In many cases, this increase in income would permit such affiliation, making available to our members the meeting, library, and other valuable facilities of these local engineering societies.

Membership Grades. Ex-President Van Dyck, in a published letter,[2] has presented partial definitions of "Associate" and "Affiliate." Unfortunately, the perti-

[1] Constitutional Amendment Section, Proc. I.R.E., vol. 32, p. 370; June, 1944.

[2] Constitutional Amendment Section, Proc. I.R.E., vol. 32, p. 436; July, 1944.

nent definitions in Webster's Dictionary seem to have been overlooked. These are:

Associate. Admitted to some, but not all, rights and privileges; as, an associate member.

Affiliate. To attach (to) or unite (with); receive into a society as a member.

The centuries have witnessed drastic changes in the meanings of many words and the illegitimacy referred to in the above letter in the definition of "Affiliate" is just as obsolete as that part of Webster's definition of a "Fellow" as being "A man of low breeding or of little worth."

There are reasonable bases on which the "Affiliate" series of names are preferable to the "Senior" group. Standardization is no longer a stepchild in engineering and we should be foolish to disregard it in our association activities. The pattern of Fellow, Member, and Associate has been well established in professional engineering societies. Those which are closest to the Institute in their memberships use it. While some societies have Junior Member as a grade below Member, the use of Senior Member for an advanced Member is not used in the radio, electronic, and electric fields. The term "Affiliate" is used by a number of socieites for those of nonprofessional status.

It has been stated that no harm resulted from setting up a Senior Member grade and transferring all existing Members to it. If one became a Member many years ago and was transferred to Senior Member in 1944, his membership certificate will indicate arrival at professional maturity at the later date. Senior Member will, in effect, reduce his apparent "seniority" by the interval between the two dates.

Publication of Results. In the 1941 ballot on Constitutional changes, the Board directed that the numerical results of the votes cast be published. . . . no information is available to the membership on the 1943 balloting which set up the new grade. . . .

Very truly yours,
HAROLD P. WESTMAN
Senior Member

July 19, 1944

NOTE—The balloting on the 1943 Amendment which set up the new grades was:—ballots mailed, 3505; ballots returned, favorable 980, opposed, 319; necessary for adoption, 974.

Executive Committee

June 16 Meeting: A meeting of the Executive Committee was held on June 16, 1944, at which the following were in attendance: H. M. Turner, president; Alfred N. Goldsmith, editor; R. A. Heising, treasurer; F. B. Llewellyn, Haraden Pratt, secretary; H. R. Zeamans, general counsel; and W. B. Cowilich, assistant secretary. A group of routine and administrative matters was considered.

July 5 Meeting: The following members attended the July 5 meeting of the Executive Committee: H. M. Turner, president; E. F. Carter, Alfred N. Goldsmith, editor; R. A. Heising, treasurer; Haraden Pratt, secretary; H. A. Wheeler, and W. B. Cowilich, assistant secretary.

Membership: The following applications for memberships were approved: for transfer to Senior Member grade, Ben Akerman, R. D. Avery, B. B. Bauer, J. A. Callanan, S. P. Chakravarti, P. B. Collison, R. C. Corderman, W. F. Cotter, A. N. Curtis, Sidney Frankel, R. K. Gessford, E. S. Heiser, L. A. Hendricks, C. K. Huxtable, Jack Kaufman, E. C. Luttgens, J. O. McNally, P. D. Miles, F. B. Mossman, F. H. R. Pounsett, Robert Serrell, Harry Sussman, W. G. Wagener, E. M. Williams, and G. A. Woonton; for admission to Senior Member grade, A. E. Barrett, H. H. Beaning, R. C. Dearle, A. M. B. deBivar, and K. C. Morrical; for transfer to Member grade, J. E. Browder, Harold Cafferata, W. F. Choat, R. N. Eubank, C. C. Fleming, L. J. Giacoletto, E. M. Goodell, F. M. Greene, N. M. Haynes, D. B. Hoisington, T. W. Hopkinson, V. M. LaPierre, G. P. McKnight, J. H. Nye, R. G. Petts, F. K. Priebe, C. W. Reash, J. H. Seidner, Q. M. Shultise, R. H. Siemens, D. C. Summerford, E. O. Swan, L. G. Swendson, R. G. Talpey, R. T. Van Niman, R. M. Wainwright, and S. D. White; for admission to Member grade, C. M. Backer, H. W. Bennett, V. T. Bowyer, H. M. Brett, A. K. Jensen, J. D. Kintzel, A. R. Knight, G. W. Rhein, M. B. Rudensey, D. A. Sandberg, Harald Schutz, J. W. Stafford, C. M. Wright, and A. J. Zink, Jr.; Associate grade, 133; and Student grade, 40.

Committees: The following committee appointments were unanimously recommended to the Board of Directors:

PAPERS PROCUREMENT

Timers and Technical Controls Group
J. M. Kleven, K. P. Puchlowski

Institute Representative in College: Unanimous approval was given to the recommendation that the Board appoint B. R. Teare, Jr., chairman of the Pittsburgh Section, as the Institute Representative at Carnegie Institute of Technology.

Visit of the President: President Turner reported on his recent two-week trip visiting several of the Sections in the East and Midwest and in Canada, and indicated that he would submit written notes to the Board members on these visits to the Sections.

Federal Communications Commission: Attention was called by the assistant secretary to the June 30, 1944, notice of hearing from the FCC, relating to Docket 6593 on "the investigation of the establishment and use of radio communications systems in railroad operations." The initial hearing will be held on September 13, 1944, in Washington.

Technical Committees

The chairmen of the Technical Committees met with Dr. F. B. Llewellyn of the Executive Committee of the Board on June 12, 1944, to discuss the technical committee work of the Institute and to lay plans for the future.

Prominent among these, is a Symposium to be held at the Midwinter Technical Meeting in January, 1945, where the attempt will be made to present the scope and methods used in committee work to the Institute in a manner that will acquaint the membership with this highly important activity. The Symposium will take the form of fairly specific examples rather than of routine reports from the various committee chairmen. It is expected that the objectives of I.R.E. standardizing activities will be discussed, with emphasis on their complete distinction from specification writing.

A number of suggestions were made relating to possible methods of extending participation in the activities of technical committees to those members located at considerable distances from the Headquarters in New York. It was agreed to bring these suggestions to the attention of the Sections Committee, and to suggest their inclusion on the agenda of the Sections

Committee meeting scheduled for the day preceding the opening of the Midwinter Technical Meeting.

The more detailed work of the individual committees was then discussed. The lack of a committee secretary as a member of the office staff who would attend all committee meetings and keep and co-ordinate the minutes is keenly felt. During the early days of the war, this service was discontinued. It was suggested that the time has now come when the situation could be reviewed, and Dr. Llewellyn accordingly agreed to bring it before the Executive Committee.

Presidential Nomination Petition

To the Board of Directors

"We, the undersigned, in accordance with Artice VII, Section 1 of the Constitution of the Institute of Radio Engineers, do hereby present this petition that the name R. A. Hackbusch of Toronto, Canada be placed on the forthcoming election ballot as a candidate for the office of President of the Institute of Radio Engineers for the year 1945."

The names of the signers are arranged in the order of arrival at the Institute headquarters.)

Page 1—Received July 17, 1944

C. A. Priest	Syracuse, N. Y.
H. R. Weir	Syracuse, N. Y.
H. P. Thomas	Syracuse, N. Y.
A. G. Manke	Schenectady, N. Y.

Page 2—Received July 24, 1944

O. Bruce Goldsmith	Williamsport, Pa.
J. J. Willendorf	Williamsport, Pa.
James G. Miles	Williamsport, Pa.
Myron O. Schilling	Williamsport, Pa.
Lewis I. Knudson	Montoursville, Pa.
L. E. West	Emporium, Pa.
Harry L. Ratchford	Williamsport, Pa.
D. W. Erickson	Williamsport, Pa.
Sidney Margolis	Montoursville, Pa.
Harry Smithgall	Williamsport, Pa.

Page 3—Received July 24, 1944

F. L. Burroughs	Williamsport, Pa.
W. C. Freeman, Jr.	Williamsport, Pa.
Allan W. Keen	Williamsport, Pa.
George N. Mahaffey	Williamsport, Pa.
C. B. Eckel	Williamsport, Pa.
Virgil M. Graham	Williamsport, Pa.

Page 4—Received July 25, 1944

Laurance M. Leeds	Schenectady, N. Y.
R. C. Longfellow	Schenectady, N. Y.
J. F. Wiggin	Schenectady, N. Y.
F. S. Rothe	Scotia, N. Y.
John Lloyd Jones	Schenectady, N. Y.
C. E. Hundstad	Schenectady, N. Y.
Styrk G. Reque, Jr.	Schenectady, N. Y.
Donald E. Watts	Schenectady, N. Y.
H. M. Crosby	Schenectady, N. Y.
F. M. Reynolds	Schenectady, N. Y.
L. H. Junken	Schenectady, N. Y.
G. H. Dunton	Schenectady, N. Y.
P. D. Andrews	Schenectady, N. Y.
J. W. Downie	Schenectady, N. Y.
H. B. Fancher	Scotia, N. Y.
K. E. Keister	Scotia, N. Y.
M. W. Scheldorf	Schenectady, N. Y.
J. F. Wilcox	Schenectady, N. Y.
J. K. Chapman	Schenectady, N. Y.
W. W. Brown	Schenectady, N. Y.

Page 5—Received July 28, 1944

F. A. Lidbury	Niagara Falls, N. Y.
F. M. Gaffney	Woburn, Mass.
W. R. G. Baker	Bridgeport, Conn.

Page 6—Received July 28, 1944

R. M. Bowie	Manhassett, L. I., N. Y.
N. L. Harvey	Emporium, Pa.

Page 7—Received July 31, 1944

Harvey J. Klumb	Rochester, N. Y.
Harry E. Gordon	Rochester, N. Y.
Arthur L. Schoen	Rochester, N. Y.
George R. Town	Rochester, N. Y.
Oliver L. Angevine, Jr.	Rochester, N. Y.
Maurice B. Huntington	Rochester, N. Y.
William F. Bellor	Rochester, N. Y.
E. S. Wilson	Rochester, N. R.
C. Traino	Rochester, N. Y.
C. A. Stutt	Rochester, N. Y.
M. J. Larsen	Rochester, N. Y.
Frederick C. Sanderson	Rochester, N. Y.
Arthur E. Newlon	Rochester, N. Y.
P. S. Schmidt	Rochester, N. Y.
Roy S. Anderson	Rochester, N. Y.
Ken L. Henderson	Rochester, N. Y.
Harold Goldberg	Rochester, N. Y.
Richard G. Talpy	Rochester, N. Y.
Edward De Mers	Rochester, N. Y.
Newton H. Odell	Rochester, N. Y.

Page 8—Received August 1, 1944

C. G. Fick	Bridgeport, Conn.
R. E. Moe	Bridgeport, Conn.
D. W. Pugsley	Bridgeport, Conn.
R. B. Dome	Bridgeport, Conn.
S. Berkoff	Bronx, New York
R. B. Gethmann	Bridgeport, Conn.
S. Goldman	Bridgeport, Conn.
J. C. Coykendall	Bridgeport, Conn.
C. S. Root	Bridgeport, Conn.
R. J. Biele	Bridgeport, Conn.

Page 9—Received August 4, 1944

G. J. Irwin	Toronto, Canada
H. W. McFadden	Toronto, Canada
Charles O. Baldwin	Toronto, Canada
J. K. Williams	Toronto, Canada
R. C. Poulter	Toronto, Canada
M. C. Patterson	Toronto, Canada
F. B. Nobbs	Toronto, Canada
R. G. Anthes	Toronto, Canada
J. R. Longstaffe	Toronto, Canada
C. A. Jarvis	Toronto, Canada
A. Bow	Toronto, Canada
E. Olson	Toronto, Canada
N. S. Dawson	Toronto, Canada
Wm. F. Choat	Toronto, Canada
J. R. Warren	Toronto, Canada
Fred J. Heath	Toronto, Canada
B. A. Coy	Toronto, Canada
R. O. Schlegelmilch	Toronto, Canada
C. J. Bridgland	Toronto, Canada
J. C. R. Punchard	Toronto, Canada
F. N. R. Pounsett	Toronto, Canada
H. C. Gillmor	Toronto, Canada
A. T. R. Armstrong	Toronto, Canada
C. N. Chapman	Toronto, Canada
F. S. Mackay	Toronto, Canada
G. F. Kelk	Toronto, Canada
J. R. Whyte	Toronto, Canada
Lloyd M. Price	Toronto, Canada
W. Happe, Jr.	Toronto, Canada
Leo Jarvis	Toronto, Canada

I.R.E. People

John J. Farrell

John J. Farrell has been appointed engineer of the transmitter division of the General Electric Company's electronics department, according to an announcement by C. A. Priest, division manager. In this capacity, Mr. Farrell will be responsible for all engineering matters pertaining to production and other activities of the division and will be located at Schenectady. He was previously designing engineer for the division.

Born in Watervliet, New York, he entered the student training course of the General Electric Company at Schenectady in 1913, then spent five years in the General Electric drafting department. From 1918 to 1920, Mr. Farrell engaged in tool-design work with the United States Arsenal, Department of Ordnance, at Watervliet, and with companies at South Bend, Indiana, and Toledo, Ohio.

John J. Farrell

In 1920, he returned to the Genera Electric Company as a radio designing draftsman. He was promoted to drafting supervisor of the transmitter division in 1921 and entered the mechanical engineering section in 1926. He became head of the section in 1934 and was appointed designing engineer of the transmitter division in 1938.

As an installation engineer, Mr. Farrell supervised the placing in service of many high-power broadcast stations. Among these were the 50-kilowatt transmitters at KOA, Denver; KPO, San Francisco; and KFI, Los Angeles; and the original 50-kilowatt transmitter at WEAF. Mr. Farrell was the General Electric project engineer on the installation of the 500-kilowatt amplifier at WLW, Cincinnati.

Mr. Farrell joined the Institute of Radio Engineers in 1943 as an Associate. He is a member of the American Institute of Electrical Engineers.

Dr. H. H. Beverage Awarded Signal Corps' Certificate

Dr. Harold H. Beverage, associate director of RCA Laboratories in charge of communications research, was presented the United States Army Signal Corps' Certificate of Appreciation on June 28, 1944. The presentation was made by Colonel Jay D. B. Lattin, Signal Officer of the Second Service Command, representing Major General H. C. Ingles, Chief Signal Officer of the United States Army Signal Forces.

As stated in a letter of citation received by Dr. Beverage from Major General Ingles, the award today was in recognition of Dr. Beverage's "tireless effort and valuable advice during the installation of a radio circuit in the North Atlantic route" which "constituted a great contribution to the Signal Corps in its gigantic task of furnishing the United States Army the world's greatest communication system."

Entering the employ of the Radio Corporation of America in 1920, after making contributions to radio communications in World War I, Dr. Beverage is the inventor of the "wave antenna," which became the standard for long-wave radio reception in America and abroad.

In 1929, when R.C.A. Communications, Inc., was formed, Dr. Beverage was named chief research engineer, and in 1940 was made vice president in charge of research and development. He was awarded the Morris Liebmann Memorial Prize of The Institute of Radio Engineers and holds a number of patents. He joined the Institute in 1915 and became a Fellow in 1928. Dr. Beverage was President of the I.R.E. in 1937.

R. J. Keogh

R. J. Keogh (A'30), has recently joined the engineering staff of Webster Products, in Chicago.

Mr. Keogh has a background of nearly twenty years of practical experience in the radio industry since his graduation from Purdue University. He was issued patents for early developments of the vibrator for auto radios. Ten years ago Mr. Keogh joined the Sears, Roebuck organization. For the past two and a half years he was with the Colonial Radio Corporation.

Frederick R. Lack

At the twentieth annual meeting of the Radio Manufacturers Association held in Chicago on June 6 and 7, Frederick R. Lack, vice-president and manager of the radio division of the Western Electric Company, was elected a director for a term of two years. Mr. Lack recently served as director of the Army-Navy Electronics Production Agency in Washington. He joined the Institute of Radio Engineers as an Associate in 1920 and transferred to Fellow grade in 1937.

John H. Ruckelshaus

The formation of a new company known as the Madison Electrical Products Corporation, with plant located in Madison New Jersey, has just been announced by John G. Ruckelshaus (A'42), its vice-president and chief engineer.

The company specializes in the manufacture of precision and wire wound resistors, electronic, electrical and radio assemblies, coil windings and special components used in communication work.

Mr. Ruckelshaus, has specialized in the design and manufacture of radio and electrical apparatus since 1921, having operated one of the first amateur licensed tube transmitters. Starting with the manufacture of crystal receiving sets, he later marketed his own line of radio receivers, using special vacuum-tube circuits of his own design and introduced the first receiving set, using a form of volume control instead of "plugs and jacks." Other achievements include novel traffic-control items, refrigeration and ignition systems and a number of patents pertaining to animated window-display devices which were in wide use up to our entry in the war. He had been doing considerable development work for the United States Signal Corps.

National Electronics Conference

A comprehensive program covering television, ultra-high frequency, and radio developments in the communications field and industrial measurements, electronic controls, induction heating, and power and medical applications of electronics has been announced by the Executive Committee of the National Electronics Conference to be held at the Medinah Club, Chicago, Illinois, on October 5 to 7, 1944.

J. E. Hobson, director of the school of engineering of the Illinois Institute of Technology is chairman of the Executive Committee of N.E.C.

Keynoter speakers for the technical sessions will give broad perspectives of progress in the various fields, and expectations for future developments. Opportunity will be given throughout the Conference for conference-type discussions.

Comprehensive Program Planned

A comprehensive program, embracing all important fields of electronics has been prepared by Prof. Arthur B. Bronwell, Northwestern University, Evanston, Ill., who is also chairman of the Program Committee. Outstanding engineers and scientists have promised to prepare technical papers for presentation at the Conference. Although the program is still subject to some minor modifications and changes, the tentative program indicates that practically all persons interested in one or more branches of the broad field of electronics will find a program suited to their interests.

Keynoting the objectives of the Conference will be an opening address by Ralph R. Beal, research director for the Radio

Corporation of America, entitled, "Electronic Research Opens New Frontiers."

W. C. White, director of the electronics laboratory, General Electric Company, will speak on "Electronics in Industry" at one of the Conference luncheons.

The tentative program of technical topics for the Conference includes the following papers grouped according to main topic divisions:

(1) TELEVISION

"Color and Ultra-High Frequency Television," by P. C. Goldmark, Columbia Broadcasting System

"Reflective Optics in Television," by I. G. Maloff, RCA Victor Division, and D. W. Epstein, RCA Laboratories

"Radio-Relay Systems," by C. W. Hansell, RCA laboratories

(2) ULTRA-HIGH FREQUENCIES

"A Lighthouse Tube; A Pioneer Ultra-High-Frequency Development," by E. F. Peterson and E. D. McArthur, General Electric Company

"Principles of Klystron Amplifiers," by Robert Haxby, Sperry Gyroscope Company

"Development of Electronic Tubes," by I. E. Mouromtseff, Westinghouse Electric and Manufacturing Company

"Wire-Frequency-Range Tuned Circuits for High Frequencies," by D. B. Sinclair, General Radio Company

"Ultra-High-Frequency Converters and Conversion Diagrams," by Harry Stockman, Cruft Laboratory, Harvard University

(3) RADIO

"A Method for the Generation of Quasi-Continuous Frequency Spectra for use with Secondary-Frequency Standards," by Harold Goldberg and Richard G. Talpey, Stromberg Carlson Company

"A Frequency-Dividing Lock-In Frequency-Modulation Oscillator Receiver," by G. L. Beers, RCA Victor Division

"Incremental Permeability Tuning," by W. J. Polydoroff, Consulting Engineer

"Audible Audio Distortion," by H. H. Scott, General Radio Company

"Broad-Band Carrier and Coaxial-Cable Networks," by F. A. Cowan, American Telephone and Telegraph Company

(4) INDUSTRIAL MEASUREMENTS AND SPECIAL DEVICES

"The Supersonic Reflectoscope: An instrument for Inspecting the Interior of Metal Parts by Means of Sound Waves," F. A. Firestone, University of Michigan

"Dynamic-Strain Gages," by C. A. Dohrenwend, Armour Research Foundation

"The Mass Spectrometer and its Practical Applications," by J. A. Hipple, Westinghouse Electric and Manufacturing Company

"Two-Million-Volt X-Ray Unit," by E. E. Charlton and W. F. Westendorp, General Electric Company

"Industrial Fluoroscopy of Light Materials," by Scott W. Smith, Kelley-Koett Manufacturing Company

"Application of Amplifier Theory to Mechanical Stability Problems," John M. Cage, Allis-Chalmers Manufacturing Company

(5) INDUSTRIAL ELECTRONIC CONTROLS

"Electronic Mechanisms in Process Plant and Industrial Laboratory," by T. A. Cohen, Wheelco Instrument Company

"Electronic Measurements of Nonelectrical Quantities in Industrial Processes," by N. D. Middell, General Electric Company

"Cathode-Ray Tubes and Their Application," by P. S. Christaldi, Allen B. DuMont Laboratories

"Electronics in Industrial Instrumentation," by Walter P. Wills, Brown Instrument Company

"Design Factors in the Application of Relays to Electronic Circuits," by R. H. Herrick, Automatic Electric Company

(6) INDUCTION HEATING

"High-Frequency Induction Heating by C. J. Madsen and R. M. Baker, Westinghouse Electric and Manufacturing Company

"New Methods and Techniques in High-Frequency Heating," by Eugene Mittelmann, Illinois Took Works

"The Use of High-Frequency Electronic Generators to Obtain Controlled-Power Concentrations for Industrial-Heating Applications," by Wesley Roberds, RCA Victor Division

(7) ELECTRONIC APPLICATIONS IN THE POWER FIELD

"A Survey of Power Applications of Electronics," by A. C. Montieth, Westinghouse Electric and Manufacturing Company

"Power Rectifiers and Inverters," by J. A. Cox and G. F. Jones, Westinghouse Electric and Manufacturing Company

"Electronic Power Converters," by E. F. W. Alexanderson, General Electric Company

(8) MEDICAL APPLICATIONS OF ELECTRONICS

"Electronic Equipment in the Medical Profession," by A. H. Carter, American Medical Association

"Electroencephelography," by Ralph Girard, University of Chicago

(9) RECENT THEORETICAL DEVELOPMENTS IN ELECTRONICS

"Theory of Microwave Oscillation Generators Using Velocity-Modulated Electron Beams," by E. U. Condon, Westinghouse Electric and Manufacturing Company

"Theorem of Lorentz and Its Importance for All Problems of Electronics in Magnetic Fields," by Leon Brillouin, Columbia University

"Transient Response of Wide-Band Amplifiers," by W. W. Hansen, Sperry Gyroscope Company

Within the limits of the secrecy imposed for National security, these papers represent frontier advancements and practical developments in their respective fields.

MEDINAH CLUB CONFERENCE HEADQUARTERS

The Medinah Club of Chicago, 505 N. Michigan Ave., Chicago, 11, Illinois, will be headquarters for the National Electronics Conference. It will have facilities for all Conference activities and can accommodate approximately 250 persons who wish to make this their Conference headquarters, in its single and double rooms. The Club will be pleased to reserve rooms in the nearby North-Side Hotels to accommodate any overflow. Those persons planning to attend the Conference are urged to make their hotel and train reservations at an early date.

Professor P. G. Andres, chairman of the Arrangements Committee, announced that his committee would be equipped to accept registrations for the Conference by September 1. Important groups in the electronics field will be circularized by mail and may return the registration card, with which they will be supplied, to Professor P. G. Andres, Illinois Institute of Technology, 3300 Federal Street, Chicago, 16, Illinois. Advance registration by mail is desirable to facilitate the rapid handling of registration during the Conference.

A refreshing program of activities to balance the rather concentrated technical conference is also being developed by Professor Andres as part of the regular Conference activities.

Further information concerning details of the Conference may be obtained from:

Dr. J. E. Hobson, Chairman, Executive Committee
Illinois Institute of Technology, 3300 Federal St., Chicago, 16, Ill.

Prof. A. B. Bronwell, Chairman, Program Committee
Northwestern University, Technological Institute, Evanston, Illinois.

Prof. P. G. Andres, Chairman, Arrangements Committee
Illinois Institute of Technology, 3300 Federal Street, Chicago, 16, Ill.

Mr. B. Dudley, Chairman, Publications and Publicity Committee
520 N. Michigan Ave., Chicago, 11, Ill. Room 1210

The National Electronics Conference is sponsored by the Illinois Institute of Technology, and Northwestern University as participating sponsors, and the Chicago Sections of the American Institute of Electrical Engineers and the Chicago Section of the Institute of Radio Engineers as cooperating sponsors.

WILLIAM ARTHUR WINTERBOTTOM

William Arthur Winterbottom was born in Liverpool, England, in 1884. At the age of 16 he was a junior telegraph operator in the British Postoffice in Manchester.

He became a cable telegraph operator for the Commercial Cables Company in New York in 1903 and rapidly rose in that organization to become director of traffic production. During this period he maintained his interest in the progress of radio, and had an amateur radio station in his home.

In 1914 Mr. Winterbottom was appointed commercial manager for the Marconi Wireless Telegraph Company of America in New York, and immediately began preparations for the opening of radio communication service between this country and Britain. The advent of the first World War curtailed this work, and Mr. Winterbottom transferred the scene of his activities to the Pacific, where the results were widely acclaimed. He visited Hawaii to open the first radiotelegraph service with Japan. At the close of the war, the Radio Corporation of America made Mr. Winterbottom its traffic manager, and he supervised the completion of an ever-increasing

William Arthur Winterbottom

number of radio circuits across the Atlantic, and between the North and South American countries. In 1926 he supervised the reception in the United States of the first picture transmitted by commercial radio service, which was sent to the *New York Times* and reproduced the following day.

As vice-president and general manager of R.C.A. Communications, Mr. Winterbottom continued his interest in the expansion of the radio communications of that company over the period of fourteen years preceding his death, and was recognized as the guiding hand behind much of the contribution made by that company to the war effort.

He was a member of the Radio Club of America, the Veteran Wireless Operators Association, and The Institute of Radio Engineers, of which he became an Associate member in 1915 and a Member in 1928. He was widely recognized as a constructive planner and effective worker in the radio communications field, and as a thoughtful and genial gentleman.

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 individual opinion of 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.

Frequency and Phase Modulation

There seems to be still some confusion about frequency modulation and phase modulation since the instantaneous value of a sinusoidal current may be defined by

$$I_t = I \sin(\Omega t + \theta) \qquad (1)$$

where I denotes the carrier level, I_t the instantaneous current level, $\Omega/6.28 = F$ the frequency level, and θ the phase level. By level is meant the undisturbed reference value when no modulation occurs.

For amplitude modulation the value of $I \pm i$ varies about the reference value I. Both Ω and θ remain fixed.

For frequency modulation we have instantaneous F_t values about the reference value F. Both I and θ remain fixed.

For phase modulation we deal with instantaneous θ_t values about the reference value θ (which may be zero in this case). Both I and Ω are fixed.

There seems to be no doubt about amplitude modulation in comparison to either phase modulation or frequency modulation and no explanation is in order.

From a mathematical point of view, it is true that we may combine $\Omega t+\theta$ and call it, say $\Omega t+\theta = \Phi t$, resulting in the expression

$$I_t = I \sin \Phi t \qquad (2)$$

and the integral and differential versions in case of phase modulation and frequency modulation are well known in literature since about 1921 in radio and about 1860 in acoustics.

From an engineering point of view a generalized Φ_t concept has to be taken "with a grain of salt" since it may get us "into deep water."

The engineer has to design circuits as well as to use certain devices to accommodate such functions as Φ_t. For this reason the designer has to distinguish between $\Phi_t = 2\pi F_t \cdot t + \theta$ and $\Phi_t = 2\pi F \cdot t + \theta_t$ since in one case F_t is no longer fixed while in the other case it is fixed. In other words it would be hopeless to think of using a "frequency-stiff" piezo master oscillator when Φ_t represents $2\pi F_t t + \theta$ since F cannot be fixed ("stiff") but swings over wide ranges and with a speed due to the modulation frequency f and a maximum deviation due to the intensity i of the modulating current. On the other hand it is not only permissible but essentially imperative to use a primary carrier frequency source with a stabilized ("stiff") frequency for phase modulation when the relation $\Phi_t = 2\pi F \cdot t + \theta_t$ holds. The reason for this is that the modulator has to vary now in phase and should not vary in the least the carrier frequency F since this would cause distortion. This is clear if we realize that a frequency-modulation discriminator in a frequency-modulation receiver is designed for the $\Delta F/f$ effect, while a phase-modulation discriminator is designed for the $\Delta\theta$ effect where ΔF and $\Delta\theta$ are respective deviations from the reference level F in case of frequency modulation and reference level θ for phase modulation. Only for a condition for which $\Delta F/f = \Delta\theta$, would both types of discriminators produce the same result at the output of the receiver. It is true that a simple correcting network of a resistance and a condenser properly connected to the output terminals of a discriminator will translate properly into faithful audio-frequency recovery when a frequency discriminator is combined with such a correcting network or when a phase discriminator is employed with a suitable corrector.

However, when both frequency and phase modulation are present, distortion will occur since the change-over by a corrector from a frequency discriminator to a phase discriminator will cause now partially wrong audio-frequency emphasis for received frequency-modulation waves and deemphasis for received phase-modulation waves since in the first case parasitic phase modulation and in the latter case parasitic frequency modulation is not translated properly.

Even if we deal with the most simple case of a sinusoidal wave train expressed by (1) we shall find a great difference between variations in Ω and variations in θ. Imagine that 20 cycles of such a wave are drawn on a piece of cardboard 1 by 10 inches. Suppose we draw also the same number of complete waves on a rubber strip of exactly the same dimensions. If we made the cardboard the slider of a slide rule and move it to and fro we have a picture of pure phase modulation since 20 complete waves move "as a whole" to and fro. The waves are neither squeezed together nor stretched apart nor changed in amplitude for such a to-and-fro operation. Matters are much different for the rubber model if we stretch it and relax the tension along the 10-inch dimension (ignoring the small crosswise constructions and expansions). We shall find that the ordinate values of the 20 complete waves still remain the same but at certain moments the waves are farther apart and at other moments more crowded. This is frequency modulation, and surely not the same picture as the slider performance representing phase modulation.

Electrical networks and space used in wave propagation have, so to speak, "no eyes" and cannot perceive such illustrations as just mentioned. Nevertheless, they must have different effects in such networks and in a propagation medium, otherwise the modulation energy recovered in a receiver would be not intelligible. Fortunately, in many cases, space is nondispersive offering when free from obstructions always the same wave resistance of essentially 377 ohms and in many cases we may assume that frequency- and phase-modulation waves arrive without medium distortion (distortion could happen in the ionized layer).

With electrical networks we do not have such a fortunate condition and they have to be designed for phase- or for frequency-modulation currents. An analysis of the rubber model in operation (frequency modulation) and the slider model (phase modulation) shows that in equivalence we have to deal practically with several side currents. This requires that all radio- and intermediate-frequency networks accommodate all the significant side currents (at least all on one side of the carrier current of frequency F). Since both frequency and phase discriminators translate frequency- or phase-modulation currents first into amplitude-modulation effects and into audio-frequency recovery thereafter, we must avoid networks which cause phase distortion even for arriving frequency-modulation waves. Otherwise equivalent frequency modulation also occurs which is also translated in the discriminator. This would result finally in audio-frequency distortion. This means that the radio- and intermediate-frequency networks have to be linear with respect to amplitude and phase for the entire bandwidth required to accommodate the significant side currents.

For frequency modulation the bandwidth is given by the modulation index $\beta=\Delta F/f_e$ if ΔF stands for the maximum frequency deviation from the assigned carrier frequency F of a station and f_e denotes the lowest audio frequency to be transmitted. The value of ΔF for broadcast work is fixed at ± 75 kilocycles per second. It corresponds to full frequency modulation, that is, maximum modulation depth. It is the lowest audio frequency $f=f_e$ which counts in the design of networks since this frequency gives the largest β value and, therefore, also the most severe bandwidth condition.

For phase modulation the required bandwidth is given by the modulation index $\beta=\Delta\theta$ if $\Delta\theta$ stands for the maximum phase deviation. This deviation is *constant* for a given transmitter design and is independent of the pitch f of the audio frequency. This is surely different from the variable $\beta=\Delta F/f$ in case of frequency modulation. It is true the value of $\Delta\theta$ can be chosen, and probably will also be so chosen by a designer as to be numerically identical with the value of $\Delta F/f_e$.

The radio- and intermediate-frequency networks have to be designed for frequency modulation according to the magnitude of $\Delta F/f_e$ and for phase modulation according to the magnitude of $\Delta\theta$. An analysis shows that for frequency modulation the bandwidth required is $2k\cdot\Delta F$. A good value for k is 1.5 for high-fidelity work.

The discriminator characteristic does have to accommodate only the range $2\Delta F$ and is independent of f in case of frequency modulation. Inasmuch as it is difficult to secure true linearity over a $2\Delta F$ range for ΔF values close to $\Delta F=\pm 75$ kilocycles it is good engineering practice to design for a range somewhat larger than $2\Delta F$.

It should be realized that the discriminator is fed by a network which requires a bandwidth according to $2k\Delta F$.

August Hund
728 Adelaide Place
Santa Monica, California

Modulated-Beam and Cathode-Ray Phase Meter

Captain Alan Watton, Jr., whose paper "Modulated-Beam Cathode-Ray Phase Meter," appeared on pages 268 to 272 of the May, 1944, issue of the Proceedings, has sent the following note to the Institute of Radio Engineers:

It has been brought to my attention by Mr. William R. McLean that some years ago he and L. J. Sivian developed a phase meter which employs a similar principle to that propounded in my paper. A description is given in "A Direct Reading Audio-Frequency Phase Meter," *Journal of the Acoustical Society of America*, Vol. 2, pp. 419–433; April, 1931.

They used a thyratron pulse circuit acting upon the anode potential in place of the present method of using a "clipper" circuit acting upon the intensity grid potential.

Books

Foundations of Wireless, by M. G. Scroggie

Published (1943) by Iliffe and Sons, Ltd., Dorset House, Stamford St., London S.E. 1, England. 351 pages+7-page index +xi pages, 221 figures. $4\frac{3}{4}\times 7$ inches. Price, 7/6.

The author planned a brief, clear, and simple presentation of radio principles. The publisher carried out the idea by printing a textbook of pocket size.

"Foundations of Wireless" amply covers the basic principles of radio with special emphasis on radio receivers. Mathematics has been reduced to a minimum, and the book will, therefore, appeal to readers who are primarily interested in gaining a clear physical picture of radio principles.

The important sections, stages, circuits, and components to be found in radio receivers and transmitters are well covered, although the author has limited himself to basic circuits, rather than covering the many variations to be found in the art. The author has written in a very readable style and the reader knows its importance before a subject is taken up.

The book is written concisely and to the point; is well organized and in logical sequence—written in lecture form so that although it is intended for receiver technicians and advanced beginners, it would be stimulating reading for the radio engineer.

The publisher tells us that this is the fourth edition, completely revised and the reviewer has found it reasonably up-to-date.

J. E. Smith
National Radio Institute
Washington, D. C.

How to Pass Radio License Examinations, by C. E. Drew

Published by John Wiley and Sons, Inc., 440 Fourth Avenue, New York, N. Y., 320 pages+v pages. 114 illustrations. $6\frac{3}{4}\times 9\frac{3}{4}$ inches. Price, $3.00.

This book is designed to aid radiomen preparing to take any type of commercial radio-license examination of the Federal Communications Commission. The main body of the book is composed of answers to the questions which appear in the government publication "Study Guide and Reference Material for Commercial Radio Operator Examinations," developed by the FCC in 1939 to furnish the prospective licensee with an idea of the scope and nature of the revised examinations.

The book is therefore divided into six sections, corresponding to the elements of the examinations, as follows:

Element 1. Basic Radio Laws
Element 2. Basic Theory and Practice
Element 3. Radiotelephone
Element 4. Advanced Radiotelephone
Element 5. Radiotelegraph
Element 6. Advanced Radiotelegraph

In addition, the book contains an appendix of four sections, as follows:

I. Rules Governing Commercial Radio Operators
II. Extracts From Radio Laws
III. *Q* Code and Abbreviations
IV. Miscellaneous

The first three sections represent transcriptions of material presented in FCC publications, while the last section includes tables of radio symbols and abbreviations, frequency-wavelength conversion tables, and a description of the marine Auto Alarm system developed by R.M.C.A.

As a whole, this work appears to be superior to previous publications of this type. Notably, one finds greater accuracy in the choice and expression of formulas, and more care in specifying the case to which the formula is applicable and the units in which the factors are expressed where basic units are not employed. Also, the author has included discussions and notes immediately following the answers with a view to enabling the reader to understand the manner in which fundamental principles were applied in arriving at the aforestated answer. This will aid the reader in handling successfully examination questions based on the same general principles but worded in a somewhat different manner.

A few minor errors or poorly expressed statements were noted. The author has continued to use the oersted as a unit of reluctance. Occasionally there has been an overlapping of sense in the parts of answers to questions of the type. "What factors determine . . . ," "What are the characteristics of . . . ," etc. For example, it is stated that the factors which determine the amplitude of an induced electromotive force are "number of lines of force, or flux density; rate of cutting the lines; angle at which the conductor cuts across or through the flux; length of the conductor." The second factor is really a composite of the other three.

The usefulness of the book could be increased by the incorporation of an index, particularly since the author has presented the questions in the sequence in which they appear in the FCC "Study Guide."

It is felt that these deficiencies will not detract seriously from the achievement of the generally accepted purpose of a book of this type, namely, to acquaint the man who has already acquired a thorough knowledge of elementary radio theory through lecture courses or the study of standard text books, with the nature of the FCC examination questions, and the general type of answer expected, so that he may face the examination in a better state of preparedness and a more confident frame of mind. As for the all too-prevalent type of operator who perversely attempts to make the study of a book of this type a substitute for a well-grounded general knowledge of radio theory acquired through the arduous pursuit of a logical course of study, it is felt that he will suffer less harm and probably acquire more genuine knowledge in spite of his attitude, from this book than from previous publications of this type.

Albert Preisman
Capital Radio Engineering Institute
Washington, D. C.

Mathematical and Physical Principles of Engineering Analysis, by Walter B. Johnson

Published by McGraw-Hill Book Company, 330 West 42nd St., New York 18, N. Y., 336 pages+10-page index+x pages. 163 illustrations. $5\frac{1}{2}\times 8\frac{1}{2}$ inches. Price, $3.00.

This book attempts rather successfully to present concisely the important physical and mathematical principles as well as the methods of approach underlying practical engineering problems. It is not an elementary book but requires a knowledge of physics, mechanics, and mathematics through calculus. Although the text includes a reasonable amount of elementary material on differential equations a previous familiarity with this subject is helpful.

In addition to the presentation of the more common mathematical subjects such as ordinary differential equations, vector representation, and Fourier series, the book contains chapters on analysis of engineering problems, basic physical principles, transient and steady-state conditions, setting up equations, checking of equations, dimensional analysis, and systems with distributed constants.

The book, although intended for all fields of engineering, is particularly helpful in the fields of electrical and mechanical engineering. The material is illustrated by many examples and a large number of problems are presented for solution. The book is well suited to use as a text for advanced engineering students and as such should prove helpful in aiding the student to correlate his knowledge of mathematics, physics, mechanics and electricity. The book should prove particularly interesting to graduate and practicing engineers who wish to review their fundamental background material from the viewpoint of mathematical approach.

Ferdinand Hamburger, Jr.
Johns Hopkins University
Baltimore 18, Maryland

Electrical Essentials of Radio, by M. Slurzberg and W. Osterheld

Published by McGraw-Hill Book Company, 330 W. 42nd St., New York 18, N. Y. 512 pages+17-page index+xl pages, 324 figures+9 pages of illustrations. $5\frac{3}{4}\times 8\frac{3}{4}$ inches. Price, $4.00.

This book was written to provide high-school, technical-school, and trade-school students and others, such as radio amateurs and workers in the communications industry, with a suitable text on the electrical essentials of radio.

The book begins with a discussion of the various methods of communication and briefly traces the history of the art up to the development of radio communication as we know it today. This is followed by a general discussion of some of the basic underlying principles and a simple explanation of radio transmission and reception. Then follow chapters on basic theory of electricity, batteries, electric circuits, magnetism, meters, electrical power apparatus, inductance, and capacitance. The last third of the book covers alternating-current circuits, resonance, and basic radio circuits.

The book is well written and contains an unusually large number of clear-cut photographs and drawings. Each chapter is followed by (1) a bibliography, (2) from 25 to 50 questions, and (3) from 15 to 45 problems. A large number of problems are worked out as examples in the text. No mathematical knowledge beyond simple arithmetic is assumed. Various topics beyond this are explaned and illustrated by examples as the need for them arises.

A few points were noticed which are either in error or questionable because of a rather inexplicit method of statement. Such an example is found on page 311. "The current of a capacitor discharing through a resistor will be an oscillatory current. . . ." Another example is found on page 475 where the idea is set forth that coupling in double-tuned air-core transformers is adjusted to the critical value by varying the *Q* of the coils whereas in the usual case it is the coil separation which is varied to provide the proper degree of coupling. Such examples are infrequent and no doubt will be corrected in future editions.

This book, in the opinion of this reviewer, is a practical, up-to-date volume which should fill a definite need. It is to be followed by a companion volume—"Essentials of Radio."

W. O. Swinyard
Hazeltine Electronics Corporation
Chicago, Illinois

Shop Job Sheets in Radio, Book 1—Fundamentals, by Robert Neil Auble

Published (1944) by The Macmillan Company, 60 Fifth Avenue, New York, N. Y., 134 pages+43 illustrations, 8×11 inches. Price, $1.50.

This is a new book which is intended to assist the beginner in radio to obtain a practical working knowledge of the electrical fundamentals of radio. It is directed to the beginner of limited experience who requires a textbook in practical radio shopwork. It should serve as a good laboratory manual in the training of beginners for installation and maintenance work. It consists essentially of some 30 job sheets; each of which covers several pages. The job sheets, each intended as one lesson or exercise, are divided into the following sections:

Objectives	What to do
References	Optional exercises
Topics for classroom discussion	Form of report to instructor
Related knowledge	Question Section
Related skills	

Each question in the last section has ample space provided for the answer including a diagram when required.

The book is intensely practical and covers the making of electrical connections, wiring, symbols, schematics, continuity checking, circuit elements, elementary laws of electricity including Ohms law and Lenz's law, measuring instruments, transformers, coil winding, and the construction of simple electrical circuits. No formulas are used and the treatment of each problem is most elementary. Reference reading as well as detailed explanation by the instructor is required. Some twelve reference books and manuals are included in the bibliography, among them being tube manuals, and texts for the radio service man.

The order in which the material is presented is logical, the arrangement is good, and the exercises well prepared. The illustrations appear to be ample and easily interpreted without aid of the instructor. The author provides ample space for notes. Since all of the student work sheets are bound in the book together with the instructor's corrections and grading, the book can be used by the student for reference after completion of the course. The book appears to be free of errors and covers the intended subject matter adequately. This is the best text of its type that has come to this receiver's attention.

F. X. Rettenmeyer
RCA-Victor Division
Radio Corporation of America
Camden, New Jersey

Ein Rohrengeraet zur Messung von Leistung, Spannung und Strom, by Alfred Spaelti

Published (1943) by Verlag A. G. Gebr, Leeman and Company, Zurich. 69 pages+38 illustrations. 6½×9 inches. Price, S. Fr. 6.

This booklet covers the theory, circuit design, and adjustment of a vacuum-tube wattmeter of the following characteristics: voltage range, 1.5 to 300 volts at 1000 ohms per volt; current range, 1 milliampere to 5 amperes at 56 millivolts drop; minimum wattage for full deflection 1.5 milliwatts; frequency range 30 to 5000 cycles per second. The circuit uses 4 matched 6F5 tubes in a balanced circuit with the operating paint so chosen that the second derivative of the plate-current—grid-voltage curve is a maximum. In this way, an unbalanced galvanometer current can be obtained which is proportioned to the product of current, voltage, and cosine of the phase angle. The theory, the errors and design are all developed in a clear and easily readable way. All factors are satisfactorily treated. The author finally gives measurements on the completed wattmeter showing errors produced by waveform distortion, low power factor, and high frequency. The performance of the device seems very satisfactory over its design range.

This volume is evidently the author's doctor dissertation. It is recommended to engineers interested in audio-frequency power measurements.

E. E. Spitzer
Radio Corporation of America
Lancaster, Pa.

"Principle of Electronics," by R. G. Kloeffler

Published (1942) by John Wiley and Sons, Inc., 601 West 26th St., New York 1, N. Y. 171 pages+3-page index+ix pages. 170 figures. 6¼×9¼ inches. Price, $2.50.

Although the scope of the book is not implied by its name, the author states in the preface that the book is intended for and actually is used by him as the text book for an introductory course in teaching electrical engineering to sophomores and juniors. He feels, also, that it can be of help to those practicing engineers who in their past curriculum lack training in electronics and who desire to obtain an understanding of this new field in science. The author suggests that the extreme simplicity of action taking place in the electronic tube justifies the use of his book as an introduction to the art of electrical engineering, instead of the customary study of electric and magnetic circuits.

The first five chapters (30 pages) deal with the general conception of the electron and ions, the atomic structure of matter and the explanation of the nature of electric current through gases, vapors, and vacuum, also, through solid and liquid bodies.

Then, a chapter (14 pages) is allotted to a general discussion of electron emission, pre-eminently from tungsten, thoriated tungsten, and oxide-coated metals. This is followed by a chapter (15 pages) with general discussion of two-electrode tubes, both of high-vacuum and gas (vapor) types (15 pages). The electronic mechanism and space charge is explained qualitatively, and representative characteristics of vacuum diodes are briefly discussed. Examples of mercury vapor diodes are mentioned and illustrated.

The longest chapter (36 pages) is given to three-electrode tubes, in which both high-vacuum triodes, the Thyratron, and Ignitron are included. The effect of the grid, also, certain tube characteristic charts, and some circuits are discussed in connection with the high-vacuum triodes. Structural features are touched upon only slightly. The discussion is built up mainly around the receiving types of tubes. The thyratron and ignitron are given special attention, especially in regards to their electronic mechanism.

In a separate chapter (12 pages) "special" tubes are briefly discussed. Among them are listed tetrodes, pentodes, beam-power tubes, cathode-ray, and electron-multiplier tubes.

The X-ray tubes, the magnetron, and electron microscope are touched upon in another short chapter (5 pages).

Relatively great attention is given to the copper-oxide and selenium rectifiers in a chapter headed "Rectifying Devices" (16 pages); they are followed by the description of the mercury tank rectifiers and the "Excitron." In the same chapter rectifier filters are briefly treated.

Considerable attention is also paid to the photosensitive devices which occupy two chapters of 20 pages total length.

The very last chapter, "Electronic Applications and Circuits" (20 pages), first describes rectifier circuits and filters; in some degree, this is a repetition of previous information, but in somewhat greater details than in previous chapters. In addition, it gives schematic drawings and a brief description of smoke and dust precipitators; the diode radio-frequency detector circuit; a typical radio-receiver circuit; automatic volume control; a typical radio-transmitter circuit; Thyratron and Ignitron circuits and their combined application in resistance welding. Finally, power inversion and some specific uses of photocells are very briefly discussed.

From this bird's-eye view of the subject matter one can see that the intended scope is pretty well covered. One may perhaps note the absence of the important modern industrial applications which would be in place in a book of this character; these are carrier-current applications and industrial heating. Also, on par with the electron microscope, the cyclotron could be briefly mentioned. On the other hand, one may point out that the extremely brief discussion of the magnetron (less than one half a page) without preceding it with the conception of electron motion in a magnetic field is insufficient even for obtaining a rough idea of its basic ideas and its possibilities.

The general treatment of individual subjects in the book is elementary; mathematics is carefully avoided, and formulae are given only when it is impossible to circumvent them, as in the case of Richardson's emission formula, or Child's equation for space-charge current. Hence, most of the discussions are qualitative.

In some places the desire to be elementary leads to rather involved explanations of ordinary phenomena which would perhaps be better conveyed to the reader by giving him a more conventional interpretation. Such for example, is the explanation of the phenomenon of repulsion between like charges (page 177). Also, the definition of the electric-field strength and its connection with voltage gradient should perhaps be given in the conventional way in an introductory chapter, as the author is anyway compelled to give these definitions somewhere else; for example, this is done on pages 26 and 31 parenthetically.

In addition to these remarks one may note that there is some repetition and overlapping between some chapters, mainly on rectifier circuits and filters, but this is not too injurious to the quality of the book as there are no inconsistencies between statements made in different places.

As to the up-to-dateness of the book, one must consider that it was published in 1942, hence, it was written still earlier; therefore, one cannot expect to find in it some of the latest developments. For example, the application of the ignitron in simple rectification of alternating-current power, which has recently become a very important factor in industry. In treating electron emitter more attention should perhaps be given to the "carbonized" thoriated tungsten, instead of describing the plain mixture of tungsten and thoria.

In spite of all the above remarks one must admit that the individual topics in the book are described thoroughly for the purpose, the reading of the book is easy, and that a beginner anxious to learn basic truth about electronics will acquire by its reading a fairly good idea of this novel and fashionable field of engineering.

To our knowledge, "Principle of Electronics" is the first published book which—in addition to the conventional basic conception of electron tubes—covers what is termed "industrial electronics." Although several other publications have appeared, the scope of Professor Kloeffler's book, its conciseness, and easy reading make it a real contribution to spreading electronics knowledge among the beginners.

I. E. MOUROMTSEFF
Westinghouse Electric and
Manufacturing Company
Bloomfield, New Jersey

Fields and Waves in Modern Radio, by Simon Ramo and John R. Whinnery

Published by John Wiley and Sons, Inc., 440 Fourth Avenue, New York 16, N. Y. 495 pages + x-page index. 206 illustrations. 6×8½ inches. Price, $5.00.

This latest addition to the literature on electromagnetic waves in general and microwave transmission in particular will be well received by students and engineers alike, and for the same reasons. When a number of books on the subject are already available, a new book could easily become "just another book"; but this will not happen to "Fields and Waves in Modern Radio." In the last fifteen years practical applications of the electromagnetic theory have grown by leaps and bounds and the theory itself has become enriched with new ideas and a new point of view. These ideas have already been expounded, applied to obtain concrete results, and proved worthy of a permanent place in the theory. This book will help immensely in their wider dissemination; and in their proper understanding since among its outstanding virtues are straightforward simplicity, clarity, and extensive explanations. In order to make room for the abundant explanatory material the authors had to sacrifice, of course, some topics; but the excluded topics are those which would interest only the more advanced students. The material which *is* included is ample for ordinary purposes and is certainly sufficient for a first course on electromagnetic waves.

The m.k.s. units are used throughout the greater part of the book; it is only in the chapters deveoted to electrostatics and magnetostatics that the older units are employed. The authors make it clear, however, that they do not wish to encourage the use of these older units; their objective is to help those who have been caught between the old and the new and to make the transition period more painless.

Calculus is, of course, essential for an understanding of the book; solutions of differential equations, on the other hand, are explained in the text and only timidity on the part of the reader may keep him from getting along nicely without a previous course in differential equations. Vector analysis is used moderately in some parts of the book.

The book starts with a principal theme: oscillations and waves. The problem of oscillations in a circuit consisting of a coil and a condenser is solved in three different ways and those who are not already familiar with the use of exponential functions in the theory of oscillations are eased into the acceptance of the best method. Wave concepts are illustrated by their application to waves in uniform transmission lines. This first chapter is a review and an introduction; for some readers more review and for others more introduction.

The two chapters on electrostatics serve several purposes: to remind the reader of the most important electrostatic results which under some conditions are applicable equally well even at very high frequencies, to prepare for the subsequent development of dynamic concepts and equations, and to explain the special mathematics useful in the theory and applications. It is in these chapters that the reader becomes familiarized with vector concepts and with various functions, such as Bessel functions, needed both in electrostatics and electromagnetics. In chapter 4, transition is made from static concepts and equations to the dynamic counterparts; in it Maxwell's equations are introduced and boundary conditions explained. Chapter 5 contains an analysis in the light of the electromagnetic theory of circuit concepts in the restricted sense—that is, "lumped" inductance and capacitance. Skin effect is the subject of the greater part of chapter 6 which contains also calculations for the internal impedances at high frequency of solid wires, plane conductors, cylindrical shells, and coated conductors. The remainder of the chapter has to do with external inductances. Chapter 7 deals with propagation and reflection of uniform plane waves. It is in this chapter that the analogy with the transmission-line theory is explained and stressed and the conception of wave impedance is introduced. Thus ends the first half of the book.

The second half is devoted to guided waves, more common wave guides, resonators, radiation, and antenna theory. The easy style of the first half is continued and the reader is likely to get through some more difficult topics before he knows it. There are some popular misconceptions about radiation; the authors are not only aware of these but in the last chapter they take special pains to explain the points which appear to cause trouble. This chapter should be read by anyone who wants a clear picture of the present status of the antenna theory. For more complete technical details he may want to refer to the original sources; but he will be in possession of information which should help to sort out oats from weeds. It is hardly necessary to describe the contents of this second half of the book in detail; suffice it to say that on completion the student should acquire a good theoretical background for understanding microwave techniques and for further study in that field.

S. A. SCHELKUNOFF
Bell Telephone Laboratories
New York, N. Y.

Contributors

Ernst Fredrik Werner Alexanderson

Ernst Fredrik Werner Alexanderson (A'13-M'13-F'25) was born on January 25, 1878, at Upsala, Sweden. He was educated at the Royal Technical Institute at Stockholm, Sweden, and at the Royal Technical Institute at Charlottenburg. In 1902 Dr. Alexanderson joined the drafting department of the General Electric Company, entering the engineering department as a design engineer of alternating-current machines in 1904. In 1910 he became consulting engineer with the General Electric Company. In 1920 he was also appointed chief engineer of the Radio Corporation of America, becoming consulting engineer to that organization. He later again devoted his entire time to the General Electric Company.

Dr. Alexanderson has been responsible for many developments and inventions in the rotating-machinery field, as well as for the design of the Alexanderson high-frequency alternator, a system of cascading radio-frequency amplifier stages, and a magnetic amplifier for radiotelephony.

He was recipient of the Medal of Honor in 1919 and of the John Ericsson Medal in 1928. In 1921 he was president of the I.R.E. He is a Fellow of the American Institute of Electrical Engineers.

❖

Austin V. Eastman

Kenneth K. Bowman was born on August 7, 1904, at Topeka, Kansas. He received the M.S. degree in electrical engineering in 1927 from Kansas State College. With the exception of a three-year period during which Mr. Bowman was engaged in elevator work in New York City, he has been associated with the General Electric Company since his graduation from college. With this organization he has been connected with the industrial control engineering department, consulting engineering laboratory, and the aeronautics and marine engineering division. At present Mr. Bowman is assistant engineer of the aeronautics equipment section of the aeronautics and marine engineering division.

He is a member of the American Institute of Electrical Engineers and of the Institute of the Aeronautical Sciences.

❖

Austin V. Eastman (A'23-M'32-F'41) was born at Seattle, Washington on May 16, 1902. He received the B.S. degree in electrical engineering in 1922 and the M.S. degree in 1929 from the University of Washington. From July, 1922, to September, 1924, he was in the employ of the General Electric Company in the radio engineering department. During the last six months of this period he was in charge of carrier-current-control equipment. In 1924 Mr. Eastman went to the University of Washington as an instructor in charge of communication work, later becoming assistant professor, associate professor, and in 1942 full professor and head of the department of electrical engineering. He is a member of the American Institute of Electrical Engineers, the Society of the Sigma Xi, the Society for the Promotion of Engineering Education, and is chairman of the Transportation Commission of the City of Seattle.

❖

Martin Arthur Edwards was born on March 22, 1905, at Chatauqua, Kansas. He was graduated in 1928 from Kansas State College of Agriculture and Applied Science with a Bachelor of Science degree in electrical engineering, and received a Bachelor of Science degree in mechanical engineering in 1929. In 1935 Mr. Edwards was awarded a Mechanical Engineering degree, and became a licensed professional engineer in New York State.

He entered the General Electric Company's test course in 1929, and later transferred to the consulting engineering laboratory as a development engineer. He engaged in all types of closed-cycle control systems, and in 1934 received the Coffin Award for outstanding work on synchronous torque amplifiers for marine applications, and a second Coffin Award in 1937 for outstanding work on steel mill control.

Kenneth K. Bowman

❖

William L. Everitt (A'25–M'29–F'38) received the E.E. degree from Cornell University in 1922, the M.S. degree from the University of Michigan in 1926, and the Ph.D. degree from Ohio State University in 1933. He has taught electrical engineering at Cornell, Michigan, and Ohio State and has been in charge of the instruction in communications at the last institution since 1926. Since 1942, Dr. Everitt has been on leave from Ohio State as director of operational research with the Signal Corps of the United States Army. Dr. Everitt initiated and has directed the annual Broadcast Engineering Conference at Ohio State. He is a Fellow of the American Institute of Eelectrical Engineers and a member of the National Defense Research Committee, Tau Beta Pi, Sigma Xi, and Eta Kappa Nu.

❖

George B. Green was born on January 25, 1912, in Biggars, Arkansas, and attended the University of Nebraska. Mr. Green did experimental radio work with the

❖

Martin Arthur Edwards

William L. Everitt

George B. Green

J. L. Hollis

Electromatic Propeller Corporation and the Douglas Aircraft Company previous to his employment with the Harvey Machine Company, Inc., in the capacity of research engineer.

J. L. Hollis (S'37–A'40) was born near Omaha, Nebraska, on January 29, 1916. He received the B.S. degree in electrical engineering in 1938.

During his school days he worked as an operator at KSAC of the Kansas State College. On graduation he was employed by First National Television, Inc., in Kansas City, Missouri, first in charge of television development and later as chief engineer of the company which included radio station KITE.

In 1939, Mr. Hollis joined the engineering department of the broadcasting branch of the Crosley Corporation. He worked on television station development and installation, moving and modernizing radio station WSAI which included the booster installation. At the present time he is engaged in international broadcast transmitter engineering.

Jess Shirlock Morrison was born on September 3, 1896, in Centerville, Kansas. For the past twenty-seven years his experience has been research engineering, developing of aircraft and mechanical devices. He developed an automatic pilot which would operate aircraft by radio, and which is able to correct for wind drift, thereby enabling it to fly a straight line between two points. For the past ten years Mr. Morrison has been with the Harvey Machine Company, Inc., in the capacity of research engineer in electronics and development of mechanical devices for radio.

John R. Nowak was born on December 27, 1911, in St. Louis, Missouri. He attended the University of Southern California, where he specialized in study of ultra-high-frequency. The past nine years Mr. Nowak has spent as experimentalist on frequencies above 30 megacycles, with the Signal Corps and other concerns. He has been with the Harvey Machine Company, Inc., for the past two years, where he has engaged in experimental radio work.

Jesse B. Sherman (J'28-A'32) was born on February 8, 1910, at New York City. He received the B. S. degree in electrical engineering from Cooper Union Night School of Engineering in 1933; the B.S. degree in electrical engineering from New York University, Evening Engineering Division, 1935; and the M.E.E. degree from Polytechnic Institute of Brooklyn, 1938. Mr. Sherman was service manager of the Colen-Gruhn Company, Inc., from 1930 to 1935, and in the research and engineering department of the RCA Manufacturing Company, Inc., RCA Radiotron Division from 1935 to 1939. From 1939 to 1942 he was an instructor in electrical engineering at The Cooper Union in New York City; since 1942, he has been an assistant professor.

For biographical sketches of L. Marton and R. G. E. Hutter, see the Proceedings for January, 1944; for Hans Salinger, see the Proceedings for February, 1944.

Jess Shirlock Morrison

John R. Nowak

Jesse B. Sherman

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SECTION MEETINGS

Baltimore

"Aircraft Radio Power-Supply Apparatus," by C. K. Hooper, Westinghouse Electric and Manufacturing Company; June 20, 1944.

Election of Officers; June 20, 1944.

Boston

"Coupled Circuits," by H. M. Turner, President; Institute of Radio Engineers; April 14, 1944.

"Frequency Modulation on Mount Washington," by I. B. Robinson, Station WNAC; May 19, 1944.

"Studio Acoustics," by S. A. Waite, Station WNAC; May 19, 1944.

Buenos Aires

"Measurements on Lines at High Frequencies," by E. Labin, Philips, June 6, 1944.

"The Doherty Amplifier," by F. Harris, Standard Electric Company, June 22, 1944.

Dallas-Ft. Worth

"The Principles and Application of Electron Microscopy," by W. J. Yost, Magnolia Petroleum Company; July 12, 1944.

"The Electrical Circuits and Operating Techniques with the RCA-Type Electron Microscope," by P. P. Reichertz, Magnolia Petroleum Company; July 12, 1944.

Indianapolis

"Ultra-High-Frequency Measurements," by E. D. Cook, General Electric Company; April 28, 1944.

"Frequency Modulation and Television," by R. F. Guy, National Broadcasting Company; May 26, 1944.

"Very-High-Frequency Applications of Radio Guides and Airport Facilities," by W. E. Jackson and P. D. McKeel, Civil Aeronautics Authority; June 23, 1944.

Kansas City

"The Electron Microscope and Its Applications," by M. C. Banca, Radio Corporation of America; March 28, 1944.

"Electronic Applications in the Paper Manufacturing Industry," by Lowell Zabel, Wilcox Electric Company; May 31, 1944.

Election of Officers; May 31, 1944.

MEMBERSHIP

The following transfers and admissions were approved on August 2, 1944.

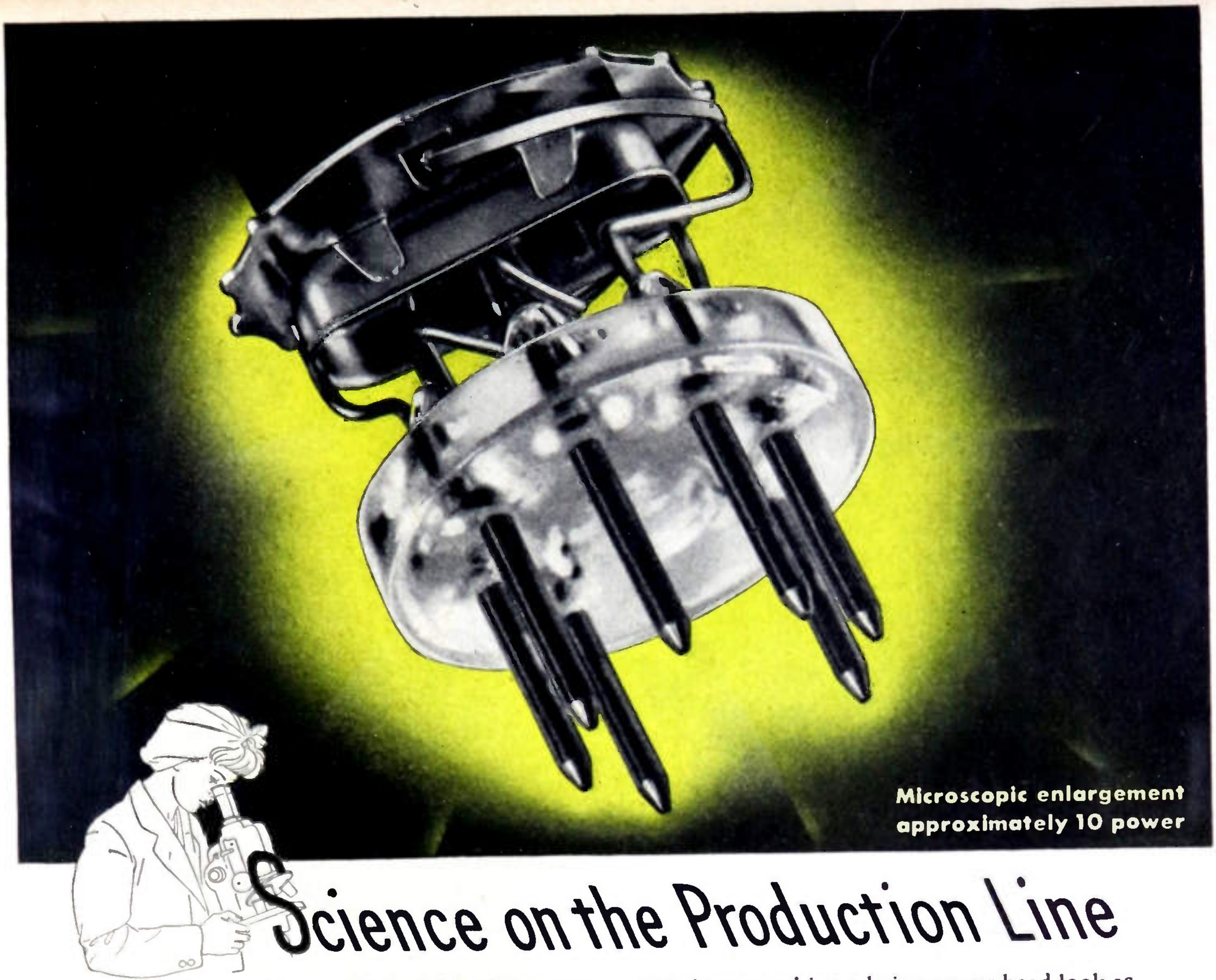
Transfer to Senior Member

Barnes, J. L., 21 N. Cherry Lane, Rumson, N. J.
Craig, P. H., 707 E. Columbia St., Gainesville, Fla.
George, R. W., R.C.A. Laboratories, Riverhead, N. Y.
Kandoian, A. G., 67 Broad St., New York, 4, N. Y.
Miller, B. F., 2845 Russell St., Berkeley 5, Calif.
Palmquist, J. F., 3807 Somerset Dr., Los Angeles, Calif.
Ware, P., 8 Glenside Ter., Upper Montclair, N. J.

Admission to Senior Member

Bowden, B. V., C.R.G., Naval Research Laboratory, Anacostia Station, D. C.
Graner, L. P., 40 E. 49 St., New York, 17, N. Y.
Holloway, F. L., 432 Sandhurst Dr., Dayton, 5, Ohio.
Schmitt, O. H., 28 S. Washington St., Port Washington, L. I., N. Y.

(Continued on page 36A)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MEMBERSHIP

(Continued from page 34A)

Singer, F. J., 234 N. Forest Ave., Rockville Centre, L. I., N. Y.

Transfer to Member

Arcand, W., 100 Third St., Wood-Ridge, N. J.
Barnes, F. P., Box 1858, Seattle, Wash.
Brace, F. R., 1258 La Playa, San Francisco, Calif.
Brown, W. N., Jr., 747 S. Monroe St., Xenia, Ohio.
Burroughs, H. A., 2124 Key Blvd., Arlington, Va.
Hill, W. R., Jr., University of Washington, Seattle 5, Wash.
Jacobs, M., 171 E. Hillcrest Ave., Dayton 5, Ohio.
Johnson, H. D., Box 175, R.F.D. 2, Emporium, Pa.
Kees, A. A., 1435 Ulloa St., San Francisco, Calif.
Klipsch, P. W., Southwestern Proving Ground, Hope, Ark.
Marston, R. S., 23 Flint Ave., Hempstead, L. I., N. Y.
Rappaport, G., 3522 S. Utah St., Arlington, Va.
Richmond, L. P., 144 Forrer Blvd., Dayton, Ohio.
Weston, S., 365 W. 20 St., New York, N. Y.

Admission to Member

Bass, H., 7363 Clovernook Ave., Mt. Healthy, Ohio.
Bechtol, H., Airplane and Marine Instruments, Inc., Clearfield, Pa.
Berg, S., 74 Barker Ave., Eatontown, N. J.
Cohen, J. S., 1514 Teakwood Ave., Cincinnati, Ohio.
Folland, D. F., 100 Anchor Way, East Hempstead, L. I., N. Y.
Hansen, C. A., 153 Norfolk Ave., Clarendon Hill, Ill.
Horvath, A., 52 Webster St., Lynbrook, L. I., N. Y.
Iversen, R. J., 36-01—31 Ave., Long Island City, L. I., N. Y.
Kiss, J. S., 2250 Cathedral Ave., Norwood, Ohio.
Langstaff, R. H., 6145 Glade Ave., Cincinnati, Ohio.
Meador, B. M., 520 W. Fairview Ave., Dayton, Ohio.
O'Bryan, H., 3297 Worthington St., N. W., Washington, D. C.
Peterson, L. J., Aircraft Radio Laboratory, Wright Field, Dayton, Ohio.
Reyling, P. M., 50 N. Munn Ave., East Orange, N. J.
Sobel, A. D., 2939 Ocean Ave., Brooklyn, N. Y.
Tyrrell, W. A., Box 107, Red Bank, N. J.
Van Horn, R. H., 463 West St., New York 14, N. Y.

The following transfers and admissions of membership have been approved by the Admissions Committee. Objections to any of them should reach the Institute office by not later than September 29, 1944.

Transfer to Senior Member

Anton, N. G., 225 Sterling Pl., Brooklyn, N. Y.
Beam, R. E., Northwestern University, Evanston, Ill.
Greig, D. D., 106-15 Queens Blvd., Forest Hills, L. I., N. Y.
Christaldi, P. S., 132 Squire Hill Rd., Upper Montclair, N. J.
Corbett, C. W., 333 E. 53 St., New York, N. Y.
DeVore, L. T., 1245 Arbor Ave., Dayton, Ohio.
Donovan, W. E., 40 E. 49 St., New York, N. Y.
Everest, F. A., 1011 Encino Row, Coronado, Calif.
Gubin, S., 4417 Pine St., Philadelphia, Pa.
MacLean, K. G., R.C.A. Laboratories, Riverhead, L. I., N. Y.
Noble, D. E., 165 Garfield Ave., Elmhurst, Ill.
Ostlund, E. M., 194 Grove St., Montclair, N. J.
Ramo, S., General Electric Company, Schenectady, N. Y.
Scheer, G. H., Jr., R.F.D. 5, Box 379, Dayton, Ohio.
Wentz, J. F., 180 Varick St., New York, N. Y.
Wright, J. W., 122 Webster Ave., Manhasset, L. I., N. Y.

(Continued on page 38A)

MEMBERSHIP

(Continued from page 36A)

Admission to Senior Member

Sherman, V. W., Federal Telephone and Radio Corporation, 200 Mt. Pleasant Ave., Newark, N. J.
Duffendack, O. S., North American Philips Company, Richmond Hill, Irvington-on-the-Hudson, N. Y.

Transfer to Member

Campbell, M. E., A.P.O. 518, c/o Postmaster, New York, N. Y.
Deerhake, F. M., 600 Oakwood St., Fayetteville, N. Y.
Edwards, H. H., 186-21—122 Ave., St. Albans, L. I., N. Y.
Ellithorn, H. E., 417 Parkovash Ave., South Bend 17, Ind.
Espy, W. D., 362—30 Street Dr., S. E., Cedar Rapids, Iowa.
Fernandez, M., 20 Ferrying Group A.T.C., Municipal Airport, Nashville, Tenn.
Fiedler, L., 53 Rosedale, Hamburg, N. Y.
Gorman, D. P., E. 521 Sharp Ave., Spokane, Wash.
Graf, A. W., 4 Midway Ct., Hammond, Ind.
Hirsch, O. C., 324 Broadway, Cape Girardeau, Mo.
McCartney, H S., 625 Second Ave., S., Minneapolis 2, Minn.
Sharp, W. O., Bell Telephone Laboratories, 395 Hudson St., New York, 14, N. Y.
Sokoloff, P. W., 68-19 Burns St., Forest Hills, L. I., N. Y.
Squires, E. G., 319 E. Jefferson Ave., Wheaton, Ill.
Stockman, H., Cruft Laboratory, Harvard University, Cambridge 38, Mass.
Thomas, H. P., 202 Huntleigh Ave., Fayetteville, N. Y.
Wang, T. S., 726 Cooper St., Camden, N. J.
Whinnery, J. R., 2047 Coolidge Pl., Schenectady, N. Y.
Williamson, R. H., 161 E. Onondaga St., Syracuse 2, N. Y.

Admission to Member

Curtis, R. C., 25 Stanley St., New Haven, Conn.
Davis, F. M., 1429 Wildwood Dr., N. E., Cedar Rapids, Iowa.
Feldt, R., 875 W. 181 St., New York 33, N. Y.
Hackett, A. H., Apartado 1226, Telephone Co., Caracas, Venezuela, S. A.
Laning, W. A., 70 Glen Ridge Ave., Glen Ridge, N. J.
Norman, S. W., 300 Buxton Rd., Falls Church, Va.
Warner, A. W., Jr., Bell Telephone Laboratories, Murray Hill, N. J.
Weid, A. C., Airborne Instruments Laboratory, 150 Old Country Rd., Mineola, L. I., N. Y.
Weissman, S., 321 W. Norman Ave., Dayton 5, Ohio.

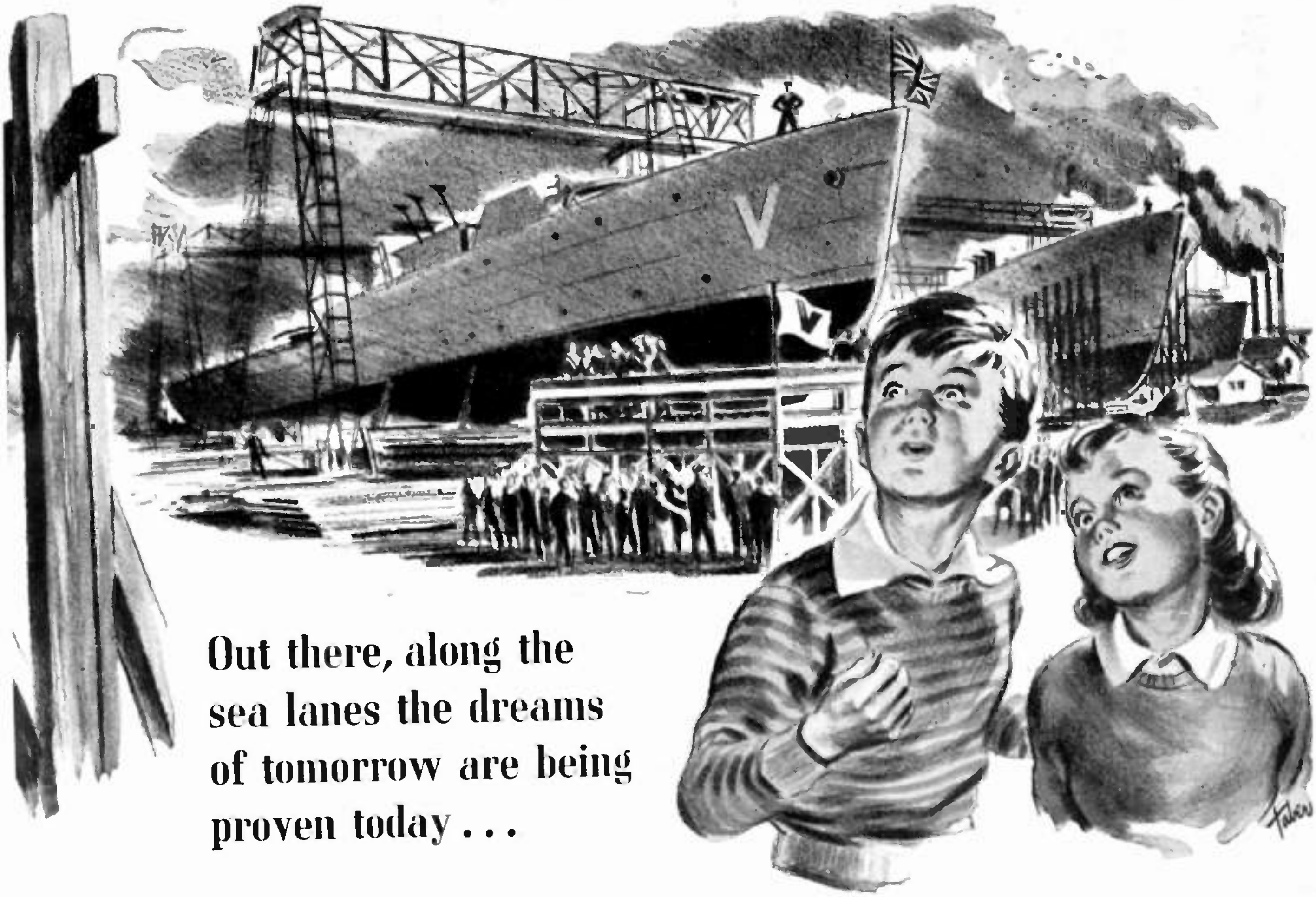
The following admissions were approved on August 2, 1944.

Admission to Associate

Artman, R. G., 37 Langdon St., Cambridge, 38, Mass.
Athersych, F. B., 129 High St., London, Ont., Canada
Ault, C. M., RR. 9, Box 618, Indianapolis, 44, Ind.
Axel, P., 1 Queensberry St., Boston, Mass.
Baker, W. K., 425 Peachtree St., N.E., Atlanta, 3, Ga.
Bauman, A. M., 3701 N. Lowell Ave., Chicago, Ill.
Beach, G. E., R.C.A.F., Clinton, Ont., Canada
Berge, O. L., 2057 S. 73 St., Milwaukee, 14, Wis.
Biedenbender, R., 5658 Lawndale Pl., Cincinnati, 13, Ohio
Birrell, A., c/o Divisional Engineer, General P. O., Cape Town, South Africa

(Continued on page 40A)

WHERE TOMORROW MEETS TODAY



Out there, along the sea lanes the dreams of tomorrow are being proven today . . .

CORVETTES "turn on a dime"—destroyers race at abnormal speed—that's the navy of today! Mastery of the sea depends on new and ever-improved equipment.

Today on our fighting ships, many pieces of electrical apparatus are designed and produced by Small Electric Motors (Canada) Limited. At the moment we are devoting all our efforts to turning out material of an advanced scientific nature. Research, engineering and inventive genius work hand in hand to produce equipment that normally would be much longer in developing.

In the days to come you may wish to benefit by this "know-how." These experiments and achievements in technical war contributions will be reflected and recognized in the electrical world of tomorrow. Small Electric Motors plan with confidence a noteworthy role in the post-war era.

DESIGNERS AND MANUFACTURERS Of All Types of Precision Electrical Apparatus Including:

D.C. & A.C. Motors for Specialized Purposes
Aircraft Generators
Aircraft Engine Starters
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Motors with Governors
Gyros, etc.

2-44

SMALL Electric Motors
(CANADA) LIMITED

LEASIDE - TORONTO - CANADA

MEMBERSHIP

(Continued from page 38A)

Bishop, J. C., Jr., Instructors' Co., Bks. 10., N.A.T.T.C., Ward Island, Corpus Christi, Texas
Bolton, J. J., Mary St., Clinton, Ont., Canada
Bonness, Q. L., 1418 Union St., Schenectady, N. Y.
Brown, W. T., 1123–26 Ave., Seattle, 22, Wash.
Byers, V. J., Box 368, Clinton, Ont., Canada
Carvin, E. A., 47–31–37 St., Long Island City, L. I., N. Y.
Ceccanti, L. P., c/o Fleet Post Office, New York, N. Y.
Chandler, H. J., Radio Station KRNR, Roseburg, Ore.
Cholmondeley-Smith, D. R., Clyde Rd., Browns Bay, Auckland, N. 3., New Zealand
Collins, G. A., Clinton, Ont., Canada
Coughlin, V. L., Box 445, Clinton, Ont., Canada
Crane, N. B., Sig. Detachment S. C., Aircraft Signal Agency, Wright Field, Dayton, Ohio
Crosson, W. J. R., North St., Clinton, Ont., Canada
Cummings, S. J., 130 Walnut St., Saratoga Springs, N. Y.
Davis, H., 4946 Camden St., Indianapolis, 3, Ind.
Diamond, S., 63 Brunswick Ave., Toronto, Ont., Canada
Dobbin, R., Box 492, Manasquan, N. J.
Downing, J. T., 150 South St., Jamaica Plain, 30, Mass.
Draganjac, M. J., 54 W. Hudson Ave., Dayton, Ohio
D'Orio, A. F., 42 N. Menard Ave., Chicago, Ill.
Ellenwood, R. C., RFD, Wooster, Ohio
Elwell, D., 10 Rockefeller Plaza, New York, N. Y.
Fleisher, H., 43 Irving St., Cambridge, 38, Mass.

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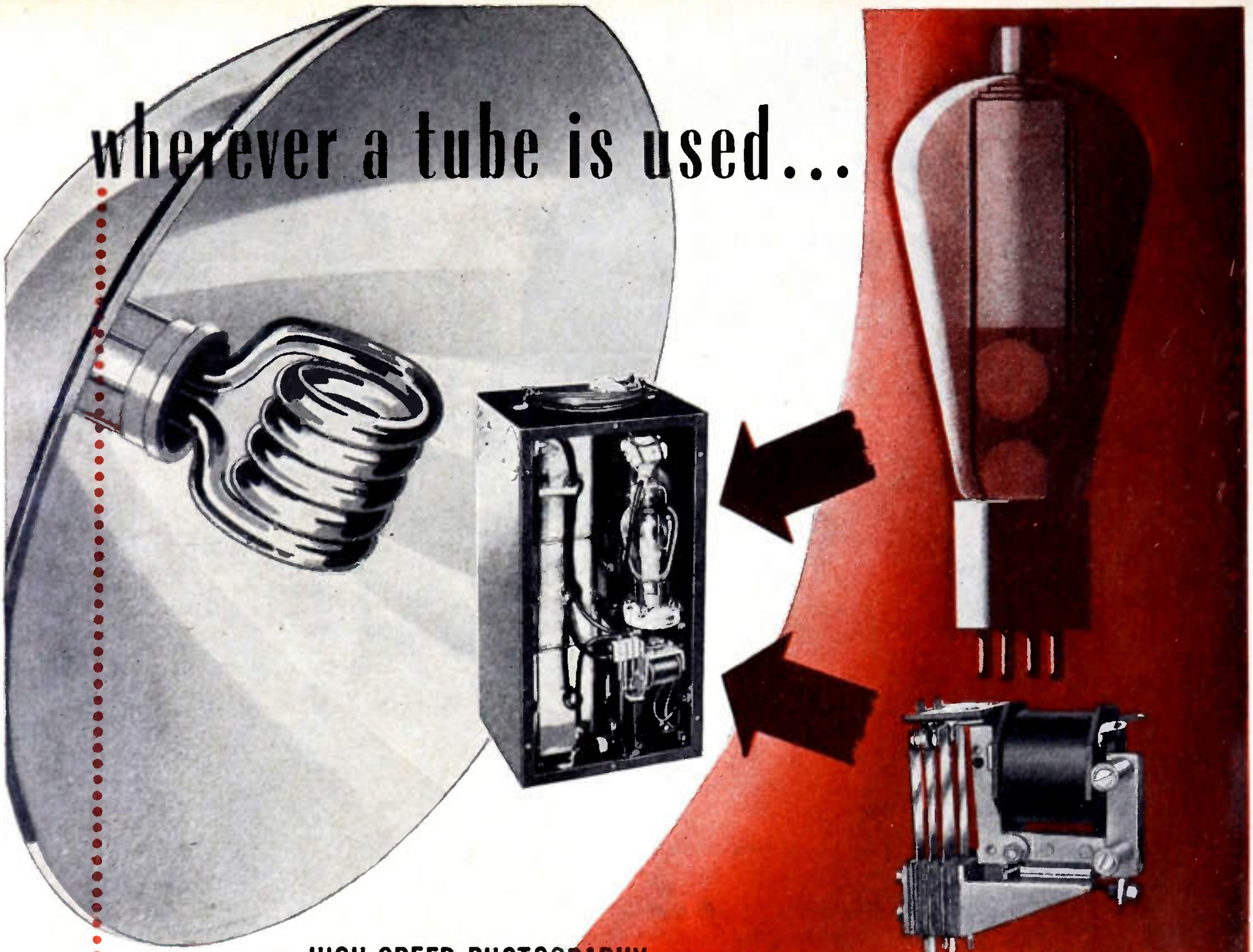
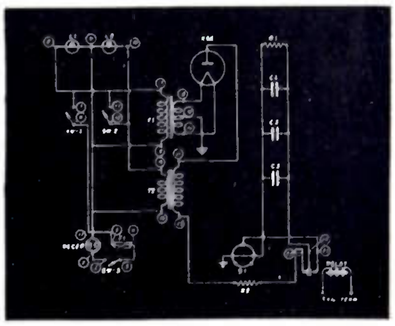




MEMBERSHIP

(Continued from page 40A)

Fouts, J. L., 827 Seventh St., Bremerton, Wash.
Fox, C. A., R.C.A.F., Clinton, Ont., Canada
Frank, N. E., 3101 W. Grand Blvd., Detroit, Mich.
Fraser, E. R., American Telephone & Telegraph Co., Box 301, West Haven, Conn.
Fry, P. F., 1503 Bolton St., Baltimore, 17, Mass.
Gale, G. G. H., R.C.A.F., Clinton, Ont., Canada
Gallo, J. M., c/o Fleet Post Office, New York, N. Y.
Garcia, J. H., 4731 E. 16 St., Indianapolis, Ind.
Gausewitz, C. H., 1500 Oak Ave., Evanston, Ill.
Grant, E. F., 1039 S. Braddock Ave., Pittsburgh, 18, Pa.
Green, D. J., 4530-38 St., San Diego, 4, Calif.
Green, W. B., General Delivery, Clinton, Ont., Canada
Groves, R. M., 1125 Briarcliff Pl., N.E., Atlanta, Ga.
Hageman, K. G., 315 Parkland Pl., S.E., Washington, 20, D. C.
Hall, D. J., 2600 W. 50 St., c/o Majestic Radio and Television Corp., Chicago, 32, Ill.
Hardcastle, C., 167 Lichfield Rd., Bloxwich, Walsall, England
Harmon, A. L., 405 Condon Ter., S.E., Washington, 20, D. C.
Harper, H. F., Signal Detachment, Signal Corps, Aircraft Signal Agency, Wright Field, Dayton, Ohio
Heininger, W. W. L., 508 W. 114 St., Apt. 82A, New York, N. Y.
Hoover, W. G., 586 Foothill Rd., Stanford University, Calif.
Hopkins, J. E., 510 North St., East Aurora, N. Y.

(Continued on page 44A)

MEMBERSHIP

(Continued from page 42A)

Hosking, W. J. C., 40 King St., Clinton, Ont., Canada
Howard, W. A., 7528 Thouron St., Philadelphia, 38, Pa.
Howells, P. W., 1112 Parkwood Blvd., Schenectady, 8, N. Y.
Hoyt, W. S., Farnsworth Television & Radio Corp., Fort Wayne, Ind.
Hunka, D., R.C.A.F., Clinton, Ont., Canada
Jefferies, D. W., Radio Station WTBO, Cumberland, Md.
Hunter, G. E., 75 Murray Ave., Greenfield Park, Que., Canada
Jensen, R. S., 306C Talbot Lab., University of Illinois, Urbana, Ill.
Kaplan, M., 806 AAF Base Unit, Sec. B, Bks. 206, Baer Fd., Fort Wayne, Ind.
Kennedy, R. J., 217 W. Lake St., Barrington, Ill.
Komm, J., 223 W. 115 St., Chicago, 28, Ill.
Klibaner, B., 99–52 64 Ave., Forest Hills, L. I., N. Y.
Knox, W. G., 207 Parkside Ave., Pittsburgh, 16, Pa.
Kramer, A. S., 377 S. Second St., Lindenhurst, L. I., N. Y.
Kurtz, M., 2 Main Ave., Passaic, N. J.
Laird, E. R., 1146 Richmond St., London, Ont., Canada
Lawrenz, F. W., 2047 Boyd St., Indianapolis, Ind.
Ledbetter, J. B., 3148 Bracken Woods Lane, Cincinnati, 11, Ohio
Low, A. R., Clinton, Ont., Canada
Mackrill, D., Electrical Dept., See Royal Naval Dockyard, Gibraltar

(Continued on page 48A)

ANNOUNCING BULLETIN NO. 143

Every engineer in the electronic field will appreciate the concise method in which the Electrical and Mechanical properties together with the design and dimensions of ALSIMAG High Frequency Insulators have been arranged and tabulated for easy and quick reference in new Bulletin No. 143.

The ALSIMAG insulators described are those most commonly used in high frequency applications. *Deliveries can now be made within a reasonable period.*

Note: *When requesting copies please include name and position of others in your organization to whom we should send Bulletin No. 143 so that you may retain your own copy.*

The insulators described in Bulletin No. 143 represent only a small portion of our output. Specially made insulators to customer's specifications are our principal products. Our Engineering Staff will be glad to cooperate on your designs.

AMERICAN LAVA CORPORATION

Chattanooga 5, Tennessee

ARMY E NAVY

ALCO has just been awarded for the fourth time the Army-Navy "E" Award for "continued excellence in quantity and quality of essential war production."

ALSIMAG

TRADE MARK REGISTERED U. S. PATENT OFFICE

CERAMIC INSULATORS

TUBES GET THE MOST UNEXPECTED ABUSE

Signal Corps tests for Electronic Tubes are exacting . . . and rightly so. For tubes to be totally satisfactory for civilian or military use, they must be built to operate under the most severe and unusual conditions. That is why "vibration testing" was a routine procedure at TUNG-SOL long before the war.

TUNG-SOL research engineers are continuously working to find "weak points" and developing ways and means of overcoming them. With the advent of the glass base tubes for instance, the cause of base fractures was discovered and a production procedure was developed to eliminate it.

Manufacturers and users of Electronic Equipment will find every tube in the TUNG-SOL line a tube of proven merit.

Why not have TUNG-SOL engineers think and work along with you while you are planning your new developments?

THE TUNG-SOL WAY

OF COOLING TUBES PREVENTS BREAKAGE OF GLASS BASES . .

While a tube is cooling, during manufacture, air is blown against the center of the glass base through a hole in the holder thus cooling the base from the center out while natural cooling takes place from the edges in. This uniform cooling relieves internal stresses in the glass, a cause of breakage.

TUNG-SOL

vibration-tested

ELECTRONIC TUBES

ARMY E NAVY

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

ALSO MANUFACTURERS OF MINIATURE INCANDESCENT LAMPS ALL-GLASS SEALED BEAM HEADLIGHT LAMPS AND CURRENT INTERMITTORS

Membership

(Continued from page 44A)

Mantey, W. F., Apt. 1C, 109 Joliet St., S.W., Washington, 20, D. C.
Marks, W. R., Box 442, Clinton, Ont., Canada
Martin, D. W., Bendix Radio Division, Baltimore, 4, Md.
McKinney, L. F., 2540 Fulton St., Berkeley, 4, Calif.
Mead, L. R., 200 N. Knight Ave., Park Ridge, Ill.
Michael, K. R., 3343 S. Halsted St., Chicago, 8, Ill.
Miller, D. A., 17 Victory Dr., West Hills, New Haven, Conn.
Moore, J., Lakeport, Via Colborne, Ont., Canada
Oakley, G. L., 2 Highland Ave., Bankstown, N.S.W., Australia
Odessey, P. H., 1528 E. Third St., Brooklyn, N. Y.
Oliphant, L. D., 1303 N. Cheyenne, Tulsa, 6, Okla.
Olson, C. P., Jr., 970 W. 43 St., Los Angeles, 37, Calif.
Owen, J. R., Box 261, Clinton, Ont., Canada
Papernow, L. N., 514½ Southern, Corpus Christi, Texas
Parker, H. L., 9824 Western Electric Co., 165 Broadway, New York, 6, N. Y.
Podbielniak, T., 8728 Colesville Rd., Silver Spring, Md.
Porter, T. R., 100 E. 42 St., New York, N. Y.
Powers, R. G., c/o Melvin Powers, RT. 1, Wallaceburg, Ont., Canada
Prise, W. J., 2538 Durant Ave., Berkeley, 4, Calif.
Riederer, L. A., Box 425, Clinton, Ont., Canada
Robinson, J., 1244 E. 13 St., Brooklyn, N. Y.
Ryan, L. P., R.C.A.F., Clinton, Ont., Canada
Russell, A. W., 16 Shepley Close, Carshalton, Surrey, England
Rybon, J. C., Box 294, Manette, Wash.
Sampson, E. S., 730 Union St., Schenectady, N. Y.
Satterleg, C., 31 Service Group, Fairmont AAF, Geneva, Nebr.
Shatzkin, J., 3339 Radcliff Ave., Bronx, 67, N. Y.

(Continued on page 60A)

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.

ELECTRICAL ENGINEERS

Needed in connection with the manufacture of a wide variety of new and advanced types of communications equipment and special electronic products. Openings available in St. Paul, Minn., Eau Claire, Wis., and Chicago. Apply or write, giving full qualifications and furnish snapshot, to D. L. R., Employment Department, Western Electric Company, Hawthorne Station, Chicago 23, Illinois.

ELECTRONIC SALES ENGINEERS

Established electronic tube manufacturer, located in Midwest, requires sales engineers to cover Midwest or East Coast. Applicants should have electrical-engineering degree, knowledge of electronic circuits and applications, and ability to contact customers. Excellent wartime and postwar opportunity for the right men. Salary and bonus. Send complete information to Box 346.

PRODUCT ENGINEER

Major manufacturer of electrical-wiring devices interested in employing a designer-engineer with a proved record of accomplishment. Firm possesses far-sighted management, varied production facilities, and ample capital to undertake and promote new products—the scope and opportunity of the position are limited only by the skill, imagination and initiative of the man. Salary open—location, New England. All applications will be held in strict confidence. Even though a USES release might not be immediately available, write to Box 347.

ELECTRICAL ENGINEER

Electrical engineer wanted for position of chief of research and development section of a Metropolitan New York division of nationwide manufacturer. Must have a sound educational background and outstanding design experience on light equipment. Salary open. Reply in confidence giving complete personal data, experience résumé, availability for release, etc. to Box 348.

FIELD SERVICE ENGINEERS

For domestic and foreign service. Must possess good knowledge of radio. Essential workers need release. Write to Hazeltine Electronics Corporation, 58-25 Little Neck Pkwy., Little Neck, L.I., N.Y.

RADIO ENGINEER

Radio engineer thoroughly experienced in ultra-high-frequency theory and technique, with or without patent law experience, preferably young, and with some knowledge of mechanical engineering, desired by established New York City patent law firm for employment as consultant and with view to becoming patent lawyer. State education, experience, age, and salary expected. Write Box 349.

COIL ENGINEER

Engineer wanted with suitable background who can be quickly trained in the manufacturing of coils. Experience in coil-forming processes and insulation problems desirable. Excellent post-war prospects. Write the Supervisor, Technical Employment, Westinghouse Electric & Manufacturing Company, Union Bank Building, Pittsburgh 22, Pa.

AUTO-RADIO-SET DESIGNER

An auto-radio-set design engineer with prewar experience needed immediately for postwar development. Write fully, outlining experience, salary expected, etc. Address your letter to Box 341.

ELECTRONIC ENGINEER

An engineer is required to head a department of industrial electronics in consulting engineer-

(Continued on page 52A)

THE WAR WILL END ON

(YOU FILL IN THE DATE)

Think of it! You as a civilian have the power to decide when the war will end. Use that power to the utmost—NOW—by

1. Buying war bonds to the limit of your capacity.
2. Working harder, longer, and uninterruptedly turning out implements of war.
3. Donating your blood to the Red Cross to save lives on the battle field.
4. Collecting waste paper and other scrap for which the government is asking.
5. Avoiding black markets as you would the plague. (Black markets cause the plague of inflation.)

All these are weapons of war—weapons that strike terror in the hearts of our enemies. Use them.

We, the management and employee alike, at Kenyon, are building better transformers than we ever built before—and building them faster for the armed forces.

THE MARK OF EXCELLENCE

KENYON TRANSFORMER CO., Inc. 840 BARRY STREET NEW YORK, U. S. A.

POSITIONS OPEN

(Continued from page 50A)

ing firm. Must have had experience in this field. Salary as well as a share in the profits. Please write to Box 342 giving detailed information on education and experience.

ELECTRONIC ENGINEER

A desirable position is open in the Electronic Research Division of one of our clients, a well-established industrial concern in Chicago. Man with mechanical engineering background preferred. Position has to do with the manufacturing problems of industrial electronic equipment and is permanent. Give full information to include extent and nature of education and experience, salary expected, age, draft and marital status. Write to Business Research Corporation, 79 West Monroe Street, Chicago 3, Illinois.

ENGINEERS FOR INDUSTRIAL ELECTRONICS

Experienced engineers wanted for design and application engineering of electronics to industry in a consulting engineering firm. Position offers unusual opportunity to qualified, reliable and responsible man. Present work will be on war contracts. Write to Box 343.

ELECTRONIC ENGINEER

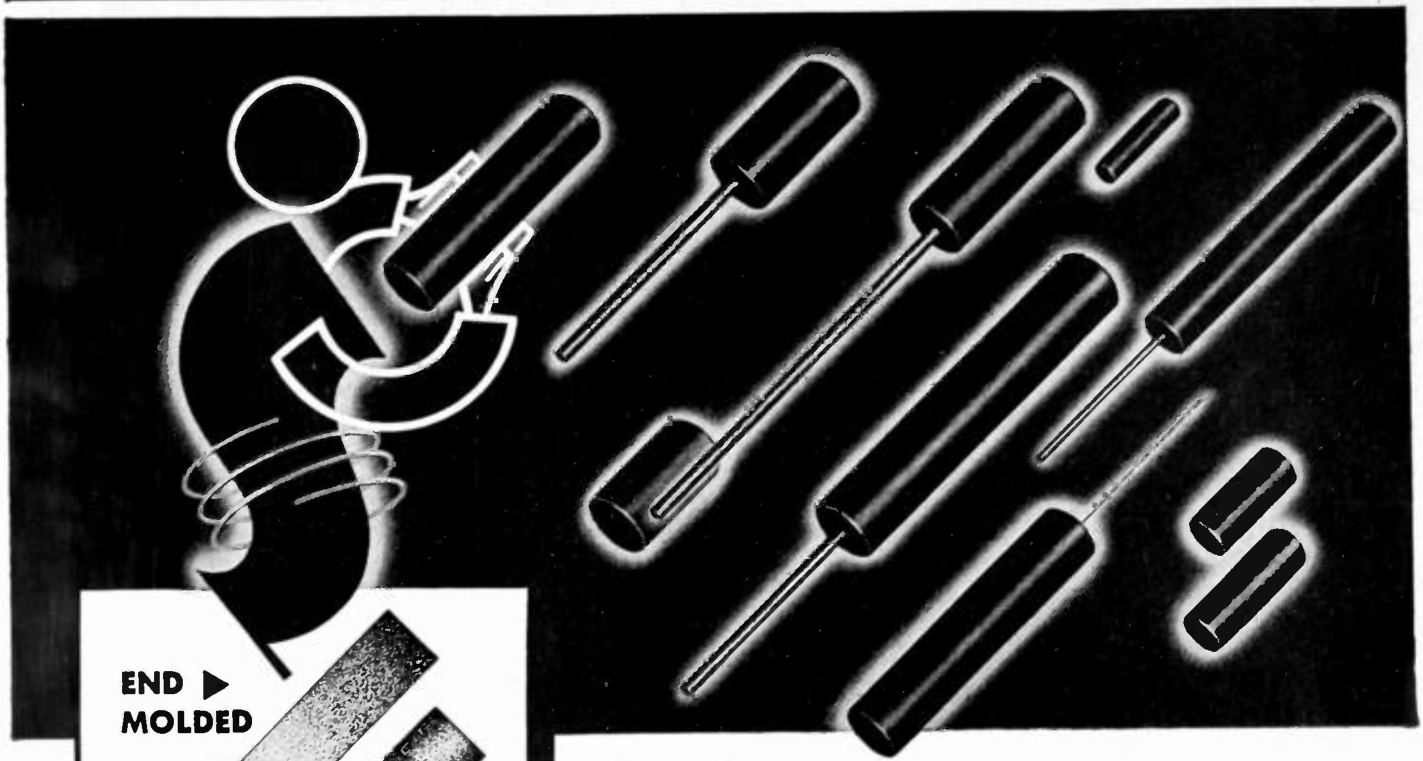
The Brush Development Company requires, for one of its research and development programs, the services of an electronic engineer preferably with acoustic or vibration experience, including a working knowledge of electrical-mechanical analogies. The project has immediate war applications and will continue as an important post-war activity. Write Personnel Director, The Brush Development Company, 3311 Perkins Avenue, Cleveland 14, Ohio.

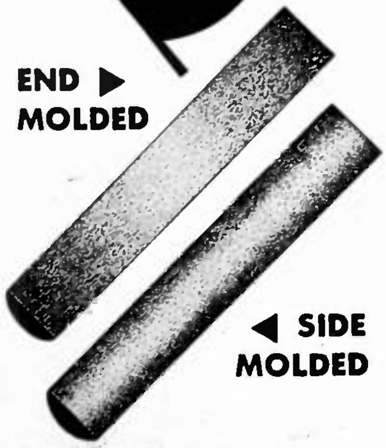
ENGINEERS AND DRAFTSMEN

A nationally known aviation accessory corporation now formulating post-war plans can use

(Continued on page 54A)

SIDE-MOLDED IRON CORES





This diagrammatic illustration shows how conventional cores, molded by applying pressure to the ends, results in a dense grouping of iron particles at these points. In side-molded cores, however, any density resulting from molding pressure extends evenly along the entire length of the core, assuring uniform permeability with respect to length.

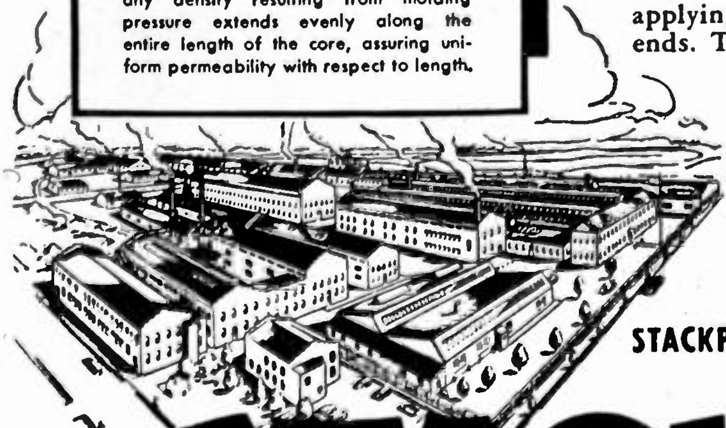
Uniform Permeability with Respect to Linearity

Use in many applications has shown Stackpole side-molded iron cores outstandingly superior to conventional end-molded cores for permeability tuning in the broadcast bands. Similar side-molded units are now available for short wave frequencies including television and frequency modulation.

As the name implies, cores of this type are molded by applying pressure from the sides rather than from the ends. The resulting units show very little variation in density or permeability with respect to length, thus assuring a high degree of uniformity.

WRITE FOR CATALOG! *Other Stackpole Iron Core types include both standard and high-frequency types; insulated types; iron cores for choke coils, etc. Our new Catalog RC6 describes these as well as fixed and variable resistors, and our complete line of inexpensive line, slide, and rotary-action switches.*

STACKPOLE CARBON COMPANY, ST. MARYS, PA.



STACKPOLE

IRON CORE HEADQUARTERS

POSITIONS OPEN

(Continued from page 52A)

the services of several electrical, mechanical and electronic engineers, experienced in research and development work.

Draftsmen: Also a number of design, detail and layout men, excellent working conditions.

Give full details of past experience and education as well as draft status and salary received in first letter. Location, Metropolitan New York. Address Box 338.

DESIGNER

A central New England manufacturer employing over 1000 people needs draftsman-designer on telephone and signaling (mechanical) apparatus.

Knowledge of die-casting and plastic applications desirable. WMC regulations prevail. Write to Box 339.

DEVELOPMENT ENGINEERS

Mechanical and electrical. Graduate or equivalent training. Required for development work in the following branches:

1. Electro-mechanical devices, communication systems. Must be interested in development and familiar with magnetic circuits.
2. Measuring and control instruments. Background should be in electrical engineering, including electronics.

Statement of availability required. Address Box 340.

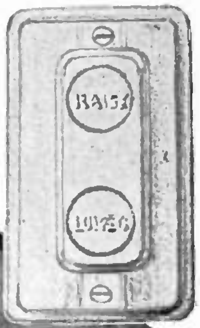
ELECTRICAL AND RADIO ENGINEERS

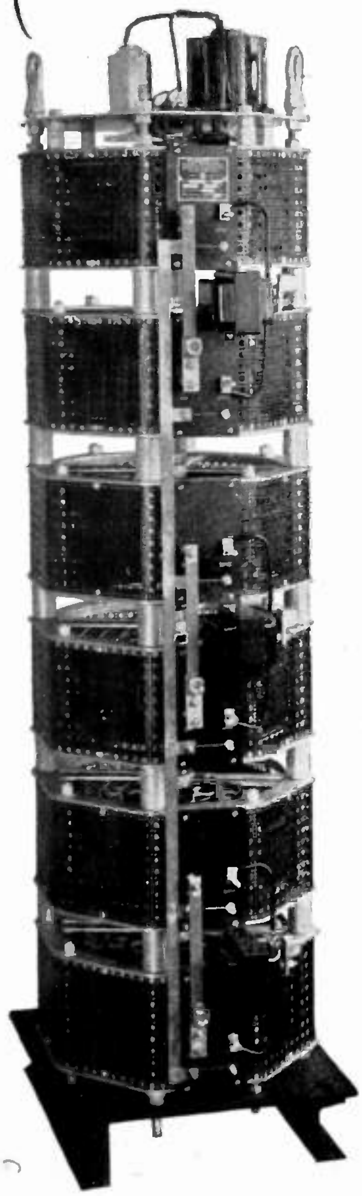
Interesting development work and test equipment design for mass production of electro-acoustical devices. Experience in electronics, acoustics or audio desirable.

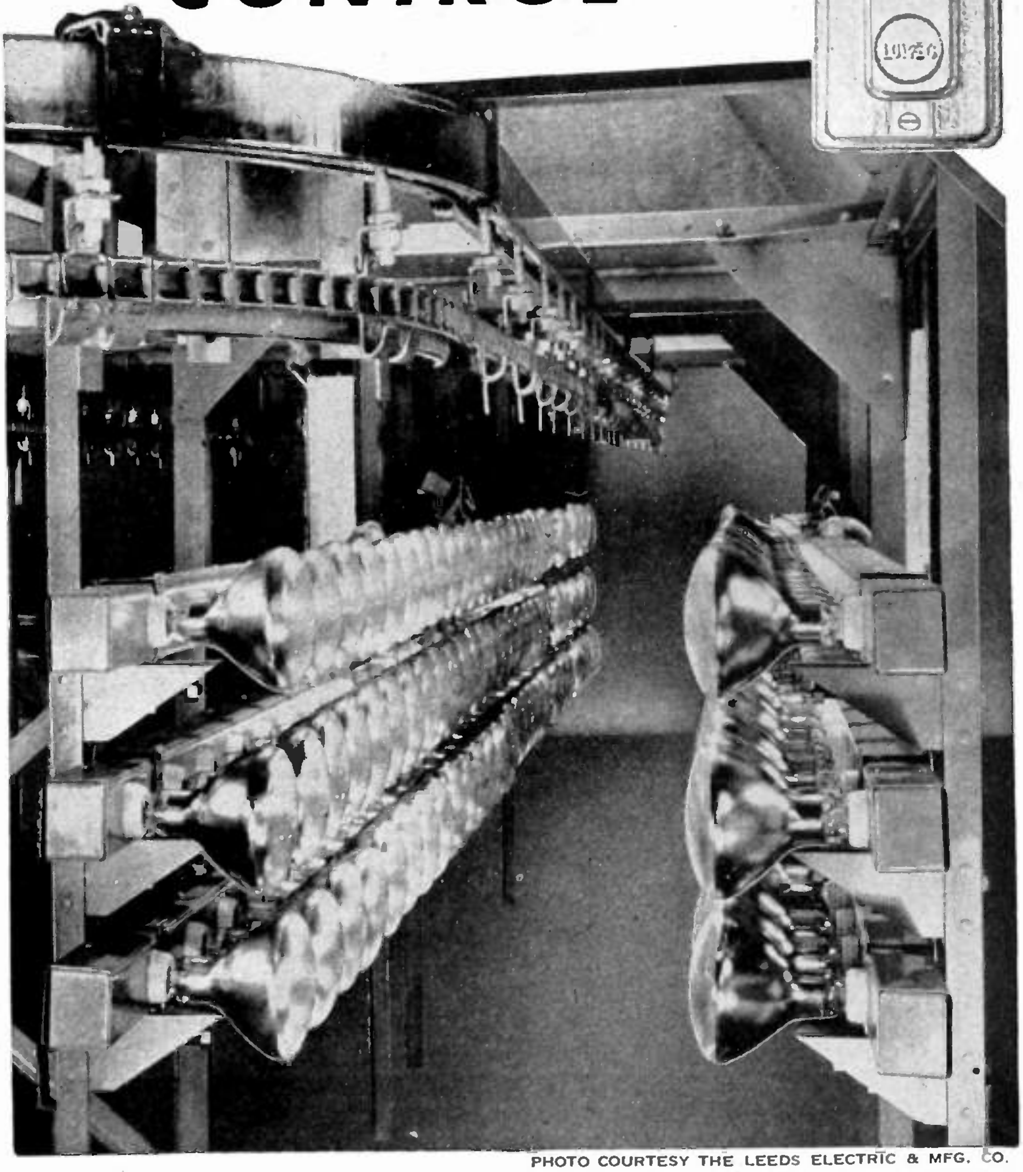
Excellent working conditions and post-war opportunities with long-established manufacturer.

Call, or write to Chief Engineer, Dictograph Corporation, 95-25 149th Street, Jamaica, L.I., N.Y.

(Continued on page 56A)







POSITIONS OPEN

(Continued from page 54A)

ELECTRONIC ENGINEERS

Leading television and electronics organization in Manhattan needs first-class engineers specializing in electronics, physics, physico-chemistry, and high-vacuum technique, for research development mainly on important post-war products. Give full details of experience and salary. Replies held in strictest confidence. Write to Box 333.

TELEVISION ENGINEERS

Long-established and well-known company requires Television Engineers:

1) Graduate engineers having had definite experience in the Television field, transmitters or receivers
2) Cathode Ray Tube Research Engineer
3) Mechanical Engineer and Designer

Excellent opportunity for well qualified men. War work now, Television later. Applicants must be U. S. citizens.

Company located in New York. Our staff knows of this advertisement and replies will be kept confidential. Write, giving all details, to Box 334.

SENIOR RADIO ENGINEERS

Mid-west radio-electronics manufacturer has present and post-war positions for one chief mechanical engineer, and two research, three development, two production, one specifications-and-standards engineers. Salaries open. Confidential inquiries respected. Write Box 336.

RADIO EXECUTIVE

Mid-west radio-electronics manufacturer seeks assistant chief engineer capable of wider responsibilities. Salary open. All queries confidential. Write Box 337.

(Continued on page 58A)

Steatite Insulators by STUPAKOFF

FOR TRANSMITTING ANTENNA

IN AM, FM and Television broadcasting, Stupakoff low loss steatite insulators have proven their superiority for high frequency installations.

Illustrated are a few styles of precision made lead-in, strain and post insulators by Stupakoff. They provide unfailing service with the ultimate in electrical performance.

Laboratory control—years of engineering experience—modern production facilities—manufacturing skill—combined, enable Stupakoff to produce a complete line of dependable ceramic insulators of unequalled quality for the electronic industry.

Stupakoff engineers, supported by two generations of experience in the manufacture of ceramics, are at your disposal and are ready to assist you in planning projects in the transmitting field.

ARMY E NAVY
"FOR GREAT ACHIEVEMENT"

Do More Than Before—Buy EXTRA War Bonds

STUPAKOFF CERAMIC AND MANUFACTURING CO., LATROBE, PA.

Ceramics for the World of Electronics

POSITIONS OPEN

(Continued from page 56A)

ELECTRICAL ENGINEERS AND PHYSICISTS

Need a few men with sound training and some experience in the lighting and electronics fields to work on the design, development, or production of indicated products. The exact type of work will depend upon the individual's interests and experience. Positions offer definite opportunities. Advanced degrees in electrical engineering or physics desirable, but not essential. Openings in Pennsylvania and Salem, Massachusetts.

Write to Sylvania Electric Products, Inc., Industrial Relations Department, 254 Essex Street, Salem, Massachusetts.

RADIO AND ELECTRONICS ENGINEERS

Engineers with the ability and experience required to design and develop radio and electronic equipment.

The men who qualify will become permanent members of engineering staff, and will participate in the post-war program of a progressive and well-established company. This firm has excellent laboratory facilities, and is one of the leaders in its field.

All inquiries will be kept confidential. Send all details of experience, etc. with reply to Box 326.

The foregoing 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. ....

READY TO TRANSMIT
—yet standby current is zero!

To reduce drain on batteries specify
KAAR *Instant-Heating* RADIOTELEPHONES

One of the special features of Kaar mobile transmitters is their instant heating tubes. When the "push-to-talk" button on the microphone is pressed, the transmitter immediately goes on the air... but between transmissions standby current is zero. By eliminating battery drain during standby periods, this 22-watt transmitter can be operated from a vehicle's 6-volt ignition battery without requiring frequent re-charging.

The PTS-22X shown above operates on frequencies between 30 and 40 megacycles. (Available up to 62-MC on special order.) Two other Kaar transmitters, the PTL-10X and PTL-22X, for operation in the 1600-2900 KC band, are likewise equipped throughout with instant heating tubes.

Notice also how the dust cover can be removed by releasing two luggage type catches. Likewise the entire chassis can be removed for checking or servicing by releasing four additional catches.

These are but two of the features which make Kaar Radiotelephones so popular for military, civil and commercial communication between mobile units and a central station.

KAAR
ENGINEERING CO.
PALO ALTO, CALIFORNIA

Export Agents: FRAZAR & HANSEN
301 Clay St., San Francisco 11, Calif., U. S. A.

MOBILE RECEIVERS—Crystal controlled superheterodynes for medium and high frequencies. Easy to service.

CRYSTALS—Low-drift quartz plates. Fundamental and harmonic types available in various holders.

CONDENSERS—Many types of small variable aircondensers available for tank circuit and antenna tuning.

MICROPHONES—Type 4-C single button carbon. Superb voice quality, high output, moisture proof.

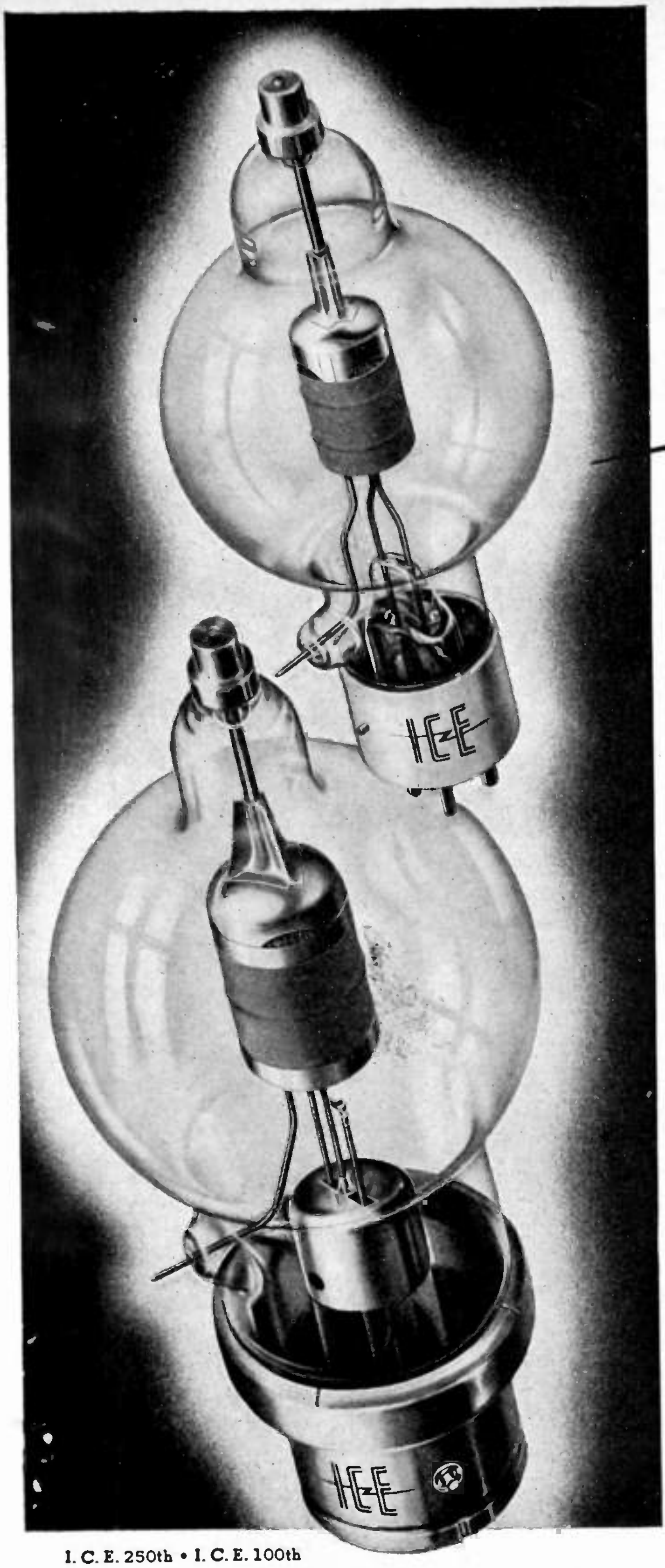
POWER PACKS—Heavy duty vibrators and power supplies for transmitters, receivers. 6, 12, 32, voltDC.

Membership

(Continued from page 48A)

Shoemaker, W. J., 1236 Hopkins Ave., Redwood City, Calif.
Sisson, E. D., 1469 Summit St., Columbus, 1, Ohio
Southern, C. O., 477 Bombardment Group, (M) Godman Field, Ky.
Spoelstra, H. E., 6607 N. Seneca St., Portland, 3, Ore.
Steed, F. S., Abbey Hotel, Great Malvern, Worcester, England
Stoeltzing, M. M., 1420 Harvard Blvd., Dayton, Ohio
Storgaard, E., R.C.A.F., Clinton, Ont., Canada
Sturley, G., 206 E. 17 St., Vancouver, Wash.
Swarthout, K. L., 21010 St. Francis, R-2, Farmington, Mich.
Sweetman, C. E., W. Blvd. & Weymouth Rd., Newfield, N. J.
Switzenberg, E. A. F., 195 Broadway, c/o Western Electric Co., Dept. T-9813, New York, N. Y.
Theedom, L. H. R., R.C.A.F., Clinton, Ont., Canada
Tull, E. H., Box 456, Clinton, Ont., Canada
Tunturi, A. R., University of Oregon, Medical School, Portland, 1, Ore.
Tuten, B. L., 3520 Glasgow St., Portsmouth Va.
Vlodek, S. F., 110 AAF Base Unit, Section H, Mitchel Field, N. Y.
Vollick, C. N., Box 352, Dunnville, Ont., Canada
Van Tersch, L. W., 112 N. 18, Marshalltown, Iowa
Walden, J. M., 1113 W. Illinois, Urbana, Ill.
Waelterman, E. H., 2033 De Soto Ave., 7, St. Louis, Mo.
Wantz, S. P., 879 Bombardment Squadron, (V.H.), S.H.A.A.F., Salina, Kan.
Watson, A. D., Clinton, Ont., Canada
Wileman, R. A., 1308 W. Albanus St., Philadelphia, 41, Pa.
Yolles, D. K., R.C.A.F., Clinton, Ont., Canada

(Continued on page 68A)



I. C. E. 250th • I. C. E. 100th

Rectifiers—

IMMEDIATE DELIVERY!

All of These Standard Taylor Tube Rectifiers Are In Stock - Ready for Shipment

TAYLOR ENGINEERS ARE AT YOUR SERVICE—READY TO HELP ON RECTIFIER PROBLEMS—

When it's advice you need, Taylor Tubes Engineering Staff, with it's extensive background of solving unusual rectifier problems, is ready and anxious to help with your plans. Taylor consultants will gladly study your requirements and make specific design recommendations. You'll find them able and willing to help you work out the best possible solution at a saving of time and money. In addition, if you require a special type of rectifier tube, we may be able to help you on that score too. Let us know about your rectifier problems—we shall be happy to direct our skill and experience in your direction.

Buy More WAR BONDS For Victory!

Taylor HEAVY **CUSTOM BUILT** DUTY **Tubes**

TAYLOR TUBES INC., 2312-18 WABANSIA AVE., CHICAGO 47, ILL.

Tropicalized

Q-MAX A-27 H. F. LACQUER

now safeguards Communication and Electrical Equipment Against

FUNGI

Fungus and mold are ever-present in humid atmospheres, especially in the tropics...ready to impair and destroy the fine precision performance of radio, electronic, signal detector, communication and other electrical equipment used by our armed forces.

To meet this vital need for adequate fungicidal protection of war material, Q-Max chemists spent many months in search of an ideal fungicidal agent to incorporate into Q-Max lacquer ingredients. Many highly effective fungicides proved to be unsatisfactory because they disturbed excellent electrical characteristics or caused the corrosion of metals.

But the search is now over, thanks to the effective blending of a potent fungicide with the outstanding dielectric coating material, Q-Max A-27 H. F. Lacquer.

With Q-Max A-27 H. F. Tropicalized Lacquer, no mixing of fungicides and lacquer is necessary—all this is done at our factory. Look for the word TROPICALIZED on the Q-Max label.

Communication PRODUCTS COMPANY, INC.
744 BROAD ST., NEWARK, N. J.
Factory: 346 Bergen Ave., Jersey City, N. J.

Communication Products Company, Inc.
744 Broad Street, Newark, N. J. Dept. J 23
Send: Q-Max A-27 Lacquer Booklet

Name.................................
Company.................................
Address.................................

Laboratory Standards

MODEL 62

VACUUM TUBE VOLTMETER

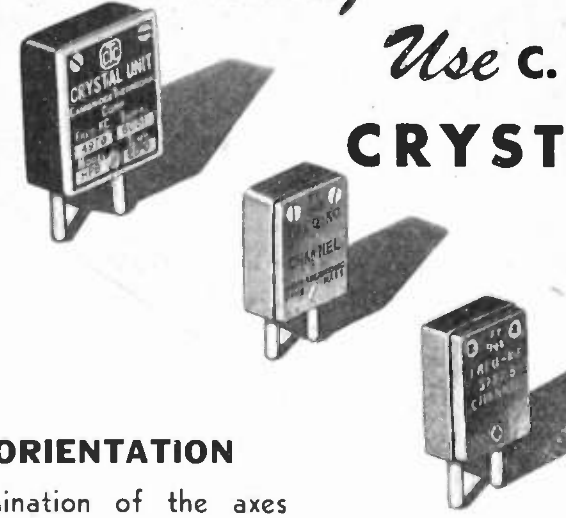
SPECIFICATIONS:

RANGE: Push button selection of five ranges—1, 3, 10, 30 and 100 volts a. c. or d.c.
ACCURACY: 2% of full scale. Useable from 50 cycles to 150 megacycles.
INDICATION: Linear for d. c. and calibrated to indicate r.m.s. values of a sine-wave or 71% of the peak value of a complex wave on a. c.
POWER SUPPLY: 115 volts, 40 60 cycles—no batteries.
DIMENSIONS: 4¾" wide, 6" high, and 8½" deep.
WEIGHT: Approximately six pounds. **PRICE:** $135.00 f.o.b. Boonton, N. J.

MEASUREMENTS CORPORATION
BOONTON, NEW JERSEY

FOR *Outstanding* PERFORMANCE

Use C. T. C. CRYSTALS

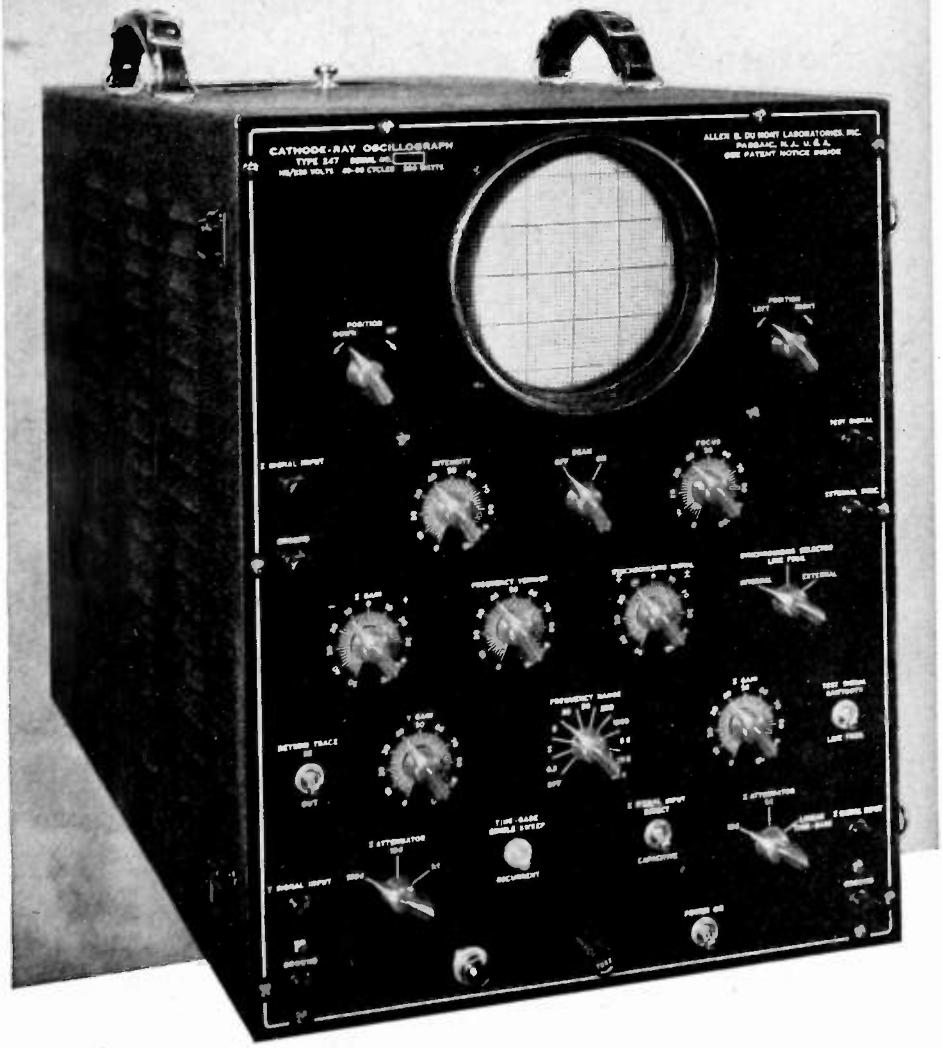


X-RAY ORIENTATION
— determination of the axes of the crystal before cutting — is your guarantee of constant frequency and high activity from every C.T.C. Crystal.
For Crystals you can count on, get in touch with

CAMBRIDGE *Thermionic* CORPORATION
447 Concord Avenue • Cambridge 38, Massachusetts

Another DuMONT *Contribution...*

TYPE 247 CATHODE-RAY OSCILLOGRAPH



Uses new Army-Navy preferred Type 5CP1 cathode-ray tube with intensifier electrode operated at overall accelerating potential of 3000 v. High-intensity patterns. 5" dia. screen.

Medium-persistence green screen, standard. Also available with short-persistence blue screen Type 5CP5 tube for high-speed photographic recording. Or Type 5CP2 long-persistence green screen for visual observation of low-speed phenomena.

Vertical or Y-axis amplifier response does not fall more than 10% below the uniform value from 2 to 200,000 C.P.S. Sufficient gain for maximum deflection factor of 0.05 r.m.s. volt input signal for 1" deflection of beam.

Distortionless, continuously-variable low-impedance attenuator or gain control. Stepped attenuator with ratios of 1:1, 10:1 and 100:1.

X-axis or horizontal amplifier accommodates signal produced by linear time-base generator. Reasonably uniform response from d-c to 100,000 sinusoidal C.P.S. Signal amplitude of 0.5 v. r.m.s. sufficient for deflection of 1" through amplifier.

Recurrent, repetitive and single-sweep operation of linear time-base generator. Continuously variable from 0.5 to 50,000 sawtooth cycles per second. Single sweep of writing rates corresponding to 0.5 to 10,000 cycles per second.

Z amplifier channel for applying external signal to grid or modulating electrode of cathode-ray tube.

Steel case. Black wrinkled finish. Copper-finished steel chassis. Two carrying handles. 14" w.; 19" h.; 26" d. 130 lbs.

This latest oscillograph facilitates the investigation of transient as well as recurrent phenomena over a wide frequency range. And since a permanent record of transient phenomena is usually desirable, this instrument provides for such photographic recording by applying comparatively high accelerating potentials to its cathode-ray tube. Furthermore, a new type of beam-control circuit is incorporated.

The sweep frequency range has been extended. The instrument may be used for observations on low-speed machinery and for other low-frequency signal functions—even down to ½ cycle per second. At the other extreme, the instrument handles radio-frequency signals as high as 500 kilocycles. The time-base has the necessary range to display such signals properly. Also, the vertical amplifier can satisfactorily accommodate them.

Literature on request . . .

DUMONT *Precision Electronics & Television*

ALLEN B. DUMONT LABORATORIES, INC., PASSAIC, NEW JERSEY • CABLE ADDRESS: WESPEXLIN, NEW YORK

If "skill to do comes of doing," this thirty-eight year old commentary explains the record of Connecticut Telephone and Electric in manufacturing telephones, switchboards, and electrical supplies for the military needs of this war.

We look forward to the *next* thirty-eight years, confident that this is the dawn of the most important era yet, in the development of communications, and every other branch of electrical science.

If our seasoned, but progressive, experience can be of help to you in connection with your communications requirements or the development and manufacture of electrical or electronic devices, we shall be glad indeed to talk with you.

CONNECTICUT TELEPHONE & ELECTRIC DIVISION

GREAT AMERICAN INDUSTRIES, INC.

MERIDEN, CONNECTICUT

TELEPHONIC SYSTEMS • SIGNALLING EQUIPMENT • ELECTRONIC DEVICES • ELECTRICAL EQUIPMENT • HOSPITAL AND SCHOOL COMMUNICATIONS AND SIGNALLING SYSTEMS • IGNITION SYSTEMS

Membership

(*Continued from page 60A*)

The following Students were transferred to the Associate grade during May and June:

Ahern, Charles R., Cambridge, Mass.
Ammon, Beatrice A., Bloomfield, N. J.
Bloom, Theodore, Portsmouth, Va.
Bonzo, Herberto M., Buenos Aires, Argentina
Borman, Edward C., Brooklyn, N.Y.
Caldwell, C. M., San Francisco, Calif.
Chedaker, Joseph, Philadelphia, Pa.
Cochran, Kenneth, Scotia, N. Y.
Daley, John F., Woburn, Mass.
Derganc, William, Woodhaven, N. Y.
Dikmen, Besim, New Haven, Conn.
Foley, Harold J., Elmore, Minn.
Galagan, Steven, Plainville, Conn.
Gilman, Bernard S., Forest Hills, L. I., N. Y.
Grumet, Alex, Bronx, N. Y.
Herr, Fred J., New York, N. Y.
Hillger, Richard E., Cambridge, Mass.
Kaplan, M. N., Beloit, Wis.
Kowalesky, Raymond J., Tower City, Pa.
Lapham, Edmund F., Jr., Norwell, Mass.
Limekiller, Andrew H., New York, N. Y.
Lockard, Ralph E., Jr., Los Angeles, Calif.
Matson, Leslie E., Jr., Merchantville, N. J.
McNabb, William, Harvey, Ill.
Morrow, G. Leigh, Minneapolis, Minn.
Peters, Philip H., Jr., Schenectady, N. Y.
Pratt, Francis E., Glencoe, Ill.
Smith, W. J., London, England
Stone, Merrill M., San Francisco, Calif
Van Spankeren, Gerard H., Buenos Aires, Argentina
Vosteen, Robert E., Medina, N. Y.
Webb, Deril T., Philadelphia, Pa.
Webber, Leonard E., St. Paul, Minn.
Wellings, A. A., San Francisco, Calif.
Westlake, Paul, Chicago, Ill.

OHMITE
RHEOSTATS AND RESISTORS

Veterans of Service on Every Battle Front

In the Fight From The Beginning

Because they have helped pioneer many resistance-control applications . . . and have proved thoroughly dependable . . . Ohmite Rheostats and Resistors have been "in the fight" . . . *from the beginning.* Today . . . they serve in countless thousands . . . in all types of critical equipment . . . on every front. They are relied on to function day-after-day under extremes of temperature, humidity and altitude. In resistance-control . . . Ohmite experience makes a difference. Widest range of types and sizes for every need.

BUY WAR BONDS

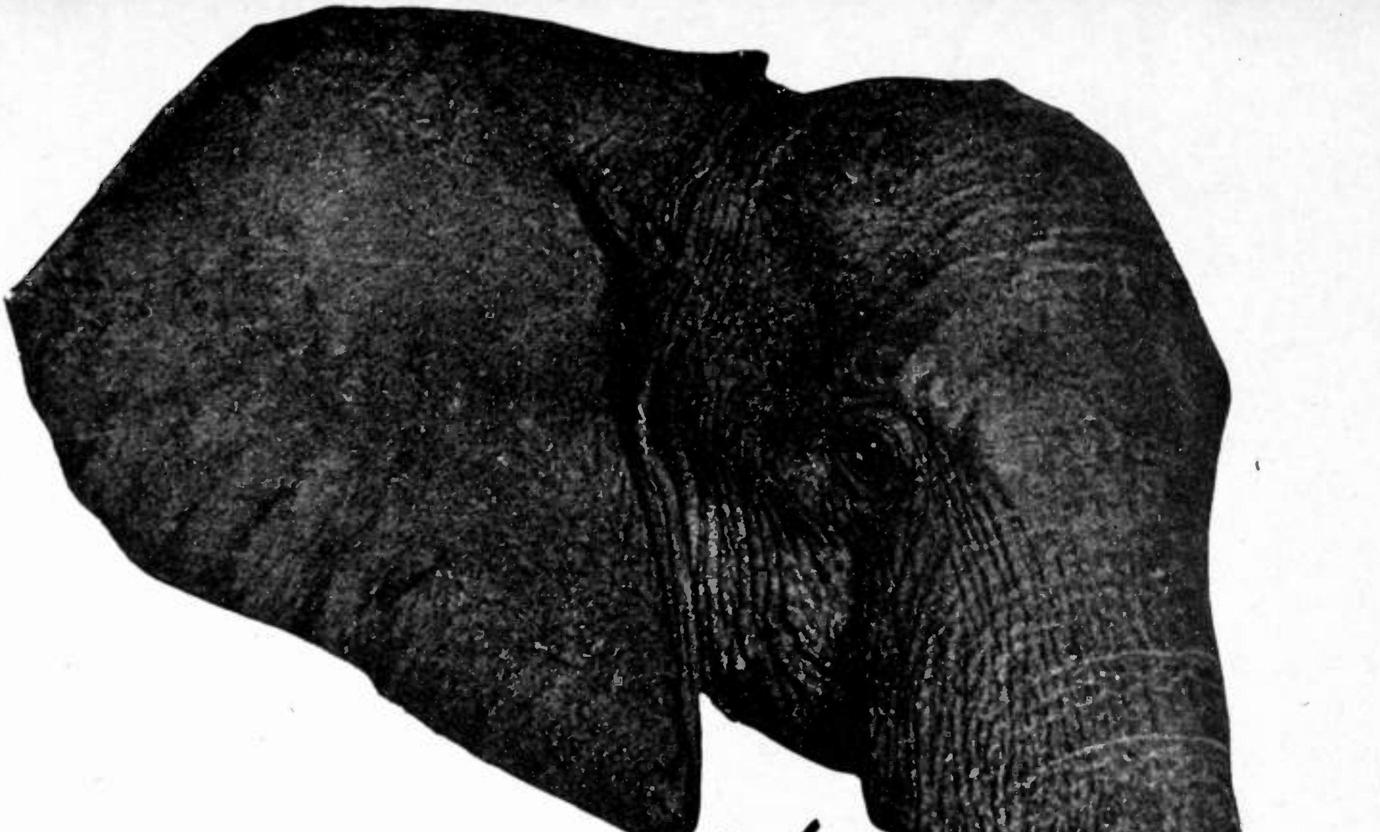
OHMITE MANUFACTURING COMPANY
4860 FLOURNOY STREET • CHICAGO 44, U. S. A.
Foremost Manufacturers of Rheostats, Resistors, Tap Switches

Your Answer Book on Resistance Problems

Write on company letterhead for Industrial Catalog and Engineering Manual No. 40. Gives helpful information on the selection and application of rheostats, resistors, tap switches, chokes and attenuators.

Be Right with **OHMITE**
RHEOSTATS • RESISTORS • TAP SWITCHES

INDEX



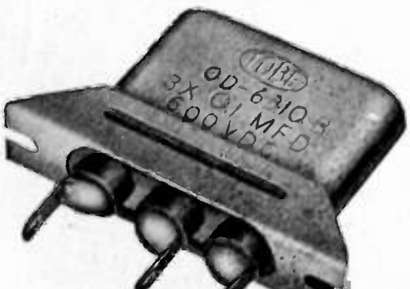
Living a Long Life

The characteristic you demand in a capacitor is long life. And in this all-important matter the record of Tobe Capacitors is an enviable one, with almost complete absence of "returns."

Lasting stamina is built into Tobe Capacitors through every step in their manufacture and is cross-checked by frequent, rigid inspections. Electrical ratings are always on the conservative side. Research is continuous in the search for an even better way, an even higher standard.

Type OD Capacitor (illustrated below) is manufactured in the careful Tobe way. Mineral oil impregnated and filled, in a streamlined drawn container, hermetically sealed. Designed for operation under a wide temperature range. Why not place your capacitor problems before Tobe engineers? Inquiries receive prompt, intelligent service.

LONG LIFE ASSURED



SPECIFICATIONS—TYPE OD* CAPACITOR

RATINGS:

600 VDC	Single Units	.05, 0.1, .25	Mfd.
	Dual Units	.05, 0.1	"
	Triple Units	.05, 0.1	"
1,000 VDC	Single Units	.05, 0.1	Mfd.
	Dual Units	.05, 0.1	
	Triple Units	.05	

STANDARD CAPACITANCE TOLERANCE—plus or minus 20.%**

TEST VOLTAGE—twice DC rating

GROUND TEST—2,500 Volts DC

OPERATING TEMPERATURE—55° F. to 185° F.

SHUNT RESISTANCE:
.05 to 0.1 Mfd.—20,000 Megohms
.25 Mfd. —12,000 Megohms

POWER FACTOR—1,000 cycles—.002 to .005

CONTAINER SIZE:
Width 9/16", length 1-11/16", height 1-17/32"

MOUNTING HOLE CENTERS—2-1/8"

Illustration shows capacitor with bottom terminals. Capacitors also available with top terminals.

*Data sheets showing complete code number for units having a specific capacitance value and voltage ratings available on request. **Other tolerances available.

TOBE DEUTSCHMANN CORP. · CANTON · MASSACHUSETTS

a small part in victory
TODAY
a big part in industry
TOMORROW


227A
(3-100E3)*
VT-127A
(3-100D2)*
327A
(3-100G3)*
327B
(3-100H3)*
53A
(3-50D4)*
15R
15E
(3-15A3)*
527
(3-300G4)*
Here are 8 special purpose Vacuum Tubes originated, developed and quantity produced by Eimac during the past few years
*The designations on these tubes are new Eimac type numbers which are descriptive of the tube characteristics. For example (3-100G3): the first digit 3 indicates triode, the figure 100 indicates plate dissipation, the letter "G" indicates physical type and the last digit 3 is a code indication of the mu of the tube.
Get Your Copy of Electronic Telesis—
a 64 page discussion of the fundamentals of electronics, written in layman's language — fully illustrated. Yours without obligation.
Follow the leaders to
Eimac
REG. U. S. PAT. OFF.
TUBES
EITEL-McCULLOUGH, INC., 882 San Mateo Avenue, San Bruno, California
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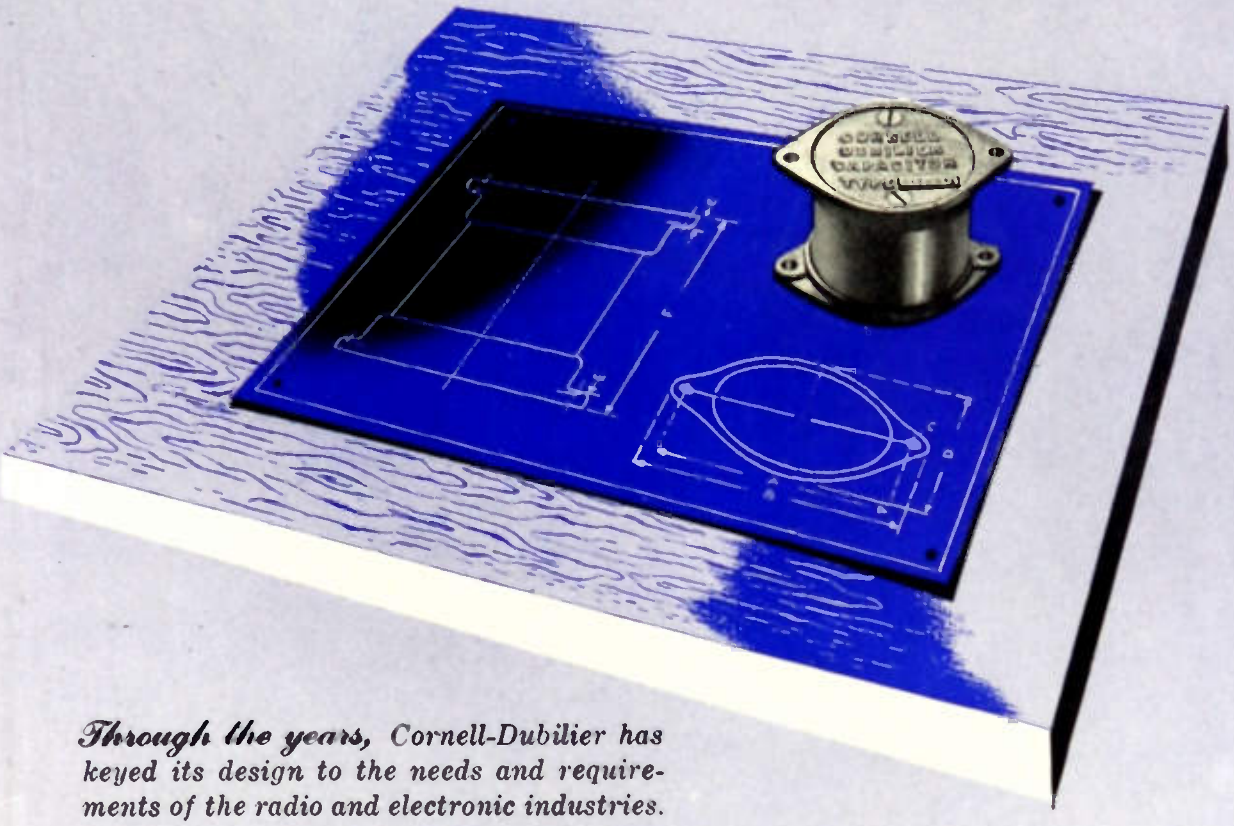
Export Agents: FRAZAR & HANSEN • 301 Clay Street • San Francisco, California, U. S. A.
882

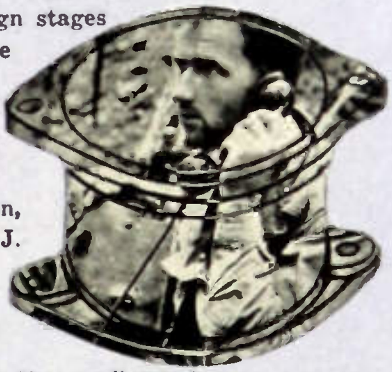
CORNELL-DUBILIER pioneers its designs on the drafting board of experience



Through the years, Cornell-Dubilier has keyed its design to the needs and requirements of the radio and electronic industries.

When the accelerated demands of war came, C-D was prepared with the experience, the skills and the equipment needed. For 34 years C-D research engineers have been active partners with equipment manufacturers. To supply their requirements, C-D has expanded from one plant in 1940 to six plants today.

The tremendous increase in production has not affected the high quality of C-D Capacitors. Their inherent stamina has been battle-tested in countless war applications. The finest materials, the same care thru every step of construction, produces the dependability which makes C-D's the choice of 4 out of 5 engineers. Consult us in the design stages of your product, we will gladly contribute our knowledge and experience. Cornell-Dubilier Electric Corporation, South Plainfield, N. J.

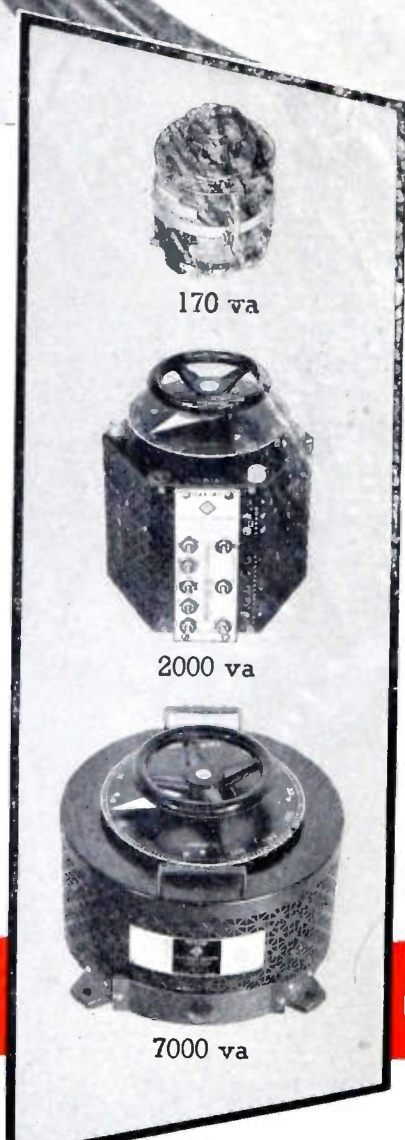


C-D HIGH POWER TRANSMITTER TYPE 59

For use as grid, plate blocking, coupling, tank and by-pass applications in high power transmitters. Low-loss, glazed ceramic cylindrical case. Can be mounted in any position. Series or parallel combinations obtained by bolting terminal ends together. Send for details.

Cornell-Dubilier Capacitors

MICA • DYKANOL • PAPER • WET AND DRY ELECTROLYTICS
WORLD'S LARGEST MANUFACTURER OF CAPACITORS



170 va

2000 va

7000 va

THE VARIAC . . . the *original* continuously adjustable, manually operated a-c voltage control . . . has these features:

- SMOOTH CONTROL — The VARIAC may be set to supply any predetermined output voltage with absolutely stepless variation.
- HIGH EFFICIENCY — Exceptionally low losses both at no load and at full load.
- HIGH OUTPUT VOLTAGES — VARIACS supply output voltages 17% higher than line voltage.
- LINEAR OUTPUT VOLTAGE — Output voltages are continuously adjustable from ZERO by means of a 320 degree rotation of the knob.
- SMALL SIZE — VARIACS are smaller than any other voltage control of equal power rating.
- CALIBRATED DIALS — VARIACS are supplied with reversible dials which read directly in output voltage both from zero to line voltage and from zero to 17% above line voltage.
- ADVANCED MECHANICAL DESIGN — Rugged construction; no delicate parts or wires; two or more units may be ganged on the same shaft for multi-phase operation.

VARIACS are stocked in nine models with power ratings from 170 va to 7000 va; prices range between $10.00 and $100.00.

Because all of our facilities are devoted to war projects, VARIACS are available at present only for War work; all orders must have a priority rating.

VARIACS are made *only* by General Radio

GENERAL RADIO CO. Cambridge 39, Mass.
NEW YORK CHICAGO LOS ANGELES

● WRITE FOR BULLETIN 885