1945 WINTER TECHNICAL MEETING

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Graduate Engineering Study
Electronic Research
Industrial Heating
Quartz-Crystal Units
Velocity-Modulation Bunching
F-M Duplex Operation
Universal-Coil Winding
Voltage-Regulator Operation
Coaxial-Cable Attenuation
The ILLINOIS TOOL WORKS has made tremendous strides in the design and development of dielectric heating equipment for such applications as moulding bakelite, heating pre-forms, joining thermoplastics, etc. AMPEREX tubes are used in all such equipment produced by this well-known concern.

With the ILLINOIS TOOL WORKS, as with many other leading concerns working with electronic tubes, it's the "Amperextra" of longer life and low-cost efficiency that has made our products a first and exclusive choice. AMPEREX pioneered in the field of tubes for industrial applications. We are familiar with the needs of industry, and we have the tubes to meet all requirements. Consult AMPEREX for assistance with your present or postwar problems.

IMPORTANT! AMPEREX tubes are now available through leading radio equipment distributors. This new arrangement may save valuable time for busy engineers by enabling them to obtain many of our standard tube types from their local supply sources.

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SYNCHRONIZATION OF VIBRATORS FOR PARALLEL OPERATION

While improvements in circuit technique developed by Electronic Laboratories have allowed commutation of currents up to 25 to 30 amperes, recent requirements for increased power have necessitated introduction of dual vibrator circuits thereby doubling the output of E-L Power Supplies. Both in-phase and two-phase systems are available permitting output powers in excess of 1000 watts.

**Parallel Operation — Single-Phase — A.C. Output**

In units furnishing A.C. power as output, the vibrators must operate in phase. This operation is secured by means of modulating voltage obtained from a secondary placed on a current dividing reactor, which insures the division of the current between the two vibrators. The primary is center-tapped with the center tap feeding the power transformer, while the ends connect to power contacts on the same side of the respective vibrators. If one vibrator makes contact before the other there will be a voltage induced in the secondary of the transformer. This induced voltage is applied to the actuating coil of the other vibrator in such a way as to be in phase and thereby cause it to increase its frequency and decrease that of the higher frequency vibrator. When the vibrators reach the same frequency it is obvious there will be no modulating voltage. The time constant of the current division network is such as to take care of small time differentials. The circuit has the further advantage of allowing the use of one large power transformer which gives higher efficiency than can be secured by using two smaller ones.

**Parallel Operations — Two-Phase — D.C. Output**

In vibrator power units which have a filtered D.C. output the advantages of a two-phase system are obvious in the reduction of the filter network required to secure a given A.C. ripple on the output.

To correct any possible frequency deviations, Electronic Laboratories' engineers have cross-modulated the D.C. voltage applied to the respective actuating coils with an A.C. voltage secured from the opposite transformer primary. The A.C. voltage is of such a value that the alternate in- and out-of-phase relationship effectively forces the vibrators to assume the same frequency. The 90° phase relationship essential to insure low ripple outputs from associated rectifiers is secured by the action of the modulating voltage, inasmuch as the vibrator having the higher natural frequency will make contact first upon the application of the input voltages. This causes the effective voltage on the actuating coil of the lower frequency vibrator to be $E_{dc} + E_{ac}$ ($E_{ac}$ is the modulating voltage received from the transformer winding associated with the higher frequency vibrator). When the lower frequency vibrator actually makes contact, the phase of the A.C. modulation is such that the effective voltage applied to the higher frequency vibrator is $E_{dc} - E_{ac}$, thus causing a reduction in its frequency until synchronism is obtained with the lower frequency vibrator and contact is broken. It then functions in the normal manner. The cycle then repeats itself and maintains the 90° phase shift.

The E-L unit, shown below is a typical Vibrator Power Supply used in the operation of communication equipment. With a 12 volt D.C. input, it develops 500 watts power output. Dimensions 20x20x8 inches.

**Electronic Laboratories Inc.**

**VIBRATOR POWER SUPPLIES FOR LIGHTING, COMMUNICATIONS AND ELECTRIC MOTOR OPERATION - ELECTRIC, ELECTRONIC AND OTHER EQUIPMENT**
What are Carbonyl Iron Powders?

Above you see the fundamental characteristics found only in G.A.F. Carbonyl Iron Powders. The text below outlines kinds of powders, chemical and physical analysis, including “Q” value, and suggested uses.

G.A.F. Carbonyl Iron Powders are obtained by thermal decomposition of iron penta-carbonyl. There are five different grades in production, which are designated as “L,” “C,” “E,” “TH,” and “SF” Powder.

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

The chemical analysis, the weight-average particle size, the “tap density,” and the apparent density as determined in a Scott Volumeter are given in the following table for the five different grades:

<table>
<thead>
<tr>
<th>Grade</th>
<th>% Carbon</th>
<th>% Oxygen</th>
<th>% Nitrogen</th>
<th>Wt. Ave. Diameter (microns)</th>
<th>Tap Density (g/cm³)</th>
<th>Apparent Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>0.005—0.03</td>
<td>0.1—0.2</td>
<td>0.005—0.05</td>
<td>20</td>
<td>3.5—4.0</td>
<td>1.8—3.0</td>
</tr>
<tr>
<td>C</td>
<td>0.03—0.12</td>
<td>0.1—0.3</td>
<td>0.01—0.1</td>
<td>10</td>
<td>4.4—4.7</td>
<td>2.5—3.0</td>
</tr>
<tr>
<td>E</td>
<td>0.65—0.80</td>
<td>0.45—0.60</td>
<td>0.6—0.7</td>
<td>8</td>
<td>4.4—4.7</td>
<td>2.5—3.5</td>
</tr>
<tr>
<td>TH</td>
<td>0.5—0.6</td>
<td>0.5—0.7</td>
<td>0.3—0.6</td>
<td>5</td>
<td>4.4—4.7</td>
<td>2.5—3.5</td>
</tr>
<tr>
<td>SF</td>
<td>0.5—0.6</td>
<td>0.7—0.8</td>
<td>0.5—0.6</td>
<td>3</td>
<td>4.7—4.8</td>
<td>2.5—3.5</td>
</tr>
</tbody>
</table>

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

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

Table 2 at right gives relative Q values (quality factors) and effective permeabilities for the different grades.
This diagram emphasizes the fact that Carbonyl Iron Powders consist of spherical particles only.

2. Note shell structure of each particle—produced by varying content of oxygen and carbon.

of carbonyl iron powder. The values given in the table are derived from measurements on straight cylindrical cores placed in simple solenoidal coils. Although the data were not obtained at optimum conditions, the Q values as expressed in percentage of the best core give an indication of the useful frequency ranges for the different powder grades.

<table>
<thead>
<tr>
<th>Carbonyl Iron Grade</th>
<th>Effective Permeability at 1 kc</th>
<th>Relative Quality Factor at 200 kc</th>
<th>1 Mc</th>
<th>100 Mc</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>4.16</td>
<td>100</td>
<td>90</td>
<td>43</td>
</tr>
<tr>
<td>E</td>
<td>3.65</td>
<td>94</td>
<td>98</td>
<td>72</td>
</tr>
<tr>
<td>TH</td>
<td>3.09</td>
<td>81</td>
<td>100</td>
<td>97</td>
</tr>
<tr>
<td>SF</td>
<td>2.97</td>
<td>81</td>
<td>98</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>93</td>
<td>72</td>
<td>84</td>
</tr>
</tbody>
</table>

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

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

Further information can be obtained from the Special Products Sales Dept., General Aniline and Film Corporation, 437 Hudson Street, New York 14, N. Y.
Centered on the B-29 radio operator’s table is the RCA-designed BC-348 long-range aircraft receiver. This is the receiver which keeps the crew in touch with its base on the thousand-mile bombing runs over Japan. It is one of the equipments which is responsible for the remarkable success of these new bombers.

Conceived by the Signal Corps before Pearl Harbor, the BC-348 was designed and put in production by RCA in time to be installed on practically every important bomber now used by the Army Air Forces. Its outstanding sensitivity, selectivity, image rejection, operating convenience and rugged construction made it the logical choice for the B-29’s of the 20th Air Force.

Many other aviation equipments have been designed by the engineers of RCA since the BC-348. When security permits, these contributions to aviation radio progress will make peacetime aviation safer, faster and more efficient.

1919-1944 - 25 Years of Progress in Radio and Electronics
The RCA-Designed 5C-348 Receiver occupies the center of the radio operator's table in the B-29.
A machine like that shown above may look like a complicated and perplexing mass of metal to you, but not to Utalins*

They visualize the precision of the resulting tools... made in Utah's own factory to Utah's undeviating standards. They know these tools will play a major part in creating the quality products that make possible the modern electronic circuit.

And Utalins* know the performance of these products! For Utah's process is absolutely comprehensive... the making of tools is only the first step. It is followed by the close supervision and painstaking testing of all steps of manufacture, from raw material to finished product... the unbroken circuit.

When finally these products become an integral part of an electronic device, those listening—as well as those working in the many phases of electronic development—can recognize the quality of the products that emanate from Utah's self-contained plant.

*Utalins—Utah's helpers.
IT ALL DEPENDS ON
WHERE YOU PUT THE BRUSH

Topside or bottom—a hair brush can be applied effectively at either place according to the result desired. But the commutator brush on an a.c. voltage regulator is different. Only one place will do for best results and that is where the Transtat's brush track is.

Instead of on the commonly used flat annular section, where brush area is limited, the Transtat brush rides on the curved outside surface of the coil. There, the uniformly laid wires permit grinding smooth, perfectly parallel, evenly spaced commutator segments. That means arc-less, practically stepless control without circuit interruption. This position allows room for the long, sturdy Transtat brushes with their larger heat dissipating surfaces and lower current density per contact area . . . cooler running, longer lasting brushes.

Being transformer type regulators, Transtats will not distort wave form or alter power factor. Their varnish-impregnated cores and coils cannot loosen in service. The balanced collector arms maintain brush setting in any position. For continuous a.c. voltage regulation in testing, heating, plating, light control, speed control and in radio transmitters and other electronic apparatus they are unexcelled.

Write for bulletin 51-2.

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NATIONAL COMPANY
MALDEN, MASS, U. S. A.

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FROM FREDERICK LEWIS

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**Lowest Temperature Rise**

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

Only the extreme pressure of essential war production has delayed our release of this small one-watt AWS RC 30 type insulated resistor.

You'll find the BTA insulated resistor a worthy and important addition to the BT family. Built to meet American War Standards specifications, the BTA is only 0.718 inches long and 0.250 inches in diameter. Wattage rating, 1 Watt at 40° C ambient. Voltage rating, 500 volts. Minimum range, 330 ohms. Maximum range, Standard: 20 megohms.

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IRC makes more types of resistance units, in more shapes, for more applications than any other manufacturer in the world.
ALCO has been awarded for the fifth time the Army-Navy "E" Award for "continued excellence in quantity and quality of essential war production."

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ALSiMag Steatite Ceramics are unsurpassed for lending permanent rigidity—permanent alignment and accurate spacing of elements in electrical circuits.

ALSiMag Insulators are permanent materials. They are strong, hard, inflexible—do not distort by loading, nor do they shrink with time. Impervious to heat up to 1000° C. Highly resistant to thermal shock. Non-corrodible. Do not absorb moisture.

If stability is a requirement of your electronic and electrical apparatus, investigate the strength and permanent rigidity of AlSiMag. Send us a blueprint or a sample. Let us prove that AlSiMag is best suited to your requirements.

AMERICAN LAVA CORPORATION, CHATTANOOGA 5, TENNESSEE
NORTH AMERICAN PHILIPS is one of the few producers of electronic tubes successfully manufacturing the type 833-A transmitting triode tube in quantity. The assembly alone calls for unusual skill and resourcefulness on the part of our engineers and craftsmen, and specially designed equipment.

Due to the unique design of the 833-A, the plate is supported from its own terminal post at the top of the glass envelope and the remaining elements from the base or stem. The tube must therefore be assembled in two sections and accurately joined on a glass lathe. Bonding of the metal grid and plate terminal posts to the glass flares is done by r-f induction heating, which is confined to the sealing points only. This operation, illustrated, is completed in a matter of seconds.

The ability to produce such difficult tube types is the result of experience gained by an organization with a background of over half a century of research and development in the electrical field. That is one of the reasons why manufacturers look to North American Philips as a reliable source of electronic tubes for their postwar requirements.

Although all the Norelco tubes we produce now go to the armed forces, we invite inquiries from prospective users. A list of the tube types we are especially equipped to produce will be sent on request.

Write today for interesting booklet, describing the background of North American Philips in the science of electronics.
This SOLA CONSTANT VOLTAGE TRANSFORMER has an important postwar future in YOUR

HEATING CONTROLS - REFRIGERATION CONTROLS - TELEVISION SETS - F-M RADIO - VACUUM TUBE VOLT-METERS - ELECTRONIC GAUGING AND INSPECTION EQUIPMENT - PHOTO-METRIC INSTRUMENTS...there are other applications of course.

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First: because it will stabilize output voltage at your rated requirements regardless of line voltage fluctuations as great as ±12 to 15%.

Second: because its small, compact size is ideal for chassis mounting.

Third: because of its low, economical cost.

Fourth: because of the saving that can be made through the elimination of other components.

Fifth: because a majority of anticipated service calls can be eliminated from your cost calculations.

Sixth: because the users of your product will get greater satisfaction from trouble-free service.

This particular transformer is rated at 6.3 volts, 17VA output and is designed primarily for the stabilization of vacuum tube filament and heater voltages. Other voltages and capacities for chassis mounting can be supplied on the same low cost, economical basis to meet your exact requirements.

Constant Voltage Transformers

To Manufacturers:
Complete specification details covering this new Constant Voltage Transformer will be furnished at your request.
Ask for Spec. No. KCV-103

Transformers for: Constant Voltage • Cold Cathode Lighting • Mercury Lamps • Series Lighting • Fluorescent Lighting • X-Ray Equipment • Luminous Tube Signs • Oil Burner Ignition • Radio • Power Controls • Signal Systems • Door Bells and Chimes • etc. SOLA ELECTRIC CO., 2525 Clybourn Ave., Chicago 11, Ill.
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If you are interested in radio broadcasting, television or frequency modulation... carrier current work, industrial heating or electronic controls, -hp- has an important date on your calendar of plans... a real stake in your future. Even though vital technical data cannot be released publicly today it is a practical idea for you to make known your requirements now so that much time may be saved in ultimately obtaining the solution to your problem. Among new instruments already perfected you may find just what is required. -hp- engineers are at your service without cost or obligation.

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Since 1934 UNITED has specialized in engineering, designing and building Transmitting Tubes that set the Quality Standard for the entire Radio Industry. When performance counts UNITED Tubes provide a maximum of electronic efficiency—plus a long and dependable life. Accept nothing less than UNITED quality for your own tube requirements.

Order direct or from your electronic parts jobber.

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813
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Worner's specified that the three relays used in this system must be sensitive but not delicate; that they require no adjustment; and that they meet Underwriter's requirements.

Guardian engineers developed the Series 155 D.C. relay as the answer to these specifications. This is a compact, sturdy, easily mounted unit with constant spring tension on the contacts. It is widely used on remote selection devices and other low voltage applications. Copper slug time delays up to .05 seconds on attract and 0.15 seconds on release are available. Coils for operation on any voltage up to 230 volts D.C. For further information write for Series 155 bulletin.

**GUARDIAN ELECTRIC**

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A COMPLETE LINE OF RELAYS SERVING AMERICAN WAR INDUSTRY

Proceedings of the I.R.E. January, 1945

Series 155 D.C. Relay
Consult Guardian whenever a tube is used—however—Relays by Guardian are NOT limited to tube applications, but are used wherever automatic control is desired for making, breaking, or changing the characteristics of electrical circuits.
Whether for today’s needs or post-war engineering, write today for your copy of this 36-page Catalog RC 6 replete with helpful engineering data.

INSULATED RESISTORS
Designed to Match War Standards Specifications

Integrally molded in one operation under laboratory controlled production standards, Stackpole Type CM Resistors in 1/2-(RC-10): 1/2-(RC-21): and 1-watt (RC-30) sizes have been specifically designed to meet the newly issued Army-Navy specifications. The construction of these new resistors is such that they offer an exceptional degree of stability under load—the average change being less than 5% after 1000 hours under test at full load. In addition to having highly satisfactory humidity characteristics well within today’s exacting requirements, Stackpole Type CM Insulated Resistors meet up-to-the-minute salt water immersion specifications.

Samples to any required tolerance on request.

STACKPOLE CARBON COMPANY, ST. MARYS, PA.
Aerovox selection ranges from tiny "postage-stamp" molded-in-bakelite units to giant porcelain-cased stack-mounting units. These many varied types are standard with Aerovox—in daily production—available at quantity-production prices.

The following factors are suggested in guiding your selection:

Electrical: (a) Capacitance and tolerance; (b) D.C. voltage rating; (c) Current-carrying capacity and frequency characteristics; (d) Allowable temperature rise and maximum operating temperature; (e) Special characteristics such as temperature coefficient, retrace, etc.; (f) Special operating conditions such as high humidity, altitude, extreme temperatures, etc. Mechanical: (g) Basic type; (h) Terminals; (i) Case; (j) Mounting holes; (k) Nameplate data.

Yes, Aerovox expects you to select that type best fitting your particular requirements in every way. And Aerovox is ready to help you make the proper selection. Remember, Aerovox Application Engineering—that "know-how" second to none in the industry—can make all the difference between disastrous makeshifts and the most satisfactory results.
Research, in the Bell Telephone System, has always been an expanding activity, growing with the scientific knowledge of the times and contributing to that knowledge. Upon it have been based important inventions and developments.

The telephone, itself, was invented in the laboratory where Alexander Graham Bell was carrying on researches in speech and hearing and laying the foundation for the electrical transmission of speech. As time went on the telephone research program expanded to cover every science which gives any promise of improved telephony and every engineering art which applies to the development, construction, installation and operation of telephone facilities.

These researches and development studies now cover electrical communication of speech—both by wire and by radio—the transmission of pictures (television)—and many important projects for war.

There is no end to progress

Every new research gives rise to new inventions and to new lines for development and design. New inventions indicate new lines for more research. Research and development work, invention and design go hand in hand. In the early years, this work was carried in part by the American Telephone and Telegraph Company and in part by the Western Electric Company, the manufacturing unit of the Bell System.

For many years, however, this work has been assigned to a specialized unit, Bell Telephone Laboratories, Incorporated. Theirs is the responsibility for the technical future of the industry. They carry their developments from the first faint glimmerings which basic researches disclose to the final design of equipment and the preparation of specifications for its manufacture. And after manufacture and installation, they follow their products in operation; and continue development work to devise still more perfect equipment, less expensive, more convenient and of longer useful life.

These policies and procedures of Bell Telephone Laboratories are distinguished by two characteristics. In the first place the Laboratories design for service. The consideration is not the profit of a manufacturer through first sales and replacement models but the production of equipment which will give the best service at the lowest annual cost when all factors are considered, such as first cost, maintenance, operation, and obsolescence. The Laboratories make no profit and the equipment they design is owned and used by the telephone companies; and the emphasis is upon that use.

Organized Co-ordinated Research

In the second place the Laboratories design always with reference to the complete communication system in which the particular equipment is to play a part.

Reliable, economical telephone service, which is the product of its efforts, is not so much an assemblage of excellent apparatus as it is an excellent assembly of co-ordinated equipment—all designed to work together reliably and economically for a larger purpose.

It is not enough that Bell Laboratories shall design a new piece of electronic equipment which has merit or a new cable or telephone receiver. They must design with reference to all the other parts of the communication system so that the co-ordinated whole will give the best possible service.

4600 People in Bell Laboratories

Bell Laboratories contributions to the Armed Forces derived in large part from the technical background that the Laboratories had acquired through their steadily maintained program of research. The Laboratories had special knowledge, skill and techniques which could instantly be diverted to war problems.

At the time of Pearl Harbor, over a quarter of the 4600 people in the Laboratories had twenty or more years of service. This breadth of background made possible many engineering developments outside the strict field of communication and these have been of value to the Armed Forces. So far the Armed Forces and the O.S.R.D. have engaged the Laboratories on over a thousand major projects. The major- ity of these assignments have been completed; and have contributed to our victories on many fronts.

Most of the Laboratories developments, of course, have been in the field of electrical communication. Communication, not simply between individuals as in ordinary telephony, but between mechanisms—as in the electrical gun director. The Laboratories techniques and electronic researches have produced many secret weapons for our country's Armed Forces.

Leader in Electronic Development

For those problems the Laboratories had a remarkable background of experiences in research and development. In World War I, they pioneered by developing radio telephone systems for talking between planes and between planes and ground stations. They also contributed methods and devices for locating enemy planes, submarines, and artillery.

In this war, Bell Laboratories have pioneered in the field of electronics. The Western Electric Company, which manufactures the designs of the Laboratories, is the largest producer of electronic and other war communication equipment in the United States and is now engaged almost exclusively in the manufacture of this equipment.

In war, Bell Telephone Laboratories devote their work to the needs of our Armed Forces. In peace, they are constantly exploring and inventing, devising and perfecting for continued improvements and economies in telephone service. Centralized research is one of the reasons this country has always had "the most telephone service and the best at the least cost to the public."
Back in 1938, Hytron began designing new dies and converting production machinery for the first BANTAM GT tubes. The industry said in effect: "You're crazy; it won't work. You can't telescope standard glass tubes to BANTAM size and get the same results." Beam tetrodes, such as the 50L6GT, particularly were considered impossibilities. The intense heat developed during normal operation would warp the elements and crack the small glass bulb.

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*1941 industry production figures: GT—52,000,000; metal—27,000,000; standard glass, G, and local—56,000,000.

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Proceedings of the I.R.E. January, 1945
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Proceedings of the I.R.E. January, 1945

26A
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Communication and electronic engineers, engaged in the difficult and complicated tasks of their profession in wartime, will find encouragement and cause for legitimate pride in certain of the thoughts expressed concerning their work by eminent industrial leaders in their field. Accordingly the PROCEEDINGS here presents, in its original form, the following views of the President of Sylvania Electric Products, Incorporated.

The Editor

The Challenge to Engineers

WALTER E. POOR

During the past four years, radio engineers have done far more than is generally known, or ever may be, to assure victory for the United Nations. They have worked out new designs in which the most advanced knowledge of the art has baffled, bested, and beaten the enemy. They have removed the time lapse between pure research and the commercial production. They have put radio quickly to work in battle. Indeed it may be said that the knowledge of the radio engineer is the secret weapon that has frustrated and destroyed much-publicized secret weapons of the enemy.

In this great work, as in all the titanic efforts the United Nations have made to win the war, skills have been joined together for the common good. Radio-tube engineers have, in some instances, proved to be the Minute Men of circuit design. Circuit engineers have, in other instances, presented almost impossible challenges to the radio-tube engineer. Together they have done a wonderful job. A far cry from yesterday's Engineering-As-Usual, today the radio-tube and the radio-circuit engineers must know the other's specific art, must be able fully to co-ordinate the knowledge that was once subdivided, specialized art.

In the peacetime to come this new united engineering effort will herald a new day of service to mankind. It will produce many new advances for the art of communication, the art of electronics in industrial production, and the art of electronics in the home.

From these postwar developments the tube and the circuit engineer, working closely together, will produce far-reaching and vital effects on the economy and social welfare of our people. They will create a host of jobs; they will create the means of better entertainment; more efficient public information; improved methods of making and controlling the quality of millions of products for millions of people. They will, I am certain, do the whole job exceedingly well, just as well as they have, through united skills and efforts, made possible the wonderful things which have made such a mighty contribution toward winning the war, so that the challenge of peace, a bigger, fuller life for everyone may be transformed into reality.
Adolph Bernard Chamberlain was born on February 3, 1901, at Franklin, Massachusetts. He enlisted in the United States Navy in 1920, and, after naval training courses, served as a radioman second class in the Eighth Submarine Division.

On leaving the Navy, he joined the pioneer technical staff of the General Electric Company's broadcast station WGY at Schenectady, New York, and as engineer in charge of field operations, was responsible for the early technical work on regional network experiments.

In 1927 he left the General Electric Company to become chief engineer for Stromberg-Carlson's station WHAM, at Rochester, New York, becoming general manager of that station in 1928. In 1929 Commander Chamberlain became technical director of the Buffalo Broadcasting Corporation, which at that time operated stations WGR, WKBM, WMAK, and WKEN, outlets of both the National Broadcasting Company and the Columbia Broadcasting System. In 1930 he became vice-president of this organization.

From 1931 to 1942 Commander Chamberlain was associated with the Columbia Broadcasting System as chief engineer and was directly responsible for the design, installation, operation, and maintenance of many phases of broadcast equipment, including standard broadcast antennas, transmitters, audio-frequency control facilities, measurement equipment and techniques, and broadcast studio acoustics. He was directly concerned with the planning and supervision of station modifications and new construction, the most outstanding of which include such installations as the 50-kilowatt transmitters at KNX, Hollywood, California; WTOP, Washington, D.C.; WBBM, Chicago; and WABC, New York. His duties included considerable work with relay and international broadcasting.

Commander Chamberlain was called to active service in the Naval Reserve in 1942, and is now on active duty in the Radio Division, Bureau of Ships, as one of four officer assistants to the Head of the Design Branch.

He joined The Institute of Radio Engineers as an Associate in 1927, was transferred to Member grade in 1930, and became a Fellow in 1942. He has been active on general and technical committees, and is a past Chairman of the Rochester and Buffalo Sections.
Concurrent Graduate Study — Its Place in Postwar Engineering Education*

F. R. STANSEL†, SENIOR MEMBER, I.R.E.

Summary—This paper, which represents some personal views of the writer, advocates a more extensive development of facilities for graduate study taken concurrently with professional duties. The advantages of such a program are pointed out, and certain changes in educational routine that may be desirable are discussed.

ANY PLAN for a postwar educational program in any branch of engineering must take into consideration the large amount of new subject matter that must be covered as a result of developments of the past decade. While some place for the new subject matter undoubtedly can be made in the curriculum by regrouping and by more emphasis on basic theory, yet there naturally arises the question of whether the engineering course should not be lengthened. Even before the war some educators advocated an undergraduate course of five or six years to allow more time for the humanities. An alternative to lengthening the period of undergraduate study is to expect more students to supplement basic training with one or more years of graduate study.

Any extension of the period of full-time education, either undergraduate or graduate, brings new problems, social, personal, as well as financial into the picture, and hence it would be well not to increase the years required to enter the engineering profession without first asking whether there is not an alternative way. Stephen Leacock, the Canadian educator, once characterized the extension of formal education in the Liberal Arts field as "education eating up life." He stated that in engineering, medicine and law "the adaptation of the means to the end is sufficiently direct to lessen the danger of wandering into the wilderness as liberal arts has done". Nevertheless, even in engineering, the danger of wandering does exist and should be avoided.

When considering alternatives to additional years of full-time study, one should remember that engineering is an experimental science to be learned as much in the laboratory as in the classroom. Once the neophyte has attained a certain degree of skill, where are there better laboratory facilities for advanced study than in industry itself? Would it not be well for the engineering profession, instead of advocating an increased period of preparation, to encourage the development of a vigorous course of graduate studies designed not to be taken on a full-time basis but concurrently with the laboratory work of the novice's early professional career?

Besides eliminating the problems arising from the ex-

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

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wish only to attain knowledge or skill in one specific subject, and concurrent courses should be organized to serve these students as efficiently as those seeking an advanced degree. For these students in particular instructors should be authorized to waive prerequisite courses when the student can demonstrate his fitness to derive benefit from the course.

A problem which should be studied in some detail by the engineering colleges is the place of the thesis in a concurrent graduate program. In the past it has been the almost universal custom for a candidate for a master's or a doctor's degree to present a thesis containing the results of some original investigation, both because of the educational value to be obtained from such research, and also to demonstrate the candidate's fitness for the advanced academic degree. This requirement is suitable for students engaged in full-time study, but for a student engaged in a concurrent program it may lead to difficulties and possibly to injustices to the student. The effect of a thesis requirement will vary from student to student, but as a starting point it would be well to consider its effect on three different groups of students.

The first group is composed of students whose professional duties are in the sales, administrative, or other fields in which there is little direct contact with the laboratory. For these students the experimental work involved in a thesis is undoubtedly beneficial, and for these students there is no need to change the present thesis program.

The second group is composed of students engaged in professional development and research work of much the same character as the investigation required for a thesis. For these students the educational value of a technical thesis is less. It may well be that they can gain more benefit from additional courses in parallel engineering or scientific subjects. Or they might profit from the preparation of a thesis dealing with some economic rather than technical aspect of their profession. Sometimes students in this group find it possible to present some phase of their professional work in thesis form. When such an arrangement is possible, it is quite advantageous from the student's viewpoint, but in modern industry development and research are often carried on by groups rather than by individuals, and it is frequently not feasible for the junior engineer to use his professional work to meet thesis requirements.

The third group consists of students who, by the time that they have completed a substantial program of studies and become candidates for the master's or doctor's degree, have independently of their studies published material which, had it been presented under the proper auspices, would have been acceptable as a master's or doctor's thesis. These men naturally feel that they have been denied an academic honor through a technicality. Before the war a number of such cases existed, and with the removal of wartime secrecy a substantial number will be added to this group. In fairness to these men, some consideration should be given to accepting their previous publications in lieu of a thesis. In order that no one college be criticized for undue leniency in this respect it might be well for all such cases to be passed on by a regional committee representing several engineering colleges.

In the matter of publication of thesis material the student may sometime find himself between two millstones, the college urging or even requiring publication, and the employer holding a restraining hand because of patent rights or editorial policies. This conflict often can be avoided by the choice of subjects of a theoretical nature not open to immediate commercial application, but the final solution of the problem can only be reached through closer co-operation between the college and the employer. In some cases it may be desirable for a representative of the employer to serve as a member of the student's guidance committee.

In conclusion, the writer feels that there is a definite need in the field of engineering for a broad program of graduate study taken concurrently with professional duties. Such a program will eliminate any need for prolonging the period of basic engineering training, and will make advanced study available to many engineers under favorable conditions. Some readjustments on the part of both the college and the employer are desirable if these courses are to produce the maximum benefits, but experience to date shows these readjustments can be made without great difficulty.

The professional engineering societies are urged, therefore, to encourage the colleges to supplement a sound, vigorous undergraduate course in the fundamentals of engineering, including due regard to the humanities, with such a program of concurrent graduate studies.
With the war victory of the Allied Nations steadily approaching, it is timely to turn attention both to the accomplishments of radio-and-electronic engineering during the war and the likely contributions it can make in the ensuing peacetime period. In this latter direction, an amazing vista is displayed—a prospect fraught with great possibilities of good for mankind. The following paper presents some of the wartime contributions and probable peacetime offerings of the radio-and-electronic field—a field in which The Institute of Radio Engineers and its Proceedings will continue to play a constructively contributory and widely useful part.

The Editor

Electronic Research Opens New Frontiers*

RALPH R. BEAL†, ASSOCIATE, I.R.E.

It is a great honor to address you on the occasion of the opening of this first National Electronics Conference. I feel that it is an especially high distinction to appear before you under the circumstances of this meeting. This is a gathering out of which should emerge a greater knowledge and understanding of the science of electronics, so vital in hastening the end of the war, and so important as a means of insuring a lasting peace—a happy and progressive peace.

I am deeply impressed with the prospects before us here. The very fact that such a conference has been called manifests the increasing urge of our scientists and engineers to move forward to the new frontiers, the challenging frontiers, which sweep across our horizons in the realm of electronics. It should give us confidence in the future to sense here a resurgence of the spirit of adventure traditional to our country, to find the same boldness and courage in pioneering on electronic frontiers that characterized the development and expansion of our geographical frontiers.

Standing out sharply against the backdrop of America's economy is the realization that our economy, our entire social and economic structure for that matter, depends upon change and progress. We must have new enterprises; we must have new services; we must have new products.

America's is an economy of plenty and not an economy of scarcity. To create employment and prosperity, we must have fresh sources of supply and raw materials—inspiring creations of science and engineering. We must cultivate change, because we thrive on change and our civilization advances on change. New things, new fundamentals, result from research. Research, and more research, is the order of the postwar world.

When war came on that terrifying Sunday morning at Pearl Harbor in 1941, only a small part of our vast manufacturing facilities had been converted for defense purposes; most of our great steel and textile mills, automobile factories, locomotive plants, radio manufacturing plants, and machine-tool works were engaged in peacetime enterprise.

The preparedness picture was dark indeed, but for one heartening fact: American research scientists and engineers were ready. The record is clear on this. Men equipped with knowledge and experience gathered so painstakingly by research and engineering between wars and before that period made an unbeatable combination when teamed with the great resources of this country and the American will to win.

We may picture Victory as a gigantic wheel, among the numerous cogs of which are all branches of science: physics, chemistry, aerodynamics, metallurgy, optics, radio, television, electronics. As this great wheel turns toward the final day of this war, we see all these cogs of science meshing perfectly with the gallant forces of our fighting services, the Army, Navy, and Air Force, and with our Allies.

During the past four years science has been mobilized into a co-operative effort unprecedented in all history. Throughout America, industrial research and engineering have been geared in perfect harmony. Internationally, the same co-operation has been in operation. Science, therefore, has been forged into an all-powerful wheel that turns to generate Victory.

When hostilities began in 1939, it looked as if science, perverted by our enemies, were on their side. But this was because in the days of peace that intervened between World War I and World War II, Germany had concentrated its research on warfare; it applied science to war, not to peace. In America, science was focused on peacetime pursuits. Our great industrial research laboratories were at work developing new commercial products and services. In the Axis countries, the laboratories

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† Assistant to Vice-President-in-Charge, RCA Laboratories, New York 20, N. Y.
were secret gateways to war; they were creating new weapons of destruction.

When war came to America, we suddenly were awakened to the realization that science must be directed to warfare if we were to defeat an enemy fortified by ingenious scientific applications. Quickly America's men of science rallied to national defense; industrial research was organized to function as a unit with one aim, to win the war. America's great resources of research joined with the Army and Navy and our fighting men on the highways, on the sea lanes, and in the air.

In war, the scientist and the engineer answer the call in the laboratory and in the field. They go into all quarters of the globe and to all battle fronts. They are summoned into swift flight to gain first-hand knowledge and to make practical applications of their discoveries. They study the techniques and devices of the enemy; they build superior weapons to combat and to overcome the foe. They work and think quickly. They telescope years of development into months, so that Victory may be hastened.

We must be quick to recognize that if science can be so effective in war, it can be even more effective in peace. As soon as this war is won we must reconvert science from destruction to construction and by so doing rehabilitate the world and bring happiness and new comforts in living to every nation on earth.

In charting a course for the future, it is important that we keep in mind the ground already covered, the progress already made. Out of the preparedness of our research scientists and engineers in electronics have emerged new and vital weapons and new means of speeding industrial output. Radio, no longer confined to dots and dashes, as in the last war, became, thanks to electronic research, the eyes and ears of our fighting machine, the voice of our high command, the directing force behind our antiaircraft guns, the unerring guides of warplanes and warships, and the swift means of communicating across every ocean and across every frontier.

Electron tubes flash facsimiles of maps, documents and photographs over great distances to aid Allied strategy. Radio broadcast stations are voices of liberty, informing and uniting our people. Yet, these are only a few of the achievements of radio and electronics. When the full story is permitted to be told, it will be an astounding chapter of scientific accomplishment.

The electronic triumphs during the Second World War become all the more remarkable when we realize that by far the majority of these wartime weapons and services were either unknown or nonexistent at the close of the first World War. In the latest developments we find clues to future progress and revolutionary trends of research and engineering. Close examination will reveal that virtually without exception the present wartime applications of electronics have their roots in the field of electrical communications, a field that has afforded fertile soil to research scientists for more than one hundred years.

The new frontiers that are opened by electronics, and the horizons that extend before us, might never have become known were it not for the earlier research of Morse, Bell, Hertz, Thomson, Edison, de Forest, and Marconi, to name but a few. Hertz conducted his classic experiments in electromagnetic waves in 1887, and in his further investigations, he observed the photoelectric effect and reported it to the scientific world. In 1897, Thomson, in England, demonstrated the characteristics of the electron.

Edison had noted earlier that when a metallic plate was sealed into the glass bulb of his carbon filament lamp, a mysterious current flowed between the plate and the filament. This is known as the "Edison effect." This current was shown to be carried by a stream of electrons emitted from the filament.

In photoelectric effect and in thermionic emission, electrons are freed from matter to which they ordinarily are bound. They may be freed also by electronic and ionic bombardment and by the influence of electric fields of extremely high intensity.

The science of electronics deals with the flow of such freed electrons in vacuum or through a vapor.

One of the earliest applications of electronics was in a communication device, the Fleming Valve of 1904. And in 1906 de Forest announced the three-element tube which opened the way for far-reaching improvements in wireless. Successive steps in research, and inventions by Armstrong, Langmuir, Arnold, and others contributed to the extraordinary ability of controlled electrons to detect and greatly amplify feeble electrical impulses, to rectify currents, and to generate oscillations from a few cycles per second to billions of cycles per second.

Thirty years ago, de Forest's three-electrode tube was applied as a repeater on the telephone-wire circuits connecting New York and San Francisco, making transcontinental telephony practical. In wire telephony and telegraphy, as well as in radio, electronic applications provide a basic means from which successive developments are made to meet the communications needs of expanding industry and national activity.

Out of research have come the vacuum-tube detectors, amplifiers, and oscillators for radio receivers and power electron tubes for transmitters, developments which made the overseas radiotelephone a practical reality.

Our present system of sound broadcasting resulted from an upsurge, after the first World War, of interest in electronics as represented by the electron tube. Broadcasting was developed as a new industry, an industry of great significance in our national development.

Electronic research also produced the necessary vacuum tubes for the transmitters and receivers that opened the short-wave spectrum from 3 to 30 megacycles for use in long-distance communications services. This greatly expanded the number of radio channels and increased the efficiency of overseas circuits. It opened the way to progress from which we derive great benefit today.

For example, Marconi, to name but a few. Hertz conducted his classic experiments in electromagnetic waves in 1887, and in his further investigations, he observed the photoelectric effect and reported it to the scientific world. In 1897, Thomson, in England, demonstrated the characteristics of the electron.
Radiotelegraph circuits over distances in excess of 5000 miles now operate at transmitting speeds of 500 words per minute. Electronics also has made possible short-wave teletype circuits which reach practically any part of the world; radiophoto services in which pictures taken on the battlefields of Europe or in the Pacific are brought, within a few hours, to our daily newspapers; radiophone circuits which carry the voice to the remotest sections of the globe; and radiotelegraph and telephone services extending to ships and planes.

Research in electronics and vacuum-tube circuits is bringing into use the vast radio spectrum which lies in the frequency range from 30 megacycles to frequencies a thousand or more times greater. This radio spectrum opens new horizons of tremendous potentialities for exploration.

Generally speaking, the distance range of these staticless, nonfading microwaves may be referred to as "line-of-sight" transmission, for unlike long waves, they fail to follow the curvature of the earth. This characteristic is adaptable to domestic broadcasting, communications, and other services. The tiny waves may well be the means of establishing a new epoch in domestic communications and ultimately have a profound influence on communications in countries throughout the world.

One of the new services to emerge through the use of frequencies in the lower ranges of this radio spectrum is frequency-modulation broadcasting. It makes possible new realism and tonal quality and substantially reduces interfering noises or static.

A service that has yet to be developed in the very-high-frequency spectrum is facsimile broadcasting, by which we mean radio transmission and reception of the printed page, illustrations, and diagrams. In commercial communications of the future, electronic applications will make possible high-speed facsimile by which printed matter by the page may be sent from one side of the country to the other in a few seconds. An entire page of a newspaper may be transmitted over thousands of miles in a matter of minutes. Printed documents, handwritten letters, diagrams, and photographs may be flashed from point to point.

In other uses, facsimile also may be employed for copying and duplicating purposes and for the production of printing plates either locally or remotely over circuits to one or more points.

Radio-and-electronic developments are an indispensable aid to man in his conquest of the skyways, in attaining speed and safety in air travel. They have opened realms of vast scope to the airplane by affording freedom of movement over land and sea. Electronic applications in aviation cover a wide variety of services and aids. They provide radio-communication services and navigation systems. They make available to aircraft means of ascertaining their positions instantly. Long-distance radio direction finders supplement other means of navigation.

Clearance- and height-measuring instruments can inform the pilot of the character of the terrain over which he is flying and enable him to remain at a safe altitude, regardless of the weather. Collision-prevention apparatus will indicate obstructions that mayloom in the plane's course and afford ample warning for changing the direction or elevation of the plane to avoid collision. Electronic means for controlling the plane itself and for connecting the controls of the plane into guiding radio systems so that it may fly to its destination automatically are entirely feasible in the postwar period.

The outlook is bright for radio-communication services that can connect automobiles and other conveyances on land or water into telephone circuits and other communication services. It is within reason to predict that individual communication sets of the walkie-talkie type will come into wide use, and may also be connected into our national and world-wide telephone circuits.

Reward has come at last to man's inherent desire and striving to extend his sight beyond its normal limitations. Electronic television, now on the verge of becoming a great new industry and a service to the public, answers fully our expectations. It stands forth as a prime example of a major achievement of research and engineering. Into the development of this marvel of the age has gone more concentrated research than into any other modern development. Television involves fundamental discoveries dating back almost a century. It has tapped virtually all of the reservoirs of knowledge in radio, chemistry, physics, optics, and electronics.

Every element, every component of the system has required exploration and pioneering. New principles had to be discovered in picture-pickup devices, electron optics, electronic amplifiers, radio transmitters and transmitting tubes and antennas, and in methods for synchronizing the transmitted and received pictures. New parts of the radio spectrum had to be explored and harnessed.

Television today rests upon its own solid foundation of research. It encompasses many remarkable scientific advances, each of which in its own right rises as a monument to the progress of science. Key contributions to a television system are the iconoscope or electronic "eye," which picks up the scenes, and the kinescope or electronic receiver tube. Out of years of research has come an improved camera tube known as the orthicon, which has remarkable sensitivity. It makes possible the transmission of scenes which previously could not be picked up; and it opens the way for still more improvements which doubtless will enable the television "eye" to observe any scene that is visible to the human eye.

Television has the greatest promise of any development in the art and science of radio. With a television receiver in your home, you will become an eyewitness to interesting events and entertainment beyond your immediate horizon. From your living room, you will see the world pass in review.

Theater television is also being prepared as a great new service. For the first time in the centuries of theater history, a method has been devised for bringing to theater audiences the thrills and drama of actual events as
they occur at a distance. Electronic research has made it possible to produce pictures in motion of theater-screen size. Connected into television networks, theaters in cities and villages throughout this country may become playhouses for showing the newest dramatic productions, and in addition bring to audiences great sports events, news events, and educational features of national importance.

Through research, scientists have succeeded in transmitting electrical impulses, the human voice, and music, over great distances with and without wires. They now have added television to their achievements, and, out of their ability to transmit sight over wires as well as through space, has come still another service with fabulous possibilities. It is industrial television.

This application envisages the use of radio sight as the "eyes" of factories, the means of co-ordinating and controlling giant manufacturing enterprises, and the means also of looking into places that otherwise might be inaccessible or dangerous to man. Industrial television may be used by the plant manager to observe critical operations. It may be used to follow the flow of materials and observe progress of work. It may be used in chemical reaction chambers to make visible complicated chemical processes.

As a development in radio-electronics, which promises a remarkable expansion in domestic communications, radio relays are attracting wide attention. Radio relays utilize extremely high frequencies, highly directive transmitting and receiving antennas, and power output of only a few watts. Unattended stations may be placed across the country at intervals of about thirty miles.

These relays will provide the wide channels required for television, for high-speed facsimile and other modern domestic services. They may be utilized in aviation communications and for navigation and control services for aircraft. They may also serve as terminal stations to connect mobile craft of all kinds to telephone lines and other lines of communication. They may serve to report weather information or other information automatically from remote regions, either directly or through additional repeater stations.

Out of the accumulation of research in television and especially in electron optics, has come a new electronic instrument, the electron microscope, which uses electrons instead of light rays to penetrate the hidden mysteries of Nature and the submicroscopic world. This achievement of RCA Laboratories has been acclaimed as the most revolutionary laboratory tool of the twentieth century. It has played an important part in wartime research.

The range is wide indeed in which electron tubes play a vital role. They perform an astonishing array of tasks, none of which appears too heavy, too precise, or too vast for them. Radio tubes are the control elements in devices which open doors, bring elevators to a level landing, operate time devices, and ring alarms. They detect smoke in fire-prevention apparatus; they count and sort merchandise, match colors, and gauge thickness of materials to a millionth of an inch. They provide safety devices in industry. They measure humidity and atmospheric pressure, and control temperatures to a point of perfection. We shall hear a great deal in the future about electronic industrial control.

Attention was focused recently upon a development in radiothermics, the fast-growing industrial use of the high-frequency power that generates heat. It is an electronic dehydrator perfected in RCA Laboratories. In thirty minutes it completes an operation requiring twenty-four hours by the conventional system in the production of the renowned drug penicillin. Electronic power heating now speeds output and reduces costs in many other manufacturing processes. Its achievements extend from sewing, riveting, and welding to dehydrating vegetables, tempering steel, and baking plywood planes.

The urgency of aircraft production, coupled with the shortage of aluminum, gave high-frequency heating one of its first opportunities. It was discovered that laminated-wood structural parts and sections combining light weight with maximum strength could be bonded more satisfactorily and rapidly with high-frequency heat than by any other means. Going still further, engineers produced high-frequency equipment that made possible the all-wood plane.

New applications of electronic devices and techniques have become partners of the woodman's ax and the sawmill to make wood one of our most versatile and serviceable materials. Informed observers foresee a broad field for high-frequency heating in the furniture industry after the war, particularly in the manufacture of curved laminated sections for radio cabinets, pianos, and other pieces of furniture requiring formed-wood sections. Radiothermics has aided production immeasurably in the wartime metals field, in the production of vital plastics and other necessities brought on by the war but which should find a variety of important postwar uses.

Advances in the science of electronics have been so rapid in the twenty years before this war and during the war years that it requires more than a brief moment to appraise the full measure of progress. But one thing is evident: In their great movement forward, research scientists, in addition to opening new frontiers, have spread before themselves a vast new world of unexplored opportunities. This means that trained men in greater numbers than ever will be needed to conduct research and to apply the results to new products and new services. The education and training of these men for research and engineering is of paramount importance, because on their success, to a large extent, will hinge the progress and welfare of our nation.

In conclusion, I wish to make this plea—that industrial research never relinquish its harmonious co-operation with the Army and Navy. Science, which has helped to win the war, must continue to assist in preserving the
THERE ARE two general methods by which radio-frequency power is used in industrial-heating applications. These are usually designated as "induction heating" and "dielectric heating." Induction heating is used when the work is some good electric conductor such as a metal. The work to be heated is merely brought near the so-called inductor coil which is usually just a few turns of water-cooled, copper tubing electrically connected to a source of radio-frequency power. Alternating magnetic flux generated by the current in the coil links the work and induces in it the eddy currents which do the heating.

The dielectric type of heating is used on substances which are relatively good electrical insulators. Here, the work to be heated is placed between electrodes which constitute the plates of a condenser. A high-voltage, high-frequency, electric field is established in the work by connecting the plates to a radio-frequency generator. Heating is caused by internal electrical losses in the work. These losses are supposed to be due to the atoms' taking up some of the vibratory motion of the bound electrons as these latter are shaken back and forth by the high-frequency electric field.

Therefore, while the two methods of radio-frequency heating use the same general type of equipment, yet they differ widely in several respects. In induction heating electrical energy is transferred from the generator to the work by magnetic flux; in dielectric heating the energy transfer is made by an electric field. In induction heating the load generally has a low impedance; in dielectric heating the load impedance is usually high. In induction heating the heat is generated in the work by conduction of induced currents; in dielectric heating there is no electrical conduction in the work, in the true sense of the term. The methods also differ in the way the heat energy is distributed. The induction method is essentially a surface-heating phenomenon, while in dielectric heating the heat is distributed quite uniformly throughout the volume of the load.

The techniques employed and the results obtained in both of these heating methods have been discussed and published on several previous occasions. Therefore, in this paper it is the author's hope only to emphasize two of the unique advantages of radio-frequency heating which so far seem not to have received their due attention.

These advantages are:

(1) By radio-frequency heating it is possible to attain controlled power concentrations which far exceed those obtainable by the more conventional methods; and

(2) In radio-frequency heating the heat is generated within the work itself. This obviates the necessity of transferring heat across boundary surfaces, which is always a very inefficient process.
The ability to create very high power concentrations is especially advantageous in processes where it is desirable to confine the heating to a small, sharply defined volume. For example, in such operations as case-hardening, welding, brazing, or soldering it is desired to heat only a thin shell or narrow strip on the work while the other parts are to remain relatively cool. This effect may be accomplished by applying the necessary energy at high power levels for very short times. This minimizes the conduction of heat and the high temperatures are created only in those regions where heating is desired.

When high power concentrations are mentioned one immediately thinks of the oxyacetylene flame or the electric arc. In the case of the torch, the transfer efficiency from source to work is extremely low so that powers, into the work, of 5 kilowatts per square inch are about the maximum attainable at present. In radio-frequency induction heating it is not difficult to put 100 kilowatts into a square inch of surface area with an overall efficiency of 50 per cent.

In the arc, the power concentrations may be comparable to those in radio-frequency induction heating but the intensity of the arc has a much lower range of control. With a 100-kilowatt radio-frequency generator the surface of a 2-inch steel bar can be brought to the melting point in half a second, or the power may be reduced until it will require 5 seconds to solder a small milk can.

Radio-frequency induction heating is generally accomplished with frequencies above 100 kilocycles and for the majority of applications the most suitable frequencies lie between 200 and 500 kilocycles. Moreover, most of the applications involve the heating of steel. It may be well therefore to trace, in a rough fashion, what happens when high powers are applied to a piece of steel work by means of high-frequency induction.

For the sake of simplicity let us assume that the work is a plane of infinite extent and depth, the inductor is a thin ribbon of width 2a, and that it is spaced a distance h above the work. (See Fig. 1.) The current in the work is distributed about as shown by the density of shading.

A very useful concept, which is used in dealing with high-frequency phenomena and which will aid in this description of the heating of steel is the so-called “depth of current penetration”, or perhaps a better term is “the penetration unit”. It is defined as the depth below the surface at which the current density is 1/e times its value at the surface. Here e is the base of the natural logarithms so that at a distance of one penetration unit below the surface the current is approximately 37 per cent of its value on the surface. The penetration unit, of course, varies with the frequency and with the electrical and magnetic properties of the substance in which the current is flowing. Table I lists the values of penetration units for a few common metals at a number of different frequencies.

Two values are given for iron. One is for iron at room
heated volume the depth of current penetration will no longer be 0.6 mil but 35 mils. (The penetration unit for steel above the Curie temperature as shown in Table I.)

The curves of Fig. 3 show the approximate distribution of current and temperature at the end of 0.01 second heating.

The curves of Fig. 4 show the approximate distributions after 0.5 second heating time.

Now these curves show orders of magnitude only, but they illustrate two important facts:

(1) The heating time must be very short, in the order of microseconds, if the high temperatures are to be closely confined to the volume occupied by the induced currents; and

(2) The greatest heating effect occurs right at the boundary between the magnetic steel and its nonmagnetic form. This high-intensity front, of course, moves inward as the steel is heated above the Curie temperature.

Another important relation is shown in the curves of Fig. 5. Here is plotted the current distribution in a lateral direction. It is seen that if the inductor has an equivalent width of ½ inch and is spaced ½ inch from the work, then more than 80 per cent of the heating effect is located in a strip ½ inch wide.

From the data of the foregoing curves and Table I it can be determined that, since the current penetration is so small, the application of 100 kilowatts per square inch may result in a power concentration in volume of 20,000 kilowatts per cubic inch.

This concentration of energy beneath an inductor makes it possible to heat a very localized area on a piece of work. Again, since the depth of current penetration is so small, the heating can also be controlled in depth by varying the frequency, power, and heating time.

However, it should be pointed out again that in order to take advantage of the localization of the induced currents to heat restricted volumes it is necessary that the heating be accomplished in very short times. This, of course, requires high power concentrations. For practical considerations it is not possible, at the present time to apply power in much greater concentrations than about 100 kilowatts per square inch. Hence the heating times must be a few hundredths of a second or more. For example, it has been found that in order to put a uniform, hard case of 20 mils thickness on Society of Automotive Engineers 1050 carbon steel it is necessary to use power concentrations of at least 75 kilowatts per square inch and heating times in the order of 1/10 second.

Aside from the greater precision of heating control offered by the use of high power concentrations there are other marked advantages of this technique. For instance, the more rapid the heating the greater is the volume of production.

Then, in the surface hardening of steels, rapid heating makes possible the self-quenching of the work. For example in the case-hardening job previously described, the high temperatures are confined to a relatively thin...
shell, perhaps 50 mils deep. The bulk of the material is thus relatively cool. At the end of the heating period, the heat is therefore rapidly conducted away from the high-temperature region. In many instances the resulting cooling is rapid enough to quench the steel surface. In general, the lower the carbon content of the steel the more rapid must be the heating and quenching cycle to produce full hardnerness. This in turn means higher power concentrations. When the work is a steel of low carbon content or when the ratio of the heated volume to the unheated volume is larger than about one to ten then a combination of self-quench and water quench may be used to produce fully hardened shells without the use of excessively high powers.

**Effect of Frequency on Power Concentration**

At first thought one might conclude that since the depth of current penetration decreases with increasing frequency, then the higher the frequency the greater are the power concentrations which are possible. Practical limitations, however, keep such a rule from being generally true. The optimum frequency is determined principally by the size and shape of the work to be heated. In general, the smaller the piece the higher is the frequency which should be used.

When supplying a given high power to a piece of work if the frequency is too low, the necessary currents in the inductor coil are exceedingly large; much power is lost in heat, and the electromagnetic forces may cause distortion of the inductor or may make it difficult to keep the work accurately positioned. Moreover, in extreme cases the efficiency of energy transfer to the work may become very small. For example, suppose the work to be heated is a thin steel strip perhaps 5 mils thick and half an inch wide. Let us say that the inductor coil is several turns of copper tubing wrapped around the strip with as close a spacing as is convenient. Let the frequency be 1 megacycle. It will be found that the strip heats quickly to a dull-red-color temperature and then fails to become any hotter. The temperature is slightly above the Curie point and the efficiency of energy transfer is only a few per cent of what it was when the steel was in the magnetic state.

The reason for this low transfer efficiency can be seen from a simple analysis of the situation. Since the inductor is wrapped around the strip the induced currents in the strip must flow across one face and back in the opposite direction across the other. When the strip is cold the current penetration unit is only about 0.4 mil and therefore approximately 99 per cent of the magnetic energy is absorbed within a depth corresponding to the half thickness of the strip. But on the other hand, when the steel is hot and nonmagnetic the current penetration unit is 24 mils, and in a half thickness of the strip only about 18 per cent of the magnetic flux energy is converted into heat. The other 82 per cent is canceled by the flux which penetrates from the opposite side.

In order to couple energy into the hot strip with high efficiency the current-penetration unit should be equal to or less than one fifth of the total thickness. This means that a frequency of several hundred megacycles is necessary to heat the 5-mil strip in the manner described.

In other cases the frequency may be too high for the size of the work. Again let us take a specific example. Suppose that 100 kilowatts are to be applied to a steel cylinder 4 inches in diameter and that the frequency is, again, 1 megacycle.

The inductive reactance of even a single-turn, 4-inch, inductor coil becomes quite large at this frequency. In fact it will be found that in order to feed 100 kilowatts into the work the voltage across the single loop must be near 1000 volts. For a close spacing between coil and work this voltage is likely to cause arcing, especially when the work is hot. A wider spacing greatly decreases the coupling to the work and results become worse rather than better. The solution to the problem is the use of a lower frequency.

There are many other difficulties encountered with high-frequency effects. In some cases where the work is very small it may be impossible to use as high a frequency as desired because of the difficulty of coupling megacycle energy into the work. At frequencies of several megacycles, electrical energy becomes quite elusive and an "inductor" coil may in reality turn out to be an electrical capacitance.

**Method of Concentrating Power**

Aside from increasing the total power input it is possible to increase power concentration in the work by decreasing the area heated simultaneously. This, of course means fewer turns in the inductor coil and at the limit, a single turn.

The most satisfactory arrangement we have found, and a great many were tried, is the use of a current transformer between the oscillating tank circuit and a single-turn inductor loop. The simplest form of transformer consists of a primary of ten or more turns in the form of a solenoid, surrounded by a split copper can which forms a one-turn secondary. The primary winding constitutes the tank inductance and the tank capacitors are connected directly across its terminals.

The single-turn inductor loop is generally of 1/4-inch outside-diameter copper tubing. It is made to fit the work with a clearance of about 0.030 inch and is connected to the transformer secondary by leads which are as short and as close together as safe insulating conditions will allow.

With this arrangement there is no difficulty in feeding 100 kilowatts into a steel rod 2 inches in diameter. The width of the current path in the work is between 1/2 inch and 1/4 inch so that the total area heated is about one square inch. In order to heat the entire lateral area of the rod it is necessary only to pass the rod through the loop in a continuous manner. Speeds vary depending
upon the heating requirements, but may run from 0.5 inch per second to 3 inches per second, or more.

**Power Concentrations in Dielectric Heating**

For dielectric heating the power concentrations are much lower than in induction heating. However, as a process for getting heat into a piece of work, it is usually possible to apply energy at far higher levels by radio-frequency heating than by any other means. In practically every other method of heating used in industry, the heat is generated in some convenient manner and then conducted or radiated into the work from the source, which of course must be at a higher temperature. Since dielectric materials are all relatively poor heat conductors, whenever an attempt is made to conduct or radiate heat into the work at a high rate the surface is usually overheated. On the other hand in high-frequency dielectric heating the heat is created within the work itself. And when the electric field has a uniform distribution and the work is homogeneous the heat is created uniformly in all parts. The electrodes, being good electric conductors, are not heated by the electric currents, and therefore are generally cooler than the work. Thus the surfaces of the work are usually kept cooler than the interior. In fact, the conduction of heat from the work to the electrodes is one of the limiting factors in producing high-energy concentrations in the work.

Let us consider an hypothetical slab of material, \(d\) centimeters thick and \(A\) square centimeters in area. Let us also say that the dielectric constant is \(k\), and that the power factor of the material is \(\phi\). In order to heat the whole slab as uniformly as possible, it is placed between electrodes which overhang the work as shown in Fig. 6. The maximum voltage which can be applied in this case is, usually, the breakdown voltage in the air between the edges of the electrodes. Let us call this voltage \(E\).

The power put into the work can then be written as \(P = EI\phi = E^2C2\pi f\phi\) where the displacement current is \(I = EC2\pi f\). Here \(C\) is the electrical capacitance of the work and \(f\) is the frequency. The capacitance of the work can be written \(C = gkA/4\pi d\) where \(g\) is the conversion factor for the system of units used. Also let us express \(E\) in terms of the electric field strength \(F\) which will cause breakdown in the air. Very approximately therefore we may say \(E = F \cdot d\).

Combining these transformations into a single formula the maximum power which can be put into the work is \(P = F^2d^2gkA2\pi f\phi/4\pi d\) or \(P = gF^2dAf\phi/2\). The product \(g\phi\) is known as the "loss factor" of the material and is listed in tables for most common materials. Above 10 megacycles this loss factor usually varies little with frequency but it generally increases rapidly with temperature. Of course \(dA\) is the volume \(V\) of work, and \(F\) is fairly constant. Combining \(F^2/2\) and \(g\) into a single constant \(G\), the power per unit volume becomes \(P/V = GF\) (loss factor). When \(P\) is in watts, \(V\) in cubic inches, \(f\) is in megacycles per second, and the loss factor is in per cent, a reasonable, safe value of \(G\) is 200, when the thickness of the load is in the order of 1 inch. Note that the power concentration varies directly with frequency. It would seem therefore that the higher the frequency the greater will be the power concentration. But, again, practical conditions limit this rule. The first of these conditions is the total power necessary. Commercial generators have been built which supply 100 kilowatts at 25 megacycles but as the frequency increases above this value the power capabilities drop rap-

![Fig. 6—General arrangement for dielectric heating.](image-url)
practical operations, such as gluing, the power concentrations seldom exceed 10 watts per cubic inch.

If the material is thin the heat may be rapidly carried away by conduction to the electrodes. A recent heating experiment in our laboratory may serve to illustrate the point. It was desired to heat a small sheet of thin plastic material for forming in a press. The electrodes were to be the press platens which were water-cooled. With no heat conduction to the electrodes the power required to heat the piece in the desired time of one second was calculated to be about 17 kilowatts. For convenience it would have been desirable to use a 10-megacycle generator to do the heating. However, it was discovered by substituting known values in the formula developed above, that the maximum power which could be put into the piece, at this frequency, without danger of arcing, was 13.5 kilowatts.

Moreover, since heat loss to the cold electrodes was not taken into account in the first estimate of power required, a more exact calculation was made. It was found that when heat losses were taken into consideration the power required to heat the piece in 1 second was not 17 kilowatts but 72 kilowatts. Moreover, this excessive power requirement could not be reduced by taking a longer heating time because, for times longer than two seconds, the power required remained practically constant at 70 kilowatts.

If it had been desirable to heat the pieces even though the power requirements were so high, then it would have been necessary to use a frequency of 50 megacycles in order to achieve the necessary power concentration in the work. Therefore it is seen that, because of heat losses in thin materials, radio-frequency heating has little to offer in heating thin samples. There are instances, however, when great convenience or some special effect of radio-frequency makes this method economical. In certain sealing operations such as the “welding” of thin sheets of thermoplastic materials, radio-frequency heating has been found to possess some advantages. In one such sealing operation power concentrations as great as 20 kilowatts per cubic inch were attained. The frequency used was 200 megacycles.

But in general the advantage of radio-frequency dielectric heating lies in heating thick specimens. Suppose it is desired to heat a stack of oak boards for gluing. Let us further assume that the stack is 8 inches thick. A practicable frequency is 10 megacycles and a power concentration of 7 watts per cubic inch will bring the temperature of the entire block up to 300 degrees Fahrenheit in about 5 minutes.

Now compare this operation with the heating which could be accomplished by conduction from hot plates placed above and below the stack. Assume that the plates are at the charring temperature of the wood, about 400 degrees Fahrenheit, and that we apply the heat until the temperature at the center of the stack has risen to the required 300 degrees Fahrenheit. It will be found that the time required is approximately 20 hours instead of 5 minutes and the average power concentration is 0.04 watt per cubic inch instead of the 7 watts per cubic inch as in the radio-frequency heating. For thicker sections the disparity between the power concentrations in the two methods would be greater; for thinner sections, less.

The Power Generators

Electronic generators of radio-frequency power are now being marketed by several companies. The frequencies range from about 100 kilocycles to 200 megacycles. But as stated before, as the frequency increases the power output becomes more limited. Typical examples of commercial radio-frequency generators for industrial heating range in power from 200 kilowatts at 100 to 500 kilocycles to 200 watts at 200 megacycles.

It should be pointed out that under the stimulation of war requirements and future industrial needs, rapid development of high-power, ultra-high-frequency generators is now under way. It is certain therefore that within a very short time commercial units of far greater power capabilities will become available.

Conclusion

Industry is rapidly making use of radio-frequency power for certain heating applications. But it should be recognized that, since the size and shape of the work restrict the use of radio-frequency in both induction heating and dielectric heating, the number of ideal applications are relatively few.

To put it another way, radio-frequency heating is not so much a substitute method as it is a supplementary process. That is, although it can be used to heat almost anything yet its particular value lies in a few applications where the unique properties of radio-frequency power can best be utilized. In such applications it is possible to perform heating operations that would be utterly impossible by any other method, or the radio-frequency method may speed up production rates by several hundred per cent, and in other instances may provide great savings in cost, time, and space.
INTRODUCTION

It is almost a quarter of a century since Cady first used the mechanical-resonance characteristics of pieces of crystalline quartz to establish with great precision the frequencies in the radio spectrum. During this period we have seen great increases in the precision with which frequencies are known and in the convenience of setting up good standards of frequency, and the development of crystal cuts giving low temperature coefficients of frequency. There has come extreme accuracy of frequency control of oscillators through quartz crystals, notably in the crystal clock and broadcast transmitters. The use of crystals has become common in radio communication systems. The number of crystal units which have been made for fixing the channels of the many models of commercial and military systems now run into many millions.

Experience with radio communication networks particularly leaves no room for doubt that the precision control of frequency and the instantaneous and dependable switching to prearranged channels, which crystal control makes possible, give both a flexibility and a reliability to radio communication which speeds up military action and maneuvering and makes possible a new order of co-ordination between co-operating field units.

There has been developed during the days of increasing use of the crystal unit a good understanding of the basic nature of the electrical behavior of the crystal. We have come to represent its electrical behavior in terms of an equivalent network and the elements of the network are commonly measured, at least in the laboratory.

Much has been done to finish and mount the crystal unit for greater uniformity of performance and to permit the development of its highest Q's. The art of orienting the crystals with precision, and of fabricating them in large quantities to close tolerances, has been pretty well mastered.

There are certain phases of the crystal art in which, in the opinion of the writer, progress has been less real. The formal treatment of the crystal unit as a circuit element having conventional electrical-circuit properties has not kept pace with its practical utilization. It appears as if most crystal oscillators were designed by the "cut-and-try" method. A crystal to be used is selected and a circuit laid out, "breadboard" fashion, to work with it. There seems usually to be little attention given to such matters of design as the consideration of the properties of the crystal unit, and of the association of such properties with the elements of the oscillator circuit. If the simple way in which the precise frequency of oscillation depends upon the characteristics of the circuit in which the crystal is placed were more widely appreciated, set designers would find greater freedom in considering alternative designs and circuit modifications. Also manufacturers of sets would pay more attention to the capacitance of the circuit into which the crystal is inserted, with the indirect result that the problem of providing, at long range, replacement crystals for sets would be a much simpler one. In this connection, it is a rather frequent experience to find that the set manufacturer has apparently no record of the capacitance across the crystal in sets which he has made in the past, and this is the one bit of information needed when one is to grind a new crystal to give the specified frequency.

There is room for some ambiguity in the term "the frequency of a crystal." Leaving out of consideration all other modes, and thinking only of the mode of the intended crystal vibration, the electrical response of that mode extends over a complete resonance curve. The crystal frequency might refer to any frequency in the resonance range, for it would probably be possible by a suitable choice of an oscillation circuit, and the use of a condenser or a coil in series with the crystal, to have the crystal control the oscillation or stabilize the frequency of an oscillator at any frequency in this range. In this paper oscillation alone will be considered and in only those common types of circuit in which the crystal operates in parallel with external capacitance between grid and filament, or grid and plate, of the oscillator tube. Crystal frequency will refer to its oscillation frequency in such a circuit.

Under these conditions, the precise frequency of oscillation depends to a considerable degree upon the
constants of the circuit into which the crystal is connected. It is higher than the frequency of series resonance (referring to the equivalent network) but a frequency where neither the quartz plate without electrodes, nor the completed crystal unit, shows any distinctive property whatsoever. The thing that is significant about the properties of the crystal unit is that at this oscillation frequency its reactance equals, though positive, the negative reactance of the external circuit across which it is placed for oscillation. This is, in other words, the condition for parallel resonance of the crystal and associated circuit elements.

By way of a brief review of some of the facts regarding the frequency of crystal oscillation, the two types of crystal-oscillator circuits which are in common use oscillate, as has just been indicated, at the frequency of parallel resonance of the crystal and its associated internal and external circuit capacitances. These common circuits are (1) that in which the crystal is connected between grid and filament of the oscillator tube, and (2) that in which the crystal is in the grid-plate position. These are often called the Miller and the Pierce circuits, respectively. The bridge-type oscillator devised by Meecham, in contrast, uses the crystal as a low-impedance device with the oscillation occurring at, or near, the series resonance of the crystal's motional properties. The difference in frequency between series and parallel resonance in a given crystal may be several hundred cycles per second per megacycle per second if the external capacitance is sufficiently small, or but 20 or 30 cycles per second per megacycle per second for large external capacitances. The parallel resonance frequency is, of course, always the higher and it is this frequency, not the series resonance, which varies with changing circuit constants. The oscillation frequency in the Miller and Pierce types of circuit, being the parallel-resonance frequency, is closer to the series-resonance frequency as the crystal is across larger external capacitances.

The extreme variation of the impedance of a crystal unit over the frequency range between series and parallel resonance probably complicates for the radio engineer the intuitive grasping of the mechanism of crystal operation in the same way that he habitually deals with the more common circuit components. In this range of twenty to a few hundred cycles per second per megacycle per second the impedance may vary many thousandfold. At one frequency the crystal unit is a circuit component which has an impedance of perhaps only 10 ohms; the same crystal unit at another frequency changes to an impedance approaching perhaps 100,000 ohms. In a way, this large change in the impedance of an element within a few cycles per second is almost as unusual a concept for electrical-circuit practice as was that of the large difference between the mutual conductances of vacuum tubes in two directions, direct and reverse, twenty years ago.

One might suppose that the basic experimental and theoretical work on the electrical properties of crystals would have found earlier application in oscillator-circuit theory. Although the electrical behavior of crystal units has been known for many years, at least in its main form, the specification of the fundamental properties of crystals for oscillator use is not yet the practice. The usual specification of a crystal unit is rather that in association with a stated oscillator or radio set the desired performance of the latter shall be obtained. This is a very practical sort of specification. It is certainly the only one which could be used in the absence of adequate information about, and understanding of, the intrinsic properties of crystals, and also in the absence of formal knowledge of the demands of the oscillator circuit as to properties in its crystal units. Any attempt to procure crystals on the basis of an idealized, simplified, or incomplete conception of their circuit performance would be likely to meet disaster and need not be risked when a safe, practical method of specification is available.

However, in the author's view, the long range course of engineering development will be toward the use of the crystal's own properties in specifications and eventually it will not be necessary to test each crystal unit in the radio set for which it was made. When it has been determined what are the necessary properties of the crystal unit, convenient instruments to measure these will become available, the crystal properties which the radio set needs will be determined, and the crystal will be specified in conventional circuit terms, impedances, or the equivalent.

Three Methods of Specification of Crystal Units

The subject of standardizing crystal units may be approached by considering the methods by which their characteristics may be specified. It is proposed to discuss three methods: first, the one just referred to, that by reference to the using circuit; second, a method which is now being tried out, partly in the interest of standardization, where the crystal is referred to a standard test oscillator; and third, the specification of the crystal's properties as such without direct reference to the character of the crystal's performance in an oscillation circuit.

The first method of specification sets up an oscillator circuit in which the oscillation must be satisfactory as to frequency and amplitude when the crystal is inserted, if the crystal is to be considered as meeting the specification. There is little more to the specification than just this practical test. (We shall not here be concerned with such matters as the statement of tolerances of frequency, or the temperature range over which these must be met; nor with the mechanical details regarding form and finish of the plate of quartz, its mounting, and the characteristics of the holder, the pin data, etc. All of these, of course, make up in large part the cost of the finished crystal unit, and without a satisfactory specification of these the unit would not be useful.) Considering only its electrical and radio-frequency performance, the
crystal unit must have just one functional property; namely, in conjunction with the radio set with which it is to be used, an oscillation of the desired frequency in suitable amplitude must be set up and dependably maintained. The most direct specification of the crystal, considering it as a component of that radio set, is that in the radio set it provide the desired oscillation.

The second or alternative method is to require the crystal to operate some standard or reference oscillator. The scale of activity performance in this oscillator can be used to evaluate the crystal’s performance in any one of a number of models of radio sets which are capable of being correlated with this standard oscillator. Whereas the first method is direct, and looks toward the manufacture of crystals for use in one single model of set, the second looks toward the manufacture of crystals to operate any set whose characteristics fall within certain ranges. It is a beginning of the standardization of crystal units when this first degree of universality is given to the use of a crystal instead of limiting it to association with a single set.

There are advantages and disadvantages in each of these first two methods of specifying the crystal. The first has a directness of approach and a readiness of application which have kept it in use for a long period. There are sometimes difficulties in furnishing models of the using radio set to the crystal manufacturer for testing his crystals, and production sets are not always suitable as standards in which to test such a product. Accordingly the practice of providing the crystal manufacturer with a “mock-up” or replica of the essential oscillator features of the radio set has grown up. This results in the use in crystal plants of many crystal “test sets,” one for testing the crystals of each different model of radio set for which crystals are manufactured. The problem of maintaining these many models of test sets in calibration is an enormous one. The variability of the individual oscillators caused by the vacuum tube, by the changing Q’s of the coils with the weather, and by the shifting of circuit capacitances with slight displacements of the wiring is notorious. Both the frequency and the activity tests of the crystal are subject to considerable uncertainty due to the difficulties of maintenance of correlation between test sets and the using radio set, or even of maintaining a standard calibration of the test circuit alone.

An advantage of the second method of specification lies in its substitution of a single-standard scale of activity values for the many scales inherent in the replica-test-set method; or if not a single scale, at least a few scales. This reduction in the number of scales of activity simplifies the problem for the manufacturer, entirely aside from the avoidance of the physical problem of having a multiplicity of test sets. When confronted with an order for a new unit which he has not made before, familiarity with the relative difficulty of making other crystals whose activities are measured on the same scale provides him with an intuitive sense of the magnitude of the task of manufacturing the new unit. He receives the new specifications in terms of a scale with which he is familiar instead of having to build a new test set, calibrate it, and become acquainted with its new scale before estimating the difficulties of producing the unit in question.

This second method of specification is by no means foolproof. There are some very definite pitfalls. There is, first, the correlation to be made in the laboratory between the activities developed in the test set and the crystal’s operation of its radio set. This correlation must be established for each radio set and dividing points established on the scale of the test set to differentiate the acceptable from the unacceptable crystals for each using set. A higher order of engineering skill is required in the specification of the activity of the crystal unit in terms of the standard test set than in terms of the replica of the using radio set. Also there are the design difficulties of providing a standard test set which it is possible to correlate for both activity and frequency to a number of different radio sets.

Another pitfall is that when any change in the method of specifying an item is considered, it is apt to be found that there have been certain items implicitly involved in the earlier form of specification which may be overlooked. They may perhaps not be implicit also in the new form, nor appear as equivalent tests. In the case of crystals, the principal measured quantities, and the numerics with which the manufacturer is concerned, are frequency and activity. It must not be overlooked, however, that the crystal is also tested for its ability to stand up and not fracture in the replica test sets. This replica uses the same tubes as the radio set and the intensity of the oscillation is provided to be about the same. This means that the crystal experiences during its activity and frequency tests a vibration of about the same amplitude that it will later be called upon to withstand in the radio set. Implicitly then the replica test set provides, but does not specify in numbers, a test for the ability of the crystal to stand up under load, and the manufacturer makes crystals which by not breaking in the testing circuit will also stand up in the radio set. Similar statements hold for the effects of internal heating of the crystal in oscillation. If there were full numerical information regarding the performance of the radio set, then the necessary power-handling capacity or the amplitude of vibration of the crystal, or perhaps its radio-frequency current in operation, would be a matter of record. In the absence of these the test for load is only implicit and requires either the replica test set, or else special attention to load tests in the standard test set.

To sum up the characteristics of the second method of specification of crystal units: specification by test in the standard circuit provides first, that the crystal develops its nominal frequency under certain known and standardized adjustments of the test set; second, that the crystal have a minimum of activity in terms of a
scale which is known and which has meaning in relation to the activity of other crystals; and third, that all crystals of the series so tested shall withstand the driving conditions which are characteristic of that circuit at the frequency and activity which the specification calls for.

In general, crystals which have been thus specified to stand the drive of the standard circuit, and to develop their nominal frequencies of oscillation when connected across a given value of external capacitance in the test set, and which have shown a given minimum activity, are suitable for use in all radio sets for which these conditions are appropriate. Accordingly, selected values of the various parameters, activity, load, and parallel capacitances, might be selected as standard and several lines of crystal units produced to meet such standards.

The suggestion has been made several times that reference to crystal properties, and the design of oscillation circuits, would be much easier if crystal units were cataloged and described on data sheets much as vacuum tubes are so listed. Much progress can be made in this direction. The principal limitation in the usefulness of such data under present conditions lies in the uncertainties of the many test sets involved. The inclusion in the data sheets of the circuit diagrams of the replica test sets would not in itself provide satisfactory information for measuring either the frequency, the activity, or the power-handling capacity of the crystal. Reference to and correlation with the accepted physical test set itself is required.

If, however, a few standard reference test sets were to become accepted, and some organization were to accept the maintenance of the primary standards, it would then become a relatively simple matter for all crystal and radio-set manufacturers to provide themselves with secondary standards. If data sheets for crystal units were to be prepared stating crystal performance in terms of such standards, the data would be unambiguous. Such data sheets would place crystal unit and crystal oscillator design on an entirely new engineering level.

Even these data sheets, however, and the degree of standardization which has been discussed, would still leave the descriptions and specifications of crystal units far behind those which are so useful for vacuum tubes. For with this method of specification the crystal is described in an entirely arbitrary circuit, and in terms of an oscillation condition of that circuit where a vacuum tube is the central feature. All of the vagaries of tube performance, the nonlinearity of the tube's characteristics, the grid biases which build up, and the effect on the latter of the changing circuit constants are all involved in the specification. This specification is as much a description of the tube and the circuit as it is of the crystal. It does not offer the ideal characterization of the crystal units.

The crystal is an item in itself; it has properties entirely its own which are completely measurable. These are relatively simple, far simpler and easier to specify adequately than those of the oscillator circuit; this is true despite the enormous range of impedance variation in the vicinity of the oscillation frequency and other disturbing factors which arise from the mechanical complexity of the vibration of the quartz plate.

The third method of specification of crystal units which has been suggested, namely, to specify the crystal's own measurable properties, would remove the necessity for setting up and maintaining primary and secondary standards of oscillation circuits for reference of crystal performance. A catalog of crystal properties in terms of impedance or the equivalent would soon, it is believed, bring about also as a natural result a large degree of classification and standardization.

Just as the reference of crystal performance to a standard oscillation circuit instead of to a replica of the using radio set requires the use of greater engineer- ing skill in designing and correlating the standard, so the use of the crystal's measured properties to predict the crystal's performance in an oscillator calls for a still higher level of engineering attainment. A more complete specification of the characteristics of the using oscillator circuit itself would be required, and there is the highly specialized problem of correlating the crystal properties with oscillation in the several forms of oscillator circuit. As is true generally of engineering, in the progress of the art there is more and more reliance on the tests and measurements made in the design and testing laboratories. An engineered crystal unit would be largely determined in the laboratory, including the details of dimensions and performance. This is in contrast to the present practice where in many cases the crystal plate is designed, or perhaps in this case the word is "fitted," or "hand-tailored," by the finishing operator who adjusts its dimensions so that it passes the direct test of replica-oscillator performance.

The emphasis upon the possession by the crystal unit of intrinsic properties which are suitable for use in its definition makes it desirable that some of the quantities which might be selected for its specification be indicated. It is not the intent of this discussion to consider the nature or the validity of particular indices. The point to be made is rather that there are properties which are simple enough to measure and to use, and that engineering progress will have been made when crystals are specified for such properties of their own.

One method of looking at the crystal unit is to consider it in terms of its equivalent circuit. Although there is some degree of simplification in the usual equivalent circuit of parallel motional and dielectric admittances, it is believed to be near enough to the facts to be the basis of tests and measurements. This common network, it will be recalled, consists of two parallel branches. The admittance of one is merely that of the dielectric
properties of the quartz and its holder, a simple quartz condenser with necessary power factor to include the losses in the holder. The other branch includes all of the motional properties of the plate, its electrical admittance depending upon the mechanical and piezoelectric properties of the quartz. This motional admittance is usually shown as a series arrangement of inductance, capacitance, and resistance. The values of these quantities are proportional respectively to the mechanical iner-tance, elastic compliance and dissipative resistance which characterize the vibration, the first and third being also inversely, the second directly, proportional to the square of the effective piezoelectric constant.

One possible method of procedure would be to measure each of the four or five parameters of the equivalent circuit and to specify that crystals be made to have those parameters within appropriate tolerances. While convenient for circuit representation, these parameters are not as convenient for direct measurement as the impedances which they represent at the oscillation frequency. It is believed that I. E. Fair of the Bell Telephone Laboratories will, in a forthcoming paper, discuss crystal performance indexes which involve such measured impedances. One possible index, and it is the one understood to be favored by Fair, is the maximum impedance which the crystal resonator and its associated parallel capacitances, including the circuit capacitance, develop at the parallel resonance frequency of this combination. Another indicator is the range through which the impedance swings from resonance to antiresonance. Both of these indexes are measurable and they provide roughly the same sort of indicator of the effectiveness of a crystal when associated with the vacuum tube as does the so-called “activity” which is commonly used in crystal specifications.

These indicators, however, are measures of the properties of the crystal and the associated condensers with which it is to be used. A principal difficulty with the common index, “Activity,” in addition to its arbitrary character and its changing value from circuit to circuit, is that the scale of activities on most test sets is likely not to be linear in terms of the intrinsic properties of the crystal. The scales of the indicators which specify only intrinsic properties of the crystal are at least as nearly linear as are the properties of the crystal unit.

A Long-Range View of Standardization

The conclusion of this academic discussion of the lines along which the development of one phase of the art of specifying crystal performance might well progress, will be still more academic in the suggestion of a rather ideal result of standardization. The practical problem of standardization is complicated, as is necessarily the case, by the existence of current designs and stocks of radio sets and crystals. These stocks might weigh heavily in any concrete standardization program, as would also uncertainties concerning the relative magnitude of crystal utilization in peace after war and of large stocks of wartime crystals and radio sets.

Predicated upon the basic simplicity of the properties which a crystal unit has to offer, it should be possible to plan in the ideal case for a few standard lines or series of crystal units in the 1- to 10-megacycle-per-second range for radio communication use. In each series the entire gamut of frequencies might be available for manufacture, but the characteristics of the series would be certain specified values in the scale of activity or other index of oscillation control, of current-carrying capacity or load factor, of circuit capacitance for which the series is intended, of tolerances as to frequency adjustment and frequency deviation over the intended temperature range, and finally of the temperature range of intended use of the crystals of the series. It would seem that not more than six or eight such series of crystals (six or eight different specifications in all for the field where now very many more apply) could be defended in any standardization plan which did not have to accommodate the existing plant and stock, and that the resulting array of crystal units would give as much flexibility as radio-set design would find useful.

The number of standardized values of any one variable which it is justifiable to introduce into a planned set of designs depends upon the relative difficulty of producing crystals to the next higher value on the scale. Thus it might be justified to double the crystal activity from one series to the next, while differences that 10 per cent in activity would not justify a new series. It is particularly because of the absence of a universally applicable scale of crystal activity that insignificant differences in this parameter today commonly exist between different specifications. Similarly, frequency tolerances of ±0.02 per cent over the temperature range are today common in many specifications. Perhaps other series with ±0.015 per cent are justified; ±0.01 per cent certainly, ±0.019 per cent certainly not.

Crystal units are made in a wide range of models of holder, and with an amazing permutation of the diameters, length, and spacing of pins. It is possible that standardization of these items would quickly follow agreement concerning the requirements in electrical performance, and the establishment of standard values on accepted scales for these. The miscellany of external forms of crystal units may but reflect the belief that a particular crystal has to be made for a particular set; if nothing else will do electrically, the magic of peculiar electrical performance is easily extended to peculiarities of holder and pins as well.

In closing, it is desired to emphasize one aspect of a standardization program. And the emphasis given is predicated on the permanence of the crystal unit and the establishment of a degree of stability of crystal design which exceeds the permanence and stability of set design. The simplicity of the crystal's function and performance suggests that in the long run particular
models of radio sets may become obsolete more rapidly than the crystals which they use. If, as appears likely, the crystal unit may have a useful life long beyond that of the using set, the adaptability of the stock of any such crystal to another set after its own shall have been outmoded deserves consideration. With crystals specified in terms of the using set, or its replica, the peculiarities of that set are so involved in the specification that a special investigation is required to determine whether a new model or another radio set can use those crystals unless its oscillator circuit is identical with that of the outmoded model. This is a severe limitation upon the progress of set design.

In contrast, a group of crystals built to have certain intrinsic properties is available for use by anyone who has the information on their properties, for the adaptation of any oscillation circuit to use crystals of known properties is a straightforward engineering procedure.

The present discussion of the evolution of standard crystal units, and of the possible development of methods of specification, does not in any sense indicate the program of the Signal Corps, nor that such changes in the methods of specification are contemplated. The discussion must be taken rather as indicating something of the train of thought of an individual who is fundamentally interested in the performance of quartz crystals in radio. It may be confessed that it has come as something of a shock to learn how far the art is from the practical utilization of the known circuit properties of the crystal, to wake up to the fact that such circuit properties have not yet come out of the academic and into engineering utilization, and at the same time to appreciate the very real difficulty in their use which has forced the continued dependence upon the method of electrically fitting each crystal directly into the place where it is to be used.

Graphical Methods for Analysis of Velocity-Modulation Bunching*

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Summary—A review of the theory of velocity-modulation tubes is used as an introduction to a number of graphical representations of electron bunching. These methods are applied to single-resonator tubes as well as multiple-resonator designs. The curves are used to illustrate a method of obtaining the efficiency and the effective phase angle of the bunched electron beam from a simple graphical integration. These methods are not new, and correspond to the equations which have been used in the past to represent electron bunching, but the graphical representation offers a convenient method of using these equations.

VELOCITY-modulation tubes have aroused great popular interest because they are a comparatively new development which extends the useful frequency range of vacuum tubes tremendously. The existence of a simple physical explanation of the operating principle (electron bunching) has helped to maintain this interest. However, most of the published material on these tubes has been either purely descriptive or quite mathematical. It is possible to extend the simple physical explanation to include most of the more complicated characteristics of velocity-modulation tubes. This is easily accomplished by graphical methods which have the added advantage that they are not limited by assumptions which are not satisfied by the operating conditions in practical tubes. It is true that this graphical analysis does not produce results which cannot be obtained by other methods, but the results are easy to present and understand in some cases easier to obtain.

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A comparison of velocity-modulation tubes with the more familiar vacuum tubes will serve as an introduction to the newer types and a review of their basic principles. A triode functions by modulating the amplitude of the electron current between the cathode and anode or plate. Ordinarily the modulation frequency is so low that the electron transit time between cathode and plate is a small fraction of a cycle, although the average electron velocity may be quite small because the electrons begin this transit with negligible velocity. A number of difficulties appear as the frequency is increased. Tube dimensions must be decreased to maintain small transit times. Electrode and lead capacitances represent a larger part of the oscillating circuit and the losses in lumped-constant circuits become intolerable.

In contrast, the electron beam in a klystron or similar velocity-modulation tube is accelerated to a high uniform velocity before it is acted upon by the radio-frequency voltage. (See Fig. 1.) The transit time in the radio-frequency field can be a small fraction of a cycle even at super-high frequencies. The small changes in velocity introduced by the buncher resonator permit the electrons which left later in the cycle, with higher than average velocity, to overtake the electrons which were slowed down by the buncher field but passed the buncher grids earlier in the cycle. As a result, the beam is converted from a uniform current to a bunched or pulsating current. This action takes place in the "drift space" which is free of any radio-frequency field and may be completely field free. The bunched beam current
is converted into radio-frequency energy at the catcher resonator. The transit time is again quite small in the region where the beam is acted upon by a radio-frequency field. The excess energy in the beam is dissipated in a suitable electron trap beyond the catcher resonator.

**Applegate Diagrams Illustrate Electron Bunching**

These relations can be visualized readily with the aid of an Applegate diagram which is shown in Fig. 2. This type of representation was proposed by Applegate in order to describe electron-bunching phenomena. A similar space-time diagram has been used by Brülcl and Recknagel, and Tombs has suggested a different graphical analysis. In an Applegate diagram, time is measured along the horizontal axis, and the position of electrons along the drift space is plotted as the vertical co-ordinate. The lines represent electrons passing the buncher at uniform time intervals. The slope of a line is the distance divided by time; i.e., the slope of a line represents the velocity of a particular electron. The electron velocities are identical and equal to the average electron velocity until the electrons reach the position of the buncher. The transit time between the buncher grids has been assumed negligible in all of the diagrams in order to simplify their construction. As a result, the electron velocities are again constant after passing the buncher at time 1, and the slopes of the lines have been modified in accordance with the velocity modulation and the transit time in the drift distance; the correct bunching for maximum energy transfer may also be obtained by varying the amount of velocity modulation, i.e., the buncher voltage, or by changing the average electron velocity. Electrons in the bunches are decelerated by the catcher field and leave the catcher at very low velocities corresponding to almost horizontal slopes. Electrons passing the catcher grids during the other half of the cycle are accelerated and absorb energy from the radio-frequency field. However, very few electrons absorb energy due to the concentration of the electrons into bunches. Considerably greater power is transferred by the electrons in the bunch than is absorbed by the few electrons which become speeded up by the catcher field, and the net result is the conversion of direct-current beam power into radio-frequency power.

This simplified physical picture agrees with the popular conception of electron bunching as a symmetrical distribution of current as a function of time. The general acceptance of this form of current distribution is a natural interpretation of the analysis of Webster and others, which is based upon a small velocity modulation and sufficient drift time to permit bunching to occur.

Under these conditions the current distribution is a symmetrical function of time. These conditions are satisfied if the drift time is an interval corresponding to 10 or more cycles. Drift times of this magnitude are obtained occasionally in tubes using low acceleration voltages; however, the usual conditions of operation correspond to drift times which are very much shorter.

Reference to Figs. 2 and 3 indicates that bunching corresponding to the acceleration voltage of the electron gun, \( v_0 \) is the peak amplitude of the velocity modulation, and \( \omega_1 \) is the angular frequency of the oscillation in the buncher resonator.

It should be pointed out that this analysis neglects space-charge effects in the electron beam, and assumes that the transit time between the resonator grids is negligible.

As a result of the velocity modulation and the transit time in the drift distance, the faster electrons overtake the slower electrons and produce electron bunching. An approximation for the current distribution at any point along the drift distance at any time may be obtained by inspection of the diagram, since the distance along the time axis between successive lines is inversely proportional to the instantaneous current in the beam. It is apparent that the electron density is uniform and the beam is direct current at the position of the buncher, but an alternating component of current is superimposed on the direct current as bunching progresses.

Maximum radio-frequency energy will be transferred to the catcher resonator if the catcher grids are placed at the position shown in Fig. 2. It is not necessary to vary the position of the catcher resonator along the drift distance; the correct bunching for maximum energy transfer may also be obtained by varying the amount of velocity modulation, i.e., the buncher voltage, or by changing the average electron velocity. Electrons in the bunches are decelerated by the catcher field and leave the catcher at very low velocities corresponding to almost horizontal slopes. Electrons passing the catcher grids during the other half of the cycle are accelerated and absorb energy from the radio-frequency field. However, very few electrons absorb energy due to the concentration of the electrons into bunches. Considerably greater power is transferred by the electrons in the bunch than is absorbed by the few electrons which become speeded up by the catcher field, and the net result is the conversion of direct-current beam power into radio-frequency power.
Fig. 2—Applegate diagram with nonsinusoidal buncher voltage giving symmetrical current distribution.

Fig. 3—Applegate diagram showing distortion of current distribution which occurs when drift time is 3.25 cycles and buncher voltage is sinusoidal.

Fig. 4—Applegate diagram showing distortion of current distribution which occurs when drift time is 3.25 cycles and buncher voltage is nonsinusoidal.

Fig. 5—Applegate diagram for an overbunched klystron amplifier. Bunching parameter is equal to 3.64.

Fig. 6—Applegate diagram for an underbunched klystron amplifier. Bunching parameter is equal to 0.92.
in these diagrams occurs during an interval of $3\frac{1}{2}$ cycles. This number of cycles has been chosen arbitrarily to correspond to one of the modes of operation of a double-resonator oscillator with zero phase shift in the feedback line. The same drift time may also be used to explain the operation of an amplifier, although any drift time is permissible in an amplifier. Fig. 3 corresponds to the actual conditions of current distribution when the velocity modulation is produced by a sinusoidal buncher voltage, while the velocity modulation in Fig. 2 has been modified to produce a symmetrical current distribution with respect to time. The importance of representing actual conditions is indicated by a comparison of these two figures. The contrast would be even more pronounced if the amplitude of the velocity modulation had been greater. There has been some tendency to exaggerate the velocity modulation in most Applegate diagrams which have been published in the past. This produces a diagram which shows bunching occurring in an extremely short interval and it has been a rather general practice to deviate from the actual velocity-modulation conditions in order to conform to the popular conception of electron bunching with symmetrical current distribution.

As a result of the nonsymmetrical distribution of the bunched current at the catcher, the electron which left the buncher when the buncher field was zero and changing from deceleration to acceleration is not the center of the bunch. Inspection of Fig. 3 will verify this fact, and also shows a slight phase shift in the catcher voltage in comparison to Fig. 2. Only a slight modification in the buncher voltage is required to make the diagram appear symmetrical; this modification is hardly apparent in Fig. 2 and close inspection is required to observe that the curve for the buncher voltage is not sinusoidal but that the amplitude of the negative portion of the curve is less than the positive portion.

There are two reasons for the unsymmetrical current distribution when the drift time is short. A large ratio of buncher voltage to acceleration voltage is required to obtain bunching in a short time; as a result, the velocity distribution is not sinusoidal and the electrons which are decelerated are slowed down more than the electrons which are accelerated are speeded up. In addition, the slowest and fastest electrons cannot be considered as traveling with the average velocity when the velocity variations are large. This factor causes the slower electrons to be comparatively overbunched while the faster electrons are somewhat underbunched. The nonsinusoidal velocity distribution and the distortion due to large variations of velocity produce an additive effect on the current distribution in the bunch.

It will be convenient to refer to the number of cycles during bunching by the designation $N$, since the term recurs quite frequently in a discussion of velocity modulation. Certain other terms will also be used and a list of the terminology is given below. The notation which is used is essentially the same as that appearing in the Klystron Technical Manual.\footnote{A. E. Harrison, "Klystron Technical Manual," Sperry Gyroscope Company, Inc., Brooklyn 1, New York, 1944.}

- $N$ = number of cycles occurring during transit from buncher to catcher
- $f_1$ = buncher frequency
- $\omega_1 = 2\pi f_1$
- $t_1$ = time an electron passes the buncher grids (departure time)
- $t_2$ = time an electron passes the catcher grids (arrival time)
- $\tau_0$ = average value of transit angle in the drift space
- $I_0$ = average value of beam current
- $E_0$ = acceleration voltage (voltage between cathode and anode)
- $E_1$ = buncher voltage (peak radio-frequency voltage at buncher grids)
- $I_3$ = instantaneous beam current at the catcher grids
- $E_2$ = catcher voltage (peak radio-frequency voltage at catcher grids)
- $\phi$ = phase angle between catcher voltage and electron with average transit angle $\tau_0$
- $i_s$ = catcher current (radio-frequency component of the bunched beam current)
- $s$ = drift distance between buncher and catcher resonators
- $v$ = electron velocity
- $v_0$ = average velocity of electrons corresponding to voltage $E_0$
- $v_s$ = peak amplitude of the velocity modulation at the buncher
- $x$ = bunching parameter defined in equations which follow
- $e$ = charge of an electron
- $m_s$ = mass of an electron

The significance of $N$ should be emphasized. The value of $N$ represents the number of cycles which occur during transit of an electron with average velocity through the drift space. $N$ may have any value in a klystron amplifier, but $N$ is restricted to certain values which satisfy the proper phase relations if the klystron tube is used as an oscillator. The value of $N$ should not be confused with the number of times the electrons may become bunched in the drift space. In an overbunched amplifier, the bunch may form, then separate and reform again farther along the drift tube. Oscillators do not become overbunched, and the electrons are formed into a bunch only once, although a number of bunches may be in the process of formation at the same time if transit of the drift space requires more than one cycle. Reference to an Applegate diagram will show that $N$ also corresponds to the number of bunches in the process of formation at any instant in time.

The relations between the various factors in an analysis of velocity modulation will not be derived, but certain important results will be reviewed. One of the
The most important relations express the output of a velocity-modulation tube as a function of the degree of bunching. If the magnitude of the catcher current, i.e., the radio-frequency component of the bunched beam current, is chosen to represent the output, the dependence is given by

\[ i_z = 2I_s J_1(x). \]  

(2)

Fig. 4 shows the catcher current as a function of \( x \).

This relation is based on the assumption that \( E_1/E_0 \) is very small but that adequate time is available for any degree of bunching to occur.

The quantity \( x \) is known as the bunching parameter. It should be pointed out that the approximations which are used in the derivation of the bunching parameter are not valid if the ratio of buncher voltage to acceleration voltage is high. However, the values determined from the equations are quite useful in a discussion of bunching regardless of the validity of the approximations. Several expressions for the bunching parameters are given below.

\[ x = \frac{\omega_0 s}{2\sqrt{2e/m}}(E_1/E_0)^{3/2}. \]  

(3)

Substitution of the expression for the electron velocity in (3) gives

\[ x = (\pi f_s/s_0)(E_1/E_0). \]  

(4)

Since the number of cycles during transit of the drift distance \( s \) is given by

\[ N = f_s/V_0, \]  

(5)

Equation (4) may be rewritten in the form:

\[ x = \pi N(E_1/E_0). \]  

(6)

Changing one or more of the design factors in an Applegate diagram illustrates the effect of changing the variables in these equations. Fig. 5 has been prepared with the same ratio of buncher voltage to acceleration voltage as shown in Fig. 3; however, the average velocity of the electrons has been reduced. These changes correspond to reducing the buncher voltage and the acceleration voltage in the same ratio. The beam is now overbunched at the drift distance corresponding to the position of the catcher in Fig. 3, since the decreased velocity gives a larger value of \( N \) for this drift distance and the value of \( x \) given by (6) is increased. This overbunching gives negligible output at the catcher. Optimum bunching occurs at a shorter drift distance; inspection of Fig. 5 will show that the bunching corresponding to the total drift distance in Fig. 3 now occurs at a shorter drift distance although the number of cycles during transit of this shorter distance is unchanged. \( (N=31/2 \text{ cycles}) \) This correlation between (6) and the Applegate diagram would be expected.

Fig. 5 shows a diagram in which the average velocity is the same as used in Fig. 3 but the buncher voltage has been reduced. This corresponds to operation with the same acceleration voltage but with the tube underdriven, i.e., the buncher voltage does not bunch the electron beam completely. Note that the electron distribution is almost symmetrical.

**Construction of an Applegate Diagram**

A simple method for constructing an Applegate diagram to fit particular operating conditions is also illustrated by Fig. 6. The lines corresponding to the electrons with average velocity are drawn first; these lines start at the times when the buncher voltage is zero (twice in each cycle). They are drawn with any convenient slope if the electron velocity and the distance co-ordinate are arbitrary; however, the slope would be determined by the number of cycles during transit of the drift distance if the average electron velocity is chosen to represent some actual operating conditions. A line is drawn to correspond to the average velocity. The choice of scale is unimportant. The instantaneous velocity is then plotted from the relation

\[ v = v_0(1 + (E_1/E_0) \sin \omega t)^{1/2}. \]  

(7)

Since the scale is purely arbitrary, only the term in the radical needs to be considered. If \( E_1/E_0 \) is less than 0.06, corresponding approximately to \( N=10 \) cycles, the relation

\[ (1 + (E_1/E_0) \sin \omega t)^{1/2} \approx 1 + (E_1/2E_0) \sin \omega t \]  

(8)

may be used. The exact relation should be used if \( E_1/E_0 \) is greater than 0.06, although the use of the approximation may be satisfactory in most cases for much larger ratios of buncher voltage to acceleration voltage if the diagram is to be used merely as an illustration of electron bunching. This approximation has been used in Fig. 6.

The curve for the velocity modulation is not directly above the buncher-voltage curve but must be shifted along the time axis until the zero points coincide with the lines drawn with the average slope. The number of lines to be used per cycle will depend upon the detail to be shown. Twelve lines per cycle as used in the figures in this paper is probably the minimum number for a reasonable representation of bunching; more lines per cycle give a better picture of electron bunching but complicate the construction of the diagram. The same number of time intervals are marked off on the velocity modulation curve, and the lines are drawn from the equal spaces along the time axis at the position of the
buncher through the time intercepts on the velocity modulation curve. The slopes of the lines are therefore proportional to the electron velocities.

As pointed out in the discussion of Fig. 5, changing the average slope of the lines without changing the percentage of velocity modulation causes the bunching to occur after the same number of cycles, but at a different drift distance. This fact can be verified from geometrical considerations of the method of construction described above.

**Applegate Diagrams for Reflex Klystrons**

Space-time diagrams are not limited in usefulness to an explanation of bunching in a double-resonator type of velocity-modulation tube. Such a diagram has been used to explain the operation of a Monotron and similar diagrams can be constructed to illustrate the principles of reflex klystron oscillators.

The electron beam in a reflex oscillator is velocity-modulated as it passes the grids of a cavity resonator; then the beam enters a decelerating electric field and is reflected back through the same pair of resonator grids. The velocity-modulated beam becomes bunched during the time it is in the reflecting space and then gives up part of its energy to maintain the electromagnetic field in the resonator. A single resonator serves as buncher and catcher. This type of oscillator is easy to operate because it is not necessary to tune two high-Q circuits to the same frequency, therefore these tubes are ideal as local oscillators in superheterodyne receivers or in other applications requiring a variable-frequency source.

**Fig. 7—Applegate diagram for a reflex klystron oscillator.**

Reflex oscillators have an electrode, known as the reflector, which is normally at a potential more negative than the cathode and furnishes the reflecting field which returns the electron beam through the resonator. This field will be assumed to have no radial component in order to simplify the pattern of the electrons on the Applegate diagram. In addition, space-charge effects will be neglected. The electron paths can then be represented by different portions of a single parabola, since the velocity modulation will change only the initial slope of the parabola. This behavior is identical to that of an object acted upon by a gravitational field. The transit time in the reflecting space is directly proportional to the initial velocity; therefore, the bunched current distribution is symmetrical if the velocity variation is sinusoidal, regardless of the magnitude of the variation. However, a large ratio of resonator voltage to acceleration voltage will produce an unsymmetrical bunch since the velocity variation under those conditions is not sinusoidal.

An Applegate diagram for a reflex oscillator, based on these assumptions, is shown in Fig. 7. Several important differences between bunching in a reflecting field and bunching in a field-free drift space are immediately apparent. The faster electrons start later in the cycle and overtake the slower electrons in a field-free drift space, and the bunch centers about the electron which passed the buncher grids when the field was zero and changing from deceleration to acceleration. In a reflex tube, the faster electrons travel farther and return to the resonator grids at the same time as the slower electrons which left later. This means that the electron which becomes the center of the bunch passes the buncher grids when the field is zero and changing from acceleration to deceleration; i.e., there is a phase difference of 180 degrees between the two kinds of bunching.

A field which will accelerate the electrons on their first transit past the resonator grids will decelerate the returning bunch and absorb energy from the beam. Reference to Fig. 7 will show that the transit time in the reflection space for an electron with average velocity must correspond to \((n - \frac{1}{2})\) cycles, where \(n\) is an integer, if the bunched beam is to deliver a maximum amount of radio-frequency energy to the resonator. A double-resonator oscillator is not limited by the relation that the buncher field is in phase with the catcher field, and two families of modes may be observed corresponding to transit times of \((n \pm \frac{1}{2})\) cycles. The latter statement is based upon the fact that two tightly coupled resonant circuits may oscillate either in phase or 180 degrees out of phase.

Note also that the current distribution in the reflected bunch is similar to that in the field-free case, but that the manner in which the electrons reach this distribution is decidedly different. In the field-free case,
an infinite current peak exists before the bunched beam reaches the catcher grids. The electrons then pass each other; i.e., there is a "crossover" of electrons traveling along the beam. The infinite current peak separates and a large but finite current exists between two diverging infinite current peaks. This current distribution is illustrated in Fig. 8. A similar current distribution occurs in a reflex tube, but there is no single infinite current peak formed prior to the double infinite current peak.

It is possible to use a simple method for constructing a reflex Applegate diagram, and this method will be derived from the analogy to an object in a gravitational field. This analogy indicates that the expression for the position of an electron as a function of time will be of the form

\[ s = vt - \frac{1}{2}at^2, \]  

where \( a \) is a constant determined by the design of the tube, \( v \) is the velocity (after the electron has passed the resonator grids) of an electron passing the resonator grids at time \( t_1 \). The velocity \( v \) has the value defined by (7). However, it will be convenient to consider a special case in which \( t_1 = 12 \) (the number of cycles in the Applegate diagram), corresponds to \( 2\pi \) radians, and rewrite (7) in the form

\[ v = v_0(1 + \frac{E_i}{E_0} \sin \frac{2\pi}{12}t_1)^{1/2}. \]  

(7a)

The arrival time at the grids on the return trip will be given by substituting \( s = 0 \) in (9).

\[ t_2 = t_1 + \frac{v}{a}. \]  

(10)

If the bunching time corresponds to \( 2\frac{3}{4} \) cycles, \( a \) may be evaluated by substituting \( t_2 - t_1 = 33 \) in (10). A table of \( t_2 \) versus \( t_1 \) can then be computed from (7a) and (10). A parabolic template is plotted from values of \( s \) and \( t \) in (9) with \( t_1 = 0 \). The template should extend from \( t = -2 \) to \( t = 35 \) in order to include the paths of electrons which have been given a greater than average velocity by the buncher. This template is then used to connect corresponding \( t_1 \) and \( t_2 \) values which should be plotted along the horizontal axis of the Applegate diagram. The base of the template must always be parallel to the horizontal axis of the diagram when the electron path is transferred from the template, to insure that the path is plotted correctly with identical velocities when the electron leaves and returns to the resonator grids.

Field-free bunching and reflection bunching may occur in the same tube; since the two effects are out of phase, the resultant bunching is decreased if the velocity modulation remains the same. This effect is shown in Fig. 9, which shows the bunching in a tube with a field-free drift space between the resonator and the reflecting field. The velocity modulation has been maintained equal to that in Fig. 7 and the electron beam is underbunched due to the effect of the field-free drift distance.

The equation for the bunching parameter can be modified to include the combination of field-free and reflection bunching. Equation (6) is then written

\[ x = \pi N_r(E_i/E_0) - \pi N_{ff}(E_i/E_0), \]  

(11)

where \( N_{ff} \) is the number of cycles during both trips in the field-free drift space and \( N_r \) is the number of cycles during the round trip in the reflecting field. Since \( N_r \) is usually greater than \( N_{ff} \) we can write

\[ N' = N_r - N_{ff}, \]  

(12)

and (11) becomes

\[ x = \pi N'(E_i/E_0). \]  

(13)

The phase of the returning electrons depends upon the total transit time \( N_t \), and for maximum output

\[ N_t = N_r \pm N_{ff} = n - 1/4, \]  

(14)

where \( n \) is an integer.

It is apparent from these relations that the beam must be considerably overbunched in the reflection space if proper bunching is to be obtained when the two types of bunching are combined in the same tube.

**Beam Current Distribution**

Applegate diagrams are very useful as a picture of electron bunching but do not give a quantitative analysis of velocity modulation. Other methods are available which give the current distribution in the bunched beam. Webster has described one method of obtaining the current curves from a family of cycloids with a rolling circle of unit radius and a generating circle with a radius equal to \( x \), the bunching parameter defined by (3), (4), and (6). The bunched beam current is proportional to the reciprocal of the value obtained from the cycloid curve when it is single-valued, and the sum of the reciprocals of the absolute magnitude of the values from the cycloid. The basis for neglecting the
negative sign is explained in the discussion of the $t_1$-versus-$t_2$ curves in Fig. 10. This point has also been explained by Webster\(^7\) in a letter to the Editor of the *Journal of Applied Physics*.

A series of cycloids representing six different values of the bunching parameter are shown in Fig. 11, and corresponding current distribution curves computed from these cycloids are illustrated by Figs. 8, 12, and 13.

Fig. 8 includes the current-distribution curves for three values of the bunching parameter; $x = 0.50$, $x = 1.00$, and $x = 1.84$. Reference to Fig. 4 will show that $x = 0.50$ corresponds to an underbunched beam and $x = 1.84$ is the value required for maximum output. A value of unity for the bunching parameter gives a single infinite current peak, but this value does not correspond to optimum bunching. More energy can be extracted from the bunched beam if the infinite current peak is allowed to diverge slightly, since the energy in the bunch is increased and fewer electrons remain in the half of the cycle which subtracts energy from the radio-frequency field in the resonator.

There is no conversion of energy if the beam is overbunched until the bunching parameter has the value 3.83, which corresponds to the first zero of the $J_1$ Bessel function. The current distribution for this case is shown in Fig. 12. Note that the beam has not become direct current. This point was mentioned in the discussion of Fig. 5. Note also that the two infinite current peaks are not 180 degrees out of phase, but actually 86 degrees, as shown by Fig. 12. The basis for zero output is not obvious from inspection of Fig. 12, but depends upon the fact that the integrated effect over a complete cycle is zero.

If overbunching is increased, the two infinite current peaks will merge and form a single infinite current peak which is 180 degrees out of phase with the first infinite peak when the bunching parameter equals unity. This second single infinite peak corresponds to a value of 4.60 for the bunching parameter. Further increase of the bunching until $x = 5.33$ produces a second maximum in the output. Reference to Fig. 4 will show that this degree of bunching corresponds to the first minimum of the $J_1$ Bessel function. These current distribution curves are shown in Fig. 13.

ELECTRON-ARRIVAL-TIME CURVES

The cycloid method of computing the current distribution depends upon the assumption that the velocity modulation is quite small and that sufficient time is allowed for bunching to occur. If a curve is plotted showing $t_2$, the arrival time of a particular electron at the catcher, as a function of the departure time $t_1$, i.e., the time that same electron left the buncher, then the cycloid gives the values of $dt_2/dt_1$ as a function of $t_2$. The fact that the bunched current is proportional to the reciprocal of $dt_2/dt_1$, i.e., $dt_1/dt_2$, can be derived as follows: Consider the number of electrons passing the buncher grids at time $t_1$. The number during an interval $dt_1$ will be $I_0 dt_1$, since the current at the buncher is the average beam current and $I_0$ is the number of electrons per unit time. These same electrons reach the catcher at time $t_2$. The same electrons will pass the catcher grids during an interval $dt_2$; therefore,

$$ I_0 dt_1 = I_0 dt_2. $$

Equation (15) may be rewritten

$$ I_2 = I_0 (dt_1/dt_2). $$

This analysis is valid only if the transit time between the resonator grids is infinitesimal. When the transit time is an appreciable part of a cycle, the current peaks indicated in Figs. 8, 12, and 13 are reduced to a finite value.

Electrons which left the buncher at a different time may arrive at the catcher at the same time $t_2$. This means that the sum of the slopes must be used to obtain the total current at any time $t_2$. A negative slope merely means that electrons which left the buncher later have arrived at the catcher first. For this reason, the absolute values of the slopes are used and the negative sign is ignored. This point was mentioned in the discussion of the cycloid curves in Fig. 11.

The curves in Figs. 10, 14, and 15 have been plotted with $t_1$ as the vertical co-ordinate. This construction correlates an infinite current at any time $t_1$ with an infinite slope of the curve. Figs. 10 and 14 show the $t_1$-versus-$t_2$ curves for $x = 0.50, x = 1.00, x = 1.84, x = 3.83,$ and $x = 4.60$. The curve for $x = 5.33$ has been plotted separately in Fig. 15 because some ambiguity is introduced by the simultaneous arrival of electrons from several bunching cycles. The curves for electrons which left the buncher during an earlier or later cycle are shown dotted. The range of $t_1$ has been chosen from $-\pi/\omega$ to $+\pi/\omega$ so that the electron bunch will occur at the center of the illustration. The buncher voltage is changing from negative to positive when $t_1$ is equal to zero.

PHASE SHIFT DUE TO DISTORTION OF THE BUNCH

All of the curves in Figs. 8, 10, and 11 to 15, inclusive illustrate bunching which is symmetrical, i.e., these curves represent the conditions when the assumption of a small buncher voltage is satisfied. As mentioned previously, a small number of cycles during the bunching interval requires a large buncher voltage; this condition causes a distortion of the bunched current distribution. Fig. 16 shows the distortion of the arrival-
time curve corresponding to \( x = 1.84 \) in Fig. 13, when the transit time is equivalent to 31 cycles. These conditions correspond to a ratio \( E_1/E_0 = 0.18 \). Line A of Fig. 16 shows the distortion due to the fact that the velocity variation is large compared to the average velocity, although the velocity variation has been assumed to be sinusoidal. The additional distortion caused by the nonsinusoidal velocity variation when the buncher voltage is large compared to the acceleration voltage is shown by the difference between A and B in Fig. 16.

There is a phase shift introduced by the distortion of the bunched current; this effect was mentioned in the discussion of Fig. 3. A drift time of \( 2/\pi \) cycles has been represented in Fig. 17 in order to emphasize this phase shift. Bunching parameter values of \( x = 0.50, x = 0.80, x = 1.00, \) and \( x = 1.28 \) have been used for computing the \( t_1 \)-versus-\( t_2 \) curves in Fig. 17. Corresponding current distribution curves are given in Fig. 18. Note that the curves for \( x = 0.50 \) do not differ greatly from the corresponding curves in Figs. 8 and 10. The distortion becomes greater as the buncher voltage is increased. As a result, the phase shift is a function of the buncher voltage.

The choice of a drift time of \( 2/\pi \) cycles means that the four values of the bunching parameter correspond to \( E_1/E_0 \) ratios of 0.25, 0.40, 0.50, and 0.64. The larger values of buncher voltage cause a nonsinusoidal variation of velocity; as a result, the average velocity is somewhat less than the velocity corresponding to the acceleration voltage, and the expression for the bunching parameter in (6) is no longer valid. The slower electrons become bunched sooner, and an infinite current peak occurs when the value of \( x \) computed from (6) is only 0.80. A value of \( x = 1.00 \) gives a decided double peak in the current distribution, and optimum bunching corresponds to a value of 1.28 instead of 1.84. This deviation from the first-order theory indicates that the output characteristic of an amplifier may differ from the curve shown in Fig. 4.

The phase shift introduced by the distortion of the beam-current distribution when the bunching time is small and large variations of buncher voltage are required is evident from an inspection of either the \( t_1 \)-versus-\( t_2 \) curves or the Applegate diagrams. In fact, an Applegate diagram may be used to compute the \( t_1 \)-versus-\( t_2 \) curves, since the arrival time, i.e., \( t_3 \), for an electron at any point along the drift space is given by the horizontal co-ordinate which represents time in an Applegate diagram. Similarly, the close approach of two adjacent lines corresponds to a large value of current, which is roughly proportional to the reciprocal of the spacing between the lines, although the limitation of a small number of lines means that \( \Delta t_1/\Delta t_2 \) is used to approximate the current instead of the exact relation \( dt_1/dt_2 \). It should be pointed out that this relation between the current and the apparent density of the lines can be misleading after lines have crossed because it is difficult to determine at a glance whether two converging lines were adjacent at the position of the buncher. Also, there is an optical illusion of less density at the point representing an infinite current peak since the lines merge and individual lines cannot be detected.

It is apparent from this discussion that very accurate Applegate diagrams may be constructed from \( t_1 \)-versus-\( t_2 \) data. Points are chosen at uniform intervals along
the time scale at a position corresponding to the location of the buncher. Arrival time at the position of the catcher is computed from the relation

\[ t_2 = t_1 + s/v. \]  
(17)

Corresponding \( t_1 \) and \( t_2 \) points are connected by a straight line. This method is usually more accurate than the simpler method described in the discussion of Fig. 6, since small errors in the slope of a line may cause considerable error when the line is extended to the position of the catcher.

**Cascade-Amplifier Klystron**

Curves of \( t_1 \) versus \( t_2 \) (not shown) and \( t_1 \) versus \( t_3 \) (Fig. 19) have been used to construct the Applegate diagram in Fig. 20 for a cascade-amplifier klystron. This type of tube has been described previously. Its theory of operation is easily explained with the aid of the sectional view of a three-resonator klystron amplifier in Fig. 21.

A review of Fig. 4 will emphasize the fact that the gain in a velocity-modulation amplifier is relatively independent of the buncher voltage when the voltage is small, and that this gain is greater than the gain of an amplifier with sufficient bunching to give optimum output. If a small radio-frequency voltage modifies the electron velocity at the buncher, the gain for the first stage will introduce a much larger voltage at the second resonator, which will be designated the cascade buncher. A large velocity variation is superimposed upon the partially bunched electron beam at the second resonator. This velocity variation is much greater than that introduced by the buncher, due to the voltage gain in the first stage, and this additional velocity variation may give sufficient bunching for optimum output at the third resonator, or catcher.

This analysis of a cascade amplifier is well illustrated by the Applegate diagram in Fig. 20. The amplitudes of the voltages in the three resonators have been chosen to represent the conditions in a typical amplifier. The over-all voltage gain for the two stages is shown as 35; this corresponds to a power gain of 1225. These figures are purely arbitrary, but are not inconsistent with the actual conditions in a three-resonator amplifier.

There is a phase difference of 90 degrees between the bunching in the first and second resonators of a cascade amplifier if the second resonator is tuned exactly to the input frequency. This relation may be verified by referring all phases to the line in the Applegate diagram which represents the position of the electron which passed the buncher grids at zero time, instead of...
using absolute time as a reference. This definition of phase is equivalent to subtracting the average transit time in the drift space from the absolute time. The electron which left the buncher at zero time becomes the center of the partially formed bunch at the second resonator. The radio-frequency voltage at the second resonator, or cascade buncher, will have a phase which will retard the greatest number of electrons if this resonator is tuned to the input frequency. For this reason, the radio-frequency voltage at the second resonator will lag the voltage at the first resonator by an angle of 90 degrees. Fig. 20 illustrates these phase relations.

The previous discussion of phase shift caused by the distortion of the bunch has been qualitative. Also, in the case of a cascade amplifier, there is no electron comparable to the electron with average velocity to be used as a phase reference; and there is no quantity comparable to the bunching parameter when the buncher is tuned to the input frequency. For this reason, the radio-frequency voltage at the second resonator will lag the voltage at the first resonator by an angle of 90 degrees. Fig. 20 illustrates these phase relations.

The phase shift for various ratios of $E_i/E_0$, corresponding to the curves in Fig. 17, have been computed from (21) and are shown in Table I. These data verify the qualitative conclusion, stated in the previous

\[ W = \frac{(\omega/2\pi)}{I_0} \int_0^{2\pi/\omega} \cos (\omega t_2 - \tau_0 - \phi) dt_2. \]  

Convenient limits are chosen for the integration since it is necessary to integrate only over one complete cycle. It is necessary to replot $E_2 \cos (\omega t_2 - \tau_0 - \phi)$ on the $t_1$ time scale before integration. This may be done conveniently by transferring the value of $E_2 \cos (\omega t_2 - \tau_0 - \phi)$ at a given time $t_2$ to the corresponding time $t_1$ given by the $t_1$-versus-$t_2$ diagram. This process is illustrated by Fig. 22, which corresponds to a catcher voltage with a peak amplitude of 0.7 $E_0$ replotted with the aid of line $B$ of Fig. 16. A phase shift of 8 degrees has been assumed.

A value for the conversion efficiency of the tube can be obtained from the ratio of the effective energy transferred to the resonator, which is given by the difference between the shaded areas below and above the line representing the acceleration voltage, to the area of the rectangle $ABCD$ which represents the direct-current energy in the beam. The value of efficiency obtained from Fig. 22 is 40 per cent. This is a theoretical efficiency and includes the power absorbed by ohmic losses in the resonator. The output efficiency would depend upon the ratio of power delivered to the load to the power losses in the resonator.

**Phase Shift from a Graphical Integration**

It is not necessary to estimate the phase shift, or obtain a value by cut-and-try from calculations of the efficiency using a number of arbitrarily chosen phase angles. A method suggested by E. Feenberg, derived in an appendix, allows the phase angle and the maximum efficiency to be computed exactly from two graphical integrations. If one integration is performed, using (19) with $\phi$ equal to zero, and a second integration is made from the following expression:

\[ W_1 = \frac{(\omega/2\pi)}{I_0} \int_0^{2\pi/\omega} \sin (\omega t_2 - \tau_0) dt_2. \]  

then the phase angle $\phi$ and the maximum value of the energy transferred $W_{max}$ may be computed from the relations

\[ \tan \phi = W_1/W, \]  

and

\[ W_{max} = \sqrt{W_1^2 + W^2}. \]  

The phase shift for various ratios of $E_i/E_0$, corresponding to the curves in Fig. 17, have been computed from (21) and are shown in Table I. These data verify the qualitative conclusion, stated in the previous

<table>
<thead>
<tr>
<th>Bunching Parameter</th>
<th>$E_i/E_0$</th>
<th>Drift Time (cycles)</th>
<th>Phase Shift (degrees)</th>
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<td>0.50</td>
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<td>6.4</td>
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<tr>
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<td>1.28</td>
<td>0.64</td>
<td>2/$\pi$</td>
<td>24.0</td>
</tr>
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</table>
discussion of Figs. 17 and 18, that the phase shift increases as the buncher voltage is increased.

There is no convenient graphical method for determining the conditions for optimum output, although the efficiency may be computed for a number of choices of buncher voltage, and the buncher voltage required for optimum output may be estimated by inspection of the curve of efficiency-versus-buncher voltage.

**Conclusions**

These graphical methods of analysis emphasize several conclusions. First-order theories which assume small bunching voltages and correspondingly long drift times are not applicable to tubes with short drift distances. Graphical methods permit exact calculation of operating conditions, and are not limited by the approximations which are required in the first-order theory. In addition, a graphical analysis is often useful, even under the conditions when the first-order equations might apply, since such an analysis provides a physical picture which may give a better understanding of the electrical characteristics of a velocity-modulation tube.

**Appendix A**

**Derivation of Integral Method of Determining the Phase Shift and Maximum Energy of a Bunched Electron Beam**

The energy transferred per cycle from a bunched electron beam to the catcher resonator will be represented by the symbol $W$ and is given by

$$W = \frac{\omega}{2\pi} E_0 I_0 \int_0^{2\pi/\omega} \cos (\omega t - \tau_0 - \phi) dt.$$  \hfill (23)

Equation (23) is equivalent to (19) in the text. The cosine term may be expanded in the form

$$\cos (\omega t - \tau_0 - \phi) = \cos (\omega t - \tau_0) \cos \phi + \sin (\omega t - \tau_0) \sin \phi.$$  \hfill (24)

The phase angle $\phi$ is a constant during integration; therefore,

$$W = \frac{\omega}{2\pi} E_0 I_0 \cos \phi \int_0^{2\pi/\omega} \cos (\omega t - \tau_0) dt_1,$$

$$+ \frac{\omega}{2\pi} E_0 I_0 \sin \phi \int_0^{2\pi/\omega} \sin (\omega t - \tau_0) dt_1.$$  \hfill (25)

Symbols may be assigned to the two parts of 25,

$$W_1 = \frac{\omega}{2\pi} E_0 I_0 \int_0^{2\pi/\omega} \sin (\omega t - \tau_0) dt_1,$$

$$W_2 = \frac{\omega}{2\pi} E_0 I_0 \int_0^{2\pi/\omega} \cos (\omega t - \tau_0) dt_1.$$  \hfill (26)

Then (25) may be rewritten

$$W = W_1 \cos \phi + W_2 \sin \phi.$$  \hfill (27)

Differentiating (28) with respect to $\phi$ and equating to zero gives an expression for $\phi_{\text{max}}$; i.e., determines the value of $\phi$ required to make $W$ a maximum.

$$- W_2 \sin \phi + W_1 \cos \phi = 0$$

$$\tan \phi_{\text{max}} = W_1/W_2.$$  \hfill (29)

Two more relations for $\phi_{\text{max}}$ may be written

$$\sin \phi_{\text{max}} = W_1/\sqrt{W_1^2 + W_2^2},$$

$$\cos \phi_{\text{max}} = W_2/\sqrt{W_1^2 + W_2^2}.$$  \hfill (30)

Equation (28) may, therefore, be written

$$W_{\text{max}} = W_1 \sqrt{W_1^2 + W_2^2} + W_2 \sqrt{W_1^2 + W_2^2}.$$  \hfill (31)

Consider next the case where $\phi \neq \phi_{\text{max}}$ due to detuning of the catcher resonator. The cosine term in (23) may be written in the form

$$\cos (\omega t - \tau_0 - \phi) = \cos (\omega t - \tau_0 - \phi_{\text{max}} + \phi_{\text{max}} - \phi)$$

$$- \sin (\omega t - \tau_0 - \phi_{\text{max}}) \sin (\phi_{\text{max}} - \phi).$$  \hfill (32)

If the sine term in (34) is expanded,

$$\sin (\omega t - \tau_0 - \phi_{\text{max}}) = \sin (\omega t - \tau_0) \cos \phi_{\text{max}} - \cos (\omega t - \tau_0) \sin \phi_{\text{max}}.$$  \hfill (35)

Substituting (26), (27), (31), and (32) into (35) and integrating from zero to $2\pi/\omega$ gives

$$\int_0^{2\pi/\omega} \sin (\omega t - \tau_0 - \phi_{\text{max}}) dt_1 = 0.$$  \hfill (36)

Therefore, the second term of (34) does not make any contribution for any value of $\phi$. Substituting (34) and (36) in (23) gives

$$W = \frac{\omega}{2\pi} E_0 I_0 \cos (\phi_{\text{max}} - \phi) \int_0^{2\pi/\omega} \cos (\omega t - \tau_0 - \phi_{\text{max}}) dt_1.$$  \hfill (37)

which may also be written

$$W = W_{\text{max}} \cos (\phi_{\text{max}} - \phi).$$  \hfill (38)

Equation (38) may be recognized as the form of the voltage across a resonant circuit in terms of the phase angle between the voltage and current in the circuit.
A Stabilized Narrow-Band Frequency-Modulation System for Duplex Working*

E. E. SUCKLING†, NONMEMBER, I.R.E.

Summary—A system is described whereby the two terminals of a duplex radiotelephone channel are stabilized against each other by the use of standard automatic-frequency-control circuits and the common use of an oscillator for both transmitting oscillator and superheterodyne high-frequency oscillator. The send and receive frequencies are separated from each other by an interval which is the frequency of the intermediate-frequency channel. The system can be designed to give adequate frequency stability** for most applications without the use of crystal control.

INTRODUCTION

A MAJOR difficulty in the design of ultra-high-frequency communication systems is the attainment of sufficient frequency stability of the transmitter and of the receiver.

The use of a wide band with either a superregenerative receiver or a wide-band superheterodyne circuit permits some variation in frequency but with the increasing use of the ultra-high-frequency spectrum these methods are no longer available and communication channels must be maintained within as narrow a band as can be used to convey intelligence. In the case of both amplitude- and frequency-modulated systems this requirement often means the use of crystal stabilized oscillators with numerous frequency multiplying stages and perhaps also a phase modulator.

In a remotely switched radio terminal it is usually necessary that whenever the unit is switched on, the assigned frequency be always available without any possibility of variation and in this case it is practically essential that a crystal-controlled oscillator be used. If the channel is frequency modulated, the Armstrong system or some modification of it will be preferable, as the controlled reactance tube oscillator, although stabilized once it has been tuned to its stabilizing source, does not necessarily start oscillating at the frequency required and the commencing frequency of such an oscillator may be beyond the control limits of the automatic-frequency-control circuit. In many installations conditions are not as rigorous and preliminary tuning may be permissible. In such cases, as the use of crystal control involves considerable complication of equipment, this factor, together with the difficulty of altering frequency when it may be required, opens the field for the development of a system which, while easily variable in frequency, has both stability and also simplicity of circuits.

The arrangement to be described incorporates these features and provides for a simultaneous two-way radiotelephone link with the characteristics which can be expected when using a frequency-modulated transmitter and a sensitive receiver.

PROPOSED SYSTEM

In the usual system of stabilized frequency modulation the transmitter frequency is stabilized against a crystal oscillator. The arrangement is very similar to the automatic-frequency-control circuits used in some domestic receivers whereby the receiver oscillator is maintained at a required frequency by reference to an incoming carrier.

In both cases the oscillator to be controlled is arranged with an electronic reactance connected across its tuned circuit which enables the frequency of oscillation to be varied by an alteration of the bias on the reactance tube. Bias for the reactance tube is derived from a frequency discriminator connected in an intermediate-frequency channel. When, due to a drift in the variable oscillator, the frequency in the intermediate-frequency channel has deviated from the center frequency of the channel a steady voltage is obtained from the discriminator and this voltage applied as bias to the reactance tube alters the oscillator frequency in such a way as to correct the original drift. As a result, the drifting oscillator is constantly corrected and brought back towards the correct frequency since any deviation produces a direct voltage which will tune the oscillator back towards the original condition.

There cannot, of course, be perfect correction as a small frequency deviation is required to produce a correcting voltage. This deviation need only be a few hundred cycles to produce sufficient voltage to correct what would otherwise be an off-frequency condition of many kilocycles.

In the system here described the frequency used to control the oscillator is that of the incoming carrier. It is, in fact, a standard automatic-frequency-control system using a superheterodyne receiver, the oscillator of which is constantly corrected to maintain the intermediate

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** Editorial Note: The term “stability” is not used in this paper in its usual sense, that is, as the ability to maintain a given carrier frequency at a constant value. The method described in the paper relates instead to the maintenance of a fixed-frequency relation, or difference of frequencies, between the two carriers involved in one system; accordingly both carriers can drift equally in the same direction without bringing the corrective means into play.
frequency at the correct value. The oscillator of a superheterodyne receiver can be used as the basis of a transmitter when it is satisfactory for the receive and send frequencies to be separated by an interval which is the frequency of the intermediate channel. This principle is used and as both send and receive channels are in simultaneous operation the automatic frequency control applied to the receive oscillator gives stability to the outgoing frequency. As the receiver oscillator (or its harmonic) is actually radiating, the transmitted frequency will have a stability similar to that of the incoming frequency (maintained by the automatic-frequency-control system), but spaced from it by the receiver intermediate frequency. The incoming carrier which supplies the stabilizing frequency for the transmitter-receiver arrangement can originate in a crystal-controlled transmitter in which case the frequency stability of the whole system will be approximately the same as that of the crystal oscillator. It is, however, possible to use at either end of the channel a transmitter-receiver arranged as described with, in each case, an automatic-frequency-controlled receiver oscillator working also as transmitting oscillator. In this case, absolute frequency stability will not be attained but the system will in itself be stable in that the two oscillators will be maintained at a frequency separation from one another which is the common frequency of both of the intermediate-frequency channels. A block diagram below shows the complete duplex-channel arrangement.

Drift of the two oscillators simultaneously is possible and is not corrected. This, of course, may cause interference with adjacent channels, or it may involve working with receiver radio-frequency tuned circuits slightly out of alignment, but actually is unlikely to be of sufficient magnitude to give trouble due to either effect. As long as the two oscillators are maintained at the correct frequency separation the correct intermediate frequencies will be developed and the major requirement for receiver tuning will be satisfied.

It can be seen that either frequency or amplitude modulation can be used with the system but in view of the necessity for a discriminator and a reactance tube to effect automatic frequency control, the use of frequency modulation is the obvious choice as it involves merely the use of a microphone transformer with the reactance tube. Frequency modulation permits a closer spacing of transmitter and receiver frequencies with a lower intermediate-frequency channel and a more stable discriminator.

**Equipment Design**

The efficient operation of the system depends upon the automatic frequency control and the design must therefore center about the automatic-frequency-control circuits. As a standard for commencement it was considered that a frequency variation due to external causes such as thermal, voltage variation, etc., of an uncompensated oscillator of reasonably careful design would be of the order of 0.1 per cent at 10 megacycles and that the consequent carrier drift to be encountered was up to 40 kilocycles at 40 megacycles. It was also considered that for a 10 kilocycle per second modulation deviation, an off-center tuning of +1 kilocycle was tolerable when the discriminator characteristic was linear to +12 kilocycles per second. The design of the automatic-frequency-control circuits must therefore be such that the discriminator reactance-tube combination produces sufficient reactance across the oscillator tuned circuit to cause a frequency deviation of 40 kilocycles when the intermediate frequency is 1 kilocycle off center.

In an experimental setup 2-watt carriers were used spaced 455 kilocycles apart, the working frequencies being 40 megacycles and 40.455 megacycles. Concise measurements of the performance of the system were not taken but the action of the automatic frequency control in "locking" the two carriers was very evident. The complete units each about the size of a domestic receiver enabled good quality duplex telephone conversation to be maintained over a distance of several miles.

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An interesting feature was the incorporation of single-dial control by which the radio-frequency and oscillator circuits were ganged. This enabled a wide choice of channel frequencies to be used but also gave the effect that on tuning around the dial and hearing the other station communication was then immediately possible as the local carrier was by the action of tuning the receiver set to and locked at the correct frequency for the remote station's receiver.

The formula and method for calculating the gear ratio to be employed in winding universal coils were first deduced and discussed by the present author. Subsequently, using a slightly different notation and nomenclature, Hershey covered essentially the same ground, and evolved a somewhat simpler, though less accurate, formula. Hershey's theoretical treatment, however, is needlessly involved, and his formula can be deduced directly from that originally given by the present author simply by neglecting certain terms, and shown to be the equivalent of that evolved by Hershey. Also the nomenclature and notation originally introduced by the author are compared with those subsequently used by Hershey. The theory underlying the selection of the correct number of crossovers per turn of the dowel is reviewed, and rules for determining the number of crossovers per winding cycle (required in the use of the gear-ratio formulas) from the number of crossovers per turn are given. The steps in making a gear-ratio calculation are outlined and a table of useful formulas is appended.

In conclusion, the details of the mathematical solution involved in the derivation of the basic formula are given.

Summary—A review is made of the derivation of the basic formula for calculating the gear ratio to be employed in winding a universal coil as a function of certain coil parameters, as given in a previous paper by the author.

From this basic formula a somewhat simpler, though less accurate, formula is derived merely by neglecting certain terms, and shown to be the equivalent of that evolved by Hershey. Also the nomenclature and notation originally introduced by the author are compared with those subsequently used by Hershey. The theory underlying the selection of the correct number of crossovers per turn of the dowel is reviewed, and rules for determining the number of crossovers per winding cycle (required in the use of the gear-ratio formulas) from the number of crossovers per turn are given. The steps in making a gear-ratio calculation are outlined and a table of useful formulas is appended.

In conclusion, the details of the mathematical solution involved in the derivation of the basic formula are given.

The radio engineer who desires to make his own gear-ratio calculations is now confronted by two sets of nomenclatures and formulas, and therefore it becomes desirable to present a critical review and comparison of the same, and that is the object of the present paper.

Parenthetically it might be noted, that since the mechanical stability, and therefore the electrical reproducibility and constancy, as well as the electrical characteristics, of a coil depend very markedly on the gear ratio used, it is imperative that every radio engineer engaged in coil design be able to carry out his own gear-ratio calculations. The practical importance of using the proper gear ratios can be illustrated by the fact that at one plant coil rejections were reduced from as high as 30 to 3 per cent simply by the use of the correct gear ratios; in fact, after their introduction, all coil trouble practically disappeared.

I. The Geometry and Mechanics of the Universal Winding

The method of winding a universal coil is such that, as the dowel or tube on which the coil is wound rotates, the wire is guided back and forth by a shuttle, which displaces the wire in linear proportion to the angle of rotation of the dowel. The shuttle is actuated by a cam mounted on a shaft, which is geared in a definite ratio to the shaft turning the dowel.

Accordingly (Fig. 1), if we denote by $x$ the linear displacement of a point $P$ of the wire parallel to the axis of the dowel, by $y$ that perpendicular thereto (on the developed surface), by $c$ the cam throw, by $d$ the diameter of the dowel, by $\theta_c$ the angular rotation of the cam shaft, and by $\theta_d$ that of the dowel, we have

$$\frac{x}{c} = \frac{\theta_c}{\pi}$$

whence

$$\frac{y}{d} = \frac{\theta_c}{2\pi}$$

If next (Fig. 2), we denote by $h$ the linear advance per crossover, by $H$ the linear advance per winding cycle, by $n$ the number of crossovers per turn of the dowel, by $q$ the number of crossovers per winding cycle, and $y/x = \tan \phi = (\pi d/2c)r$. If next (Fig. 2) we denote by $h$ the linear advance per crossover, by $H$ the linear advance per winding cycle, by $n$ the number of crossovers per turn of the dowel, by $q$ the number of crossovers per winding cycle, and...
by $s$ the spacing between centers of adjacent wires on the surface of the dowel, we have the relations

$$c \tan \phi = \pi d/n \pm h$$  \hspace{1cm} (5)

$$s = H \cos \phi = qh \cos \phi$$  \hspace{1cm} (6)

where the positive sign is taken for a progressive winding and the negative sign for a retrogressive one.

If now we take note of the empirical fact that for best results the spacing factor, (that is the ratio of $s$ to $\delta$, where $\delta$ is the nominal diameter of the wire) should be 1.25, (11) takes the form

$$r = 2/n(1 \pm 1.25 \delta/qh).$$  \hspace{1cm} (12)

Equation (12) will suffice for most practical purposes; (10) can be used where a higher degree of accuracy is necessary.

II. COMPARISON OF NOTATION OF THE AUTHOR AND HERSHEY

Hershey denotes by $g$ the actual gear ratio between the dowel shaft and the cam shaft; by $g'$ the number of cam cycles per turn; by $q'$ the number of cam cycles per winding cycle; by $w$ the diameter of the wire; and by $\alpha$ the angle which the wire makes with a line perpendicular to the axis of the dowel. In view of these definitions there exist the following relations between the various quantities as defined by the author and by Hershey

$$r = \frac{1}{2n(1 \pm \frac{a^2}{b^2})}$$  \hspace{1cm} (13)

$$n = \frac{2g'}{q'}$$  \hspace{1cm} (14)

$$q = 2q'$$  \hspace{1cm} (15)

$$\delta = w$$  \hspace{1cm} (16)

$$\phi = (90 \text{ degrees} - \alpha).$$  \hspace{1cm} (17)

If we make these substitutions in the basic equation (4), there results

$$\tan \alpha = \frac{2c g}{\pi d}$$  \hspace{1cm} (4a)

which is (1) of Hershey's paper. Furthermore, if we make these same substitutions in (12), we obtain

$$\frac{1}{g} = \frac{1}{g'}(1 \pm 0.63\frac{w}{q'c})$$  \hspace{1cm} (12a)

which is the gear-ratio formula as given by Hershey, namely his equation (12).

III. SELECTION OF THE NUMBER OF CROSSOVERS PER TURN

In (10) and (12) there still remain two quantities which need further discussion, namely, $n$, the number of crossovers per turn, and $q$ the number of crossovers per winding cycle.

As pointed out in the previous paper by the author, the choice of $n$ depends on the fact that for a mechanically stable coil the winding angle $\phi$ must lie between certain limits, and, as can be seen from (4), for a given gear ratio $r$, the angle will increase with the winding diameter; hence, to build a coil as high as possible, the angle $\phi$ should be at its lower limit at the surface of the dowel, i.e., at the dowel diameter.

Moreover, it is found that for a stable coil, the wire must not make too many excursions before completing the winding cycle; this means that in practice $n$ must be an integer or a simple fraction.

Empirically it is found that $\phi$ is near its lower limit when $n$ is chosen in accordance with the formula

$$n = \frac{2d}{3c}.$$  \hspace{1cm} (18)

This corresponds to a value of $\phi$ of approximately 78 degrees.

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4 The details of the mathematical solution are given at the end of this article.
Hence the procedure in selecting \( n \) is to calculate its value as given by (18) and then select the nearest integer, or integer plus a simple fraction, less than the calculated value.

On substituting for \( n \) its value as given by (14), (18) takes the form

\[
g' = d/3c
\]  

which is the form of the same equation as given by Hershey, namely his (3). Also from (17), it is seen that \( \phi = 78 \) degrees corresponds to a value of \( \alpha \) of 12 degrees, as given by Hershey.

We come now to a consideration of the value of \( q \). The latter is determined once \( n \) has been fixed, and may be obtained either by drawing the corresponding winding pattern and counting the number of crossovers per winding cycle; or, better, by means of the following rule.\(^6\)

Write \( n/2 \) in the form

\[
n/2 = i_1/i_2
\]

(19)

where the right-hand side is expressed as a fraction in its lowest terms. The quantity \( q \) will then be given by

\[
q = 2i_1.
\]

(20)

For example, for the case \( n = 1 \), we have \( n/2 = 1/2 = i_1/i_2 \) which gives \( i_1 = 1 \) and \( q = 2 \); for \( n = 2 \), we have \( n/2 = 2/2 = 1/1 \) which gives also \( i_1 = 1 \) and \( q = 2 \); for \( n = 1 \), we have \( n/2 = 3/4 \) which gives \( i_1 = 3 \) and \( q = 6 \), etc. Hence it is possible to set up the following supplementary rules:

1. For \( n \) an odd integer, \( q = 2n \).
2. For \( n \) an even integer, \( q = n \).

For fractional values of \( n \), the fundamental rule is best applied directly.

IV. SUMMARY OF THE METHOD OF GEAR-RATIO CALCULATION

Whether or not the reader has followed the details of the foregoing theory, as a result, it can be stated that the gear ratio to be used in winding a given universal coil is determined by three factors:

1. The diameter \( d \) of the dowel or tube on which the coil is to be wound;
2. The cam throw \( c \);
3. The nominal diameter \( \delta \) of the wire.

The first step in the calculation of the gear ratio is the selection of the quantity \( n \). The latter is determined from the value calculated according to (18) by selecting the nearest integer or integer plus a simple fraction, which is less than this calculated value.

The second step is the determination of \( q \), either by drawing the winding pattern and actually counting the number of crossovers per winding cycle, or by means of one of the special rules given above.

The third step is to calculate the numerical value of \( r \)

\(^6\) This rule is the equivalent of a relation first pointed out by Hershey, footnote reference 2.

V. TABLE OF GEAR-RATIO FORMULAS

For convenience there is given, in Table I, gear-ratio formulas for frequently occurring values of \( n \), that is, number of crossovers per turn. This table is based on the approximate formula for the gear ratio, namely, (12).

In the table \( \delta \) represents the nominal diameter of the wire in inches, and \( c \) the cam throw, also in inches. The gear-ratio formula gives the ratio of the number of teeth in the cam gear to the number of teeth in the driving gear. The values of \( q \) are included for reference. The value of \( n \) is, of course, determined from (18).

<table>
<thead>
<tr>
<th>( n )</th>
<th>Gear Ratio</th>
<th>( q )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>((1 \pm 0.625 \delta/c))</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>((1 \pm 0.625 \delta/c))</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>((1 \pm 0.208 \delta/c))</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>((1 \pm 0.313 \delta/c))</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>((1 \pm 0.313 \delta/c))</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>((1 \pm 0.208 \delta/c))</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>((1 \pm 0.0893 \delta/c))</td>
<td>14</td>
</tr>
<tr>
<td>8</td>
<td>((1 \pm 0.125 \delta/c))</td>
<td>10</td>
</tr>
</tbody>
</table>

VI. DETAILS OF THE MATHEMATICAL SOLUTION OF THE FUNDAMENTAL EQUATIONS

From trigonometry and (4), we have

\[1/\cos \phi = (1 + \tan^2 \phi)^{1/2} = [1 + (\pi d/2c)^2]^{1/2}.\]

(21)

Next if we substitute in (5) for \( h \) its value as found from (6), and furthermore transpose one term, we obtain

\[c \tan \phi - (\pi d/n) = \pm s/q \cos \phi.\]

(22)

After squaring both sides of (22), substituting therein for \( \tan \phi \) and \( \cos \phi \) their values as given by (4) and (21), respectively, and rearranging, there results

\[r^2(1 - a^2) - (4r/n) + 4/n^2(1 - b^2) = 0\]

(23)

wherein \( a \) and \( b \) are as defined by (8) and (9). Equation (23) can be solved as a quadratic in \( r \), to yield the result given by (7).

\(^4\) See, for example, "Mathematical Tables from Handbook of Chemistry and Physics," Chemical Rubber Publishing Company, Cleveland, Ohio, 1936; "Logarithmic and Trigonometric Tables," The Macmillan Company, New York, N. Y.
Analysis of Voltage-Regulator Operation*

W. R. HILL, JR.†, MEMBER, I.R.E.

Summary—The performance of any regulator circuit is analyzed in terms of two parameters defined as the internal resistance and the regulation factor. These two parameters together with a simple equivalent circuit permit calculation of the regulator performance in conjunction with any load circuit and direct-current supply. Typical regulator circuits are analyzed to evaluate the two parameters and to show the effect of circuit changes in improving regulator performance. A compensated circuit is presented which makes it possible to provide an output voltage that is substantially independent of any input-voltage or load-current change.

PRINCIPAL SYMBOLS

Instantaneous values of alternating components

- \(e_c\) = glow-tube plate-to-cathode voltage
- \(e_g\) = grid-to-cathode voltage
- \(e_p\) = plate-to-cathode voltage
- \(e_r\) = regulator output voltage
- \(e_i\) = regulator input voltage
- \(i_p\) = plate current
- \(i_r\) = regulator output current
- \(i_i\) = regulator input current

Instantaneous total values

- \(e_i\) = regulator input voltage
- \(e_o\) = regulator output voltage
- \(i_i\) = regulator input current
- \(i_o\) = regulator output current

Effective values of alternating components

- \(E_o\) = open-circuit rectifier supply voltage
- \(E_r\) = regulator output voltage
- \(E_i\) = regulator input voltage
- \(I_o\) = regulator output current
- \(I_i\) = regulator input current

Average values

- \(E_c\) = glow-tube plate-to-cathode voltage
- \(E_i\) = regulator input voltage
- \(E_o\) = regulator output voltage
- \(I_i\) = regulator input current
- \(I_o\) = regulator output current

Parameters

- \(g_m\) = grid-plate transconductance, mhos
- \(r\) = internal resistance of regulator at output terminals, ohms
- \(R\) = regulator regulation factor
- \(r_p\) = plate resistance, ohms
- \(Z_L\) = load impedance presented to regulator, ohms
- \(Z_s\) = internal impedance of supply rectifier, ohms
- \(\mu\) = amplification factor
- \(\omega\) = angular velocity, radians per second

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The increasing use of electronic regulator circuits has led to the need for an analysis of regulator-circuit performance to assist in the design of regulator circuits for best regulation and to permit calculation of the regulator performance when used in conjunction with a given rectifier and load.

The following analysis shows that the performance of any regulator circuit can be predicted by the use of two factors, one defined as the internal resistance and the other defined as the regulation factor of the regulating circuit. These factors are dependent upon the configuration of the regulating circuit, and by proper design can be made substantially equal to zero, in which case the output voltage of the circuit is not materially affected by either the input voltage or the load current. The analysis of regulator operation in terms of two parameters was suggested by Hunt and Hickman in 1939. The present article extends this analysis to the use of equivalent circuits and alternating components familiar to the communications engineer.

GENERAL ANALYSIS

The output voltage of a regulator circuit is an approximately linear function of the input voltage and the output current. This may be expressed by the following relations:

\[ e_o = a + be_i + ci_o \]  

where \(a\), \(b\), and \(c\) are constants to be investigated. In practice an analysis based on the assumption of linear operation gives results that are accurate for any particular point on the operating curve of the circuit, but which for engineering purposes can be applied to the whole useful range of regulator operation.

Constant \(a\) of (1) is determined by the output-voltage setting of the regulator circuit. Since it contains no information concerning the performance of the circuit under changes of load or input voltage, it is of no interest in predicting the regulation of circuit. The nature of \(b\) can be determined by taking the partial derivative of \(e_o\) with respect to \(e_i\). This gives

\[ b = \frac{\partial e_o}{\partial e_i} = R \]  

which will be defined as the regulation factor of the circuit. Symbol \(R\) will be used for this term. This factor is a measure of the effectiveness of the regulating circuit in reducing the effect of input-voltage variations on the output voltage.

Taking the partial of \(e_o\) with respect to \(i_o\) gives

\[ c = \frac{\partial e_o}{\partial i_o} = -r \]  

where \(r\) is defined as the internal resistance of the regulating circuit. The negative sign takes account of the
fact that an increase in output current normally produces a decrease in output voltage which is imagined to be produced by the voltage drop in a positive internal resistance.

Placing the newly defined factors into expression (1) the following is obtained:

\[ e_o = a + R e_i - i o r. \] (4)

For \( e_o \) to be independent of input-voltage and load-current variations it is apparent that both the regulation factor \( R \) and the internal resistance \( r \) of the circuit should be as small as possible.

In analyzing the stability of a regulator circuit it is the variations of voltage and current that are of interest. Consequently, it is convenient to consider each of the variables of (4) as consisting of a steady-state or direct-current value plus a number of alternating components that go to make up the complex variation under study. Application of the superposition theorem then permits the analysis to be carried out for each component alone. Rewriting (4) in terms of a steady-state value and single component

\[ E_o + E_{r,\text{max}} \sin \omega t = a + R E_i + R E_{i,\text{max}} \sin (\omega t + \theta_i) \]

\[-r I_o - r I_{r,\text{max}} \sin (\omega t + \theta_i).\] (5)

Under steady-state conditions the alternating components are zero so that

\[ E_o = a + R E_i - r I_o. \]

Therefore,

\[ E_{r,\text{max}} \sin \omega t = R E_{i,\text{max}} \sin (\omega t + \theta_i) - r I_{r,\text{max}} \sin (\omega t + \theta_i).\]

Rewriting this in terms of effective vector values

\[ E_r = R E_i - r I_r. \] (6)

A schematic circuit showing the supply rectifier, the regulator, and the load impedance is shown in Fig. 1.

By Thevenin's theorem the rectifier is represented as a single voltage and internal impedance for each frequency component of the input voltage. For slow variations, such as those caused by line-voltage changes, \( Z_0 \) is equal to the direct-current internal resistance of the rectifier; i.e., the slope of the voltage-current characteristic. For ripple-and higher-frequency components \( Z_0 \) is practically equal to the reactance of the output condenser of the filter system.

It is now possible to eliminate \( E_i \) from (6) by substituting the relation

\[ E_i = E_o - I_z Z_0. \]

This gives as a result

\[ E_r = R E_o - R I_o Z_0 - r I_r. \] (7)

This relation can be simplified by taking advantage of the fact that in practical regulator circuits the input and output current changes are nearly equal. \( I_i = I_r. \) Although this is not strictly true it can be made almost exactly so by considering any impedances in the regulator that shunt the input or output terminals as part of impedances \( Z_0 \) or \( Z_L. \) For most engineering purposes this refinement is not necessary. With this simplification, (7) becomes

\[ E_r = R E_o - I_r (R Z_0 + r). \] (8)

This relation is important because it can be represented by the simple equivalent circuit shown in Fig. 2.

Fig. 2—Simplified equivalent circuit of regulating system.

Using the circuit of Fig. 2 it is easy to compute the over-all regulation of the circuit which will be defined as \( E_r/E_o. \) This can be written from an inspection of the circuit as

\[ \text{over-all circuit regulation} = R Z_L / (R Z_0 + Z_L + R Z_r + r). \] (9)

In a well-designed regulator, factor \( R \) is much smaller than unity and the internal resistance \( r \) is small compared to \( Z_L. \) Consequently, the over-all regulation is equal to the regulation factor \( R \) within a few per cent. If the regulator output is shunted with a condenser, however, \( Z_L \) may become very small for high frequencies with a consequent improvement in the regulation for high-frequency components. Ordinarily the rectifier-filter system removes all but low-frequency components from the regulator input so that the regulation of the system for high-frequency input variations is of secondary concern.

Another characteristic of importance is the internal impedance of the regulator appearing between the output terminals. Inspection of Fig. 2 shows this impedance to be

\[ \text{regulator output impedance} = Z_r = R Z_o + r. \] (10)

The factors \( R Z_0 \) and \( r \) are usually comparable in magnitude for low-frequency variations where \( Z_0 \) is equal to the internal direct-current resistance of the rectifier. For higher frequencies where \( Z_0 \) is smaller (approximately equal to the filter output condenser reactance) the regulator output impedance is practically equal to \( r. \)

A knowledge of this output impedance is of importance in predicting the stability of the regulator output voltage under conditions of changing load, either slow changes or high-frequency changes due to alternating-current components drawn by a vacuum-tube amplifier load. With normal circuits, impedance \( Z_r \) is less than 10
ohms so that a regulator is more effective than large amounts of capacitance in reducing the low-frequency supply impedance presented to an amplifier.

No restriction has yet been placed on the nature of factors $R$ and $r$. Both factors are pure numbers up to frequencies where stray circuit capacitance and ionization delay in the gas tube cause phase shifts to take place. For normal circuits this covers a range extending from zero frequency through the audio-frequency band. Above this range the factors become complex quantities which can be measured for predicting the regulator performance through the use of Fig. 2 and (9) and (10).

The following analysis of factors $R$ and $r$ is restricted to the frequency range in which they appear as real quantities although many of the conclusions drawn are essentially correct outside of this range.

**Analysis of Specific Circuits**

An analysis of several typical regulator circuits will now be carried out to determine the regulation factor and the internal resistance of each. In this way it is possible to show clearly the effect of circuit arrangement and choice of circuit components on the magnitude of these factors. Reference to Fig. 2 indicates that the most desirable circuit is one possessing the smallest value of internal resistance and regulation factor, because changes in input voltage and output current will then have the least effect on the output voltage.

**Analysis of Fig. 3 for $r$**

In obtaining an expression for the internal resistance of each of the voltages and currents in the circuit will be considered to consist of a steady-state and an alternating component, as indicated on the diagram. The analysis will then proceed using only the alternating components similar to amplifier analysis.

As defined in (3),

$$r = \frac{-\partial e_0}{\partial i_0}.$$  
(11)

To find $r$, then, it is necessary to find the relation between $e_i$ and $i$, required by the regulator circuit. This will now be done.

Voltage $e_i$ produces a grid-to-cathode voltage change at $V_i$ of magnitude

$$e_{i2} = P e_i - i_{p2} R_0.$$  
(12)

where $P$ represents $R_0/(R_1 + R_0)$ to simplify the writing, $i_{p2}$ is the alternating component of plate current of $V_2$, and $R_0$ is the internal resistance of the gas-filled tube, i.e., the slope of the voltage-current characteristic at the operating point. This is not a negligible resistance, being of the order of several hundred ohms. Voltage $e_{i2}$ causes a plate-current change

$$i_{p2} = (\mu_2 e_{i2})/(r_{p2} + R_0)$$

where the effect on $i_{p2}$ of the small change in plate-to-cathode voltage caused by the drop in $R_0$ has been neglected. This produces an error of less than 0.5 per cent in typical circuits. Eliminating $i_{p2}$ from (12)

$$e_{i2} = P e_i - i_{p2} R_0.$$  
(13)

Voltage $e_{i2}$ produces an amplified voltage at the plate of $V_2$

$$e_{p2} = A e_{i2} = - (A P e_i)/Q.$$  

where $A$ is the expression for the amplification of a triode, $\mu_2 R_0/(r_{p2} + R_0)$ and $Q = 1 + (\mu_2 R_0)/(r_{p2} + R_0)$. The net grid-to-cathode voltage at $V_i$ is

$$e_{p1} = e_{p2} - e_i = - e_i [1 + PA/Q].$$

At tube $V_1$

$$i_{p1} = (\mu_1 e_{p1} + e_{p1})/r_{p1}.$$  
(13)

But, since the input voltage is held constant as required by (11)

$$e_{p1} = - e_i.$$  

Substituting in (13) for $e_{p1}$ and $e_{p1}$

$$i_{p1} = (- \mu_1 e_i [1 + PA/Q] - e_i)/r_{p1}.$$  
(14)

By neglecting the small current change through $R_1$ and $R_0$ (a few microamperes in a practical circuit) the current $i$ can be substituted for $i_{p1}$. For circuits where this approximation cannot be allowed, a rigorous approach is to consider terminals $a$ and $b$ as the regulator terminals. Then, having computed the internal resistance between $a$ and $b$, the impedance appearing between $b$ and $c$ is equal to the $a-b$ value in parallel with any shunt impedances connected between $b$ and $c$.

Substituting $i$, for $i_{p1}$ in (14) provides an expression that can be solved for the ratio $e_i/i$. Performing this operation

$$r = \frac{e_i}{i} = - 1 + \left(\frac{1}{\nu_1 \left[1 + \frac{PA}{Q}\right] + \frac{1}{r_{p1}}} \right).$$
Replacing \( P, Q, \) and \( A \) by their equivalent expressions and substituting \( g_{n1} \) for \( \mu_1/r_{p1} \) the final expression is obtained for the internal resistance \( r \).

\[
r = \frac{1}{g_{n1}} \left[ 1 + \frac{R_1}{R_1 + R_2} \left( \frac{\mu_2 R_L}{r_{p2} + R_L} \right) \frac{1}{1 + \mu_2 R_e/(r_{p2} + R_L)} \right] + \frac{1}{r_{p1}}. \tag{15}
\]

Investigation of the expression for \( r \) shows that to obtain a small internal resistance the transconductance of \( V_1 \) should be as large as possible. This substantiates the common use of 2A3s in regulator circuits. Factors \( \mu_1 \) and \( r_{p1} \) are secondary considerations. The ratio \( R_2/(R_1 + R_2) \) should be as large as possible. Since this ratio is nearly equal to the ratio \( E_c/E_0 \) this indicates that the constant-voltage regulator tube should be rated for a voltage that is a large fraction of the output voltage. However, \( E_s \) must be small enough to permit forcing the grid of \( V_1 \) sufficiently negative to afford proper control so that the ratio \( R_2/(R_1 + R_2) \) can seldom exceed 0.5. Factor \( \mu_2 R_L/(R_{p2} + R_L) \) which represents the amplification of \( V_2 \) should be as high as possible so that the use of high-\( \mu \) triodes or pentodes for \( V_2 \) is indicated. Supply of constant screen voltage for the pentode, however, increases the complexity of the circuit, and the extra gain is not always justified. The internal resistance \( R_e \) of the gas-filled tube should be as small as possible; this is mainly a matter of tube selection.

A sample computation for the circuit of Fig. 3 will serve to indicate the value of internal resistance that can be obtained with typical circuit constants. The circuit components selected are as follows:

- \( V_1 \): triode-connected, type 6L6, \( g_{n1} = 0.0047 \) mho, \( r_{p1} = 1700 \) ohms, \( \mu_1 = 8 \)
- \( V_2 \): type 6SF5, \( \mu_2 = 100 \), \( r_{p2} = 70,000 \) ohms
- \( V_3 \): type 150/30, \( E_c = 150 \) volts, \( R_e = 370 \) ohms
- \( R_L = 250,000 \) ohms
- \( R_1 = R_2 = 100,000 \) ohms
- \( R_3 = 25,000 \) ohms
- \( E_1 = 500 \) volts
- \( E_0 = 300 \) volts

Substitution of these values into (14) gives

\[
r = \frac{1}{0.0047} \left[ 1 + \frac{1}{2} \left( \frac{100(250)}{320} \right) \right] + \frac{0.00059}{100(0.37)/320} = 5.9. \tag{16}
\]

The measured value of the internal resistance for this circuit using commercial tubes and resistors was 5.3 ohms at 75 milliamperes output and 6.7 ohms at 40 milliamperes output. The change is due primarily to the change in transconductance of \( V_1 \) with plate current.
A study of (21) shows that to obtain the smallest regulation factor the amplification factor \( \mu_1 \) of \( V_1 \) should be several times larger than unity, but that large values of \( \mu_1 \) are of little benefit. This fits nicely with the requirement that the transconductance of \( V_1 \) be as high as possible to insure a low value of \( r \). Again the value of \( R_2(R_1+R_2) \) should be as large as possible consistent with other circuit requirements, and the amplification of an improvement of three to one obtained by a simple circuit change. Although placing \( R_3 \) at the output reduces the available output current by using part of the allowable capacity of \( V_1 \), the current drain can be made reasonably small by suitable selection of \( V_3 \) and \( R_3 \).

The circuit change has only a slightly detrimental effect on the internal resistance, as shown by the following expression for the internal resistance.

\[
r = \frac{1}{g_m \left[ 1 + \left( \frac{R_2}{R_1 + R_2} - \frac{R_3}{R_3 + R_2} \right) \right ]} \left[ \frac{\mu_2 R_L}{r_{p2} + R_L \left( 1 + \frac{\mu_2 R_L}{(r_{p2} + R_L)} \right )} + \frac{1}{r_{p1}} \right].
\]

\( V_3 \) should be made high. One serious defect of the circuit is that the input-voltage variation \( e_s \) produces an appreciable voltage change \( e_e \) across \( V_3 \). This is reflected in (21) by the factor \( \mu_2 R_L/(R_e + R_3) \) in the numerator.

The value of \( R_2 \) for the circuit of Fig. 3 using the circuit constants previously listed is

\[
R = \frac{1}{8[1 - (1 - 1.46)250/320(1.115)]} = 0.04.
\]

The experimentally determined regulation factor for this circuit was 0.042 which checks closely with the computed value.

**Improved Regulator Circuit**

A regulation factor of 0.04 does not represent particularly good regulation, and a great improvement can be made by obtaining the operating current for the regulator tube \( V_3 \) from the regulated output rather than from the input. This circuit change is shown in Fig. 4.

The regulation factor derived in the appendix for this circuit is given by the expression

\[
R = \frac{1}{1 + \frac{\mu_1 R_L}{r_{p2} + R_L} \left[ 1 + \mu_2 \left( \frac{R_2}{R_1 + R_2} \right ) \right ] + \frac{1}{R_c + R_e}}.
\]

![Fig. 4-Improved regulator circuit.](image)

Unfortunately, however, this circuit change requires that \( V_3 \) operate in the region of cutoff, since at one end of the operating range the grid bias of \( V_1 \) and consequently the plate current of \( V_2 \) must approach zero. An estimate of the grid bias required at \( V_1 \) for an output current of 40 milliamperes shows that the plate current of \( V_4 \) is only 0.06 milliamperes, at which value the plate resistance of the 6SF5 rises to 500,000 ohms. Computation of \( R_2 \) under these conditions gives 0.0087 which checks closely with the measured value of 0.0093. Comparison with the value of regulation factor obtained for Fig. 4 (0.0124) shows the improvement to be unimportant. Coupled with this is the disadvantage that \( V_3 \) is operating on an excessively curved portion of its characteristic. This results in an undesirably large variation of internal resistance and regulation factor over the operating range of the circuit.

Inspection of (22) and (23) for the regulation factor and internal resistance of Fig. 4 shows that, \( V_3 \) and \( V_4 \) having been chosen, the most important factor affecting
the value of \( R \) and \( r \) is the amplification provided by \( V_2 \). This suggests the use of a high-\( \mu \) triode or pentode for \( V_2 \) or even the use of several tubes in cascade. However, this only results in decreasing the two factors in proportion to the effort expended in increasing the amplification; it still is not possible to make them zero. The reason for this is that the information regarding the correction comes from the output voltage only; the output voltage must change in order to provide the correcting voltage to counteract that change. Consequently, it is impossible to prevent fluctuation in the output voltage.

To eliminate output voltage changes due to input-voltage fluctuations it is necessary to obtain the information from the input circuit, since this is the source of the variation that must be eliminated. Likewise, to eliminate output-voltage fluctuations caused by load-current changes, it is necessary to obtain the correction voltage from the load current. If this is done it is then theoretically possible to select the circuit constants such that both factors \( R \) and \( r \) are equal to zero or, if desired, actually negative.

The modification of Fig. 4 required to compensate for input-voltage and load-current fluctuations is shown by Fig. 5. Resistors \( R_4 \) and \( R_5 \) in this circuit serve as a voltage divider across the input that applies a fraction of the input-voltage change to the grid of \( V_2 \) for the purpose of correcting for input-voltage variations. Resistor \( R_6 \) provides a voltage drop proportional to the load current which is then applied to the grid of \( V_2 \) through the \( R_1 - R_4 \) and \( R_5 - R_6 \) networks. Proper adjustment of \( R_4 \) makes \( E_o \) substantially independent of the load current and thus reduces factor \( r \) to zero.

An analysis of the circuit of Fig. 5 shows that for a zero regulation factor the following relation must exist between resistors \( R_4 \) and \( R_5 \):

\[
\frac{R_5}{R_4 + R_5} = \frac{(1 + 1/\mu)(1 + \mu_2 R_e/(r_{p2} + R_L))}{R_1 + R_2}
\]

where \( \mu_2 \) is the amplification provided by \( V_2 \). This is normally a small ratio so that \( R_5 \) is much smaller than \( R_4 \). Using the same circuit components as those of Fig. 4 the computed value of the ratio required by (25) was 0.012. In the experimental circuit with \( R_4 \) equal to 100,000 ohms, \( R_5 \) was adjusted until zero regulation factor was obtained. Measurement of \( R_5 \) showed a value of 1160 ohms. Computing the ratio \( R_5/(R_4 + R_5) \)

\[
\frac{R_5}{(R_4 + R_5)} = \frac{1160}{101160} = 0.0115
\]

This agrees with the computed value.

In practice it is convenient to make \( R_5 \) adjustable so that it can be set experimentally to the correct value. A convenient method of making this adjustment is to load the regulator with a resistance and connect an oscilloscope across the output terminals. Resistor \( R_6 \) is then adjusted until the output ripple is reduced to zero. If the regulator-input ripple is insufficient for this purpose, a few volts of ripple can be temporarily introduced at the input.

The internal resistance of the regulator circuit is controlled by \( R_6 \). For zero internal resistance \( R_6 \)

\[
R_6 = \frac{1 + \mu_2 R_e}{r_{p2} + R_L} \left( \frac{1}{g_{m1}} - \frac{\mu_2 R_e}{r_{p2} + R_L} \right) \left( \frac{R_1}{R_1 + R_3} \right)
\]

The value of \( R_6 \) is usually less than 10 ohms, so that it is practicable to introduce it into the circuit as shown in Fig. 5. This requires that the negative return of the rectifier circuit be isolated from ground. The voltage drop across \( R_6 \), however, is so small that this involves no insulation problems. Likewise \( R_6 \) is so much smaller than the shunting impedance presented by the rectifier-circuit capacitance to ground that no trouble is experienced from this source. The computed value of \( R_6 \) for a circuit having the constants previously listed is 6.05 ohms. The experimentally determined value for the circuit was 7.0 ohms at a load of 40 milliamperes. Part of the discrepancy between computed and measured values is due to the difficulty of accurately measuring the regulator internal impedance of less than an ohm in the presence of the direct-current output voltage.

The circuit analysis presented is based on the assumption that the behavior of the circuit is linear. This is not exactly true because of the curvature of the vacuum-tube characteristics. As a result the regulation factor and internal resistance actually vary over the operating range of the circuit. Consequently, the performance of the circuit of Fig. 5 is not so perfect as might be inferred from the existence of (25) and (26) for making both the regulation factor and internal resistance equal to zero. Both factors can be set at zero for any particular point on the operating curve, but at other points they will not be zero. The magnitude of this variation can best be shown by the curves of Figs. 6 and 7.

Fig. 6 shows the effect of input voltage on output voltage with \( R_6 \) set for best regulation near the middle of the useful operating range. A corresponding curve
showing the effect of output current on output voltage is given by Fig. 7. Both curves indicate that it is possible to maintain the output-voltage constant to within 0.1 volt over a large range of input-voltage and load-current variations. Both curves were taken with a cathode-ray oscilloscope by changing the variable under test at a 60-cycle rate. The long-time stability of the circuit is less, because of temperature changes of the resistor and tubes and aging of the gas tube. Selection of low-temperature-coefficient resistors will reduce trouble from this source but expansion of the vacuum-tube elements also affects the stability; in one circuit a suddenly applied load tending to heat the gas tube produced a gradual change in voltage of about 0.1 volt over a period of 10 seconds. Temperature changes also affect the gas-tube voltage drop considerably but stable operation is usually reached after several minutes of operation. There is no assurance, however, that the gas tube will operate in exactly the same fashion after each firing. At times the operation of removing and reapplying the input voltage will result in a change of as much as a volt in the output potential. This is especially likely to happen when the gas tube is operated near a critical point in the operating curve where the glow discharge shifts from one area of the cathode to another. This shift usually results in a slight discontinuity of the voltage-current characteristic for the tube. Operation near this point should be avoided.

It should be observed that with Rs set for best average performance of the circuit the internal resistance may be negative over part of the range. If the resistive component of the load impedance is smaller than the negative internal resistance of the regulator at some frequency oscillations will occur. This is invariably the case when the output of the regulator is shunted with a condenser. If the use of a condenser in shunt with the output is desired, Rs must be so set that the internal resistance is positive at all points on the operating curve.

APPENDIX

ANALYSIS OF COMPENSATED CIRCUIT

Analysis of Fig. 5 for R

In terms of alternating components the expression for R in (2) is

$$\mathcal{R} = \frac{e}{e_t} \bigg|_{t = 0}. \quad (27)$$

Across the gas tube V3 two alternating components of voltage will appear, one caused by e, and the other by the plate current i2. 

$$e = Se + i_2 R_e$$

where $S$ is the ratio $R_e/(R_e + R_3)$ to simplify the writing. The net grid-to-cathode voltage caused by $e$, and $e_t$ is then the result of three components, a change proportional to $e$, a change proportional to $e_t$ provided by the drop across $R_4$, and the change in voltage, $e_r$. Thus

$$e_t = P e + U(V) e_t - (Se + i_2 R_e)$$

where $P = (R_3 + R_4 + R_5)/(R_1 + R_2 + R_4 + R_5)$, $U = R_1/(R_1 + R_2)$, and $V = R_3/(R_1 + R_2)$. In practical circuits $R_4$ and $R_5$ are so much smaller than $R_1$ and $R_2$ that they can be neglected in the computation of $P$. This makes $P = R_1/(R_1 + R_2)$ as previously defined. The expression for $V$ is an approximation, in that $R_1$ should be replaced by the value of $R_1$ in parallel with $R_1 + R_2$. Since the sum $(R_1 + R_2)$ is usually several hundred times $R_1$, the error is negligible.

Combining terms

$$e_t = (P - S)e + UV e_t - i_2 R_e. \quad (28)$$

This grid voltage together with the input voltage $e$, produces a plate current

$$i_{p2} = (\mu_2 e + e_t)/(r_{p2} + R_L). \quad (29)$$

The small effect of $e_t$ on $i_{p2}$ has been neglected as in the previous analysis. Substituting (28) into (29) and solving for $i_{p2}$

$$i_{p2} \left[ 1 + \frac{\mu_2 R_e}{r_{p2} + R_L} \right] = \frac{\mu_2 (P - S)}{r_{p2} + R_L} e, + \frac{1 + \mu_2 UV}{r_{p2} + R_L} e_t$$

Indicating the quantity $1 + \mu_2 R_e/(r_{p2} + R_L)$ by the term $Q$

$$i_{p2} = \left[ \frac{\mu_2 (P - S)}{Q(r_{p2} + R_L)} \right] e_e + \left[ \frac{1 + \mu_2 UV}{Q(r_{p2} + R_L)} \right] e_t. \quad (30)$$

This plate current produces a net grid-to-cathode voltage at tube $V_1$

$$e_{g1} = e_e - i_{p2} R_L - e_r.$$
Substituting from (30) for $i_{p2}$
\[ e_{p1} = \left[ 1 - \frac{R_L}{Q} \left( \frac{1 + \mu_2 UV}{r_{p2} + R_L} \right) \right] e_r \]
\[ - \left[ 1 + \frac{A(P - S)}{Q} \right] e_r \]  
(31)

where $A$ represents the quantity $\mu_2 R_L/(r_{p2} + R_L)$.

Equation (27) on which this analysis is based states that $i_r$ is zero. By neglecting the current change through $R_1$ and $R_3$ as justified in derivation of (15) $i_{p1} = i_r = 0$.

For constant plate current in $V_1$
\[ e_{p1} = e_r - e_c = - \frac{\mu_1 e_{p2}}{Q} \]  
(32)

For the uncompensated circuit of Fig. 4, resistor $R_6$ is equal to zero and $R_4$ is infinite. This makes factor $V$ equal to zero. Inserting this fact and replacing $A$, $P$, $Q$, and $S$ by their equivalents results in the expression (22) given for the regulation factor of Fig. 4.

For the compensated circuit it is desired to obtain zero regulation factor. Since $P$ is larger than $S$ the denominator of (32) is finite so that the numerator must equal zero to reduce $R$ to zero. Setting the numerator of (32) to zero and solving for $V$
\[ V = \frac{(1 + 1/\mu_1) [Q(r_{p2} + R_L)]}{(1 + \mu_2 U(R_1 + R_2))} - 1/U_{p2} \]  
(33)

Solution is made for $V$ because the other factors are determined by the choice of tubes, circuit constants, and operating voltages, whereas the ratio between $R_1$ and $R_4$ which determines $V$ can be set at any required value to obtain zero regulation. Substituting for $Q$, $U$, and $V$ their equivalent expressions, the final expression for the establishment of zero regulation factor is obtained.

\[ R_4 + R_6 = \frac{(1 + 1/\mu_1) [Q(r_{p2} + R_L)]}{(1 + \mu_2 U(R_1 + R_2))} \]
\[ = \frac{R_1 + R_2}{\mu_2 R_1} \]  
(34)

**Analysis of Fig. 5 for $r$**

In terms of alternating components, the expression for $r$ in (3) is
\[ r = - e_r / i_r \mid _{s = 0} \]  
(34)

Across $V_2$ two alternating components of voltage will appear, one caused by $e_r$ acting through $R_3$, and the other by the plate current $i_{p2}$.
\[ e_c = S e_r + i_{p2} R_c \]

where $S$ is the ratio $R_c/(R_4 + R_2)$. The net grid-to-cathode voltage $e_{p2}$ caused by $e_r$ and by $i_r$ flowing through $R_3$ is given by the expression
\[ e_{p2} = P e_r - i_{p2} U - (S e_r + i_{p2} R_c) \]
where $P$ and $U$ are as defined for (28). The approximation has been made that the current through $R_3$ is $i_r$ whereas it actually consists of $i_r + i_{p2}$. The error in making this simplification is usually less than 5 per cent.

Combining terms
\[ e_{p2} = (P - S) e_r - i_{p2} R_c - i_{p2} R_c \]  
(35)

This grid voltage produces a change in plate current
\[ i_{p2} = \frac{\mu_2 e_{p2}}{(r_{p2} + R_L)} \]  
(36)

where the small effect of $e_r$ on $i_{p2}$ has been neglected as before. Combining (35) and (36) and solving for $i_{p2}$
\[ i_{p2} = \frac{(\mu_2(P - S) e_r)(r_{p2} + R_L)}{(\mu_2 R_4 U i_r)/(Q(r_{p2} + R_L))} \]  
(37)

where $Q$ is as defined in (30).

At $V_1$ this plate-current change produces a net grid-to-cathode change of
\[ e_{p1} = - i_{p2} R_L - e_r \]  
(38)

Substituting for $i_{p2}$
\[ e_{p1} = - \left[ 1 + \left( A - S \right) Q \right] e_c + \left( A U R_6/Q \right) i_r \]  
(39)

Neglecting the extremely small current changes in $R_3$ and $R_1$, the plate current $i_{p1}$ of $V_1$ is equal to $i_r$. Hence
\[ i_r = i_{p1} = \frac{(\mu_1 e_{p2} - e_c)}{r_{p1}} \]  
(40)

Substituting from (38) for $e_{p1}$
\[ i_r = \frac{\mu_2 A U R_6}{r_{p2} Q} \left[ \frac{1}{r_{p2} - r_{p1}} \left( 1 + \frac{A(P - S)}{Q} \right) \right] e_r \]  
(41)

Rearranging (39) and solving for the ratio $-e_r/i_r$, the expression for $r$ is obtained.
\[ r = - \frac{e_r}{i_r} = \frac{1 - (g_{m1} A U R_6/Q)}{g_{m1} \left[ 1 + \left( A - S \right) Q \right] + 1/r_{p1}} \]  
(42)

The transconductance $g_{m1}$ has been substituted for the ratio $\mu_1/r_{p1}$.

For the uncompensated circuit of Fig. 4 resistor $R_6$ is equal to zero. Inserting this value of $R_6$ into (40) and replacing $A$, $P$, $Q$, and $S$ by their equivalent expressions results in (23) given for the internal resistance of Fig. 4.

For the compensated circuit it is desired to make the value of $r$ equal to zero. To do this the numerator of (40) must equal zero. Setting the numerator of (40) equal to zero and solving for $R_6$
\[ R_6 = Q / g_{m1} A U \]  
(43)

Substituting for $A$, $Q$, and $U$ their respective expressions
\[ R_6 = \frac{1 + \mu_2 R_4 (r_{p2} + R_L)}{g_{m1} (\mu_2 R_L [(r_{p2} + R_L)/(R_1 + R_2)])} \]  
(44)
A Method of Measuring Attenuation of Short Lengths of Coaxial Cable*

CHANDLER STEWART, JR., ASSOCIATE, I.R.E.

Summary—Measurement of attenuation of coaxial radio-frequency transmission cables has generally been made by methods requiring non-standard equipment and long samples. A method of measurement employing a standard "Q meter" and requiring short samples is described.

With the recent tremendous increase in the rate of production of flexible coaxial cable used on aircraft as radio- and video-frequency transmission lines, there has come quite naturally a requirement for testing samples of this cable in production. The measurement of attenuation of this cable has generally been made by at least three methods:

1. Use of diode voltmeters on a cable sample terminated in its characteristic impedance, as described by Race and Larrick.1
2. Use of diode voltmeters at either end of a resonant length of open circuited cable, as described by Seeley and Barden.2
3. Use of tuned circuits to couple cable sample to an oscillator and a voltmeter. The ratio of the voltage obtained with the cable sample in the circuit to the voltage obtained directly without the cable is used as a basis for determining the attenuation.

These methods of attenuation measurement have been found in practice to have the following limitations:

1. Each requires special testing equipment; procurement of testing equipment may be difficult and results of tests in different laboratories or factories may not be directly comparable.
2. About a hundred feet of each sample is required. The handling of the sample requires considerable time and effort and the effects of small local defects in a sample may be "averaged out" and so pass unnoticed.
3. Results of tests on widely differing lengths of the same sample have not always agreed closely.

A fourth method of measurement of attenuation, employing radio-frequency bridges to measure the input impedance of resonant lengths of samples, has been suggested by Easton.3 Although this method uses standard instruments, it also requires long samples and is limited to the lower frequencies.

In order to overcome these limitations, a new and convenient method of measuring samples of cable less than 5 feet in length has been developed by the Signal Corps Aircraft Radio Laboratory at Wright Field, Dayton, Ohio. A description of this method follows:

1. Equipment Required for Making Measurements

Standard Q meter, capable of measuring at 100 megacycles, such as the Boonton Type 170A.
Two high-Q air-wound coils of number 10 American wire gauge tinned copper wire, formed on a ½-inch rod; \( L_1 \), approximately 0.15 microhenry inductance, with \( Q \) of \( Q_{L1} \).
\( L_2 \), approximately 0.05 microhenry inductance, with \( Q \) of \( Q_{L2} \). These are easily made and checked on the \( Q \) meter.
Lugs or other means of connecting the cable samples to the \( Q \) meter and coil.
For samples of cable an odd number of quarter wavelengths long, a 1-megohm \( \frac{1}{2} \)-watt resistor, to provide a grid return circuit for the \( Q \) meter.

2. Measurement Procedure

Samples of cables of lengths to resonate at the desired frequencies are cut, and connected to the \( Q \) meter individually as shown in the diagrams. The frequency used with the series circuit (Fig. 1) is chosen so that short-circuiting the connected end of the cable will have no effect upon the setting of \( C_1 \) required for resonance.

Fig. 1

Fig. 2

---

* Decimal classification: R282.1. Original manuscript received by the Institute, May 1, 1944; revised manuscript received, July 28, 1944.
† 433 Brightwood Ave., Dayton 5, Ohio.
Similarly, the frequency used with the circuit of Fig. 2 will be such that disconnecting the inner cable conductor at the Q meter will not change the C₂ setting required for resonance.

To insure minimum termination inductance in short-circuiting the end of the cable away from the Q meter, the inner strands are spread out umbrella-fashion, each contacting the outer shield.

The Q meter is operated in the usual fashion, obtaining Q and C readings for each condition. To obtain the attenuation, the results are substituted in one of the following formulas:

For samples an odd number of quarter wavelengths long,

$$N = \frac{868.6}{l} \sqrt{\left(1 - \frac{1}{Q_{01}}\right)\left(1 - \frac{1}{Q_{02}}\right) \frac{C_2}{C_1}} \text{ decibels per 100 feet} \tag{1}$$

where $Q_{01} = Q$ obtained with open-circuited cable as in Fig. 1

$Q_{02} = Q$ obtained with short-circuited cable as in Fig. 2

$l =$ length of cable in feet.

For samples an even number of quarter wavelengths long,

$$N = \frac{868.6}{l} \sqrt{\left(1 - \frac{1}{Q_{01}}\right)\left(1 - \frac{1}{Q_{02}}\right) \frac{C_2}{C_1}} \text{ decibels per 100 feet} \tag{2}$$

where $Q_{01} = Q$ obtained with short-circuited cable as in Fig. 1

$Q_{02} = Q$ obtained with open-circuited cable as in Fig. 2.

3. Comparison of Results of Typical Measurements

Data obtained at approximately 100 megacycles on three samples of Type WC-549 cable, from Amphenol reel 3305B, are listed in Table I. Attempts were made to use this method at 200 megacycles, but excessively large errors were introduced by the inductance of the Q-meter terminals at that frequency. Although several different coils were used experimentally in this work, two would be sufficient for production testing under given conditions. The requirements that the circuit Q readings lie in a region of good meter accuracy prohibits the use of the same coil for L₁ and L₂.

A comparison of results obtained by this method with those of other measurement methods was made on samples of Type WC-549 cable from the same reel. These are listed in Table II.

Data of this type provide the only basis yet obtained for estimating the possible error in results by this method. In general, these results lie in the middle of the range of values obtained by other methods, and are just as easily duplicated.

4. Velocity of Propagation

The data obtained from these attenuation tests can be used for determining velocity of propagation, if the frequency is accurately checked with a frequency meter. This, however, is beyond the scope of this paper and consequently will not be treated here.

**Definition of Terms**

- $\alpha =$ attenuation of cable in nepers per foot
- $\beta =$ wavelength constant of cable in radians per foot
- $C =$ series capacitance in Q-meter circuit in farads
- $\lambda =$ wavelength constant of cable in radians per foot
- $\gamma =$ wavelength constant of cable in nepers per foot
- $l =$ length of cable in feet
- $L_1 =$ inductance used in first test, in henries
- $L_2 =$ inductance used in second test, in henries
- $n =$ any whole integer
- $N =$ attenuation of cable in decibels per 100 feet
- $Q_{01} =$ Q of complete circuit (Fig. 1) for cable open-circuited and $\beta l = (n + \frac{1}{2}) \pi$
- $Q_{02} =$ Q of complete circuit (Fig. 2) for cable open-circuited and $\beta l = n \pi$
- $R_{11} =$ radio-frequency resistance of coil L₁
- $R_{12} =$ radio-frequency resistance of coil L₂
- $R_{01} =$ input impedance of open-circuited cable (Fig. 1), in ohms, when $\beta l = (n + \frac{1}{2}) \pi$
- $R_{02} =$ input impedance of open-circuited cable, in ohms (Fig. 2), when $\beta l = n \pi$

### Table I

<table>
<thead>
<tr>
<th>Length in inches</th>
<th>Frequency, megacycles</th>
<th>C₁, micromicrofarads</th>
<th>L₁, henries</th>
<th>L₂, henries</th>
<th>C₂, microfarads</th>
<th>Q₀₁ = Q of complete circuit (Fig. 1) for cable short-circuited and $\beta l = n \pi$</th>
<th>Q₀₂ = Q of complete circuit (Fig. 2) for cable short-circuited and $\beta l = (n + \frac{1}{2}) \pi$</th>
<th>Q₀₁ = Q of complete circuit (Fig. 1) for cable open-circuited and $\beta l = (n + \frac{1}{2}) \pi$</th>
<th>Q₀₂ = Q of complete circuit (Fig. 2) for cable open-circuited and $\beta l = n \pi$</th>
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<td>megacycles</td>
<td>C₁, microfarads</td>
<td>L₁, henries</td>
<td>L₂, henries</td>
<td>C₂, microfarads</td>
<td>Q₀₁ = Q of complete circuit (Fig. 1) for cable short-circuited and $\beta l = n \pi$</td>
<td>Q₀₂ = Q of complete circuit (Fig. 2) for cable short-circuited and $\beta l = (n + \frac{1}{2}) \pi$</td>
<td>Q₀₁ = Q of complete circuit (Fig. 1) for cable open-circuited and $\beta l = (n + \frac{1}{2}) \pi$</td>
<td>Q₀₂ = Q of complete circuit (Fig. 2) for cable open-circuited and $\beta l = n \pi$</td>
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### Table II

<table>
<thead>
<tr>
<th>Method of measurement</th>
<th>Length of sample in feet</th>
<th>Attenuation in decibels per 100 feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method using diode voltmeters on cable sample terminated in its characteristic impedance, as previously described</td>
<td>Feet</td>
<td>133</td>
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<td>Method using diode voltmeters on open-circuited cable sample at resonant frequencies</td>
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<td>133</td>
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<td>Even number of quarter waves</td>
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<tr>
<td>Odd number of quarter waves</td>
<td>Feet</td>
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<tr>
<td>Method using tuned circuits to couple cable sample to oscillator and voltmeter</td>
<td>Inches</td>
<td>184</td>
</tr>
<tr>
<td>Method of this report</td>
<td>Inches</td>
<td>184</td>
</tr>
</tbody>
</table>
\( R_{S1} \) = input impedance of short-circuited cable, in ohms (Fig. 1), when \( \beta l = \pi \)

\( R_{S2} \) = input impedance of short-circuited cable, in ohms (Fig. 2), when \( \beta l = (\pi + \frac{1}{2}) \pi \)

\( \omega \) = angular velocity of testing voltage in radians per second at resonant frequency of cable sample.

\( Z_{S0} \) = input impedance of open-circuited cable, in ohms.

\( Z_{S2} \) = input impedance of open-circuited cable, in ohms.

**DERIVATION OF MEASUREMENT FORMULAS**

From basic circuit theory

\[
Q_{L1} = \frac{1}{\omega C_1 R_{L1}} \quad (3)
\]

\[
Q_{o1} = \frac{1}{\omega C_1 (R_{L1} + R_{o1})} \quad (4)
\]

\[
Q_{L2} = \frac{\omega L_2}{R_{L2}} \quad (5)
\]

\[
\omega L_2 = \frac{1}{\omega C_2} \quad (6)
\]

\[
Q_{S2} = \frac{R_{S2}}{j \omega C_2 \left[ R_{S2} - \frac{j}{\omega C_2} \left( R_{L2} + j \omega L_2 + \frac{1}{j \omega C_2 R_{S2} + 1} \right) \right]} \quad (7)
\]

Combining (3) and (4) yields

\[
R_{o1} = \frac{1}{\omega C_1} \left[ \frac{1}{Q_{o1}} - \frac{1}{Q_{L1}} \right] \quad (8)
\]

In a similar manner it can be shown that

\[
R_{S1} = \frac{1}{\omega C_1} \left[ \frac{1}{Q_{S1}} - \frac{1}{Q_{L1}} \right] \quad (9)
\]

Combining (5), (6), and (7) to eliminate \( R_{L2} \) and \( L_2 \) yields

\[
Q_{S2} = \frac{\omega C_2 R_{S2} Q_{L2}}{1 + j \omega C_2 R_{S2} + Q_{L2}} \quad (10)
\]

In actual practice, a high-Q coil is used for this measurement, so that

\[
Q_{L2} > 100. \quad (11)
\]

This justifies the following approximation of (10):

\[
Q_{S2} = \frac{\omega C_2 R_{S2} Q_{L2}}{\omega C_2 R_{S2} + Q_{L2}} \quad (12)
\]

from which

\[
R_{S2} = \frac{1}{\omega C_2 \left[ \frac{1}{Q_{S2}} - \frac{1}{Q_{L2}} \right]} \quad (12a)
\]

In a similar manner it can be shown that

\[
R_{o2} = \frac{1}{\omega C_2 \left[ \frac{1}{Q_{o2}} - \frac{1}{Q_{L2}} \right]} \quad (13)
\]

In accordance with equation (64), page 168, of Everitt's "Communication Engineering"

\[
\tanh (\alpha + j \beta l) = \sqrt{Z_{Sc}/Z_{oc}} \quad (14)
\]

\[
\sinh \alpha l \cos \beta l + j \cosh \alpha l \sin \beta l = \sqrt{Z_{Sc}/Z_{oc}} \quad (14a)
\]

For the case of an open-circuited cable connected as in Fig. 1, and of a short-circuited cable connected as in Fig. 2,

\[
\beta l = (n + 1/2) \quad (15)
\]

in which case, since \( \alpha l \) is positive and therefore \( Z_{Sc}/Z_{oc} \) real,

\[
\coth \alpha l = \sqrt{R_{S2}/R_{o1}} \quad (16)
\]

Substituting (6) and (12a) in (16),

\[
\coth \alpha l = \frac{1}{\sqrt{\left( \frac{1}{Q_{o1}} - \frac{1}{Q_{L1}} \right) \left( \frac{1}{Q_{S2}} - \frac{1}{Q_{L2}} \right) \frac{C_2}{C_1}}} \quad (17)
\]

In actual practice, \( \alpha l \) will always be less than 0.01, so that the following approximation of (17) is justified:

\[
\alpha l = \sqrt{\left( \frac{1}{Q_{o1}} - \frac{1}{Q_{L1}} \right) \left( \frac{1}{Q_{S2}} - \frac{1}{Q_{L2}} \right) \frac{C_2}{C_1}} \quad (18)
\]

Similarly, it can be shown that, for the case of a short-circuited cable connected as in Fig. 1, and of an open-circuited cable connected as in Fig. 2, when \( \beta l = \pi \)

\[
N = \frac{868.6}{l} \sqrt{\left( \frac{1}{Q_{o1}} - \frac{1}{Q_{L1}} \right) \left( \frac{1}{Q_{S2}} - \frac{1}{Q_{L2}} \right) \frac{C_2}{C_1}} \quad (19)
\]

**CONCLUSIONS**

This appears to be the most convenient method for measuring attenuation yet proposed.

Velocity of propagation can be obtained in the same operation in which attenuation is determined.

Measurements can be made on extremely short samples (less than 5 feet in length), making handling of samples more convenient.

Since short samples are used, nonuniformities along the length of the cable, which would be "averaged out" in tests by methods using long samples, are easily detected.

Only one instrument is required, a standard very high-frequency Q meter. A minimum amount of time is required in setting up equipment in preparation for a test, since the instrument is completely self-contained.

Results made by different agencies should be directly comparable, since duplicate instruments are commercially available.

The results of tests by this method appear to be as reliable and accurate as those of more widely used methods; however, commercially available Q meters limit this method to frequencies in the neighborhood of 100 megacycles.
Winter Technical Meeting
January 24, 25, 26, and 27, 1945
Hotel Commodore, New York, N.Y.

This is the second of the Winter Technical Meetings, which have supplanted, during the war period, the prewar Annual Conventions. There is much hope that 1945 will see a reduction of many of the restrictions which have interfered with such gatherings; this 1945 Winter Technical Meeting may be considered as the transition between the war meetings and those which may be anticipated in the postwar era. The Meeting, therefore, has been expanded over the one held last year, both in time and in program content. A record attendance is anticipated since there are indications that members of the Institute and nonmember radio engineers as well are becoming concerned over the long hiatus in free dissemination of technical information. Although accommodations for out-of-town members and guests will probably be more difficult to obtain than in any previous year, the choice of our largest city for the Meeting assures the maximum of hotel facilities.

The increase in Institute membership and the growth of its Sections have led to considerable emphasis on better co-ordination and co-operation between geographically separated groups. The entire first day of the Meeting, Wednesday, January 24, is to be devoted to Section affairs and there is good ground for hope that the discussions among Section representatives will lead to greater unification and a stronger Institute. A joint meeting with the American Institute of Electrical Engineers will be held on Wednesday evening. At this session the A.I.E.E. will award their Edison Medal and a very interesting and timely paper has been scheduled. The other A.I.E.E. meetings to be held January 22-26 will also include papers of interest to our own members. The titles of some of these are listed on page 57.

On Thursday morning, the Annual Meeting will be held, as required by the articles of incorporation, followed by the opening technical session, of which more later. Other high lights in the program are the Banquet, Thursday evening, at which the annual awards will be presented, and the guest speaker will be Francis De Wolf of the U. S. Department of State. The two special luncheons will be held on Friday in honor of the President of the Institute and, on Saturday, in honor of the many members and guests who are in the armed services. The commercial exhibits also add to the attractions of this year's Meeting.

An interesting program has been arranged for the women guests attending this meeting. It is hoped that as many women as possible will be able to attend and participate in the women's activities.

The technical program reflects the changing conditions which have arisen as the war continues toward a successful termination. On Thursday morning, there will be a most interesting Symposium on the work of the Technical Committees. These Committees have continued their work throughout the war despite many difficulties, and it is expected that their activities will be intensified in the early postwar period. Every member of the Institute will be interested in the description of this work, and many, who have not actively participated in Technical Committee work, will be stimulated to contribute in the future. The large number of other papers were obtained chiefly by invitation and have been arranged in a number of special sessions to form an over-all well-balanced program. Some of the papers describe important war developments, which have only just been released; others show the growing diversity of radio as it expands into electronic and industrial applications; still others will have great significance in their import on postwar activities. It will be noted that the 40 or so papers come from 21 different organizations, a fact which indicates the diverse origin of much recent work.

In planning the technical program considerable emphasis was placed on originality, so that no member or guest at the Meeting need anticipate hearing material which is already available elsewhere. Because the presentation of a paper and its publication are considered to be separate and distinct matters, there can be no assurance that all or any of the papers presented will appear in print. Preprints or reprints of the papers are not available.

In the following program, papers are numbered in order, while the summaries which follow the program are listed alphabetically by the names of the authors and are given their order numbers as well. At the Meeting itself, special programs will be made available in which it is hoped to list also the approximate time at which each paper will be presented.
PROGRAM OF EVENTS

Wednesday, January 24, 1945
9:30 A.M.-12:30 P.M.
West Ballroom
Annual Meeting of Sections' Representatives
12:30 P.M.-2:00 P.M.
West Ballroom
Luncheon for Sections' Representatives
2:00 P.M.-5:00 P.M.
West Ballroom
Annual Meeting of Sections' Representatives

Joint Meeting of A.I.E.E. and I.R.E.
8:00 P.M.-10:00 P.M.
Engineering Societies Building
Award of Edison Medal to Dr. E. F. W. Alexanderson

Thursday, January 25, 1945
8:30 A.M.-5:30 P.M.
Grand Ballroom Foyer
Registration and Sale of Tickets
8:30 A.M.-9:45 A.M.
West Ballroom
Exhibits of Manufacturers
9:45 A.M.-10:30 A.M.
Grand Ballroom
W. L. Everitt, Chairman
Annual Meeting of The Institute of Radio Engineers

Technical Session
10:30 A.M.-12:30 P.M.
Grand Ballroom
F. B. Llewellyn, Chairman

1. Symposium on the I.R.E. Technical Committees
   Introduction
   The Committee Structure
   F. B. Llewellyn
   Electronics Committee
   (a) Scope and Activities
      R. S. Burnap
   (b) Cathode-Ray-Tube Problems
      L. B. Headrick
   (c) Admittance Coefficients for the Specification of Vacuum-Tube Performance
      J. A. Morton
   Piezoelectric Committee
   How Crystal Cuts Are Specified
      W. G. Cady
   Circuits Committee
   What Should a Circuits Committee Standardize, and Why
      E. A. Guillemin
   Facsimile Committee
   A Common Language for all Kinds of Picture Transmission
      C. J. Young
   Radio Wave Propagation Committee
   C. R. Burrows
   Frequency-Modulation Committee
   Translating Amplitude-Modulation Concepts to Frequency Modulation
      C. C. Chambers
   Transmitters Committee
   Functions and Objectives
      R. F. Guy
   Symbols Committee
   Co-ordination of Communication and Power Symbols
      E. W. Shafer
   Television Committee
   Television Standards
      I. J. Kaar
   Electroacoustics Committee
   Possible Future Activities
      G. G. Muller
   Receivers Committee
   Rating of Receiver Noise
      L. F. Curtis
   Antennas Committee
   Andrew Alford
   Annual Review Committee
   The Institute Adds a Chapter to Its Survey of Radio Progress
      L. E. Whittemore
   Standards Committee
   Expansion of Standards Activities
      H. A. Wheeler

Exhibits
10:30 A.M.-7:00 P.M.
West Ballroom

Technical Session
2:00 P.M.-5:00 P.M.
Grand Ballroom
H. M. Turner, Chairman


Annual I.R.E. Banquet—Awards—Address of Retiring President—Dress Informal
7:00 P.M.—10:30 P.M.
Grand Ballroom

Guest Speaker, Francis De Wolf, U. S. Department of State

Friday, January 26, 1945
9:00 A.M.—5:00 P.M.
Grand Ballroom Foyer

Registration
9:00 A.M.—9:00 A.M.
West Ballroom

Exhibits

Technical Session "A"
9:00 A.M.—12:00 NOON
Grand Ballroom

HARADEN PRATT, Chairman

VACUUM TUBES
8. "New Miniature Tubes," by R. L. Kelly and N. H. Green, RCA Victor Division, Radio Corporation of America, Harrison, N. J.


Technical Session "B"
9:30 A.M.—12:00 NOON
Parlors B and C

KARL S. VAN DYKE, Chairman

QUARTZ CRYSTALS


President's Luncheon
Honoring Dr. W. L. Everitt
12:30 P.M.
Grand Ballroom

Technical Session "A"
2:00 P.M.—5:30 P.M.
Grand Ballroom

W. L. EVERITT, Chairman

INDUSTRIAL ELECTRONICS
20. "Is Industrial Electronic Technique Different?," by W. D. Cockrell, Industrial Engineering Division, General Electric Company, Schenectady, N. Y.


Technical Session “B”
2:00 p.m.–5:30 p.m.
Parlors B and C
R. A. HACKBUSCH, Chairman


Cocktail Party
6:00 p.m.–9:00 p.m.
East Ballroom

Saturday, January 27, 1945
9:00 a.m.–12:00 noon
Grand Ballroom Foyer

Registration

Technical Session “A”
9:30 a.m.–12:00 noon
Grand Ballroom
RALPH BOWN, Chairman

Radio Links and Relays
“Introduction,” by Ralph Bown, Bell Telephone Laboratories, Inc., New York, N. Y.


Technical Session “B”
9:30 a.m.–12:00 noon
East Ballroom
G. B. Hoadley, Chairman


Luncheon in Honor of Men in the Armed Forces
12:30 P.M.–2:00 P.M.
Grand Ballroom

Final Adjournment
2:00 P.M.

SUMMARIES OF TECHNICAL PAPERS

35. ULTRA-SHORT-WAVE RECEIVER FOR THE CAPE CHARLES-NORFOLK MULTIPLEX SYSTEM

D. M. Black, G. Rodwin, and W. T. Wintringham
(Bell Telephone Laboratories, Inc., New York, N. Y.)

The requirements for an ultra-short-wave receiver for use in a multiplex radiotelephone link circuit are outlined. The technical details of a receiver designed to meet such requirements in the circuit between Cape Charles and Norfolk, Virginia, are described.

19. AGING OF QUARTZ CRYSTAL UNITS

Virgil E. Bottom
(Signal Corps Ground Signal Agency, Asbury Park, N. J.)

Large numbers of quartz oscillator plates are made today in the frequency range of 6 megacycles per second and above. When the frequencies of such plates are adjusted by lapping, the units are unstable with respect to frequency and activity. The changes are aggravated by moisture. The effect is associated with the surface of the plate which is left in a disoriented condition as a result of the stresses produced in lapping. The remedy is removal of the disturbed material and adjustment of frequency by etching.

The stability of the unit is also affected by the material of the holder. Most plastics are quite permeable to water vapor resulting in unsatisfactory performance under conditions of high humidity. Much study is being given to the design of holders for tropical use.

The new order of permanence and frequency stability which is provided and the economy in the use of the etching method in quantity production opens the door to the widespread use of thinner crystals and thus to both higher-frequency crystal units and the extension of the range of application of AT-cut units with their better temperature coefficients to the frequency ranges now covered only with BT-cut plates.

25. THE RADIO-FREQUENCY DEHYDRATION OF MATERIALS LABILE WITH HEAT

George H. Brown, R. A. Bierwirth, and Cyril N. Hoyler
(RCA Laboratories, Princeton, N. J.)

Methods and equipment for dehydrating certain pharmaceutical materials which are sensitive to high temperatures have been worked out. The radio-frequency dehydration method particularly applicable to penicillin dehydration has been divided into two discrete steps. The first is a system for concentrating the material in bulk. This concentrate is then measured into the final containers, where it is then dried under sterile conditions by means of radio-frequency power. The two separate systems will be described, and the extension of this technique to other biologics will be discussed.

34. ULTRA-SHORT-WAVE MULTIPLEX

Charles R. Burrows
(Bell Telephone Laboratories, Deal, N. J.)

And

Alfred Decino
(Formerly, Bell Telephone Laboratories, Inc., New York, N. Y.)

The technical requirements of a twelve-channel ultra-short-wave multiplex system are discussed and the means of meeting them are described. The intermodulation between channels in equipment based on this design has been reduced to the point where it is possible to use twelve-channel radio systems in the toll plant. By employing a sufficient amount of envelope feedback, the transmitter can be operated with a high-modulation factor without the use of spread sidebands.

42. APPLICATIONS OF HIGH-FREQUENCY SOLID-DIELECTRIC FLEXIBLE LINES TO RADIO EQUIPMENTS

H. Busignies
(Federal Telephone and Radio Laboratories, New York, N. Y.)

The importance of the flexible lines in radio design, advantages and inconveniences of solid dielectric transmission lines versus air lines in radio design will be discussed. When the flexible transmission line is of paramount importance, the type of equipments and installations requiring flexible lines will be considered. Examples of applications are ship installations, aircraft installations, ground demountable equipments, and automotive installations. Particular problems involved in the direction-finder field, in the instrument landing field, and their solution with solid dielectric flexible transmission lines will be treated.
20. IS INDUSTRIAL ELECTRONIC TECHNIQUE DIFFERENT?

W. D. Cockrell

(Industrial Engineering Division, General Electric Company, Schenectady, N. Y.)

With the reduction in production of military electronic equipment it is logical for radio engineers to consider entering the field of industrial electronics. This junior branch of the industry differs from communication work especially in the emphasis on costs and the type of personnel available for operation and routine servicing. The range of industrial electronics extends from standard communication equipment at one end to the large pumped ignitron and multianode tanks capable of rectifying thousands of kilowatts.

5. EXALTED-CARRIER AMPLITUDE- AND PHASE-MODULATION RECEPTION

Murray G. Crosby

(Consulting Engineer; formerly, RCA Laboratories, Riverhead, L. I., N. Y.)

An amplitude- or phase-modulation receiving system is described in which the harmonic distortion produced by fading of the carrier with respect to the sidebands is eliminated. The various parts of such a receiver including the carrier filter, automatic-frequency-control discriminator, and detecting systems are described. Analyses are given of the selectivity effect due to carrier exaltation and of exalted-carrier diode and multigrid detection. The optimum degree of carrier exaltation and the effect of carrier limiting are discussed. Results are given of observations of reception on an exalted-carrier diversity receiving system.

7. KLYSTRON CHARACTERISTICS

Coleman Dodd

(Sperry Gyroscope Company, Inc., Garden City, L. I., N. Y.)

Some of the most evident differences between a klystron-tube amplifier and a conventional triode amplifier are pointed out. Typical klystron-tube amplifier characteristics are illustrated and some practical conclusions about the operation of the tube are mentioned. Typical two-resonator klystron-tube oscillator characteristics are shown and the effects of some of the variables are discussed. Block diagrams of the equipment which will be used to demonstrate these characteristics are included.

28. NOTES ON SELECTIVITY-DESIGN PARAMETERS OF SUPERREGenerative RECEIVERS

Allen Easton

(Emerson Radio and Phonograph Company, New York, N. Y.)

The general impression that superregenerative reception and poor selectivity are synonymous is shown to be erroneous. Actual tests on specific designs are reviewed and analyzed.

15. CRYSTAL QUALITY

I. E. Fair

(Bell Telephone Laboratories, Inc., Murray Hill, N. J.)

Expressing the quality of crystals by their performance in certain oscillator circuits has been found to be unsatisfactory in many respects. It is more desirable to express quality in terms of the equivalent circuit constants in much the same manner as for coils and capacitors. The quality of coils and capacitors is defined as the ratio of reactance to resistance or Q of the element. Because of the fact that a crystal is equivalent to a combination of three elements, its quality is not so simply defined.

This paper discusses the factors which determine the performance of crystals in oscillators and suggests a measure of quality called figure of merit, M and a measure of performance called performance index PI. M is a ratio of the Q of the motional arm to the ratio of capacitance of the crystal while PI is a measure of the antiresonant resistance of crystal and circuit capacitance in parallel at the oscillating frequency. The relations between M, PI, and oscillator grid current will be shown.

38. THE SERVO PROBLEM AS A TRANS-MISSION PROBLEM

E. B. Ferrell

(Bell Telephone Laboratories, Inc., New York, N. Y.)

The purpose of a servo is to reproduce a signal at a place or power level or form different from the original signal, but under its control. It is, therefore, a signal-transmitting system. It uses negative feedback to minimize noise and distortion, which the servo designer usually calls error. It generally uses mechanical and thermal circuit elements as well as electrical circuit elements, but the problems of circuit design are the same.

The methods of Nyquist and Bode, which have proved so useful in the design of electrical-feedback amplifiers, are equally useful in the design of servo sys-
tems. They encourage the determination of the significant constants of the system by experimental means involving steady-state amplitude measurements of the loop transmission characteristics. These measurements lead to quick estimates of errors and stability and of the transmission changes required to give various degrees of performance.

30. HIGH-VOLTAGE RECTIFIED POWER SUPPLY USING FRACTIONAL-MU TRIODE RADIO-FREQUENCY OSCILLATOR

R. L. Freeman and R. C. Hergenrother
(The Hazeltine Corporation, Little Neck, L. I., N. Y.)

An oscillator circuit designed to operate with a triode having a small fractional mu has been used to develop across its grid-leak resistor a bias voltage whose value is over twenty times as great as the anode-supply voltage. The principle can be demonstrated by connecting a triode so that its grid and anode are interchanged. However, special tubes of unconventional design were constructed for generating several thousand volts. The rectified voltage is negative in polarity relative to cathode and thus is adapted for oscilloscopes and perhaps for television-picture tubes.

17. FREQUENCY ADJUSTMENT OF QUARTZ-OSCILLATOR PLATES BY X RAYS

Clifford Frondel
(Director of Research, Reeves Sound Laboratories, Inc., New York, N. Y.)

A BT quartz oscillator plate irradiated with X rays gradually becomes smoky in color, and undergoes an accompanying change in the elastic constants which lowers the oscillator frequency. There is little or no accompanying change in crystal activity. The total frequency change is limited and varies with the initial frequency (thickness) of the plate. Changes of the order of 500 to 3000 cycles per second can be obtained in the frequency range from 5 to 9 megacycles. The rate of change of frequency is primarily determined by the intensity and wavelength of the X radiation. Both the rate of change and the total change of frequency increase with increasing initial frequency of the plate. Rates now achieved in production average about 40 cycles per second per minute of exposure to X rays. The frequency change brought about by irradiation can be reversed and the plate restored to its original frequency and color by baking at temperatures over about 175 degrees centigrade. Irradiated plates are stable at lower temperatures. The plates also can be sensitized to irradiation by prior baking.

Other kinds of radiation also have been found to cause color and frequency changes in quartz, including gamma rays, alpha particles, electrons, and deuterons. X rays, however, are the only practical choice for manufacturing operations although the radioactive radiations have, under certain circumstances, a definite application.

The irradiation technique presents a number of practical advantages in the manufacture of oscillator plates: (1) Extremely precise frequency adjustments can be made by oscillating the plate in the X-ray beam, following visually the frequency change on a meter until the desired value is reached. The adjustment can be effected, under suitable circumstances, while the crystal is oscillating in its permanent holder. (2) The frequency of stabilized crystals can be adjusted without disturbing the surface condition of the quartz. (3) The fact that the frequency change is downward permits the salvage of crystals that have been overshot in frequency during manufacture. Similarly, plates that have gone over frequency due to aging, recleaning, or underplating may be recovered.

27. ACTIVITIES OF THE RADIO TECHNICAL PLANNING BOARD

Alfred N. Goldsmith
(Vice-Chairman, RTPB, New York, N. Y.)

The sponsorship, organization, panel activities, and reports of the RTPB and its Panels will be discussed. The nature of the contributions of the RTPB, as well as the co-operation of the I.R.E. in the work of the RTPB will also be considered.

10. TWO-RESONATOR KLYSTRON OSCILLATORS

D. R. Hamilton
(Sperry Gyroscope Company, Inc., Garden City, L. I., N. Y.)

The relation between the concepts of the two-resonator klystron oscillator and those of the conventional lower-frequency tubes and circuits is discussed with a view to making clear the points of similarity and differ-
ence. It is shown that once the somewhat different origin of the beam transconductance in the two cases is understood, the remainder of the analysis follows conventional lines. The application of this analysis to calculations of dependence of power output and oscillation frequency in the two-resonator oscillator is then discussed.

32. AN ELECTROMETER TUBE AND ITS USE IN MINUTE MEASUREMENTS

W. A. Hayes
(Westinghouse Electric and Manufacturing Company
Bloomfield, N. J.)

In this paper an electrometer tube is described which permits the measurement of minute currents and/or potentials down to $10^{-18}$ ampere and $10^{-4}$ volt, respectively. The sensitivity of the tube is made possible by an extremely low grid current and a high grid-to-cathode resistance. Important construction and processing features of the tube are presented. Techniques involved in maintaining the standards required for sensitivity, stability, and long life are given. Characteristics are included with data relative to linearity of output current as a function of grid bias.

Zero control current is effected by proper selection of negative grid bias. This feature is described and data given. Stability of the tube with respect to random fluctuations internal and external to the tube is summarized relative to the accuracy of test results. Several special applications of the tube in the field of chemistry, metallurgy, and the medical professions are described.

16. THE PERFORMANCE INDEX METER

C. W. Harrison
(Bell Telephone Laboratories, Inc., New York, N. Y.)

The principal features of this instrument which measures the antiresonant impedance of the quartz crystal and associated circuit will be pointed out and discussed. The difficulties associated with trying to measure high impedances at high frequencies are avoided by making certain measurements within the resulting resonant circuit embodying the crystal, and making certain calibrations. The operation occurs at a frequency determined by the crystal being tested. Measurements are facilitated by constructing the circuit so that constant amplitude occurs for the driving voltage at the point of application regardless of adjustments being made. The most important error likely to be introduced by the method employed will be pointed out and the magnitude of possible error mentioned.

14. QUARTZ-CRYSTAL SUPPLY PROGRAM

Major Edward W. Johnson
(Signal Corps, Office of the Chief Signal Officer,
Washington, D. C.)

At the start of the war the Signal Corps found itself committed to a policy of using quartz crystals as a means of frequency control, with military demands running into millions a year and with the then-existing industry capable of producing at most 100,000 units a year. Laboratory methods were used in those plants, no production machinery was available, no techniques standardized, and the situation on the supply of raw material from Brazil was such that the utmost economy had to be observed and appropriate processing methods adopted. The raw-quartz problem was further complicated by the then-prevailing belief in the industry that only the very best grades were suited to the manufacture of oscillator plates.

As a result of the concerted efforts of the Signal Corps and the wholehearted co-operation and ingenuity of the industry the latter was expanded from some 15 prewar firms to approximately 115, and the capacity to the point where it is now producing at a rate of approximately 30,000,000 units a year. This expansion was made possible by the adoption of standardized equipment, improved techniques, and a continued search for improvements. The quality of the units has been vastly improved.

The Signal Corps has spent in excess of $200,000,000 for crystals alone since the outbreak of the war. This sum represents about 50,000,000 crystal units. The efficiency of the industry in the utilization of critical raw material has improved substantially, costs of comparable crystals have been reduced by at least a 4-to-1 ratio, and processing techniques have progressed to the point where semiautomatic machinery is in widespread use.

In order to meet emergency demands for small quantities of crystals on special frequencies, field crystal-grinding equipments, manned by specially trained personnel, have been set up in all active theaters.

41. SOME NEW ANTENNA TYPES AND THEIR APPLICATIONS

A. G. Kandoian
(Federal Telephone and Radio Laboratories, New York, N. Y.)

Three newly developed types of antennas will be described. The radiation pattern of each is substantially omnidirectional in the horizontal plane. The first has horizontal polarization, the second vertical polarization, and the third is elliptically or circularly polarized.

Variations of the above types, bandwidth considerations, tuning range, advantages, and limitations of each type will be discussed as well as the use of these antennas singly or in directive arrays for high-power gain. Applications to very-high-frequency and ultra-high-frequency broadcast, television, and link communication will be considered.

Experimental models and measured characteristics, design and construction for various particular applications, the problem of transmission-line efficiency, elimination of balanced feeder, coaxial feeding system, and a typical installation will be presented.
8. NEW MINIATURE TUBES

R. L. KELLY AND N. H. GREEN
(RCA Victor Division, Radio Corporation of America, Harrison, N. J.)

In the development of electronic equipment for use in World War II, a need was indicated for improved receiving tubes to satisfy the highly specialized requirements of the Army and Navy. Foremost among the features desired in these tubes were small size, excellent ultra-high-frequency performance, adequate mechanical strength, and minimum effects due to climatic variations.

The miniature type of tube design offers excellent possibilities of meeting these objectives and, therefore, a group of heater-cathode miniature tubes has been developed for war purposes.

Although dissipation problems were anticipated with the use of miniature envelopes, these proved to be less troublesome than expected because the short leads employed in this design are efficient heat conductors.

High-frequency performance is also exceptionally good because of the low-inductance leads and because of the stability provided by the all-glass base. The small size and light weight of miniature tubes have proven especially advantageous in the design of aircraft equipment.

36. ULTRA-SHORT-WAVE TRANSMITTER FOR THE CAPE CHARLES-NORFOLK MULTIPLEX SYSTEM

R. J. KIRCHER
(Bell Telephone Laboratories, Inc., New York, N. Y.)

AND
R. W. FRIIS
(Bell Telephone Laboratories, Inc., Deal, N. J.)

Design features of an unattended ultra-short-wave double-sideband multiplex transmitter are described. Forty decibels of envelope feedback is utilized over the 12- to 60-kilocycle band of the twelve type-K carrier-signal channels which modulate the last stage of the transmitter. Accessibility of apparatus and ease in maintenance contribute toward obtaining maximum reliability of the equipment in commercial service.

21. PRACTICAL METHODS OF SHIELTING DIELECTRIC-HEATING INSTALLATIONS

G. W. KLINGAMAN AND G. H. WILLIAMS
(Radio Corporation of America, Camden, N. J.)

This paper will discuss the field strengths to be expected around unshielded installations, based on measurement; shielding theoretically required to eliminate radiation; experiments to determine the minimum amount and kind of shielding required to reduce radiation to a satisfactory level, and methods and instruments used in locating points of maximum radiation in the installation.

37. RADIO-RELAY COMMUNICATION SYSTEMS IN THE UNITED STATES ARMY

LIEUTENANT-COLONEL WILLIAM S. MARKS, JR., CAPTAIN O. D. PERKINS, AND W. R. CLARK
(Signal Corps Ground Signal Agency, Asbury Park, N. J.)

This paper describes the use of frequency-modulated, very-high-frequency radio sets in place of wire lines in Army tactical communication circuits. During the early phases of the war and pending development and production of equipment designed to meet requirements, standard police-type frequency-modulation sets were adapted for use. These were used with great success during the Tunisian, Sicilian, and Italian campaigns. They principally provided simplex teletype circuits from higher headquarters to lower units. By the use of radio repeater or relay stations these circuits were extended several hundred miles. Representative circuits are shown illustrative of employment, distances covered and antenna elevations. A broad-band frequency-modulated very-high-frequency set designated AN/TRC-1 was developed for use in conjunction with voice-frequency-carrier equipment CF-1 and CF-2 to provide multichannel voice and teletype circuits over a single radio frequency. This has met with great success and was a most important communication factor in the Normandy Invasion and Battle of France. It marks the first real marriage of wire and radio communications in the Army and provides an integrated communication system. The advantages of a radio system over conventional wire lines under certain conditions are pointed out, such as a saving in men and material, establishment and maintenance of communications in a fast-moving situation, use over water, enemy territory, rugged and mountainous terrain. Expanding and wider application of the principle is indicated.

9. INTRODUCING THE DISK-SEAL TUBE

E. D. McARTHUR
(Research Laboratory, General Electric Company, Schenectady, N. Y.)

Several factors which limit the operation of grid-controlled tubes at ultra-high frequencies are discussed qualitatively. Starting with these problems, certain new basic principles in tube design are developed and it is shown that ultra-high-frequency tube design and development must include detailed knowledge and consideration of the entire electromagnetic system rather than just the evacuated bulb.

The evolution of typical generalized cavity circuits is traced and from these units the grid-separation circuit is developed. It is shown how the disk tubes used in conjunction with cavity resonators co-operate to alleviate many of the aforementioned problems so that very much higher operating frequencies can be attained.

The detailed structure of several typical disk tubes is
shown and an example of the grid-separation type resonant cavity oscillator.

Only a limited amount of operating data is given due to the need for military secrecy.

2. MEASUREMENT OF RECEIVER IMPULSE-NOISE SUSCEPTIBILITY

JERRY B. MINTER
(Measurements Corporation, Boonton, N. J.)

A method of measuring receiver susceptibility to impulse noise (such as ignition noise) will be described. Some data typical of prewar frequency-modulation receiver designs will be shown. Application of the method to television-receiver measurements together with typical data will also be presented.

The general application of this method should result in improved impulse noise rejection in postwar frequency-modulation and television receivers. These measurements can be made with equipment already available to most engineering laboratories.

24. A HIGH-FREQUENCY WATTMETER AND ITS USES IN INDUSTRIAL APPLICATIONS

EUGENE MITTELMANN
(Illinois Tool Works, Chicago, Ill.)

An instrument is described which allows separating the amount of power which is fed into the charge of a high-frequency heating generator from other losses associated with the circuit, such as radiation losses, circuit losses, etc. It can be shown that the indications of the instrument are independent of the geometrical configurations of the load and of the electrodes and are independent of frequency.

Methods for using the instrument to match properly the load to the generator, and to maintain that matching, are discussed. Tests showing the accuracy of the instrument indications for various applications are shown.

12. A NEW VERY-HIGH-FREQUENCY TETRODE FOR MEDIUM POWER OUTPUT

CLAYTON E. MURDOCH
(Eitel-McCullough, Inc., San Bruno, Calif.)

A stable, efficient amplifier operating up to 200 megacycles, and capable of power outputs of up to 800 watts has been needed in several fields. The new 4-125-A adequately covers this range and also permits circuit and component simplicity because of its design. No neutralization is required except possibly at the higher frequencies, and the tube is easily plugged into its socket with only the plate connector to be made up. It will stand high voltage and has high overload capabilities.

The tube possesses extremely low feedback capacitance, low input and output capacitances, small physical size and short leads, tantalum plate and processed grids, and very close interelectrode spacings for short electron transit time.

Typical operating conditions for a pair at class C are 3000 volts plate, 300 volts screen, 335 plate mils, less than 5 watts grid drive, and useful power output of 750 watts.

It is an excellent zero-bias class B tube when the grid and screen are tied together, having very low distortion up to 500 watts output.

3. VERY-HIGH-FREQUENCY AND ULTRA-HIGH-FREQUENCY SIGNAL RANGES AS LIMITED BY NOISE AND CO-CHANNEL INTERFERENCE

K. A. NORTON
(Formerly, Federal Communications Commission; now, War Department, Washington, D. C.)

AND

E. W. ALLEN, JR.
(Federal Communications Commission, Washington, D. C.)

It is proposed to prepare theoretical service-area maps for frequency-modulation broadcasting at several frequencies so as to show the variation in the size of the primary service area within the 50-microvolt-per-meter contour as well as the rural service area, say within the 10-microvolt-per-meter contour. The maps will also show the required spacing between co-channel stations, taking into account tropospheric effects to the extent to which they have been determined at this time. The sky-wave interference curves presented at the allocation hearing will be included and the effect of the sky-wave interference in reducing the station service area will be shown for each of the above frequencies.

In addition, it is planned to present signal-range-versus-frequency curves for frequencies from 30 to 3000 megacycles, for 1-kilowatt power, and for several antenna heights. One set of curves is planned for broadcast stations and a second set for communications services, such as police, where the range is limited by noise conditions.

11. REFLEX OSCILLATORS

J. R. PIERCE
(Bell Telephone Laboratories, Inc., New York, N. Y.)

This paper discusses qualitatively the behavior of reflex oscillators. Power production, electronic tuning, variation of frequency with resonator voltage, effect of modulation coefficient, and influence of load are considered.

6. THE APPLICATION OF DOUBLE-SUPERHETERODYNE RECEIVERS FOR BROADCAST RECEPTION

JOHN D. REID
(Crosley Corporation, Cincinnati, Ohio)

This paper will cover the technical details of design, construction, and performance of a standard broadcast
18. EQUIPMENT FOR FREQUENCY ADJUSTMENT OF QUARTZ OSCILLATOR PLATES BY X RAYS

CHARLES RODDY

An account is given of preliminary experimental work on the frequency adjustment of quartz oscillator plates by means of X rays.

The necessity of relatively "soft" radiation of high intensity is demonstrated by radiating crystals directly on the windows of diagnostic X-ray tubes with non-shockproof apparatus.

Voltage and current were determined for economical time of radiation within present limits of tube design.

Absorption measurements were made to check the efficacy of copper and tungsten anode tubes under the same electrical loading.

Equipment was designed for the above purpose in order to satisfy the following conditions:

(1) Maximum intensity at shortest anode-crystal distance.
(2) Radiation of two plates simultaneously.
(3) Accommodation of various crystal sizes.
(4) Oscillation of plate while being radiated.
(5) Protection of operator from X radiation.
(6) Protection of operator from electrical shock.

23. OPERATING EXPERIENCES WITH INDUCTION-HEATING OSCILLATORS

WALLACE C. RUDD
(Induction Heating Corporation, New York, N. Y.)

This paper will discuss the operating experiences gained in the observation of many hundreds of large-capacity induction-heating oscillators. Problems arising in long-continued operation of these units and their solution will be considered.

33. CAPE CHARLES-NORFOLK ULTRA-SHORT-WAVE MULTIPLEX SYSTEM

N. F. SCHLAACK AND A. C. DICKIESON
(Bell Telephone Laboratories, Inc., New York, N. Y.)

This paper describes the general features of a radio multiplex system which has been installed between Cape Charles and Norfolk, Virginia. The radio-frequency equipment operates in the vicinity of 160 megacycles. The system employs the 12 telephone channels of the type-K cable-carrier system which are in the frequency range 12 to 60 kilocycles.

26. THE INTERDEPARTMENT RADIO ADVISORY COMMITTEE

CAPTAIN E. M. WEBSTER
(Vice-Chairman, Interdepartment Radio Advisory Committee, Washington, D. C.)

The Interdepartment Radio Advisory Committee was founded in 1922 at the invitation of the Secretary of Commerce. Originally dealing only with government radio broadcasting, its activities developed with the Federal Government's growing interests in other facets of radio. Frequency assigning, at first a minor consideration, gradually increased in importance until now it constitutes almost the entire business of the Committee.

With an average of more than 150 requests for frequency assignments each month, a standardized procedure and record system has developed. Symbols and notes indicate the relative priority of users and any limitations deemed necessary to prevent interference.

The Interdepartment Radio Advisory Committee is related to the State Department, Federal Communications Commission, and Board of War Communications through the dovetailing of activities, but lines of responsibility are well established and no overlapping of functions results.

4. EQUIVALENT NETWORKS FOR THE THREE KINDS OF TRIODE CIRCUITS

HAROLD A. WHEELER
(Hazeltine Corporation, Little Neck, L. I., N. Y.)

There are three simple ways of connecting a triode in a four-terminal network, because the "common" or "grounded" electrode may be the cathode, anode, or grid. The grounded-cathode circuit is the original voltage-reversing one-way repeater, amplifying both voltage and current to give greatest amplification of power at low frequencies. The grounded-anode (cathode-follower) circuit is a nonreversing one-way repeater but amplifies only the current and, in a less degree, the power. The grounded-grid circuit has degenerative feedback by conductive coupling, in such a manner that it amplifies only the voltage and, in a still lesser degree, the power. It may be treated as a hypothetical "repeater-transformer" with an impedance ratio of \(\mu + 1\), which also multiplies the power in the same ratio. It has some advantages at high radio frequencies because the grid shields against capacitive-feedback coupling and because the input conductance decreases as higher frequencies while that of the other two circuits increases.

The input conductance may be simulated by cathode-lead inductance, which gives a new picture of this phenomenon and its associated thermal noise. Series impedance in the common lead decreases the transconductance in the first two circuits. The double-triode circuit with cathode intercoupling is interesting as a nonreversing one-way voltage and current amplifier with less than
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half the transconductance and much less capacitive-feedback coupling.

29. A PORTABLE TWO-CHANNEL RECORDING OSCILLOSCOPE FOR BATTERY OPERATION
R. F. WILD AND D. C. CULVER
(Brown Instrument Company, Philadelphia, Penn.)

This paper deals with the construction and design considerations of a portable cathode-ray oscilloscope for photographic recording. This instrument is self-contained, battery-operated, and designed for simultaneous recording of two signals and recording of marking signals of standard frequencies. The frequency band from 5 to 300 cycles is covered in three ranges. The total weight of the instrument is 27 pounds, the size is 6\times12\frac{1}{2}\times16\frac{1}{3} inches.

The instrument has a high input impedance and is primarily designed for use in connection with strain gauges and vibration pickup devices.

13. A VACUUM-CONTAINED PUSH-PULL TRIODE TRANSMITTER
MAJOR H. A. ZAHL, J. E. GORHAM, AND G. F. ROUSE
(Signal Corps Ground Signal Agency, Asbury Park, N. J.)

A push-pull triode-transmitter type of construction is described in which the resonant circuits are contained inside the evacuated envelope to reduce lead effects and make possible the use of the resonant circuits to increase the anode dissipation. The internal resonant circuits consist of short-circuited sheet tantalum parallel transmission lines attached directly to the tantalum plates and grids in such a way as to provide coupling between the plate and grid loops. Each side of the push-pull circuit has two sets of plate-, grid-, and thoriated-filament elements in parallel.

Although the tuning of the loop circuits inside the envelope cannot be changed, a limited control of the frequency is possible because of the tunable external-filament line. The radio-frequency output circuit consists of a parallel transmission line, which is connected directly to the two pairs of plates. The combined tube, transmitter, and appropriate shielding occupy a much smaller volume than is required for external resonant circuits at frequencies of 200 to 700 megacycles and weigh only a few pounds. Similar tubes having a radio-frequency grounded plate, grounded grid, and grounded-cathode type of construction are described.

22. HEATING WITH HIGH-FREQUENCY ELECTRIC FIELDS
PAUL D. ZOTTU
(Thermex Division, Girdler Corporation, Louisville, Ky.)

The history of high-frequency heating will be reviewed. The process of generating electrical heat in nonconductors, semiconductors, and conductors will be described. The variation of the electrical properties of the materials to be heated with temperature, moisture content, and other factors will be discussed.

The general requirements of radio-frequency power generators as to frequency, power output, controls, and circuits, together with a description of a number of dielectric heating units and some commercial installations will be given.

A.I.E.E. WINTER TECHNICAL MEETING, JANUARY 22–26, 1945

COMMUNICATION AND ELECTRONICS PAPERS

“Transient Response of Controlled Rectifier Circuits,” by P. T. Chin and G. E. Walter, General Electric Company


“Rectifier-Fault Currents,” by C. C. Hershkind and H. L. Kellogg, General Electric Company

“Voltage and Current Relations for Controlled Rectification with Inductive and Generative Loads,” by K. P. Puchlowksi, Westinghouse Electric and Manufacturing Company


“Problems and Accomplishments of Industrial Electronic Control,” by O. W. Livingston, General Electric Company

“An Interval Timer for Arc Duration,” by J. S. Quill, General Electric Company


“The Tapered Transmission Line,” by J. W. Milnor, Consulting Engineer


“Power-Line Carrier Channels,” by M. J. Brown, Westinghouse Electric and Manufacturing Company
Board of Directors

November 1 Meeting: At the regular meeting of the Board of Directors, which was held on November 1, 1944, the following were present: H. M. Turner, president; R. A. Hackbusch, vice-president; S. L. Bailey, W. L. Barrow, E. F. Carter, J. S. Coggeshall, W. L. Everitt, Alfred N. Goldsmith, editor; R. F. Guy, R. A. Heising, treasurer; L. C. F. Horle, Haraden Pratt, secretary; H. J. Reich, B. E. Shackelford, H. A. Wheeler, W. C. White, and W. B. Cowilich, assistant secretary.

Executive Committee Actions: The actions of the Executive Committee at its October 3, 1944, meeting were unanimously ratified.

Committees

Appointments: On recommendation of the Executive Committee, the following members were appointed:

W. L. Everitt, Chairman
S. L. Bailey
W. L. Barrow
B. E. Shackelford
H. A. Wheeler

Awards: Dr. Everitt, as chairman of the Awards Committee, presented the report of his committee relating to Institute awards. On recommendation of the committee, H. H. Beverage was awarded the Medal of Honor for 1943 and W. W. Hansen was the recipient for the Morris Liebmann Memorial prize for 1944.

Building Fund: Vice-Chairman Coggeshall reported that F. A. Grisette, who has had professional experience in the raising of funds, attended a recent meeting of the group which discussed with him matters including cost, relating to the Institute's campaign for raising the building fund of $500,000. Mr. Grisette has since presented a letter of proposal covering the matter.

Following the meeting, Mr. Coggeshall received a further letter of October 28, 1944, from Mr. Grisette, concerning the campaign and terms for management service.

It was also stated by Mr. Coggeshall that the prospects are favorable for accomplishing the financial goal which had been set. Chairman Shackelford of the committee was present and answered several questions concerning the building-fund campaign.

After the discussion, the following motion, including the recommendation of the Executive Committee, was unanimously approved:

"The Board approves in principle the general plan explained in the mentioned letter from Mr. Grisette, and asks that the Building-Fund Committee obtain other competitive bids from established fund-raising organizations and that it provide additional safeguards covering detailed expenditures of funds and the power to review and diminish or discontinue expenditures at reasonable intervals during the campaign."

Education: On recommendation of Chairman Everitt the following members were appointed to the Committee on Education:

W. Arcand
R. C. Manhart
F. R. Stansel

Section Committees on Committee Personnel: The following motion was made and unanimously approved:

"Moved, That the President be requested to address letters to Section Chairmen to the effect that they set up Section Personnel Committees for the purpose of recommending qualified individuals, giving the qualifications on fields of interest of such potential committee members, and promoting the transfer of Associates to a higher grade by assisting in supplying sponsors and transmitting other pertinent information to the Admissions Committee."

Chairman of Standing Committees: It was moved that the President request all committee chairmen, two months before their retirement, to submit recommendations to the appropriate appointing bodies or individuals, regarding members of their committees who by their interest, activities, and capabilities should be seriously considered for appointment to committees for the next term.

Tellers: The report of the Tellers Committee, dated October 26, 1944, was accepted and the following officers elected:

President: R. C. Manhart
Vice-President: W. L. Everitt
Chairman of the Board of Directors: H. J. van der Bijl

Appointments: These appointments, reported by President Turner and including those recommended by the Executive Committee, were given unanimous approval.

Facsimile Committee:
A. G. Cooley
W. E. Stewart
H. C. Ressler
E. F. Watson

Electronics Committee:
J. H. Hutchings

Institute Representatives in Colleges
Polytechnic Institute of Brooklyn: G. B. Hoagley
University of Iowa: L. A. Ware
North Carolina State College: W. S. Carley
University of Pittsburgh: L. E. Williams
Stanford University: Victor Carson
Virginia Polytechnic Institute: R. R. Wright

Institute News and Radio Notes

Institute News and Radio Notes

Radio Technical Planning Board: Secretary Pratt, the Institute's Representative on the RTPB reported on the two proposed amendments of the RTPB "Organization and Procedure," which had been submitted to the Institute for a vote. The amendments were given the consideration, explained below:

a. Limit on Balloting: The amendment of Article VIII on "Amendments," to be in the form of an additional sentence, was unanimously approved.

"Such amendment may be made by letter-ballot in which case the period between the mailing and the counting of the ballots shall not exceed 60 days."

(continued on page 64)
I.R.E. Board Sets Goal of

$541,000 for the purchase of land. Thereupon Carnegie added a gift of $1,050,000 for the present Engineering Societies Building. When the American Society of Civil Engineers became the fourth Founder Society in 1916, its 7900 members raised $262,500, which was applied to putting additional stories on the building. Altogether, the total cost of land and building has been $2,000,000, of which practically $1,000,000 was raised by engineers of the Founder Societies and their friends.

The Institute of Radio Engineers now has more than 12,000 members whose financial status must be of a level corresponding to that of the engineering profession generally. What others did years ago, we can undertake to repeat under the present favorable conditions.

The Board, while welcoming corporate gifts, attaches significant importance to gifts from the ranks of its own membership. Outsiders should hardly be asked to contribute to the Building Fund without definite evidence of interest made manifest by financial support on the part of our entire membership. As the campaign unfolds, the responsibility of the members, both in making contributions themselves and in securing them from friends of the Institute, will be made clear. The organization of the Sections will be availed of for the purpose.

Assuming universal and generous support by the Institute's membership, the Directors are counting upon a wide response from the radio-and-electronic industry to an appeal for capital funds—in fact, in terms of specific sums, the expectation of attaining our goal is based upon raising much of the fund through corporate and special individual nonmember gifts at the request of our members.

The philosophy underlying the decision to approach the industry for gifts is based upon the twofold dependence of modern industrial laboratories upon the universities and upon the scientific and technical societies for the constant replenishment, from without, of ideas and men with ideas. We, who are in the profession and the industry, see the importance of the detached and unselfish attitude of the engineer and scientist perhaps less clearly than those who survey the whole gamut of human endeavor. Thus, Wells, in "The Outline of History" (xxxiv, 6), points out that "the essential use and virtue" of scientific societies "is publication... Frank report... and open discussion... is the life of the modern scientific process. For the true scientific method is this: to trust no statements without verification, to test all things as rigorously as possible, to keep no secrets, to attempt no monopolies, to give out one's best modestly and plainly, serving no other end but knowledge."

Again, Lippmann, in "A Preface to Morals" (xii, 2) says that, at the heart of research, "the habit of disinterested realism in dealing with the data is the indispensable habit of mind.... This is an original and tremendous fact in human experience: that a whole civilization should be dependent upon technology, that this
Building Fund at $500,000

technology should be dependent upon pure science, and that this pure science should be dependent upon a race of men who consciously refuse... to regard their 'own desires, tastes, and interests as affording a key to the understanding of the world.' An elaborate method of detecting and discounting their prejudices has been developed," he says, consisting of "instruments of precision, an accurate vocabulary, controlled experiment, and the submission not only of their results but their processes to the judgment of their peers. This method provides a body in which the spirit of disinterestedness can live... The scientific discipline has become... an essential part of our social heritage. For the machine technology requires a population which in some measure partakes of the spirit which creates it."

So broad and firm a base obviously would justify (from the viewpoint of an actual, if not acknowledged, indebtedness) an appeal for public support of the Institute. Perhaps such a claim for sympathetic consideration will be entertained, during the course of the campaign, by one or more public-spirited individuals or foundations having no direct connection with the radio-and-electronic industry.

How much greater the force of the suggestion within the industry itself! Hardly a company now successful in its field but has drawn mightily upon the organized engineering effort of I.R.E. The Institute was on the job during World War I, before organizations now directly supported by the returns of the industry were created. Its technological publications in the radio-boom decade of the '20's were fundamental to that expansion. For its detached attitude in recording scientific progress in investigation of electron tubes, the relationships of circuit elements, in measurements, standards, and the mathematics of the art, when it might have spent its energy merely exploiting detailed applications of technology to the radio business, the Institute is to be credited with the initial dissemination of information upon which radio manufacturing, industrial electronics, and much of modern electrical communication is now built. The greatest minds in the field have contributed to its pages. In turn, it has reached out to serve the industry in all its phases, making for the broadest conceivable example of exchange of information. Among industrial laboratories the Institute has not been a dead-leveler but a dynamic catalyzer, putting at the disposal of all, the fundamental contributions of each laboratory.

The Proceedings has similarly leveled upwards the teaching staffs and curricula of the universities, whence comes the industry's technological raw material. By publication, meetings, and conventions the engineers have been continuously stimulated and re-educated, it being axiomatic in a branch of technology as rapidly expanding as ours that static dependence upon knowledge acquired in college will be found deficient in competition with the learning of those who, because more recently trained, bring to the industry new skills and fresher outlooks.

The Institute is not making a monetary claim for these services, nor is it rendering the industry a statement of indebtedness. It recognizes the reciprocal benefits it has received in the form of time given to it, gratis, by its authors, speakers, committee-men, and officers, many of them working "on company time," gratis, by its authors, speakers, committee-men, and officers, many of them working "on company time." Even more fundamentally, it recognizes its indebtedness to businessmen and industrialists for their permission for their technologists to disclose the results of millions of dollars' worth of laboratory effort. In one sense, such a co-operative effort between the industry and its technical society is purely mutual and completely satisfied without exchange of funds. But because the Institute must have more office space to meet the expanding needs of its engineering activities and services to the industry which naturally arise therefrom, and because the engineers alone cannot finance so great an objective without help, it is felt that most businesses founded on radio and electronics will wish to make a substantial contribution towards permanently housing an institution whose permanence to date has been the best assurance that the art will continue to progress.
The Board of Directors of the Institute of Radio Engineers has earmarked a fund of $20,000 to be used, according to present plans, for the postwar publication of wartime papers. This fund, translated into pages in the PROCEEDINGS, means that about 1000 extra pages can be printed. The average manuscript runs approximately ten PROCEEDINGS pages, so the Institute is greatly interested in obtaining information on the likely future availability of an additional 100 worth-while papers, dealing with matters which, for security reasons, cannot now be released.

With victory, these papers may be released, and now is the time for prospective authors to start gathering material and to think about papers which would be suitable for publication in the PROCEEDINGS. At this time, author advice will be preparing outlines for future papers and assembling illustrations for them. Undoubtedly, when censorship restrictions are relaxed, a large number of papers will be released. Obviously only the best and most carefully prepared of these can be accepted for publication in the PROCEEDINGS and, on any particular subject, those papers which are first received by the Institute and are of acceptable character, will be published. This may prejudice the acceptance of later papers covering similar ground.

Headquarters will be glad to furnish authors with copies of "Suggestions to Authors" and "Abbreviations of Publications." These will be found in the adjoining description of manuscript. It would be appreciated if requests were to be accompanied by a stamped, self-addressed envelope.

PROCEEDINGS: A new design for the front cover of the PROCEEDINGS was described and favorably received. Unanimous approval was given to the motion authorizing Editor Goldsmith to redesign the front cover in the manner described, and to begin using the new cover design starting with the January, 1945, issue of the PROCEEDINGS or earlier if possible.

Sections

**Ontario:** Mr. Wheeler pointed out that the Ottawa Section agreed to the indicated areas as its territory, considered to be satisfactory to the adjoining Montreal and Toronto Sections, as previously reported:

**Counties in Ontario**

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<th>Lennox</th>
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<td>Lannark</td>
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<td>Grenville</td>
<td>Frontenac</td>
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<td>Stormont</td>
<td>Russell</td>
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</tbody>
</table>

**Quebec**

- Pontiac
- Laval (Labelle)

It was understood that these counties and districts would constitute the official territory of the Ottawa Section.

**Summer Convention:** Unanimous approval was given to the motion stating that the Executive Committee plans to hold a summer convention to be held approximately June, 1945, at a location other than New York City. It was understood that the Executive Committee would decide the location of the 1945 Summer Convention. The appointment of the committee for this convention was given consideration, and it was stated that the personnel of this group would be named at the next meeting.

**Rochester Fall Meeting**

In spite of wartime pressure, some 700 radio engineers found time to attend the annual Fall Meeting at Rochester on November 13 and 14. A total of 439 were registered, and some 300 were at the banquet at which Major General Colton, Army Air Force, was the guest speaker.

In the two-day session, technical papers were delivered on subjects ranging from a reactance theorem for a resonator as presented by W. R. MacLean of Polytechnic Institute of Brooklyn, to the organization of research in radio after the war, discussed by Rupert Maclaurin, economist at Massachusetts Institute of Technology.

The evening of November 13 was devoted to some backward glances and much forward looking at the industry by the professional optimist, Kenneth W. Jarvis. Tribute was paid by him to industry figures who had been faithful attendants at these annual meetings but who had been lost during the war.

At this evening meeting, a vigorous discussion developed over a talk by Sarks Tarzian on the subject of frequency-modulation broadcasting. Mr. Tarzian's thesis was that frequency modulation was an unwarranted expenditure of space in the ether, that frequency-modulation receivers will inevitably cost more to produce than amplitude-modulation sets; that listeners have shown no interest in high-fidelity broadcasting; that narrow-band broadcasting on the high frequencies would make it possible for the Federal Communication Commission to grant many more licenses than will be possible with frequency modulation; and that ignition noise is the limiting factor on possible with frequency modulation; and that narrow-band broadcasting on the high frequencies would make it possible for the Federal Communication Commission to grant many more licenses than will be possible with frequency modulation; and that ignition noise is the limiting factor on frequency-modulation receivers will...
for "his many years of unselfish service to the radio and electronic industry through the technical press." Previous recipients of Fall Meeting plaques are W. R. G. Baker for his "accomplishments in the organization and direction of the National Television Systems Committee"; L. C. F. Horie, past-president of the Institute for his "accomplishments in the Radio Manufacturers' Association Material Bureau"; R. A. Hackbusch, vice-president of the Institute for his "work in forwarding the technological war effort by direct action in the elimination of unnecessary detail."

**IRE People**

**W. L. EVERITT**

Appointment of Dr. W. L. Everitt (A'25-M'29-F'38), one of America's foremost authorities on electronics, as professor and head of the department of electrical engineering at the University of Illinois was recently announced by the University's president, Arthur Cutts Willard.

Dr. Everitt has been granted an automatic leave of absence from his new post because of the importance of his present work with the Army, for which he has been, since 1942, Chief of the Operational Research Branch in the Office of the Chief Signal Officer, at Washington, D. C. He will take up his duties at the University immediately on release from war service.

Since 1934, Dr. Everitt had been professor of electrical engineering at Ohio State University, and previously an instructor at Cornell University and at the University of Michigan. He is the author of several books and a number of technical papers on radio and telephone communications; he has served as research and consulting engineer to the American Telephone and Telegraph Company and to various manufacturing concerns, and he is the inventor of a number of electronic devices.

In 1942, Dr. Everitt was elected to the Board of Directors of The Institute of Radio Engineers, and has served on numerous committees. He is President-Elect of the Institute for the year 1945. He is a Fellow of the American Institute of Electrical Engineers.

**DONALD B. SINCLAIR**

Associate in 1933, to Member in 1938, Senior Member in October of 1943, and was made a Fellow in December of the same year.

**ROBERT BURDETTE WOOLVERTON**

Robert Burdette Woolverton (A'13-M'13-F'15) was born on September 22, 1884, at Greensboro, Pennsylvania. He received the B.S. degree from Harvard University in 1912.

From 1904 to 1908, Mr. Woolverton served in the United States Navy as chief radio electrician on the U.S.S. Kentucky, and maintained for that vessel the world's long-distance record for radio communication. In 1905, when reception through head-phones was just being initiated into use, Mr. Woolverton conceived the idea of a very high spark frequency for improved reception through interference and static. In partial recognition of this pioneer work he was made a Fellow of the Institute of Radio Engineers, in 1915.

Upon graduation from Harvard, Mr. Woolverton joined the National Electric Signaling Company, in Brooklyn, N. Y., as research engineer, devoting his efforts exclusively to the development of the Fessenden system of heterodyne reception. From 1913 to 1916 he was Pacific coast radio inspector for the Department of Commerce, and left government service in 1916 to become associated with the Federal Telegraph Company of San Francisco, as a radio and electrical engineer. During this association he assisted in the design of the high-power arc transmitters for the United States Navy, and later installed the 250-kilowatt station at San Diego, California, and the 500-kilowatt stations at Pearl Harbor, Hawaii, and Cavite, Philippine Islands.

In 1918, Mr. Woolverton was commissioned a captain in the Signal Corps Reserve, and served in France until the Armis- tice. Upon his return to the United States in 1919, he served as Pacific Coast radio supervisor for the United States Shipping Board until 1920, when he returned to the Signal Corps as a radio engineer in the office of the Chief Signal Officer. In this capacity he founded the War Department Radio Net, connecting the headquarters of the ninth corps areas of the War Department. Commissioned as a Captain in the Army Signal Corps in 1920, he became officer in charge of all Army radio stations, ashore and afloat, continuing in charge of the radio plant and traffic section of the office of the Chief Signal Officer as the War Department Net grew to include 58 stations and increased its service.

From 1927 to 1929 he served as officer in charge of the Second Section, Alaska Communication System, with headquarters in
Seward, Alaska. Returning from this post, Captain Woolverton was assigned as radio officer to the Ninth Corps Area, with headquarters at San Francisco, and in 1935 became Executive Officer of the Signal Office, Seventh Corps Area, at Omaha, Nebraska. In 1938 he returned to the Alaska Communication System, with headquarters in Seattle, Washington, and in the following year was promoted to the rank of Major. In 1941, as Lieutenant Colonel, he became officer in charge of the Alaska Communication System, and later in the same year was transferred to Hawaii, where he served as radio officer for the Hawaiian Department, at Fort Shafter.

Ordered to Recife, Brazil, in 1943, Colonel Woolverton was assigned as Theater Signal Officer for the South Atlantic Theater, and was promoted to the rank of Colonel. He was retired from the Army for physical disability in September, 1944, after more than forty years of continuous experience in radio work, and long and useful service as an officer of the Army.

Correspondence

Correspondence on both technical and nontechnical subjects from readers of the PROCEEDINGS OF THE I.R.E. is invited, subject to the following conditions: All rights are reserved by the Institute. Statements in letters are expressly understood to be the individual opinion of the writer, and endorsement or recognition by the I.R.E. is not implied by publication. All letters are to be submitted as typewritten, double-spaced, original copies. Any illustrations are to be submitted as inked drawings. Captions are to be supplied for all illustrations.

A Circuit Study

When I first read the article on "Phase-Shift Oscillators" by Messrs. Gintzen and Hollingsworth which appeared in the PROCEEDINGS INSTITUTE OF RADIO ENGINEERS in February, 1941, I set myself to the task of finding another resistance-capacitance circuit with 6 elements which would produce a 180-degree phase shift. In this I did not succeed. However I found that the circuit which appears in Fig. I possesses the same properties as the well-known Wien circuit, so widely used in the Wien bridge and in the resistance-capacitance oscillators.

By a simple application of Kirchhoff's laws or by considering the circuit as two voltage-dividing networks connected in tandem the ratio between the output and input voltages can be easily shown to be

\[ \frac{e}{E} = \frac{-j \times R}{R^1 - x^2 - 3jRx}. \]  

(1)

For the frequency for which \( x = R \) this equation becomes

\[ \frac{e}{E} = 1/3. \]  

(2)

It would now be convenient to find whether or not the maximum value that the ratio \( e/E \) can have is 1/3. This may be done by rationalizing (1), finding its absolute value, and setting the first derivative of the output voltage which respect to the capacitive reactance equal to zero, since we can rightfully consider \( e \) as a function of \( x \). The absolute value of (1) when rationalized gives

\[ \frac{e}{E} = \frac{\sqrt{x+R^2} + \sqrt{x^2+R^2}}{\sqrt{R^2 - x^2} + \sqrt{R^2 - x^2}}. \]  

(3)

To obtain the maximum value of \( e \) only the numerator of the derivative of (3) need be
considered. When this is done and some simplifications are made the following expression is obtained:

\[
\frac{1}{E} \frac{de}{dx} = \left[ (R^2 - x^2) + 9R^2x^2 \right] \\
\left[ 18R^2 - 2x(R^2 - x^2) + (R^2 - x^2)^2 \right] \\
- 9x^2R^2 + x(R^2 - x^2)^2 \\
18xR^2 - 4x(R^2 - x^2) = 0.
\]

Equation (4) is satisfied only when \( R = x \) and therefore the maximum value of \( e/E \) is 1/3. Thus this circuit has exactly the same properties and uses the same number of circuit elements as the Wien Circuit.

The circuit obtained by interchanging the positions of the condensers and the resistances on the accompanying figure has also the same properties.

**Braulio Dueño**

University of Puerto Rico, Mayaguez, P. R.

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**Proposed Changes to Bylaws**

October 10, 1944

Mr. Haraden Pratt, Secretary

Institute of Radio Engineers, Inc.

330 West 42nd Street

New York 18, New York

Dear Mr. Pratt:

It appears to me that a system of membership with fixed dues, rather than on the sliding scale, is the only sensible way of conducting an organization such as ours, and the proposals brought forward by the Canadian members regarding classes might work out to an advantage.

A number of years ago I became a member of an engineering society as a junior member, and upon completing 25 years of full membership, I was handed a life membership ticket, the same as had been set up for other 25-year members, relieving me of the payment of further dues, but which does not relieve me of my obligations to the society as a fellow engineer. I merely mention this in order to show that sometimes there is a reward for continuous co-operation and membership in an organization, and perhaps our Institute might consider some type of a life membership at some time in the future, if the time is not right now to add this type of membership.

In conclusion I wish to say that, in my humble opinion, our executives and board have carried through a very fine program, and it is my hope that they may continue to grow and prosper, and hold their place among the engineering profession in the years to come. It would be commendable indeed to be associated with some organization with club rooms, a meeting hall, etc., in the Metropolitan area in New York, and that could only be accomplished by a large membership, and by proper and adequate financing.

Yours very truly,

R. E. Stark

Vice-President

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**Francis A. Hubbard**

Francis A. Hubbard, a development engineer of Bell Telephone Laboratories, Inc., died on June 6, 1944, in his office, of a heart attack. He was fifty-four years old.

Mr. Hubbard was born in Cambridge, Massachusetts, and was graduated from Harvard College with an A.B. degree, in 1911. He received the degree of Master of Electrical Engineering in 1914. After a year's teaching at Cornell he entered the engineering department of the Western Electric Company in 1915. When the foreign business of Western Electric was sold to the International Telephone and Telegraph Company, Mr. Hubbard joined its subsidiary International Standard Electric Company. As its transmission engineer and later assistant chief engineer he laid out the Stockholm-Gothenburg long-distance telephone cable and a similar cable connecting Milan, Turin, and Genoa. He also established the first trans-Andean telephone circuit in 1928. Later he became vice-president and general manager for the Mexican Telephone and Telegraph Company.

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**Books**

**International Telecommunications, by Osborne Mance and J. E. Wheeler**

Published (1944) by Oxford University Press, 114 Fifth Avenue, New York 11, N. Y. 86 pages+4 page index+7 vii pages. 8½x5½ inches. Price, $1.00.

This book, recently written in England, was issued under the auspices of the Royal Institute of International Affairs. This Institute is an unofficial and nonpolitical body, founded in 1920 to encourage and facilitate the scientific study of international affairs. It is started on the flyleaf that since the Institute, as such, is precluded by its Royal Charter from expressing any opinion on any aspect of international affairs, the opinions in the book are purely individual. The authors explain that they were entrusted with the preparation of a study of International Transport and Communications, and that for this communication work they enjoyed the assistance of a large number of important official and unofficial experts and had access to facilities and information of the Foreign Office, the General Post Office, and the Air Ministry.

The subject matter is nontechnical and is presented largely from the standpoint of postwar planning. It would be most useful to persons not fully versed in the ramified aspects of international communications, who expect to have some future part in activities either directly or indirectly associated with this subject, particularly legislators, administrators, and other officials.

The major portion of the book deals with the history and present status of international agreements, presented in an easy and understandable manner, commencing first with the machinery of international regulation and then continuing with a brief review of the general provisions of the Telecommunication Convention, followed by specific information on telegraphy, telephony, radio communications, propaganda broadcasting, and special services.

All the various committees and international organizations concerned with telecommunications are briefly explained. A chapter tells the reader considerable about cable and wireless concessions from an historical point of view, giving a helpful background for understanding the present situations in China, South America and elsewhere. The British Imperial System of Communications is discussed briefly from a world standpoint.

The closing chapter attempts to state factors and problems that will influence the makeup of a future world organization of telecommunication, considering both commercial and political aspects. Here the authors indulge in some speculation as to a type of organization that they believe would overcome some of the handicaps of the present and past.
Sampling Inspection Tables—Single and Double Sampling, by Harold F. Dodge and Harry G. Romig

Published (1944) by John Wiley and Sons, Inc., 601 W. 26 St., New York 1, N. Y. 101 pages +4-page index +vi pages. 18 illustrations. 8\(\frac{1}{2}\)\times 5\(\frac{1}{2}\) inches. Price, $1.50.

Broadly speaking, the object of industry is to set up economic means of satisfying human wants, and in doing so to reduce manufacturing techniques to routine times requiring a minimum amount of human effort. Through the use of modern statistical concepts, it has been found possible to set up limits within which the results of routine efforts must lie if they are to be economical. The application of statistical methods to inspection technique is the natural outgrowth of efforts that have been made by a number of scientists to develop a scientific basis for obtaining economic control of quality of manufactured products. It has long been recognized, where sampling instead of complete inspection is used, that certain errors or risks are unavoidable. Modern statistical theory, however, offers means of computing probability of acceptance curves for given boundary conditions. It is with such curves and data that this book is concerned.

This book consists of a re-edited version of two papers by the authors and a paper by D. B. Koelz and L. E. Crane, all of which have previously been published in the Bell System Technical Journal. These papers and the book deal with sampling inspection tables that have come into general use by industry. The text includes the three papers mentioned, and in addition, contains a brief introduction. The papers have been reproduced without modification except for rearrangement of the material. Chapter I outlines the pertinent factors to be considered in setting up inspection plans and develops the theory of single sampling inspection. Chapter II covers single and double sampling, the average outgoing quality limit (AOQL) concept and the mathematical background of the tables. Chapter III outlines the shop procedures required for the application of the tables given in the text.

The tables contained in the text are developed around the concept of lot tolerance, that is, an allowable percentage of defective articles in a given lot. Two levels of quality are considered, referred to by the authors as consumer’s risk and producer’s risk. Two general types of tables are given: one based on the concept of lot tolerance, and the other on the average outgoing quality limit. The broad conditions under which the different types have been found best adapted are discussed in detail in Chapter II. For each of the types, tables are provided both for single sampling and for double sampling. Each of the individual tables constitutes a selection of solutions to the problem of minimizing over-all inspection. The tables indicate acceptance number, sample size, and the average number of pieces per lot for specified risks. Appendices to Chapters I and II give the mathematical bases for the tables and for the curves used in the text.

This book is intended for inspection personnel concerned with mass production of quantities of essentially identical items to which statistical theory may be applied. It is well written and appears adequately to cover the ground intended by the authors. The information is presented in a clear and logical fashion, and the material has already stood the test of time since it has been previously published in the Bell System Technical Journal. It is believed that this book will be found a useful and worthwhile compilation for engineers and executives dealing with inspection methods and inspection techniques for mass production.

F. X. Röstenmeyer
RCA Victor Division
Camden, N. J.

Instrument Flying and Radio Navigation, by Holland L. Redfield

Die Beziehungen Zwischen Nutzspannung und Störspannung bei den Frequenzumschaltungen der Drahntlosen Mehrkanالtelefonie (The Relationships Between Useful and Interfering Voltages in the Frequency Translations of Multiplex Radio Telephone Systems), by Erwin Huber

Published (1944) by the Ronald Press Co., 15 E. 26 St., New York 16, N. Y. 189 pages +5-page index. 107 illustrations. 8\(\frac{1}{2}\)\times 5\(\frac{1}{2}\) inches. Price, $3.00.

Four chapters of this book are devoted to the fundamentals of flight, five chapters to radio-range flying, two chapters to direction-finder navigation, and one chapter to the link trainer. The first four chapters carefully review the fundamentals of flight for the benefit of the pilot and radio personnel, and the latter chapters are devoted to problems concerning radio-range technique, direction-finding technique, and link-trainer problems.

The author has covered the subject quite thoroughly, evidently based on an intimate knowledge and experience in connection with the various systems in use. However, due to military restrictions, the book obviously does not cover all of the latter phases of radio navigation. The book is very well planned and the various subjects are treated in considerable detail and clarity which would no doubt find definite application in the training of pilot personnel as well as radio personnel.

The chapters on radio ranges and the various problems regarding orientation and navigation are exceptionally well done and these chapters should be of prime interest to pilot personnel. The author has attempted to avoid repetition insofar as possible and, in most cases, has accomplished that aim and has only used repetition for emphasis and correlation of one particular problem to another insofar as radio-range operation is concerned.

The chapters devoted to radio direction finding particularly stress the aural-null-type direction finder and the left-right indicators. These two chapters are not perhaps as complete as they might be in that greater detail should have been included regarding
automatic direction finders of both the single and dual types. It is a generally recognized fact that under difficult radio conditions it is necessary, for safety's sake, to revert to an aerial-nulled direction-finder operation. However, the automatic-type direction finder can also be used to considerable advantage, and if the dual units are utilized it is much easier for the pilot to hold a straight course than when only one direction finder is utilized. In connection with the boxing procedure utilizing the direction finder for letdown, it seems that considerable additional explanation is in order concerning the boxing procedure with drift due to wind conditions. This point would be of interest as boxing procedure is usually begun above a cloud layer, in which case the wind components can be of considerable magnitude, while at lower altitudes and in blind operation wind components rapidly decrease.

There has been a definite need for a book of this kind for several years and it is felt that it should be of considerable interest to personnel in the aviation industry.

H. C. Leuteritz
Pan American Airways, Inc.
New York, N. Y.

Contributors

W. R. Hill, Jr. (A'43), was born at Seattle, Washington, on February 1, 1911. He received the B.S. degree in electrical engineering from the University of Washington in 1934. From 1934 until 1936 he was associated with the Northern Radio Company, Seattle, as a radio engineer. He then became a teaching assistant at the University of California, and in 1939 was awarded the M.S. degree in electrical engineering.

From 1938 to 1941 Mr. Hill was employed as an engineer by the Standard Oil Company, Inc., 250 Fifth Avenue, New York, N. Y.

Ralph R. Beal

Ralph R. Beal (A'15) was born at Maude, Kansas, on November 22, 1887. He received a degree in electrical engineering in 1912 from Leland Stanford University. From 1912 to 1926, he conducted technical studies of continuous waves and engaged in the development, design, and application of long-wave radio equipment of the Poulsen-arc converter type.

During the First World War, Mr. Beal was a resident engineer in Washington, D. C., and actively supervised the installation of high-power arc converter equipment in stations constructed by the United States Navy for transoceanic communications.

In 1926 he became associated with the Radio Corporation of America as a research engineer, and was attached to the New York office, and in 1937 was appointed research director of the Radio Corporation of America. Since 1943 Mr. Beal has held his present position as assistant to the vice-president in charge of R.C.A. Laboratories.

Arthur E. Harrison (A'41) was born on January 20, 1908, at San Luis Obispo, California. He received the B.S. degree in electrical engineering from the University of California in 1936. From 1936 to 1939 he was a teaching fellow at the California Institute of Technology, and received the M.S. degree in 1937 and the Ph.D. degree in 1940. He did research work for the department of mechanical engineering at the University of California in 1940. Mr. Harrison joined the klystron laboratory of the Sperry Gyroscope Company at San Carlos, California in May, 1940 and is now located at the Sperry Research Laboratories in Garden City, Long Island, New York. He is an associate of the American Institute of Electrical Engineers and is a member of Sigma Xi, Tau Beta Pi and Eta Kappa Nu.

W. R. Hill, Jr.

Contributors

Electronics Today and Tomorrow, by John Mills


This book is intended for the intelligent layman and definitely not for the expert. It presents an interesting introduction to many things electronic, especially suitable for those people who have been using electronic devices without ever stopping to wonder how they work.

In the Introduction there is given a necessarily cursory but interesting discussion of the physics underlying the new science of electronics and a brief recapitulation of applications such as telephony, broadcasting, and television. In elucidating the concept of electromotive force the author calls it "electrom moving force."

Part I starts with hot cathodes and continues with diodes, triodes, multigrid tubes, phototubes, and gas-filled tubes giving uses and applications of each.

Part II treats more complicated topics—electron guns and their application to cathode-ray tubes for oscillographic and television use; electron optics and its application to electron microscopy; ultra-high frequencies and their generation; and finally a discussion of the cyclotron.

The book contains no line drawings, diagrams, or photographs. The exposition is clear, simple and interesting.

V. K. Zworykin
RCA Laboratories
Princeton, New Jersey
Proceedings of the I.R.E.

From 1925 to 1927 Mr. Roberds was assistant professor of physics at the University of Kansas, and was on the staff of the University of Arkansas from 1927 to 1942. In 1942 he became associated with the Radio Corporation of America as development engineer in the field of applications of radio-frequency power.

He is a member of Sigma Xi and the American Physical Society.

Alfred W. Simon was born in Chicago, Illinois, on September 16, 1897. He studied physics and mathematics at the University of Chicago, receiving the degrees of B.S. in 1921 and Ph.D. in 1925. Subsequently, as a National Research Fellow in Physics at the California Institute of Technology, he carried on researches on electrostatic generators. Entering the industrial field in 1927, he was appointed director of the Cottrell Research Laboratory of the Tennessee Coal, Iron and Railroad Company, a subsidiary of the United States Steel Corporation, and held this position until 1932. From 1935 to 1937 he was employed as research physicist in the radio laboratory of the Stewart Warner Corporation, where he specialized in the design of coils for radio receivers; from 1937 to 1939 he was employed as a geophysicist by the Geophysical Research Corporation and the Stanolind Oil and Gas Company of Tulsa, Oklahoma; and from 1939 to 1941 he was chief engineer of the American Harmonica Company in Chicago. At the outbreak of the war, Dr. Simon transferred to the Naval Ordnance Laboratory of the United States Navy Yard in Washington, D. C., where he stayed until 1943 when he was appointed instructor in mathematics and communication engineering in the Army Specialized Training Program at Washington University in St. Louis. At present, he holds the position of chief engineer with John Luellen and Company at Hazel Crest, Illinois.

Dr. Simon has been a frequent contributor to scientific and engineering journals since 1921.

F. R. Stansel (A’26-M’33-SM’43) was born in Raleigh, North Carolina, on August 7, 1904. He received the B.S. in E.E. degree from Union College in 1926, the M.E.E. degree from the Polytechnic Institute of Brooklyn in 1934, and the D.E.E. degree from the same institution in 1941. In 1926 he joined the Bell Telephone Laboratories and until 1936 was engaged at their Whippany laboratory in the development and design of high-power radio transmitters. Since 1936 Dr. Stansel has been engaged in the development and design of special testing equipment for the armed forces. He is a member of the American Institute of Electrical Engineers and Sigma Xi.

Chandler Stewart, Jr. (S’39-A’41) was born in San Francisco, California, on February 1, 1916. He received the B.S. degree in electrical engineering from the University of California in 1939.

From 1939 to 1940 he was employed as a radio engineer by R.C.A. Communications, and from 1940 to 1941 he was with the United States Navy Bureau of Ships. Since 1941 Mr. Stewart has been with the United States Army Signal Corps, for whom he spent a year instructing inspectors and trainees, and later became engaged in developing methods for and making specialized electrical measurements at the Aircraft Radio Laboratory, Wright Field, Ohio. He is a member of Tau Beta Pi.

Karl S. Van Dyke (M’26-SM’43) was born at Brooklyn, New York, on December 8, 1892. He received the B.S. degree in 1916 and the M.S. degree in 1917 from Wesleyan University, and the Ph.D. degree in 1921 from the University of Chicago. From 1916 to 1917 Dr. Van Dyke was an assistant in physics at Wesleyan University; 1917 to 1919 in the general engineering department of the American Telephone and Telegraph Company; 1919 to 1921, assistant in physics at the University of Chicago; 1921 to 1925, an assistant professor of physics at Wesleyan University; 1925 to 1928, associate professor; 1928 to date, professor; and 1941 to date, on leave of absence; 1941 to 1942, assistant director of Division of Defense Research, University of California; 1942, associate director; 1942 to 1943, expert consultant, Office of the Chief Signal Officer, Army Service Forces; 1943 to date, chief physicist. He is a Fellow of the American Association for the Advancement of Science, and a Member of the American Physical Society, the Acoustical Society of America, and Sigma Xi.
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Proceedings of the I.R.E. January, 1945
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Admission to Senior Member
Young, L. Mc., 152 Patterson Rd., Dayton 9, Ohio

Transfer to Member
Albertson, F. W., Dow, Lohner and Albertson, Munsey Bldg., Washington 4, D. C.

The following admissions and transfers (December) were approved on November 27, 1944:

Transfer to Senior Member
Bridgland, C. J., 266 S. Kingsway, Toronto, Ont., Canada
Clark, J. H., 1132 E. Elmwood Ave., Burbank, Calif.
Cobine, J. D., 80 Douglas Rd., Belmont 78, Mass.
Deardorff, R. W., 7627 S.E. 30 Ave., Portland 2, Ore.
Everett, L., 40 S. Muna Ave., East Orange, N. J.
Goldberg, H., 215 Brett Rd., Rochester 9, N. Y.
Marks, W. S., Jr., 668 Broadway, Long Branch, N. J.
Mittlemann, E., 427 W. Wrightwood Ave., Chicago 14, Ill.
Pekin, H. T., 543 Centre St., Newton 58, Mass.
Sapiro, L. C., 250 W. 99 St., New York, N. Y.
Simson, A. G., 1701-16 St., N.W., Washington, D. C.
Walz, R. F., 265 Forest Ave., Glen Ridge, N. J.

Admission to Senior Member

Transfer to Member
Adams, J. J., 447 Cottage Hall Ave., Elmhurst, Ill.
Baptist, W. G., 1907 Willow Spring Rd., Dundalk 22, Md.
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Burks, A. W., Moore School of Electrical Engineering, Philadelphia, Pa.
Cutting, W. A., United States Civil Aeronautics Administration, Box 1807, Portland, Ore.
DeShong, J. A., Jr., 1414 N. Austin Blvd., Oak Park, Ill.
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Konskie, P. J., 1704 Melvin Clr., Cincinnati 31, Ohio
Mitchell, F. T., Jr., 4500 Dexter St., N.W., Washington 7, D. C.
Montgomery, B. E., United Air Lines Communications Laboratories, 5595 S. Cicero Ave., Chicago, Ill.
Novy, E. W., 3310 Glenhurst Pl., Cincinnati 9, Ohio
Oxent, J. L., 58-25 Little Neck Pkwy., Little Neck, L. I., N. Y.
Ostaf, W., 2817 Connecticut Ave., N.W., Washington 6, D. C.
Palmer, V. L., 316 Engineering Hall, University of Washington, Seattle 5, Wash.
Probeck, C., 914 S. Menard Ave., Chicago 44, Ill.
Reed, O. W. B., Jr., 170 National Press Bldg., Washington, D. C.
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Admission to Member
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(Continued on page 384)

Proceedings of the I.R.E. January, 1945
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Curtis, D. L., Section B 3508 Base Unit, Trux Field, Madison 7, Wis.

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(Continued on page 40A)

Proceedings of the I.R.E. January, 1945
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## 1/2 HP at 3900 RPM

The output—the weight—the size—of these 4000 Frame Motors are features well worth remembering. Every adaptation of the standard design is engineered for the precise requirements of an aircraft, portable, or industrial application.

### Electrical Features
- Series, shunt, or compound-wound
- Unidirectional or reversible
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- Ventilated or enclosed types
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- Low space factor
- Ball bearing equipped
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- Rugged construction

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<table>
<thead>
<tr>
<th>Feature</th>
<th>4030 Series (Max.)</th>
<th>4030 Series</th>
<th>4030 Series</th>
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<tr>
<td>Watts, Output, Con.</td>
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<tr>
<td>Torque at 3900 RPM (ft. lbs.)</td>
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<td>1.4</td>
<td>1.4</td>
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<td>Torque at 6000 RPM (ft. lbs.)</td>
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<td>Speed Regulation (%)</td>
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<td>Lock Torque (ft. lbs.)</td>
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<td>Volts Input (min.)</td>
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<tr>
<td>Volts Input (max.)</td>
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</tr>
<tr>
<td>Diameter (in.)</td>
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<tr>
<td>Length Less Shaft (in.)</td>
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<td>7 1/4</td>
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</tr>
<tr>
<td>Shaft Dia. (max.) (in.)</td>
<td>6 1/4</td>
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</tr>
<tr>
<td>Weight (lbs.)</td>
<td>9.2</td>
<td>9.2</td>
<td></td>
</tr>
</tbody>
</table>

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(Continued on page 42A)
Seven years ago we started out as a west coast distributor of aircraft parts. We named our company Aircraft Accessories Corporation. Then we started developing aircraft hydraulics. The next thing we knew we were full-fledged manufacturers—and out of the parts business. Later, someone came along with an embryo electronic plant in Kansas City. Being young and ambitious—we bought it. To everyone's amazement—and somewhat to our own—we made it grow. And pay.

NEW NAME
NEW HORIZONS

We're still young, ambitious. Our explorations in hydraulics, electronics and other fields promise post-war growing pains. And so we've outgrown our name. Aircraft Accessories Corporation no longer adequately describes our operations. We couldn't think of a name that did. So we coined one: Aireon. It's a name that's partly aircraft, partly electronics; but it will be largely what we make it. We hope—and intend—to make Aireon worthy of a place among America's most honored corporate and trade names.
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Their use cannot be told but statistics may be interesting. In producing this one type of coil for the Army and Navy we have consumed one-half million miles of wire ... 136,000 pounds of copper. The machines used in winding them have turned 3 TRILLION, 360 BILLION revolutions.

We hope soon to be able to put some of this production capacity and experience to work on YOUR postwar problem.

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(Continued from page 40A)

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MacLeod, D. A., M.T.D., R.M.S. 2344-1, Naval Research Laboratory, Washington 20, D. C.

Madill, L. L., 37 Elmwood Ave., London, Ont., Canada

Main, W. F. Jr., 119 Anastasia Rd., S.E., Washington 19, D. C.


Manning, R. G., 4112 First, N.W., Seattle, Wash.

Marsh, R. A., R.C.A., Clinton, Ont., Canada

Marrano, R. W. S., 44 Ripponoet Ave., Long Branch, N. J.

Masters, E. W., 27-43 Farewell Ave., Chicago 45, Ill.

Mattson, E., 250 S. Beresley Ave., Pasadena 8, Calif.

McKinley, G., 6149 N. Ozark Ave., Chicago 31, Ill.

Meador, R. E., 1504 Wyoming Ave., Dayton, Ohio

Mefford, M. E., 1024 Evans St., San Bernardino, Calif.

Meikle, J. F., 605 W. 95 St., Los Angeles 44, Calif.

Meyer, C. F., 3909 Erie St., S.E., Washington 20, D. C.


Middleton, E. J., 178 St. Frusquin St., Johannesburg, South Africa

Mihelich, J. B., 3313 Fauport Rd., Baltimore 15, Md.


Milne, D. D., National Union Radio Corp., 251 Plane St., Newark, N. J.

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Modley-Jones, H. B., 32 Marl owe Cresc., Ottawa, Ont., Canada


Moon, W. E., 34 Mary Ave., Dayton 5, Ohio

Moskowitz, L., 7 Mockingbird Lane, Audubon, N. J.

Muir, J., 1903 Broderick St., San Francisco 15, Calif.


Nelson, A. E., 121 Galveston Pl., Washington 20, D. C.

Nexon, V. J., Hq. Air Technical Service Command, Box 1208 Area "A," Wright Field, Dayton, Ohio

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Pearson, P., 15 Lime Cresc., Old Trafford, Manchester 16, England

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Pierce, C. T., 74 Pavia Ave., Kearney, N. J.

Phillips, C. W., 72 Grand Ave., Ely, Cardiff, South Wales, England

Powers, J. B., 4035 N. Mozart St., Chicago 18, Ill.

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Quijano, R. A., Box 124, Angola, Ind.

Ramler, W. J., 1156 Murray Hill Ave., Pittsburgh 17, Pa.

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Reiner, I. C., 5 Huntingdon Pl., Dayton 10, Ohio

Rosen, A. C., 162 St. Lawrence St., Longueil, Que., Canada

Ross, A. L., Jarvis Apartments, Princess Ave., London, Ont., Canada


Runkle, E. G., Jr., R. F. D. 10, North Kansas City 16, Mo.

Sanford, C. V., Box 1133, New London, Conn.

Scallum, J. D., 109 Smithwood Ave., Catonsville 28, Md.


Schmitt, E. C., 2218 N. Sixth St., Harrisburg, Pa.

Schlegel, R. A., 6237 Union St., New York 1, N. Y.

Spenner, J. C., 346 Beacon St., Boston 15, Mass.

Scott, G. H., 502 N. College Ave., Fayetteville, Ark.

Sharp, A. G., 321 N. Lawn, Kansas City, Mo.

Sharrard, L. L., 12 Bosworth St., Springfield 8, Mass.

(Continued on page 44A)

Proceedings of the I.R.E.

January, 1945
FINEST PICTURE QUALITY IN BLACK AND WHITE AND IN FULL COLOR!

Sharper, more brilliant pictures than ever before possible are now a reality with Federal's new broadband television technique . . .

In a revolutionary contribution to the television art, Federal's system permits combining sight and sound on one carrier frequency . . .

For the broadcaster—a single transmitter, and consequently, lower first cost, lower power consumption, less space requirement, and fewer high power tubes . . .

For the television audience—a simpler, less expensive receiver, more compact and efficient, and requiring fewer tubes.

This great forward stride is the logical outcome of Federal's long list of achievements in the field and the contribution of Federal's engineers to the development of the "Micro-ray" more than a decade ago . . . the forerunner of modern television technique.

And as a result . . . Federal has been selected by the Columbia Broadcasting System for the construction of its new television transmitter atop the Chrysler Tower in New York.

Federal's modern television technique will also be reflected in an equally advanced Federal television receiver for the home . . . producing the finest picture quality.

Federal has the experience, the facilities, the technique needed to build television equipment for any broadcasting requirement. For the best in television—see Federal first.
ONE CENTRAL SOURCE FOR
All Types of Industrial
ELECTRONIC TUBES

PHOTO-ELECTRIC TRANSMITTING
- - - RECEIVING
RECTIFIER

Write for it!
on Request
BUYING

CONTROL

AVAILABLE

POWER

GUIDE

HELPFUL

METERS, BROADCAST STATION EQUIPMENT, RELAYS, CONDENSERS, CAPACITORS, RESISTORS, RHENIUM, TRANSFORMERS,
SWITCHES, COAXIAL CABLE, WIRE, SOLDERING IRONS, MICROPHONES, SPEAKERS, TECHNICAL BOOKS, ETC.

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Immediate Delivery

Here you have the advantage of a complete, centralized service on all types of industrial electronic tubes. Many are "on-hand" for rush delivery! This enables you to obtain the exact type you require, in the shortest possible time. Rectifier, power, control, photo-electric, cathode ray, transmitting, or receiving ... in RCA, G.E., Raytheon, Ampex, Eimac, Taylor, and other well known makes.

Save time and work — Call Allied First!
Write, Wire or Phone Haymarket 6800
Engineering Service Available

EVERYTHING IN ELECTRONICS & RADIO
It's faster, simpler to get all your electronic and radio supplies from this one central source. We carry the largest and most complete stocks of parts and equipment under one roof ... ready for immediate shipment. Besides, our procurement experts are in constant contact with all leading manufacturers. This complete service simplifies and speeds supply of diversified needs.

ALLIED RADIO CORPORATION

833 W. Jackson Blvd. Dept. 3-A-5 Chicago 7, Illinois

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Scheer, A. C., 1829 Lunt Ave., Chicago 26, Ill.
Screator, A. C., 20 Fleet Post Office, San Francisco, Calif.
Sublett, R. H., 3103 E. Ave., N.E., Cedar Rapids, Iowa
Swanson, R. E., 1268 W. 72 St., Kansas City, Mo.
Swingle, L. M., 4723—48 St., N.W., Washington 16, D. C.
Tarasut, S., 3510 W. Cortland St., Chicago 47, Ill.
Tharp, B. W., 3055 N. Illinois St., Indianapolis 8, Ind.
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Vore, M. P., 2519 Wilkins Ave., Baltimore 3, Md.
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Wolfson, G. W., 2718 W. 51 Ter., Kansas City, Kan.
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Young, H. A., 587 N. Madison Ave., Pasadena, Calif.
Zumsteg, H. O., 105 Chadbourne Ave., Millbrae, Calif.

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Allen, J. E., 425 Albert St., East Lansing, Mich.
Arnett, D. H., 2115 Hamphill St., Fort Worth, Texas
Arsem, A. D., M.I.T., Student

(Continued on page 46A)
The United States Navy has awarded the men and women of Hallicrafters a special "Certificate of Achievement"... first award of its kind... for outstanding service with the radar-radio industries of Chicago in speeding vital war material to the Navy. Added to the four Army-Navy "E" awards, this makes five times Hallicrafters workers have been cited for distinguished service. They promise that this kind of service will be continued until total victory is ours.

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hallicrafters RADIO

THE HALLICRAFTERS CO., MANUFACTURERS OF RADIO AND ELECTRONIC EQUIPMENT, CHICAGO 16, U. S. A.
BLAW-KNOX speaks to you over the air

Tonight when you tune in, it's highly probable that your favorite programs will emanate from stations equipped with Blaw-Knox Radio Towers.

These Vertical Radiators have been specified by major broadcasting systems because they are both electronically and structurally sound — providing clear signals and maximum range.

It is of note, too, that Blaw-Knox Directional Radio Beacons are used to guide all air transport service in the United States.

BLAW-KNOX vertical RADIATORS

(Continued from page 44A)
"Tailor-made"

ELECTRONIC EQUIPMENT
ASSEMBLIES

Designed and produced from stem to stern by recognized experts to match your needs exactly.

DIELECTRIC AND INDUCTION HEATING EQUIPMENT • TUNING UNITS • TEST EQUIPMENT • RADIO TRANSMITTERS • HIGH AND ULTRA-HIGH FREQUENCY EQUIPMENT

B & W is neither too large for the smallest job nor too small for the largest. Write for details, outlining your requirements.

BARKER & WILLIAMSON

AIR INDUCTORS • VARIABLE CONDENSERS • ELECTRONIC EQUIPMENT ASSEMBLIES

DEPT. EL-114, 235 FAIRFIELD ROAD, UPPER DARBY, PA.

Exp. LINDETEVES, INC., 10 Rockefeller Plaza, New York, N. Y., U. S. A.

Proceedings of the I.R.E. January, 1945
FROM −55°C (−67°F) to +85°C (+185°F) FOR OVER 2400 HOURS and STILL HERMETICALLY SEALED!

Two hundred and forty seven cycles of alternating heat and cold for over two thousand four hundred hours failed to break the seal or cause failure of oil filled Chicago Transformers.

Chicago Transformer’s bushing construction and deep-sealed drawn steel cases will withstand the severest conditions.

Write for full particulars on this improved hermetic line.
DO YOU MAKE:

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- Loud Speakers
- Headsets
- Microphones
- Hearing Aids
- Electrical Musical Instruments
- Sound-powered Telephones
- Telephone Ringers
- Voltage Regulators
- Phonograph Cutting Heads
- Phonograph Pick-ups
- Vibration Pick-ups
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AUTOMOTIVE AND AVIATION EQUIPMENT?
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- Voltage Regulators
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- Speedometers
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- Ammeters
- Voltmeters
- Galvanometers
- Seismographs
- Oscillographs
- Flux Meters
- Watt-hour Meters
- Light Meters
- Cardiograph
- Recorders
- Vibration Pick-ups

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- Magnetic Chucks
- Magnetic Conveyors
- Magnetic Clutches
- Magnetic Damping Devices
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- Temperature and Pressure Control Equipment
- Circuit Breakers
- Limit Switches
- Holding Magnets
- Clocks
- Toys and Novelties
- Coin Separators
- for Vending Equipment

IF YOU make any of the above products, it will pay you to find out how better permanent magnets can improve efficiency and reduce costs. Put your design, development or production problems up to The Arnold Engineering Company. Arnold engineers have been of great assistance to many manufacturers and are at your service to advise exactly what Alnico permanent magnet will solve your particular problem.

NEW! Get your copy of this valuable, up-to-the-minute manual on the design, production and application of modern Alnico permanent magnets. Write us, on your company letterhead, today.

THE ARNOLD ENGINEERING COMPANY
147 EAST ONTARIO STREET, CHICAGO 11, ILLINOIS
Specialists in the manufacture of ALNICO PERMANENT MAGNETS
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. 

PROCEEDINGS of the I.R.E.

TELEVISION TECHNICIANS
The Television Laboratories of the Columbia Broadcasting System, in New York, need television technicians. Men having had definite experience in the television field, transmitters, or receivers, preferred. Excellent opportunity for well qualified applicants. Our staff knows of this advertisement and replies will be kept confidential. Write, giving all details, to CBS Television Engineering Department, 485 Madison Avenue, New York 22, New York.

ENGINES
A Midwestern manufacturer of radio transmitters and associated equipment has openings for several junior project engineers qualified to supervise or assist development of transmitters, speech input systems, control apparatus, and similar items. Salary average $2500 per year. Give full details first letter. Address Box 365.

ELECTRICAL ENGINEER FOR ELECTRONIC RESEARCH
An unusual opportunity for a man who has a knowledge of hot and cold cathode tubes and tube applications in amplifiers, multivibrators, triggers, and switching circuits. Permanent position in laboratory of established manufacturer, doing research and development work, both present and postwar. Salary open and commensurate with experience, initiative, and ability. Include complete details of education, experience, and WMC availability with reply to Box 365.

ELECTRICAL OR RADIO ENGINEER
Should have general experience in Electrical or Radio Measurements. Graduate engineer (radio or electrical) from recognized engineering school, desirable. Long-established radio-electrical components manufacturer in New England, doing war work at present. Postwar future for right man. Give detailed outline of experience, etc., salary requirements. Address Box 367.

ELECTRONIC ENGINEER
Electronic engineer or physicist for developmental work. Also, electronic technician for construction work on radio test equipment. Post-war future in both positions. Write to Premier Crystal Laboratories, 63 Park Row, New York 7, N.Y.

ASSISTANT PROFESSORS
Assistant professors or instructors in electrical engineering to specialize in electronics and communications, and illumination. Strong eastern engineering college. Submit professional record and photograph with application. Positions permanent. Address Box 362.

ELECTRONIC ENGINEERS AND DRAMSMEN
The services are required of several electronic equipment design engineers capable of supervising the system layout of electronic and electro-mechanical devices.

For laboratory with adequate facilities to take on the design of R.F. precision measuring instruments on a contract basis. Send reply to Box 359.

ELECTRONICS ENGINEERS
Development engineers on television and ultra-high-frequency tubes. Technician on tubes. Radio engineers on special applications. Write full details to Box 363.

(Continued on page 53A)

For Laboratory with adequate facilities to take on the design of R.F. precision measuring instruments on a contract basis. Send reply to Box 359.

ELECTRONICS ENGINEERS
Development engineers on television and ultra-high-frequency tubes. Technician on tubes. Radio engineers on special applications. Write full details to Box 363.

(Continued on page 53A)
When Victory is ours, and Peace returns to the land ... will YOU be snug in your own paid-for home—with security against illness, provision for retirement, education for your children—all ASSURED BY BONDS?

Or will you be one of those “too busy” people who “meant to buy Bonds tomorrow”? Who find themselves entering the postwar period empty-handed . . . facing the future with uncertainty? The choice is yours.

For, wherever you are, in the service, the factory, the farm, the office, YOU and that family you love so much can be provided for—or can be neglected . . . it's up to you.

Yes, actually! It all depends on what you do. On what you do before the war's over; on what you do, in fact, TODAY!

You must know by now that the best, the safest investment in the world—the one with the most liberal terms—is United States' WAR BONDS. What you may not know is that they are the best insurance policy there is. If you regularly invest a percentage of your weekly income in bonds—and also buy them with your savings or extra earnings, NOW—you can accumulate that very Nest Egg which spells security for your family . . . easily, painlessly, right away. And, in just ten short years, you'll have 4 DOLLARS FOR EVERY 3 you invest!

We guess that makes War Bonds just about the best darn buy there is. You're helping the boys to come home sooner—and you're insuring a bright, safe future for those you love. When you invest in Bonds, the full faith and credit of the United States Government is behind that future of yours!

If You Believe in America . . . BUY BONDS!

Here at Kenyon, we're proud to play our small role on the stage of a BIG war. That's why EVERY Kenyon transformer used by our fighting forces throughout the world reflects only the highest precision craftsmanship. Kenyon workers are doing their share—bringing Victory closer by turning out top quality transformers uninterruptedly—and as fast as possible!
**INSTRUMENT ENGINEER WANTED**

Engineer needed to develop and apply electronic instruments for measuring vibrations, strains, pressures and temperatures. Experience with electro-mechanical devices desirable. Position of permanent nature and at present concerned with measurement of aircraft and engine characteristics on projects of war urgency.

Apply in writing stating education, experience and salary expected.

Persons now utilized at highest skill in essential industry need not apply as all hiring is done in accordance with Hartford area stabilization plan.

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**ENGINEERS**

For Mechanical Design of Radio Instruments

A good connection today can mean security for you in the postwar era. Aggressive, successful newcomers in home radio, we have openings for several men with prewar experience in producing low-cost designs for fast manufacture. Write today. Postwar program in the offing!

**WANTED**

Radio Engineer

Experienced in **MICROWAVE TECHNIQUE**

To work with experienced designers in developing new products and applications of the microwave spectrum. Must have had prewar radio and wartime microwave experience. Ph.D. or D.Sc. preferred. Large postwar program planned. Write today.

**MAGUIRE INDUSTRIES, INC.**

Electronics Division

342 W. Putnam Ave., Greenwich, Conn.

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**MICROWAVE TECHNIQUE OFFERING!**

**POSTIONS OPEN**

(Continued from page 50A)

**ELECTRONIC EXPERT**

Needed in management of large New York plant. Capable of supervising manufacture of transmitting and receiving radio assemblers, transformers and other electronic equipment. Excellent opportunity. Write personal and professional qualifications, salary expected, to Box 210, Suite 1024, 122 E. 42 St., New York 17, N.Y.

**ELECTRONIC ENGINEER**

Radio or electronic engineer for design and development of Army and Navy electronic equipment. Position offers excellent opportunity with well established and expanding company in Connecticut, employing over one hundred personnel. The company's big post-war program in the industrial electronics, radio, and aircraft communications fields assures engineering personnel a continued opportunity for advancement. Address reply to Box 364.

**RADIO ENGINEERS, SUPERVISORS AND TECHNICIANS**

Chief Radio Engineers, Transmitter and Studio Supervisors and Technicians between thirty and forty-five years of age are needed at once in important war work in the Pacific to construct and operate radio stations. These positions are with the United States Government, with good salaries and subsistence, and for the duration plus six months. Interested persons with actual broadcast experience should write, giving details of radio work, to Box 356.

**RADIO, ELECTRICAL AND MECHANICAL ENGINEERS**

In the development and production of all types of radio-receiving and low-power transmitting tubes. Excellent post-war opportunities with an established company in a field of opportunities. Apply in person, or write to Personnel Manager of Raytheon Manufacturing Company, 55 Chapel Street, Newton, Mass.

**RADIO ENGINEERS**

Need radio engineers with experience in Frequency-Modulation transmitting and receiving equipment. Familiarity with E.C.C. rules and field operation of equipment desirable. Send complete experience and education in letter of application, and state salary desired. Company located in the Midwest where living conditions are good, and expenses below average. Address to Box 351.

**RADIO ENGINEER**

Unusual opportunity for experienced radio engineer. Well established medium-size Midwest radio manufacturer. Large post-war program. Nationally advertised radio line. Write qualifications and experience to the Agency Service Corporation, 66 East South Water Street, Chicago 1, Ill.

**VACUUM-TUBE DESIGNERS**

Engineers and physicists for research and development work on small vacuum tubes.

An opportunity for post-war employment with a growing organization doing both war and essential civilian production. Recent graduates with adequate training and experienced personnel will be considered for these positions. Certificate of availability required. Write to Director of Research, Somatone Corporation, Elmhurst, 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 exist at 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, Ill., and Locust St., Haverhill, Mass.

**FIELD SERVICE ENGINEERS**

For domestic and foreign service. Must possess good knowledge of radio. Essential workers need release. Write to Hazeltine Electronics Corporation, 36-23 Little Neck Pkwy., Little Neck, L.I., N.Y.

(Continued on page 54A)

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**WANTED ENGINEERS**

Radio

* Electrical

* Electronic

* Mechanical

* Metallurgical

* Factory Planning

* Materials Handling

Manufacturing Planning

Work in connection with the manufacture of a wide variety of new and advanced types of communications equipment and special electronic products.

Apply (or write), giving full qualifications, to: R.L.D.

EMPLOYMENT DEPT.

**Western Electric Co.**

100 CENTRAL AVE., KEARNY, N.J.

*Also: C.A.L.

111 Locust St., Haverhill, Mass.

Applicants must comply with WMC regulations
"East is east 'and west 'is west," wrote the poet, "and never the twain shall meet."

But he was wrong.

The twain shall meet. The peoples of the earth shall begin to know each other — and work together — for peace and plenty for all.

And the miracle will be due in great part to the coming Age of Flight. . .

Communications will help make Air Transport safer — more economical — faster. Harvey-Wells Electronics produces communications equipment designed for complete dependability, engineered for maximum efficiency . . . selected for War, perfected for Peace.

In the Age of Flight, look to Harvey-Wells for ideas, skill, imagination — setting the pace for progress in communications!

Know the company that wants your business! Our CASE BOOK tells the story of Harvey-Wells and its place in Electronics. Send for it today. Your name on your letterhead is sufficient.
CHIEF BROADCAST RECEIVER ENGINEER

Large eastern radio manufacturer has an opening for a Chief Engineer in its Broadcast Receiver Section. Excellent opportunity for the right person. Must have adequate experience and background. Salary $8,000 to $12,000 per year depending upon ability and experience of applicant.

War Manpower Commission Regulations Apply.

Address all replies to:
BOX NO. 360
THE INSTITUTE OF RADIO ENGINEERS
330 West 42nd St.
New York 18, N.Y.

CHIEF LOUD SPEAKER ENGINEER

The Rola Company, Inc. requires the services of an Engineer who has had several years experience and capable of heading this division. Present work is on 100% urgent war products.

Excellent post-war opportunity with an outstanding, financially sound, long-established manufacturer of radio loudspeakers and transformers.

This Company now has definite plans for an extensive expansion in its Engineering and Manufacturing Divisions.

Salary open.

Write to
The Rola Company,
Inc.
2530 Superior Avenue
Cleveland 14, Ohio

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.

RADIO-ELECTRONIC ENGINEERS

A young progressive radio-electronic firm needs top-flight men for these key positions: Electronic engineers and technicians, Electro-mechanical engineers, familiar with mechanical design of electrical and electronic equipment.

Chief inspector
Supplier's contact engineer
Master mechanic
Transformer engineers
Project engineers

Engaged 100% in war work, with excellent post-war future and possibilities. Our staff knows of these openings. Write in confidence to Box 352.

ELECTRICAL ENGINEERS

Electrical engineers for research and development in the field of radio communications and electrical test equipment. Good post-war opportunity. Address reply to Allen D. Cardwell Mfg. Corp., 83 Prospect Street, Brooklyn, N.Y.

A NEW JUNGLE FIGHTER

TROPICALIZED Q-MAX A-27

H. F. Lacquer Protects Communication Equipment Against FUNGI

Tropical fungus and mold does not respect the finest workmanship and performance which can be built into communication and electrical equipment. Ruthless as any Jap, it attacks unprotected surfaces and swiftly deteriorates vital communications such as walkie-talkie, handy-talkie, radar, power plants, signal detector apparatus and scores of other electrical devices that "move up" with our armed forces and contribute to victory. But they can "move up", jungle-proofed against this insidious enemy, if you use Tropicalized Q-Max A-27 H.F. Lacquer.

The tropicalizing of this effective dielectric coating material was a wartime achievement of our chemists who sought and found an ideal fungicide that would combine well with Q-Max Lacquer, and yet retain its good electrical characteristics and its high corrosion resistance.

To fungus-proof components of your communication equipment destined for the tropics and shut out harmful moisture, play safe by using this tropicalized lacquer.

MAX VAN PELS
441 LEXINGTON AVE., NEW YORK 17, N.Y.
This complete line, covering a power range of 50 to 5,000 watts, embodies 18 years of pioneering and experience in the design and manufacture of tantalum tubes. Special plate, grid, and filament design, and new metal-to-glass seals, give Gammatrons remarkable VHF performance. Other features: ability to withstand high plate voltages, complete protection against tube failure due to overloading, and long, efficient operating life. The Gammatron engineers responsible for these developments will be glad to help you with your special problems.
Now, Even Greater Facilities

The new and larger Templetone plant at New London, Conn.

Our entire Electronics Division is now located in new quarters—affording not only greater facilities to meet ever-expanding wartime production, but also greater scope to anticipate the great electronics developments of peacetime. From this vast, new plant—containing 100,000 square feet of space—will come rich contribution to the vast commercial requirements at war's end.

Temple
Electronics Division
TEMPLETEONE RADIO MFG. CORP.
New London, Conn.
The part illustrated is an airborne radio insulating part... made from grade "L" DILECTO... a laminated phenolic plastic. It was sawed, milled, drilled, countersunk and tapped. Tolerance requirements were close. DILECTO parts such as this one will be widely used in all branches of air transportation.

Here is a strong, tough plastic... with high electrical insulating properties that remain stable under extremes of temperature and humidity. DILECTO is readily fabricated on ordinary metal working tools. It is NON-corrosive and highly resistant to many chemicals.

This versatile plastic may be the answer to your "What Material?" problem. C-D technicians will be glad to help you find out. Their wealth of "Know-How," the result of a half century of service to industry, makes available to you thousands of case histories of solved design and operational problems.

C-D PRODUCTS

The Plastics
DILECTO—A Laminated Phenolic.
CELORON—A Molded Phenolic.
HAVEG—Plastic Chemical Equipment, Pipe, Valves and Fittings.

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DIAMOND Vulcanized FIBRE
VULCOID—Resin Impregnated Vulcanized Fibre.

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Available in Standard Sheets, Rods and Tubes; and Parts Fabricated, Formed or Molded to Specifications.

Descriptive Literature
Bulletin GF gives Comprehensive Data on all C-D Products. Individual Catalogs are also Available.

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Throughout the entire war, Permoflux Acoustical Devices have consistently surpassed the efficiency specifications of Army and Navy requirements. In addition, they have established new standards of durability under the most grueling service conditions. Permoflux products for postwar will reflect these achievements as they render improved performance in hundreds of applications. Let us consult with you on your specific design problems.

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3. Continuous sweep circuit has a range when free-running of from 15 c.p.s. to 150 kc. When moderately synchronized with a signal of higher frequency, however, it will operate at much faster rates. This oscillograph shows a one megacycle sine wave at a sweep frequency of approximately 300 kc. Return trace is normally completely blanked but may be seen if necessary by fully advancing the intensity control. Notice the good linearity of this time-base as well as that of the driven sweep in (2).

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January, 1945

Proceedings of the I.R.E.
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**OM-CAPACITORS**

| **RATINGS**   | .05, .1 and 2 x .05 600 V.D.C. |
| **STANDARD CAPACITY TOLERANCE** | 20%** |
| **GROUND TEST** | 2,500 V.D.C. |
| **OPERATING TEMPERATURES** | -55° F to 185° F |
| **SHUNT RESISTANCE** | 20,000 megohms |
| **POWER FACTOR** | At 1,000 cycles—.0075 |
| **CONTAINER SIZE** | Width 5/8", length 1-5/16", height 1-11/64" |
| **MOUNTING HOLE CENTERS** | 1/2" |

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This new separate mounting is stronger and helps prevent leaks caused by breaks in can. This outstanding Tobe design takes the minimum amount of space.

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Proceedings of the I.R.E. January, 1945

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If you haven’t seen these plates before, you may think them the futuristic effort of a designer on the day after the night before. Actually they represent some of the steps in the development of an entirely new circuit for ultra-high-frequency use.

The problem of designing a compact ultra-high-frequency circuit with a large and continuously-adjustable range, and with no sliding contacts, is a difficult one.

Transmission lines, with none of these desirable features, have been used widely in the past. They offer numerous mechanical difficulties, very precise machine work being required to obtain acceptable accuracy. In addition, very often they are too large to be incorporated in many instruments.

The new circuits, developed by General Radio, are for obvious reasons called Butterfly Circuits. They have no sliding contacts, afford a tuning ratio of about 4 to 1, are very compact, can be designed for a satisfactory value of Q, and are mechanically comparatively simple.

The design of Butterfly Circuits is described in detail in the October 1944 issue of the G-R Experimenter. If you haven’t seen a copy, we’d like to send you one.