PROCEEDINGS OF
The Institute of Radio Engineers

Volume 13 APRIL, 1925 Number 2

CONTENTS

CORRECTION

On page 805 of The Proceedings for December, 1924 (Volume 12, Number 6), in footnote 3, line 4, change "Major Le Fry" to "Major Lefroy."

GENERAL INFORMATION

The Proceedings of the Institute are published every two months and contain the papers and the discussions thereon as presented at the meetings in New York, Washington, Boston, Seattle, San Francisco, Philadelpha, or Chicago.

Payment of the annual dues by a member entitles him to one copy of each number of the Proceedings issued during the period of his membership.

Subscriptions to the Proceedings are received from non-members at the rate of $1.50 per copy or $9.00 per year. To foreign countries the rates are $1.60 per copy or $9.60 per year. A discount of 25 per cent is allowed to libraries and booksellers.

It is understood that the statements and opinions given in the Proceedings are the views of the individual members to whom they are credited, and are not binding on the membership of the Institute as a whole.

PUBLISHED BY
THE INSTITUTE OF RADIO ENGINEERS, Inc.
37 WEST 39TH STREET, NEW YORK, N. Y.
EDITED BY
ALFRED N. GOLDSMITH, Ph.D.

OFFICERS AND BOARD OF DIRECTION, 1925

Terms expire January 1, 1926; except as otherwise noted

PRESIDENT
John H. Dellinger

VICE-PRESIDENT
Donald McNicol

TREASURER
Warren F. Hubley

SECRETARY
Alfred N. Goldsmith

EDITOR OF PUBLICATIONS
Alfred N. Goldsmith

MANAGERS

(Serving until January 1, 1926)

Edward Bennett
Lloyd Espenschied
John H. Morecroft
Louis A. Hazeltine
John V. L. Hogan

(Serving until January 1, 1927)

A. H. Grebe
H. W. Nichols

(Serving until January 1, 1928)

Melville Eastham
A. E. Reoch

WASHINGTON SECTION

ACTING EXECUTIVE COMMITTEE

CHAIRMAN
Comm. A. Hoyt Taylor
Navy Department,
Washington, D. C.

SECRETARY-TREASURER
C. B. Mirick,
Naval Research Laboratory, Bellevue
Washington, D. C.

BOSTON SECTION

CHAIRMAN
George W. Pierce
Harvard University,
Cambridge, Mass.

SECRETARY-TREASURER
Melville Easthan
11 Windsor St.,
Cambridge, Mass

SEATTLE SECTION

CHAIRMAN
Charles E. Williams
8326 13th Avenue, N.W.
Seattle, Washington

SECRETARY-TREASURER
R. H. Berkheimer
1426 Elizabeth Street,
Bremerton, Washington

SAN FRANCISCO SECTION

CHAIRMAN
Major J. F. Dillon
526 Custom House,
San Francisco, Cal.

SECRETARY-TREASURER
D. B. McGown
Custom House,
San Francisco, Cal.

SOME TRANS-PACIFIC RADIO FIELD INTENSITY MEASUREMENTS*

By

L. W. Austin

(Laboratory for Special Radio Transmission Research, Bureau of Standards, Washington, D. C.)

(Conducted jointly by the Bureau of Standards and the American Section of the International Union for Scientific Radiotelegraphy.)

Radio field intensity measurements for frequencies varying roughly between 1,000 and 15 kc. (300 m. and 20,000 m.), and for distances up to 6,500 km. by daylight and over salt water, have been made by a number of independent observers and the results with some exceptions[1] are in fair agreement. For frequencies from 1,000 at least down to 60 kc. (300 m. to 5,000 m.), the observed results agree within the limits of experimental certainty with the values calculated from the Austin-Cohen formula, up to the greatest distances attempted (5,500 km.).[2] The lower frequencies ordinarily used for long-distance communication, say from 15 to 30 kc. (10,000 to 20,000 m.), give observed values somewhat larger than those calculated. At a distance of 6,000 km. this ratio of observed calculated values amounts, on an average, to about two to one.[3] Only a limited number of observations have been taken at distances much greater than this, and these have generally indicated a considerable increase in the observed to calculated ratio.[4]

*Received by the Editor, January 24, 1925. Published by permission of the Director of the Bureau of Standards of the United States Department of Commerce.

[1] G. Vallauri, Proceedings of The Institute of Radio Engineers volume 8, page 286, 1920.
M. Guierre, "Radio Review," volume 2, page 618; 1921.
M Baumler, "Elek. Nach. Tech.," volume 1, page 50; 1924.

[2] L. W. Austin, "Bureau of Standards Scientific Papers, number 159, 1911, and number 286, 1914.
R. Bown, C. R. Englund and H. T. Friis, Proceedings of The Institute of Radio Engineers, volume 11, page 115, 1923.

[3] G. W. Pickard, Proceedings of The Institute of Radio Engineers, volume 10, page 161, 1920.
J. L. Eckersley, "Jour. I. E. E." (London), volume 58, page 677, 1921.
L. W. Austin, Proceedings of The Institute of Radio Engineers, volume 11, page 459, 1923 and volume 12, page 389, 1924.

[4] M. Guierre, "Radio Review," volume 2, page 618, 1921.

In order to get more reliable data at these greater distances, observations were taken in August and September, 1924, at San Diego, California, on the signals from Cavite, Philippine Islands, and from Malabar, Java, the distance from Cavite to San Diego is 11,000 km. with a difference in time of eight hours. This gives about two hours for observations in September without approaching the time of sunrise or sunset too closely. The distance from Malabar is 14,700 km., with a time difference of nine hours. These are about the greatest distances that can be obtained for all daylight and approximately all water signal path with the present high-power stations of the world, except perhaps between Japan and Chili. This last would, however, give about ten hours difference in time and bring the sending and receiving stations rather close to their respective sunrise and sunset times.

The receiving measurements were made in the United States Naval receiving station, Point Loma, San Diego, under receiving conditions which, while not ideal, are believed to have given errors not greater than twenty per cent. On account of the weakness of the signals, in comparison with the atmospheric disturbances, and to keep out strong interference from eastern stations, it was generally found necessary to make the measurements on Cavite and Malabar with uni-directional reception, using the general type of circuit described in the work on the direction of atmospheric disturbances in 1920.[5]

The arrangement of circuits is shown diagrammatically in Figure 1. Here *A* is a single-wire antenna approximately 30 m. long and 20 m. high, *B* a square coil antenna of 48 turns and 2.44 m. on a side. This was mounted so as to be capable of rotation, with its lower side about 3 m. from the ground. *C* is an intermediate circuit to reduce interference, *D* is the detector circuit, and *E* represents three stages of radio-frequency transformer coupled amplification adjusted to prevent regeneration. *F* is a heterodyne generator for producing the local oscillations for beat reception. *H* is a telephone comparator.[6] consisting of a General Radio tuning fork oscillator which generated a thousand cycle current which was measured on a thermo-galvanometer and then passed through a voltage divider and resistances so that a known 1,000-cycle emf. could be impressed on the telephones. In making the measurements, the heterodyne was adjusted so as to give a beat frequency with the signal equal to

[5] L. W. Austin, "Jour. Franklin Institute," page 619, 1921.

[6] Austin and Judson, PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 12, page 521, 1924.

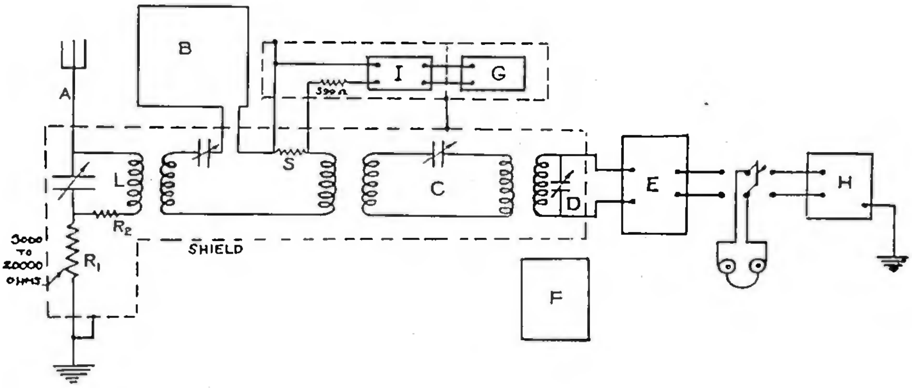


FIGURE 1

the frequency on the telephone comparator. The telephones could than be switched rapidly from the receiver to the telephone comparator, and the voltage divider adjusted until the telephone note was of the same intensity in each. The couplings between *B*, *C*, and *D* were all loose and remained fixed during the whole course of the experiments. The heterodyne was coupled to the detector so as to give the loudest signal, and the coupling was separately adjusted for the different wave lengths received. The inductance *L* was connected to the antenna thru a reversing switch so that the elevated antenna coil combination could be made to receive from either direction in the plane of the coil, while reception from the opposite direction was practically zero.

The receiving set was calibrated by introducing a known emf. in the coil antenna from the radio-frequency generator *G*. This consisted of a tuned plate electron tube generator proper, the output current of which, after being measured with a thermoelement and galvanometer passed thru an attenuation box (artificial line) *I*, kindly loaned by the Western Electric Company. From this it passed to a 1-ohm resistance *S* inserted in the loop. Ordinarily the current from *G* was adjusted to 1.6 milliamperes, which was reduced in the attenuation box *I* to 1/500th of its value, thus giving 3.2 microamperes in the resistance *S*. To prevent capacity coupling, the coil antenna was grounded at one terminal of *S*. The generator with its dry cell batteries and the attenuation box were enclosed in grounded copper boxes; as was the whole receiving set with the exception of the coil antenna.

The calibrating generator was furnished with a fixed condenser giving a frequency of 23.06 kc. (13,000 m.). It had been intended to replace this in San Diego by a variable condenser so that calibration could be made at all the frequencies of the stations being measured. Unfortunately no variable condenser was found available which was small enough to be used in the copper box, so that it was necessary to do the calibrating at the single wave length and make corrections for the effect of change of frequency. As the calibration was made on the coil antenna with the elevated antenna disconnected, a correction for the presence of the elevated antenna in the reception of the signals was also necessary. This correction was determined by measurements made on the stronger stations with and without the elevated antenna. Reversal experiments with the coil antenna showed that the effect of its capacity to earth was negligible.

Table I gives the date for calculation of the field intensities of the sending stations. The Malabar antenna[7] is suspended by steel cables in a mountain ravine about 1.5 km. wide at the top and with an average depth of about 550 m. According to information kindly furnished by Mr. Schotel of the Dutch Colonial Office, the antenna current is approximately 500 amperes at the frequency measured in San Diego. Estimates of the radiation height, from measurements made at moderate distances, vary between 320[8] and 480 m. These varying results are probably due to the mountainous character of the surrounding country. In the calculations the lower value, 320 m. has been used. Even with this value the observed to calculated ratio of Malabar at San Diego is considerably less than that of Cavite, notwithstanding its greater distance. This may be due to the mountainous surroundings.

TABLE I

TRANSMITTING STATION DATA

	Pearl Harbor NPM	Tuckerton WGG	Cavite NPO	Malabar PKX
Frequency, kc.	24.80	18.86	19.34	18.98
Wave length, m.	12,090	15,900	15,500	15,800
Antenna current, Amp.	170	470	180	500
Radiation height, m.	120	67.5	120	320
Distance, km.	4,200	3,800	11,800	14,700

[7] C. J. DeGroot, PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 12, page 693, 1924.

[8] Other engineers give even lower values.

Table II shows the field strength in microvolts per meter for 1 ohm on the voltage divider of the telephone comparator at the various frequencies observed, with the amplifier adjusted so that 3.2 microvolts in the coil *B* gave 50 on the telephone comparator.

TABLE II

TELEPHONE COMPARATOR FACTOR (*A*) FOR VARIOUS FREQUENCIES

f (kc.)	λ (m.)	*A*
24.80	12,090	0.402
19.34	15,500	0.504
18.98	15,800	0.524
18.86	15,900	0.545

Comparator reading $\times$ *A* = Electric field intensity in microvolts per meter.

On account of an accident to the calibrating apparatus and delays in getting replacements, the first part of the work had to be confined to comparisons of Cavite (NPO) and Malabar (PKX), with the stronger stations, Pearl Harbor (NPM) and Tuckerton, New Jersey (WGG). The Cavite and Malabar average readings were later reduced to microvolts per meter, assuming that the average strengths of Pearl Harbor and Tuckerton were the same as their averages during the second period when the calibrations were being made.

Table III gives the comparator readings and the ratios of the various stations for the first period of the observations, while Table IV shows the results during the second period when the field intensities were measured directly.

The observations contained in the tables were all taken between two and four o'clock in the afternoon, Pacific time. A few observations taken in the morning when the signal path was partly in daylight and partly in darkness, indicated a somewhat greater strength than the afternoon observations; while observations taken by the station operators at the time of darkness along the whole signal path, were reported to be many times stronger than the daylight observations, approaching at times the strength of Pearl Harbor (NPM).

The final values of the field strengths of Cavite and Malabar as derived from comparison with the signals of Tuckerton and

Pearl Harbor, and by direct measurement, are shown in Table V. Below the average observed values are given the values calculated from the Austin-Cohen formula,

TABLE III

Comparisons of Cavite (NPO) and Malabar (PKX) with Tuckerton (WGG) and Pearl Harbor (NPM)

1924	Telephone Comparator Readings				Telephone Comparator Ratios				Disturbances $\mu v./m.$
	NPH	PGG	NPO	PXX	NPM/NPO	WGG/NPO	NPM/PKX	WGG/PKX	
Aug. 28	85	....	7.5	....	11.3	....	....	....	14
30	110	....	6.5	13.0	16.9	....	7.4	....	23
Sept. 1	55	....	3.5	4.0	15.7	....	13.7	....	....
2	....	45	....	5.0	....	....	....	9.0	12
3	....	40	....	3.0	....	....	....	13.3	....
4	....	100	....	17.0	....	....	....	5.9	38
5	....	100	3.0	....	....	33.4	....	....	....
6	100	100	6.3	....	15.8	15.8	....	....	....
8	30	80	4.3	....	11.6	18.6	....	....	50
9	55	80	4.3	7.7	12.8	18.6	7.1	10.4	25
10	45	80	5.0	6.0	9.0	16.0	7.5	13.3	30
11	50	78	4.3	....	11.6	18.1	....	....	....
12	40	70	3.0	10.0	13.3	23.4	4.0	7.0	5
13	50	80	6.3	....	7.9	12.7	....	....	20
15	48	80	....	17.0	....	....	2.8	4.7	25
Average					12.59	19.60	7.05	9.08	

TABLE IV

Direct Measurements Using the Calibrating Generator

Sept. 1924	Pearl Harbor (NPM)		Cavite (NPO)		Tuckerton (WGG)		Malabar (PKX)		Atmospheric disturbances $\mu v/m.$
	Telephone Comp.	$E \frac{\mu v}{m}$	Telephone Comp.	$E \frac{\mu v.}{m.}$	Telephone Comp.	$E \frac{\mu v.}{m,}$	Telephone Comp.	$E \frac{\mu v.}{m.}$	
17	40	16.1	4.0	2.0	....	....	7.1	3.7	14
			5.0	2.5					
			4.0	2.0					
18	45	18.1	6.0	3.0	90	49.0	4.8	2.5	
	60	24.2	3.0	1.5					5–10
19	60	24.2	....	....	100	54.4	7.5	3.9	5–10
20	30	20.1	4.0	2.0	50	27.2	....	....	15
	30	12.0	6.0	3.0	70	38.1			
	40	16.1			60	32.6			
					70	38.1			
22	60	24.2	4.0	2.0	70	38.1	13.0	6.8	5–10
					90	49.0			
Average	48.3	19.4	4.5	2.27	75	40.9	8.1	4.2	

$$E = \frac{377\, I\, h}{\lambda d} \sqrt{\frac{\theta}{\sin \theta}}\ \varepsilon^{-u} \qquad (1)$$

where $u = 0.0015 d/\sqrt{\lambda}$ and θ is the angle between the stations from the center of the earth.

The observed value of field intensity in the case of Cavite in Table V is seen to be approximately three times that calculated from equation (1), while the observed strength of Malabar is about twice that calculated from equation (1). These ratios of observed to calculated values are much less than those given in M. Guierre's paper.[8]

TABLE V

Averages of Field Intensity

	Cavite $E \frac{\mu v.}{m.}$	Malabar $E \frac{\mu v.}{m.}$
From direct measurements	2.27	4.22
From comparison with NPM	1.93	3.55
From comparison with WGG	1.93	4.26
Observed averages	2.04	4.02
Calculated from equation (1)	0.69	1.83

SUMMARY: The paper describes measurements on the daylight radio field intensity produced in San Diego, California, by the arc stations at Cavite, Philippine Islands, 11,800 km., and Malabar, Java, 14,700 km. distant. These distances are nearly twice as great as any previously studied, except for a few scattered measurements. The average observed intensities were, from Cavite 2.04 $\mu v./m.$, and from Malabar 4.02 $\mu v./m.$, while those calculated from the Austin-Cohen formula are respectively 0.69 $\mu v./m.$, and 1.83 $\mu v./m.$ These ratios of observed to calculated values indicate an increase in the divergence from the formula with increasing distance, but not so great as was indicated by earlier scattered observations.

THE MAGNETRON AMPLIFIER AND POWER OSCILLATOR*

By

Frank R. Elder

Introduction

It is well known that there are two general methods of affecting the motion of charged particles, namely by an electrostatic field or by a magnetic field. Therefore in electron tubes these principles may be employed to control the flow of electrons. As an example of the first type we have the ordinary three-electrode tube or radiotron. The second type is exemplified by the magnetron. There are two kinds of magnetrons. In the first the magnetic field coil which acts as the control member is external to the tube, while in the second the magnetic field of the current that heats the filament is the control agent.

The radiotron has come into quite general use and its capabilities have become well known. The magnetron is still in its infancy, however, and comparatively little has been written about it. The magnetron has been described and some of its uses briefly mentioned in a paper by A. W. Hull.[1] The axially-controlled magnetron has been described by the same author.[2] It is the purpose of the present paper to set forth in detail some of the data which have accumulated in this laboratory on two applications of the magnetron, first as an amplifier and second as a power oscillator.

Design of Tubes

The magnetron is a vacuum tube with two elements, a filament and an anode, like a simple kenotron, its only distinguishing feature being the symmetrical arrangement of its electrodes. As generally made, the filament was a single strand of wire in the axis of the anode (Figure 1). A spiral spring in series with the filament served to keep the filament straight when heated. The anode, which was usually of molybdenum, was spaced from the glass wall of the container by spirals of fine molybdenum or tungs-

* Received by the Editor, September 20, 1924.

ten wire attached near the ends. In order to prevent eddy current losses in the anode as much as possible, the anode was split longitudinally. The anode lead was sometimes brought out thru the side as shown in Figure 1, or at the end as shown in Figure 2. In the second case the anode lead had to be protected by a glass tube (or a quartz tube if high voltage was to be applied to the anode), otherwise the symmetry of the device was spoiled and the magnetic control made very poor. It was also observed,

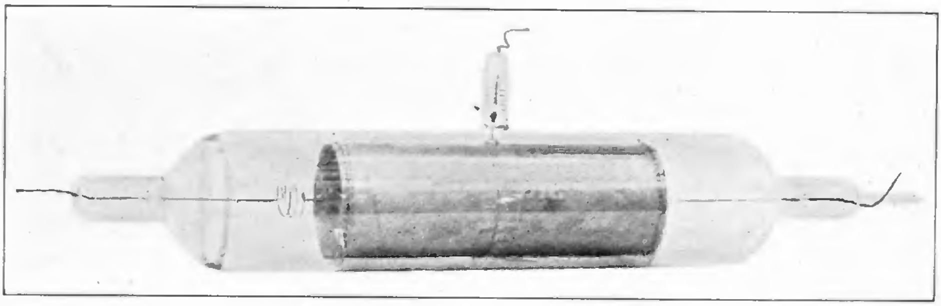


FIGURE 1—Magnetron[3]

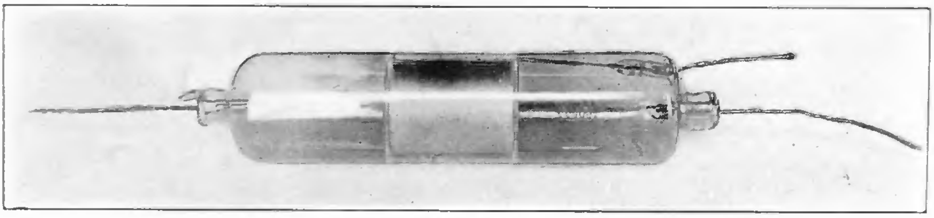


FIGURE 2—Magnetron

when high voltage was applied to the tube of the form shown in Figure 1, that tiny bright arcs frequently appeared, when the magnetic field was applied, at the points of contact of the supporting spirals with the glass wall. This led to the construction shown in Figure 3 where the anode was supported by conical spiral springs terminating in quartz insulators.

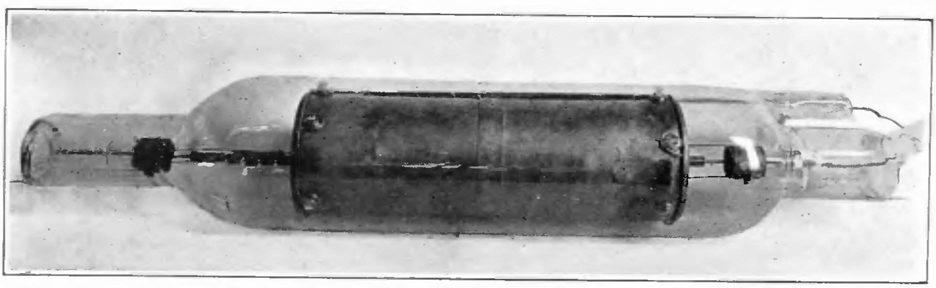


FIGURE 3—Magnetron

Many sizes of tubes have been made and studied; a partial list follows:

I	II	III	IV
¾×1½″	1″×4″	1″×12″	1¼″×1¾″
1.9×3.31	2.54×10.16	2.54×30.5	3.17×4.45 cm.
V	VI	VII	VIII
2″×2″	2″×4″	2″×6″	4″×12″
5.08×5.08	5.08×10.16	5.08×15.25	10.16×30.5 cm

The first dimension given is the anode diameter, the second dimension the anode length. The sizes marked IV and V were used chiefly as amplifiers while all sizes were studied as oscillators. With the first a few watts output at about 180 meters was obtained; with the last several kilowatts at 10,000 meters.

Theory

In the absence of a magnetic field the current which can flow between a cathode and a concentric cylindrical anode tube is given by the relation [(3) (4)].

$$i=14.65\times10^{-6}\frac{l}{r\,\beta^2}V^{\frac{3}{2}} \qquad \text{(I)}$$

where i is the current in amperes, l the length, and r the radius of the anode, V the voltage of the anode, and β^2 a factor depending upon the ratio of the radii of anode and cathode. For practical tubes β^2 is approximately unity.

If now a uniform magnetic field is applied parallel to the axis of the tube, this current is not affected until a certain critical value of field H is reached when the current falls abruptly to zero. The relation between voltage and field has been shown to be [(5]

$$V=8\frac{e}{m}\,r^2\,H^2$$

where V is the voltage of the anode, r the radius of the anode, and H the applied field, e the charge, and m the mass of an electron in e. m. units. In practical units (volts, cm., gausses), this equation is $V=0.0221\,r^2\,H^2$ (11)

This may also be written in the form

$$H=\frac{6.73}{r}V^{\frac{1}{2}} \qquad \text{(III)}$$

That this is the correct relationship has been abundantly verified by experiment. A series of characteristics taken on a 4″×12″ tube is shown in Figure 4. There may be a small residual current with strong field due to electrons reaching the anode after colliding with gas molecules. The steep portion of the curve is not quite vertical but becomes more nearly so as the voltage is increased. For moderate voltages a 10-percent change in magnetic field suffices to change the current from the full space charge value of equation (1) to practically zero.

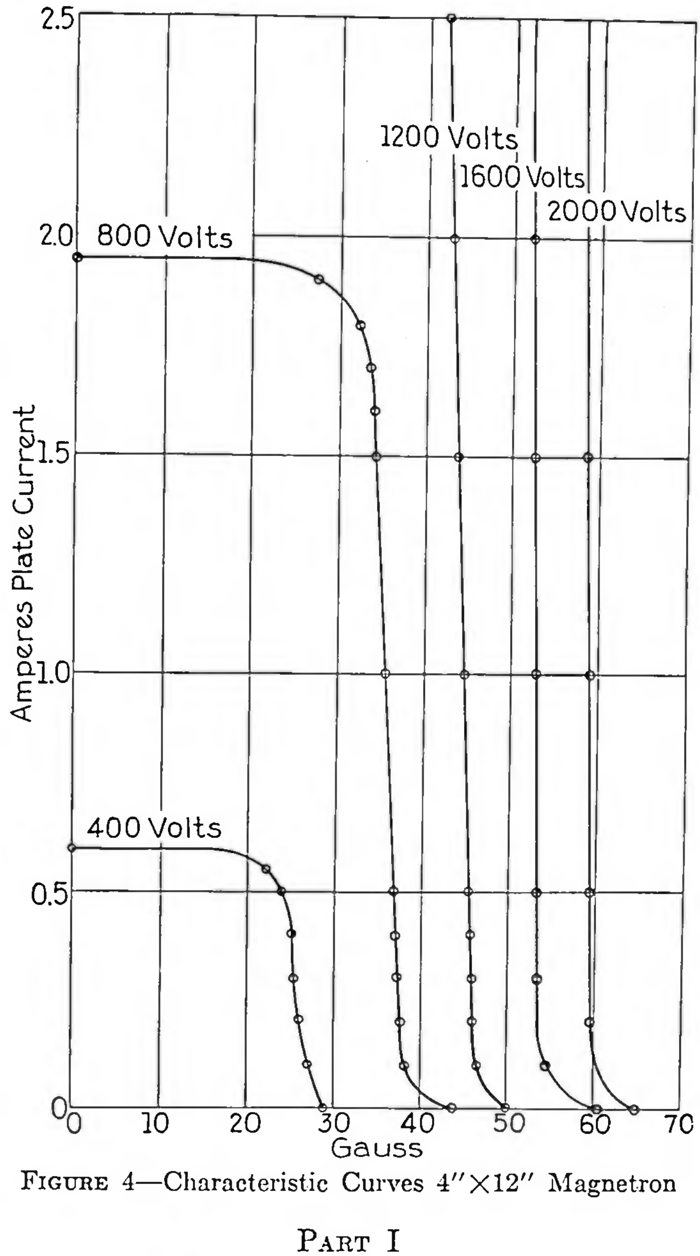


Figure 4—Characteristic Curves 4″×12″ Magnetron

Part I

The Magnetron Amplifier

Most of the amplification tests were carried out at a wave length of 8,000 meters, and the discussion will be limited to the results obtained at this wave length.

The Circuit

The circuit used in these tests is shown in Figure 5. The field coils serve to "polarize" or "bias" the plate current to some point on the steep part of the characteristic curve (Figure 4), usually rather well down on the curve in order to limit heating of the anode. At L_1 and L_2 are shown the control coils by which the signal is impressed on the tubes, C and C_1 are tuning condensers which are variable, and C_2 is a stopping condenser to prevent short circuiting of the plate voltage in case the insulation of C_1 fails. Between the plate voltage supply and the plate of the tube is a choke coil to prevent the radio frequency going to ground thru the plate battery or generator.

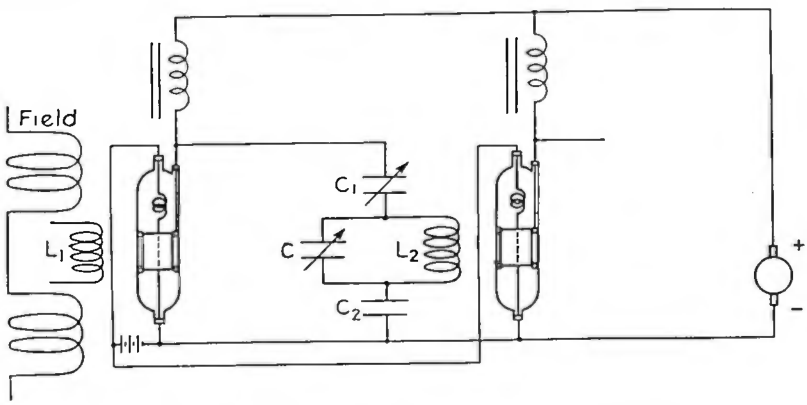


FIGURE 5—Circuit for Magnetron Amplifier

In order to obtain the best results the impedance of the output circuit must be made to fit the output impedance of the tube. Let us consider briefly the result of impressing a voltage $E \sin \omega t$ across the combination C, C_1, L as represented in Figure 6. A

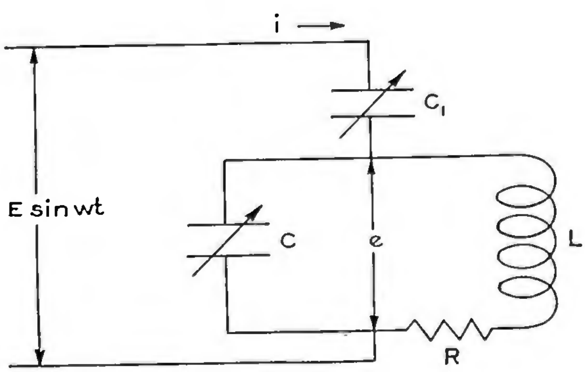


FIGURE 6

current i will flow thru the circuit and a voltage e will be set up across C and L. As is usually the case with radio circuits, the resistance of the coil L can be neglected in comparison with ωL, and thus in the complex notation,

$$\frac{i}{e} = \frac{1}{\omega L} \cos\theta + j\,\omega \left(C_1 + \frac{1}{\omega L} \right) \qquad \text{(IV)}$$

where $$\cos\theta = \frac{R}{\sqrt{\omega^2 L^2 + R^2}}$$

Inverting equation (4) we have

$$\frac{e}{i} = \frac{\frac{1}{\omega L}\cos\theta - j\left(\omega C_1 - \frac{1}{\omega L}\right)}{\left(\frac{1}{\omega L}\cos\theta\right)^2 + \left(\omega C_1 - \frac{1}{\omega L}\right)^2} \qquad \text{(V)}$$

which is of the form

$$\frac{e}{i} = X + j\,Y \qquad \text{(VI)}$$

where X represents the total impedance of the circuit and Y represents the inductive reactance of the combination C and L, which is to be tuned out by C_1, when C is a capacity less than that required to tune L to resonance at the frequency ω. It is thus seen that the circuit will act as a pure resistance of any desired value X. Reduction of equation (V) leads to

$$C = \frac{\frac{1}{\omega L} - \sqrt{\frac{\frac{1}{\omega L}\cos\theta - \left(\frac{1}{\omega L}\cos\theta\right)^2}{X}}}{\omega} \times 10^{-6} \textit{ microfarads} \qquad \text{(VII)}$$

and

$$C_1 = \frac{10^{-6}}{\omega \sqrt{\frac{X}{\frac{1}{\omega L}\cos\theta} - X^2}} \textit{ microfarads} \qquad \text{(VIII)}$$

Tube Impedance

The tube impedance was found in the following manner: A non-inductive resistance R and an ammeter A were substituted in place of C_1, C, L (see Figures 5 and 7) and with a constant input I thru coil L the output determined as R was varied. This was done for several values of plate voltage. Figure 8 shows the results obtained with a 2″×2″ tube. At 700 volts and above there is a maximum at 400 ohms. Below this value the impedance of the tube seems to be higher and less well marked.

Actual test showed that within the experimental error the values of C and C_1 found agree with those calculated from equations VII and VIII when the value of tube impedance was used as determined from Figure 8.

CONTROL COILS

Several types of control coils were wound up and compared. The results can be briefly summarized as follows:

(a) Drop turn or bank wound coils gave about 20 percent more amplification than ordinary multiple layer coils.

(b) Litzendraht was about 50 percent better than solid copper wire of comparable conductivity.

(c) The winding length should be at least 1.5 or 2 times the length of the anode.

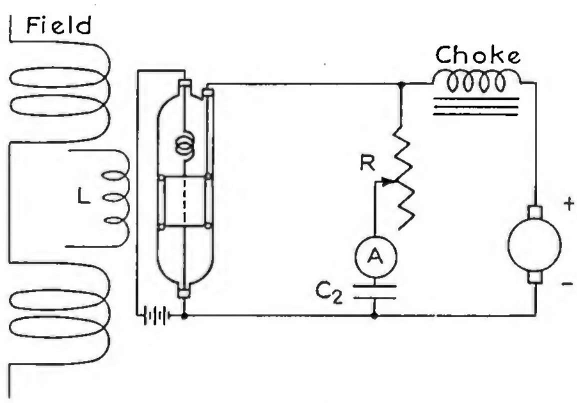


FIGURE 7—Circuit for Determination of Plate Resistance

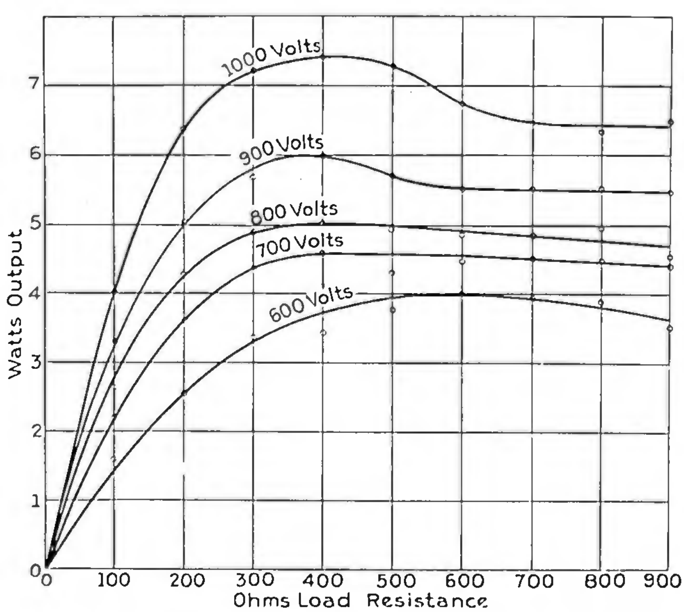


FIGURE 8—Output—Load Resistance Curves 2″×2″ Magnetron

AMPLIFICATION

In order to determine the amplification obtainable and its dependence upon plate voltage the apparatus was set up as indicated in Figure 9. (The field coils are not shown). Tube 2 was the tube being measured, tube 3 served as the measuring instrument. The ammeter A_2 in series with the proper resistance R, was calibrated in terms of current in coil L_2 and the plate voltage of tube 3 held constant. In order to avoid uncertainty of input resistance the input was introduced thru tube 1. The plate voltage of tube 1 was also kept constant. The amplification ratio was then the result obtained by dividing the current in L_2 as determined by tube 3, by the input current read on A_1. The results obtained are shown in Figure 10 where amplification is plotted against plate voltage. As can readily be seen the amplification is practically linear with plate voltage. It is also seen that the 1¼″×1¾″ tube gives higher amplification than the 2″×2″ tube.

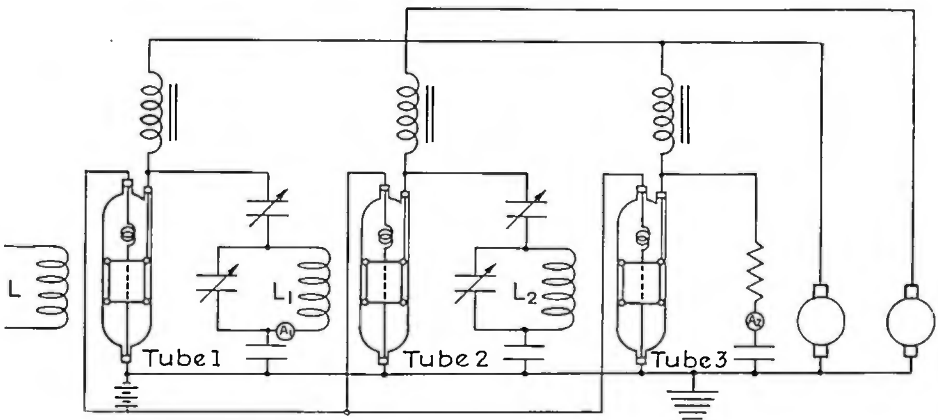


FIGURE 9—Circuit for Determination of Amplification per Tube

This method of determining the amplification has the advantage that the result found is the real amplification as obtained in practice since all losses are included. In order to be certain that these results held for the much weaker signals of radio telegraphy, the amplification was checked, using a very weak signal and testing with a small tube detector, using telephones and audibility meter or "mile-box." The results obtained by this method checked the values of Figure 10.

POLARIZING FIELD

For demonstration work a pair of Helmholtz coils of any convenient number of turns is very satisfactory, as the field can be quickly and easily adjusted; but when the building of a multistage amplifier is contemplated some consideration must be given

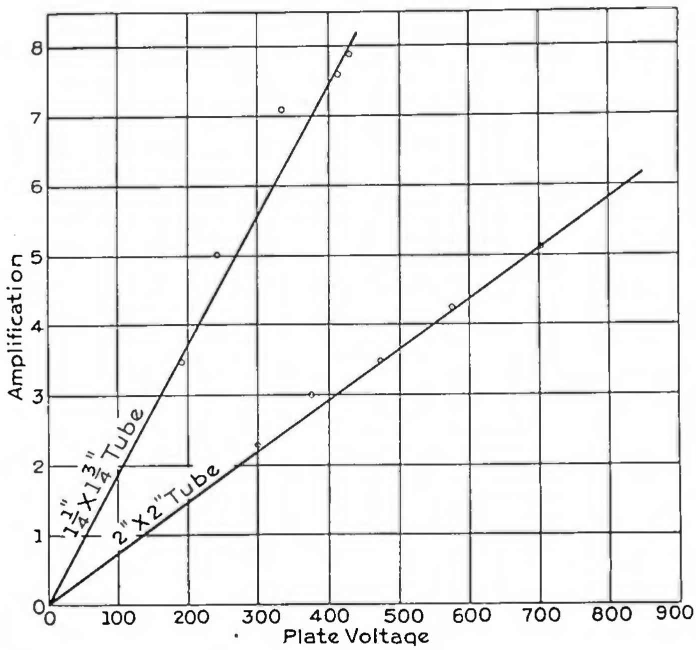


FIGURE 10—Magnetron Amplifier—Amplification per Tube

the design of field coils. In the first place the coils must be large enough so that they exercise no deleterious effect on the control coil. If the field is produced by the same voltage as that which supplies the anode of the tube, great constancy of this voltage is necessary. Figure 11 is a plot of voltage against field. The straight line represents the actual variation of field with voltage, while the parabola represents the variation required by the tube.

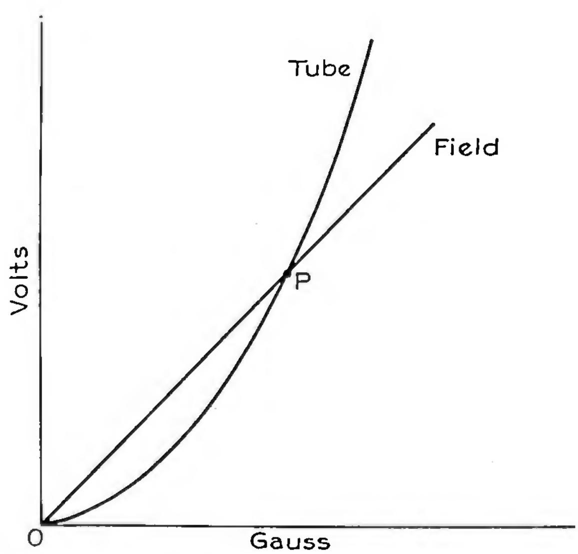


FIGURE 11—Characteristic of Magnetron with "Shunt" Field

This type of field will be called a shunt field. It is readily seen that there is only one point of intersection P. This point represents the only voltage at which the given coils produce the correct polarizing field. If, on the other hand, the field is produced by the plate current of the tube, its value will be correct at all voltages. This is shown in Figure 12. The curves are gauss-ampere characteristics of the tube at the voltages V_1, V_2, V_3; the line F represents the gauss-ampere characteristic of the field coils. While this arrangement, which will be called a series field, is always automatically stable, the field coils will be very large and heavy due to the great number of turns needed to produce the field with small plate currents, and further the resistance drop will be high.

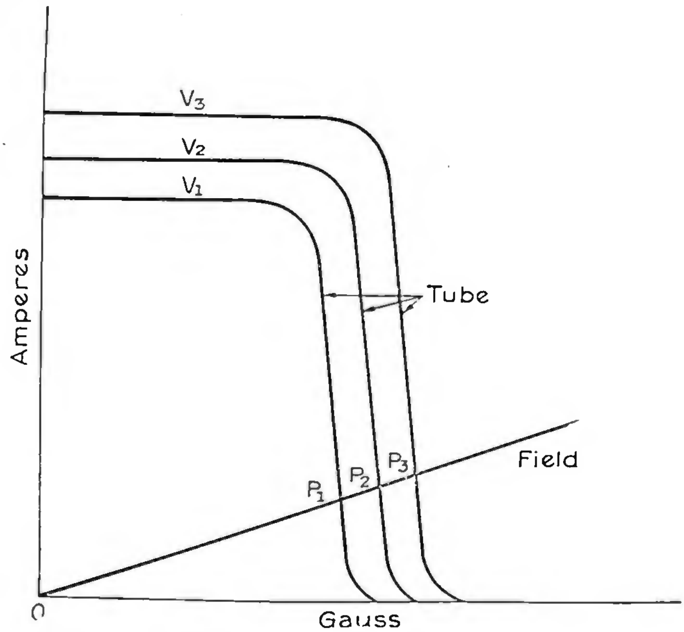


FIGURE 12—Characteristic of Magnetron with "Series" Field

It was decided, therefore, to use a combination of the two types of field, the connections being so made that the series field added to the shunt field. By adjustment of the resistance in the shunt field circuit the tube was brought to the desired operating point. It was found that when the series field was of the order of 10 percent of the shunt field the anode current remained practically constant when the anode voltage varied thru the range 400±25 volts. It was thought that this provided ample margin to care for all ordinary fluctuations of the voltage supply. It was also found that the series field was a sufficiently good choke at the frequencies used so that an additional choke coil was unnecessary.

Multi-stage Amplifier

The separate parts having been worked out, they were finally incorporated into a four-stage amplifier. The tubes used were the 1¼″×1¾″ tubes and the plate voltage supply was about 400 volts. This should give, according to Figure 10, an amplification of between 5- and 6-fold per stage. The control coils were wound up of litzendraht (32 strands of 0.005″ enameled wire) in the form of 10-layer bank wound coils of about 700 turns. The inductance was approximately 8 millihenrys and the resistance 6 to 6.5 ohms at a frequency corresponding to 10,000 meters. While these 700-turn 10-layer coils gave no better control than 300-turn 4-layer coils, the much higher value of inductance determined the choice, since the condenser units required were much smaller with the large coils. The diagram of connections is shown in Figure 13. As first set up, no shielding was provided and as a result never more than two stages could be operated. The amplifier was therefore rebuilt providing a copper lining to the box and a copper partition between each stage. There resulted an amplifier which was much more stable. With very careful adjustment all four stages were operable and three stages under practically any circumstances. With strong signals, such as those from the New Brunswick Station, the results were very good. When the atmospheric conditions were not too bad, signals from POZ, Nauen, Germany, were heard. The development of the magnetron amplifier was not pushed any further than this, but work taken up on the magnetron oscillator which will be the subject of the remainder of the paper.

Experience gained with the magnetron oscillator, where a

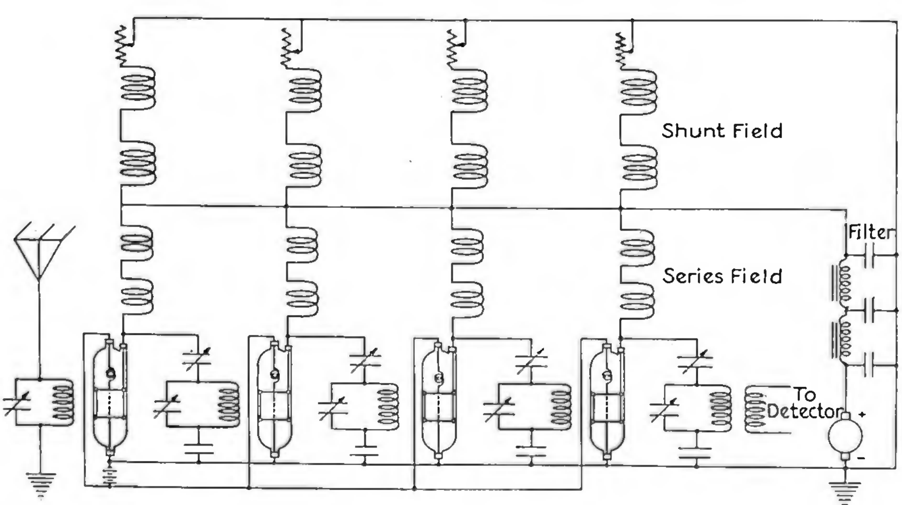


Figure 13—Circuit for Four-Stage Magnetron Amplifier

similar circuit was used, makes it seem probable that a great deal of the difficulty with the amplifier was due to improper shielding and that it would be entirely possible to redesign the amplifier and make it just as stable and give as much amplification as the same number of three-element tubes.

Part II

The Magnetron as a Power Oscillator

In the development of the magnetron oscillator, two circuits have been used. There is no choice between the two on the basis of efficiency. The first circuit was used by Mr. Glenn Mercer in the early work on the magnetron and is illsutrated in Figure 14.

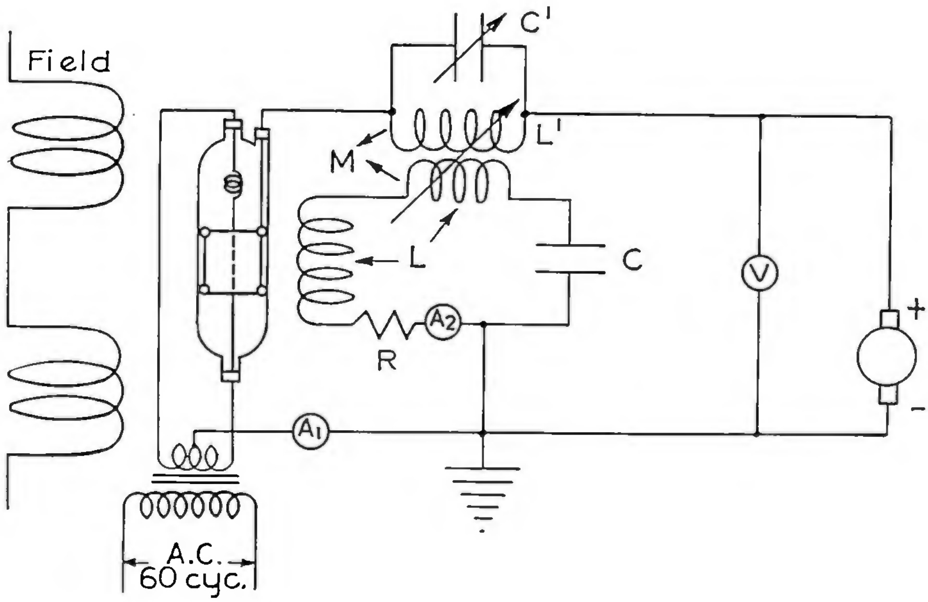


Figure 14—Circuit for Magnetron Oscillator

The second circuit, which has been used by the present writer, is shown in Figure 15 and will be easily recognized as the same circuit used in the amplifier but modified to suit the oscillator case. This circuit will be the only one discussed in detail. It is somewhat simpler of adjustment and in ease of operation and has been chosen for this reason.

Since the magnetron is a rather unfamiliar object outside of this laboratory, it seems advisable to give a rather full description of the component parts of the circuit in order to give a clearer conception of the proportions of these parts. For the sake of simplicity, the whole discussion will be based on the 4″×12″ magnetron. Obviously *mutatis mutandis,* it applies equally well to all sizes of tubes.

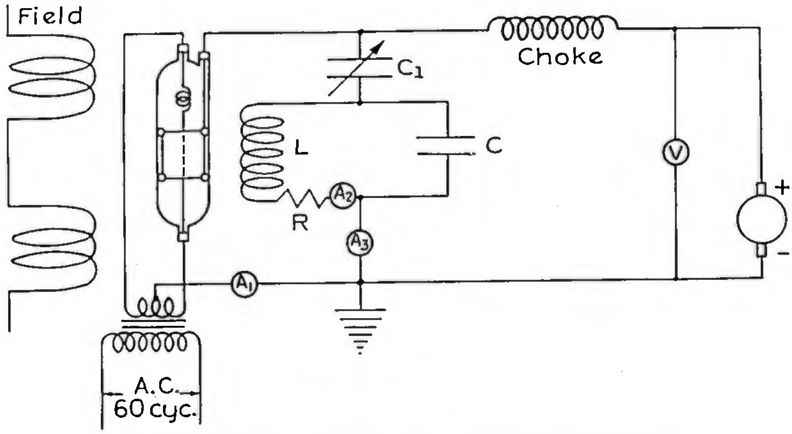


FIGURE 15—Circuit for Magnetron Oscillator

DESCRIPTION OF CIRCUIT

The "polarizing" or "biasing" magnetic field H_o is produced by a pair of Helmholtz coils or other combination of coils giving a sufficiently extended and uniform field. These coils must be large enough in diameter to avoid seriously affecting the operation of the tube by coupling with the control coil L. This coupling manifests itself in two ways: high voltages may be induced in the field coils causing breakdown of the insulation, and secondly, the apparent inductance of the coil L is decreased and its resistance increased which means a loss of useful power. This coupling effect is absent or negligible at power frequencies but becomes of more and more importance as the frequency rises.

Coils of an inside diameter of about 24″ are satisfactory. The particular set used consists of five identical coils arranged as indicated in Figure 16. Each coil has a winding section of 2″×4″, an inside diameter of 22″ wound with approximately 4,000 turns of 0.040″ enamelled wire and then impregnated with insulating varnish. Each coil weighs about 125 pounds and has a resistance of about 172 ohms. The coils are all connected in multiple across the 250-volt shop lines with a variable resistance in series. The current thru the middle coil (coil 3) was adjusted by a series resistance X, so that there resulted a field uniform to within less than 1 percent thruout a volume represented by a cylinder 6″ in diameter and 16″ long. This was done by trial using a small magnetron as an exploring instrument.[6] The constant for the system is 45.3 gauss per ampere combined current and was determined by comparison with a standard solenoid.

The filament is generally lighted from an alternating current supply. A small transformer of the proper rating with a midpoint tap brought out from the low voltage winding has proved satisfactory.

The control coil L when used at high frequency should be wound with litzendraht in a single layer. The coil used had the following constants: 124 turns of 12-conductor litzendraht (12 insulated conductors wrapped around a rope core and again insulated, each conductor consisting of 32 strands of 0.005″ enamelled copper wire braided together). This cable will carry about 40 amperes at 30,000 cycles without too great loss. The coil was wound on a form of small maple slats giving a mean winding diameter of 7½″ and a length of 24″. The inside diameter of the slat form was 5⅞″ giving a ventilation space between it and the tube. The inductance of the coil was 0.795 millihenry and had an effective resistance of approximately 0.6 ohm measured at 12,300 meters and with a tube inside the coil.

For power frequencies the control coil presents much less of a problem. Any suitable size of wire may be used and further, the voltage per turn being less, multiple layers may be used as insulation difficulties are not encountered.

The main tuning condenser C consisted of a bank of four 0.012 microfarad mica condensers connected in multiple. The combined capacity was 0.505 microfarad, rated for 15,000 volts and safely carried 50 amperes at 10,000 to 12,000 meters.

The condenser C_1, or bridging condenser, which also serves as a stopping condenser, was variable to allow operating adjustments. The capacity range was 0.0013 to 0.0029 microfarad and would withstand 20,000 volts.

The load is represented by the resistance R. The total resistance of the circuit was of the order of 6 ohms.

The choke coil was a single layer solenoid wound with 0.064″ double cotton-covered wire and treated with insulating varnish. The form was a piece of insulating tubing 13¼″ in diameter by 48″ long. The maximum inductance was 30.5 millihenry and convenient taps were brought out to allow adjustment.

Tube Operation

It is obvious that for efficient operation of the tube, the plate current must flow at a time when the plate voltage is low. The control field must therefore be in phase with the instantaneous plate voltage. The instantaneous plate current which flows will thus be 180° out of phase with plate voltage and control field. Such a set of conditions is represented in Figure 8. At (a) is shown the instantaneous plate voltage e_p as a sine wave of maxi-

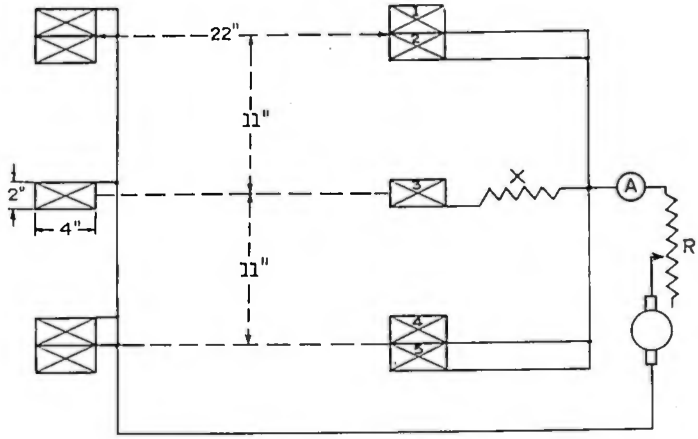


FIGURE 16—Magnetic Field—Coil System

mum amplitude V superimposed on the impressed direct voltage V_o. The minimum value of e_p will be termed the emission voltage V_e.

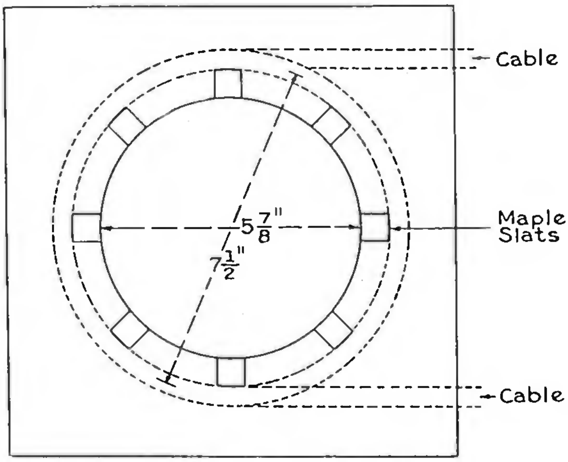


FIGURE 17—Section Thru Control Coil Support

At (*b*) is shown the instantaneous plate current i_p, trapezoidal in shape, rising from a value zero to a value I_e in the time angle $(\theta_2 - \theta_1)$, remaining equal to I_e for the time $2\ \theta_1$, and falling to zero again in the time $(\theta_2 - \theta_1)$. The average value of i_p as read on a direct current ammeter is shown by the dotted line I_{pa}.

Finally at (*c*) is shown the control magnetic field as a sine wave of amplitude H superimposed on the "biasing" field. H_o.

While at first sight the choice of wave shapes seems rather arbitrary, nevertheless such is not the case. As the alternating control field is of considerable magnitude, the current thru the coil must be large, and thus there is a large ratio of circulating volt-amperes to dissipated watts. The control current is thus very closely sinusoidal and produces a sinusoidal voltage across the coil L and condenser C. The plate voltage e_p also will be nearly sinusoidal in the absence of other means of distorting it, and oscillograms show this to be true. The choice of a trapezoidal shape for the plate current rests entirely on experiment, that is, the oscillographic record. Measurements on films show the time angle $(\theta_2 - \theta_1)$, to be approximately $\frac{\pi}{6}$ and for simplicity of calculation has been so chosen. The departures from these simple forms in actual practice are slight and lead to no appreciable errors.

Having considered the wave forms, the actual magnitudes can be discussed in a general way. The tube is characterized by three important features: (a) voltage rating, (b) filament rating, and (c) the maximum safe continuous power dissipation at the anode. The voltage rating determines the applied direct voltage V_o, while the filament rating fixes the maximum current that should be drawn thru the tube. This value of current has been designated I_e and is the maximum electron emission compatible with the desired life of the filament. The power dissipation of the anode determines the maximum output permissible.

Efficient use of the electron emission from the filament then demands that the minimum plate voltage does not fall too low. By use of equation (1) the proper value of V_e can be calculated.

The values of H_o and H will be determined by applied plate voltage V_o, the constants of the control coil L, and the power output desired. A rather wide variation of relative values of H_o and H is permissible, thus allowing considerable latitude for adapting them to the case at hand. In any case, however, the value of H should not be much in excess of the value of H_o, since then there is a possibility of a field (in the reverse direction to H_o) of sufficient strength to prevent electrons from reaching the anode at the voltage V_e.

Having thus considered the general features of tube operation, detailed calculation of expected performance can be made. Referring to Figure 18, let,

V_o = impressed direct voltage measured with respect to the filament.

V_e = minimum instantaneous plate voltage.

V = amplitude of alternating plate voltage.

e_p = instantaneous plate voltage with respect to the filament.

i_p = instantaneous plate current.
I_e = maximum instantaneous plate current.
I_{pa} = average plate current.
H_o = "polarizing" or "biasing" field.
H = amplitude of alternating control field.
θ_i = time angle during which current flows.

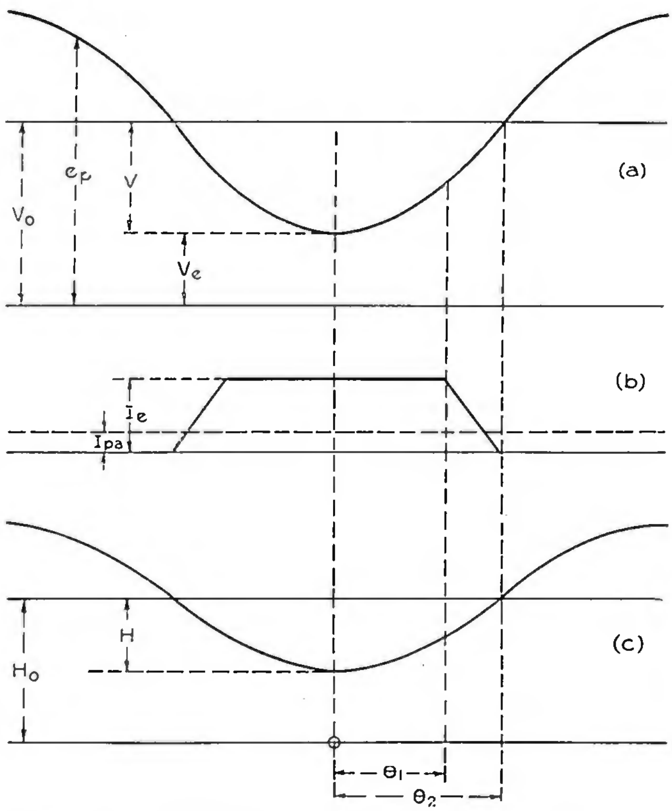


FIGURE 18—Plate Voltage, Plate Current and Magnetic Field Relationships in Magnetron Oscillator

It then follows that neglecting the filament loss, the instantaneous power input into the system is $V_o\, i_p$, the instantaneous tube loss is $e_p\, i_p$, the instantaneous output is $V_o\, i_p - e_p\, i_p$, the instantaneous efficiency is $\frac{V_o\, i_p - e_p\, i_p}{V_o\, i_p}$. In order to obtain average values, these instantaneous values must be integrated over a complete cycle, thus the

Average power input is $P = \frac{1}{2\pi}\int_o^{2\pi} V_o\, i_p\, d\theta = V_o\, I_{pa}$ (IX)

Average tube loss is $P_1 = \frac{1}{2\pi}\int_o^{2\pi} e_p\, i_p\, d\theta$ (X)

Average tube output is $P - P_1 = V_o I_{pa} - \frac{1}{2\pi}\int_o^{2\pi} e_p i_p \, d\theta$ (XI)

Average tube efficiency is $\eta = \dfrac{V_o I_{pa} - \frac{1}{2\pi}\int_o^{2\pi} e_p i_p \, d\theta}{V_o I_{pa}}$ (XII)

If at the time $t=0$, $\theta=0$, and $e_p = V_e$, then we have $e_p = V_o - V \cos\theta$, and $i_p = I_e$ from $\theta = 0$ to $\theta = \theta_1$, and $i_p = I_e\left(\frac{\theta_2 - \theta}{\theta_2 - \theta_1}\right)$ from $\theta = \theta_1$ to $\theta = \theta_2$.

Since the cycle is symmetrical about 0, and no current flows after $\theta = \theta_2$, we have for the average plate current $I_{pa} = \frac{I_e(\theta_2 + \theta_1)}{2\pi}$ and for the average tube loss $P_1 = \frac{1}{2\pi}\int_{-\theta_2}^{\theta_2} e_p i_p \, d\theta$ or

$P_1 = \frac{1}{\pi}\int_o^{\theta_2} e_p i_p \, d\theta.$

Substituting in the value of e_p and i_p

$$P_1 = \frac{1}{\pi}\int_o^{\theta_1} I_e (V_o - V\cos\theta)\, d\theta + \frac{1}{\pi}\int_{\theta_1}^{\theta_2} i_e \left(\frac{\theta_2 - \theta}{\theta_2 - \theta_1}\right)(V_o - V\cos\theta)\, d\theta$$

and carrying out the integrations indicated,

$$P_1 = \frac{I_e V_o (\theta_2 - \theta_1)}{2\pi} + \frac{I_e V}{\pi(\theta_2 - \theta_1)}(\cos\theta_2 - \cos\theta_1)$$

Now the power input is $P = V_o I_{pa} = I_e V_o \left(\frac{\theta_2 + \theta_1}{2\pi}\right)$, and hence the power output is

$$P_2 = -\frac{I_e V}{\pi(\theta_2 - \theta_1)}(\cos\theta_2 - \cos\theta_1) = \frac{I_e V}{\pi(\theta_2 - \theta_1)}(\cos\theta_1 - \cos\theta_2)$$

and the efficiency is $\eta = \frac{V}{V_o}(\cos\theta_1 - \cos\theta_2)\dfrac{1}{(\theta_2 - \theta_1)\left(\frac{\theta_2 + \theta_1}{2}\right)}$.

Experiment having shown that $\theta_2 - \theta_1$ is $\frac{\pi}{6}$ there finally results

$$P = \frac{I_e V_o}{2\pi}\left(2\theta_1 + \frac{\pi}{6}\right) \quad \text{(XIII)}$$

$$P_1 = \frac{I_e V_o}{2\pi}\left(2\theta_1 + \frac{\pi}{6}\right) - \frac{6}{\pi^2} I_e V (\cos\theta_1 - \cos\theta_2) \quad \text{(XIV)}$$

$$P_2 = \frac{6}{\pi^2} I_e V (\cos\theta_1 - \cos\theta_2) \quad \text{(XV)}$$

$$\eta = \frac{6}{\pi}\left(\frac{V}{V_o}\right)(\cos\theta_1 - \cos\theta_2)\frac{1}{\left(2\theta_1 + \frac{\pi}{6}\right)} \quad \text{(XVI)}$$

In Table I are given data for use in equations XIII to XVI calculated for values of θ_1 from 0° to 90°.

TABLE I

$\theta_1°$	$\cos\theta_1$	$\cos\theta_1 - \cos\theta_2$ $\theta_2 = \theta_1 + 30°$	$(\cos\theta_1 - \cos\theta_2)\frac{6}{\pi^2}$	$\frac{\theta_1+\theta_2}{2\pi}$	$\frac{(\cos\theta_1 - \cos\theta_2)\frac{6}{\pi^2}}{\frac{\theta_1+\theta_2}{2\pi}}$
0	1.000	0.1340	0.0815	0.0833	0.9779
5	0.9962	0.1770	0.1076	0.1111	0.9685
10	0.9848	0.2188	0.1330	0.1389	0.9576
15	0.9659	0.2588	0.1573	0.1667	0.9438
20	0.9397	0.2969	0.1805	0.1944	0.9285
25	0.9063	0.3327	0.2023	0.2222	0.9102
30	0.8660	0.3660	0.2225	0.2500	0.8900
35	0.8192	0.3966	0.2411	0.2778	0.8679
40	0.7660	0.4240	0.2578	0.3056	0.8435
45	0.7071	0.4483	0.2725	0.3333	0.8177
50	0.6428	0.4692	0.2852	0.3611	0.7899
55	0.5736	0.4864	0.2957	0.3889	0.7603
60	0.5000	0.5000	0.3040	0.4167	0.7295
65	0.4226	0.5098	0.3099	0.4444	0.6974
70	0.3420	0.5156	0.3134	0.4722	0.6638
75	0.2588	0.5176	0.3147	0.5000	0.6293
80	0.1736	0.5156	0.3134	0.5278	0.5939
85	0.0872	0.5098	0.3099	0.5555	0.5579
90	0.0000	0.5000	0.3040	0.5833	0.5211

The relation between plate voltage and plate current is given in Figure 19 as calculated from equation (I). The ratio of maximum plate voltage swing to impressed voltage or $\frac{V}{V_o}$ is given in Figure 20 for values of emission current I_e from 0 to 10 amperes and from 5,000, 10,000, and 15,000 volts for V_o.

Figure 21 gives the average plate current I_{pa} as a function of time angle θ for emission values of 1, 2, 4, 6, 8, and 10 amperes.

A set of input, output, loss, and efficiency curves has been calculated from the data of Table I and figures 19, 20, and 21, for filament emissions of 2, 4, 6, and 8 amperes and an applied direct voltage of 10,000 volts. These curves are plotted in Figure 22. Inspection of this figure shows that maximum output is obtained for a time angle of $\theta_1 = 75°$ and, based on this value, Figure 23 represents the relation between output and applied voltage for a filament emission of 4 amperes.

Circuit Design

In order that the calculated performance may be realized the various parts of the circuit must be properly proportioned. In Figure 24 is shown the vector diagram of the current and voltage relationships of the circuit, tho somewhat distorted in order to obtain clearness in the drawing. This diagram is drawn keeping in mind the fundamental facts (see Figure 18) that plate voltage

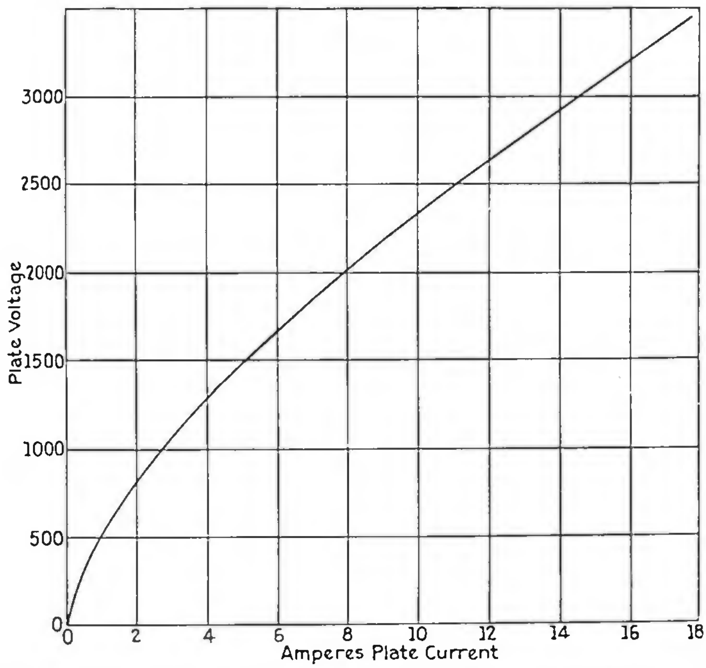


Figure 19—Space Charge Current for 4″×12″ Magnetron

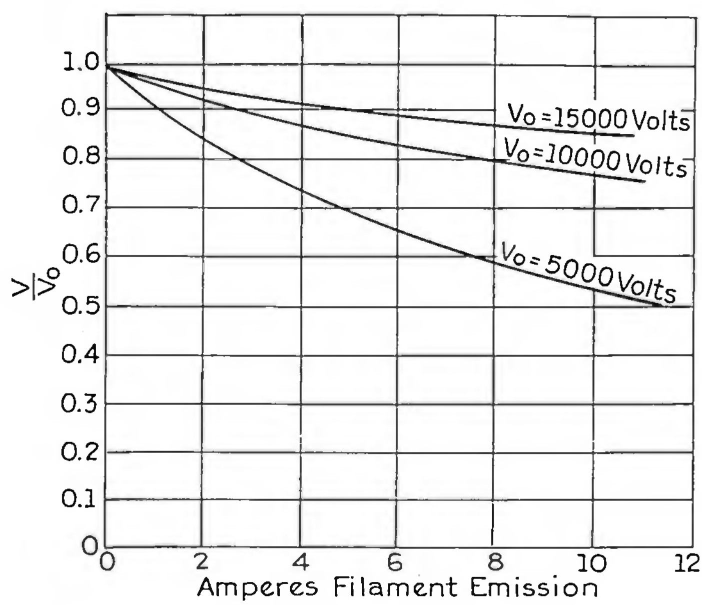


Figure 20

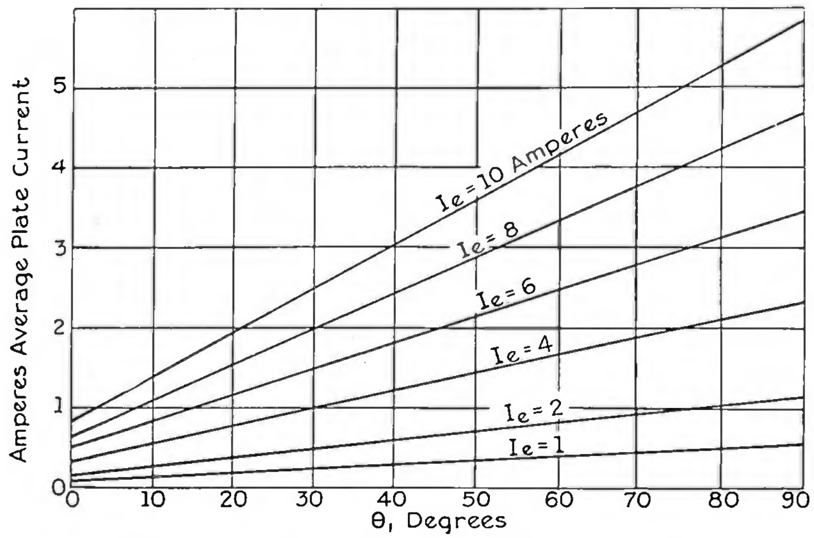


FIGURE 21—Average Plate Current as a Function of Time Angle 4″×12″ Magnetron

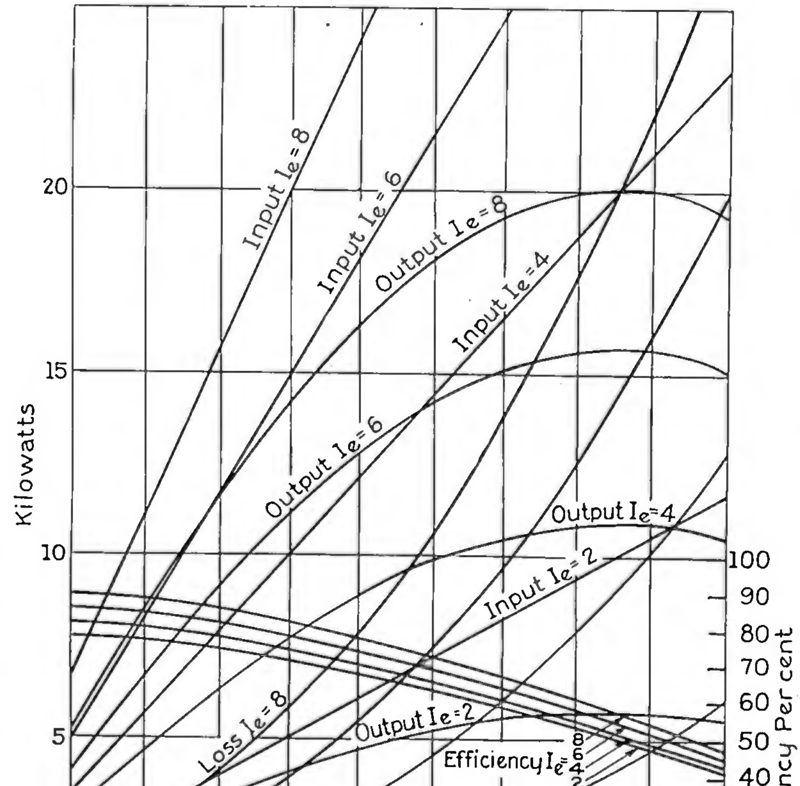


FIGURE 22—Input, Output, Loss and Efficiency Curves for 4″×12″ Magnetron Operating at 10,000 volts, D.C.

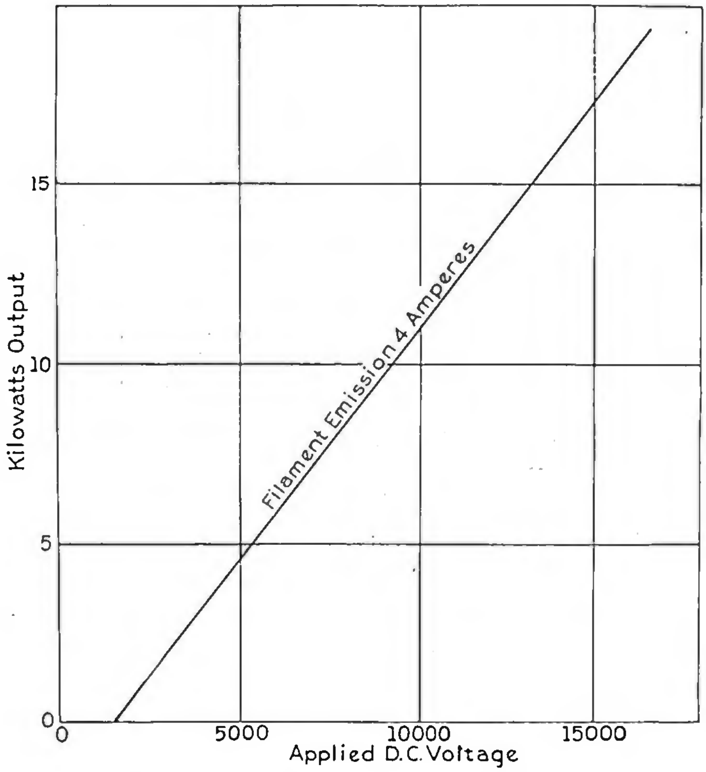


FIGURE 23—Output as a Function of Plate Voltage for 4″×12″ Magnetron

should be in phase with control current and that plate current should be 180° out of phase with plate voltage, therefore I_L and e_p are laid off in the same direction and to the proper scale, while i_p is laid off in the opposite direction along the same line. The current I_L flows thru inductance L and resistance R which gives a component $\omega L I_L$ lagging 90° behind I_L and a component $R I_L$ in phase with I_L (see Figure 15). The resultant voltage E_c is also impressed across condenser C and thus gives rise to the current I_c leading E_c by 90°. As a resultant of I_L and I_c we have the series line current I_{c_1}, and this current flowing thru condenser C_1 gives the voltage E_{c_1} where I_{c_1} leads E_{c_1} by 90°. The plate voltage e_p must then be the resultant of E_c and E_{c_1}. If it were not for the choke coil the plate current would have to be I_c', which is I_{c_1} reversed, since the vector sum of the currents leaving and entering such a point as 0 must be zero. The plate voltage e_p is also impressed across the choke coil, thus e_{choke} coincides with e_p, but the ckoke draws a current I_{choke} lagging 90° behind e_{choke}. This choke current then combines with I_{c_1}' to give as a resultant i_p and if the choke is properly designed i_p can be brought in line with I_L and e_p and in the opposite direction, as was required initially.

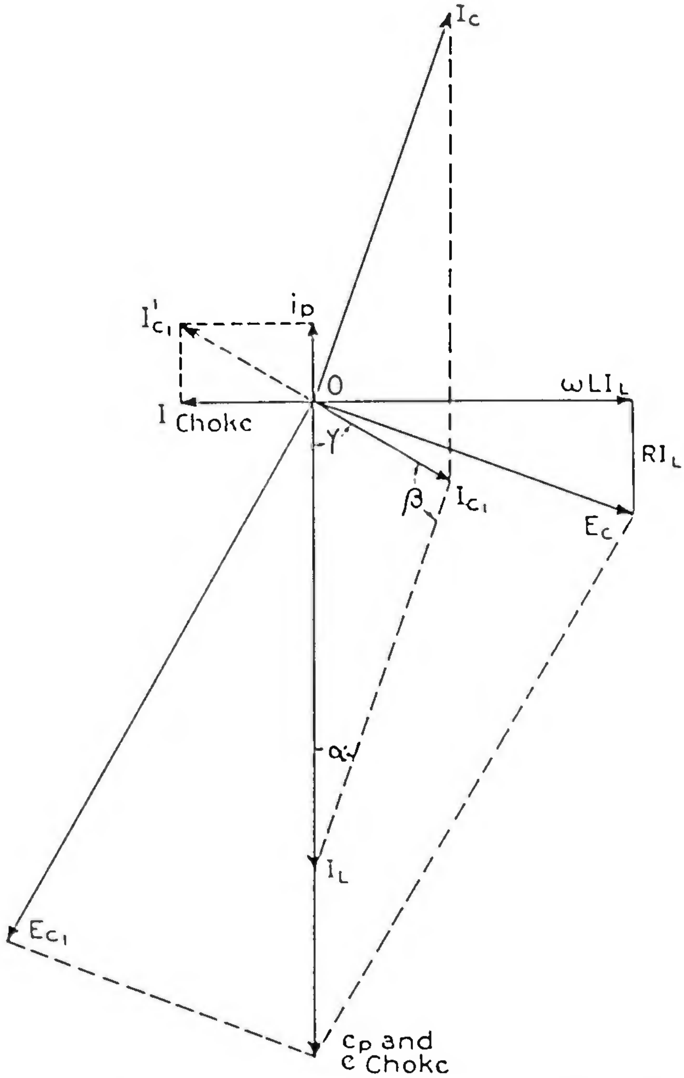


FIGURE 24—Vector Diagram for Magnetron Oscillator

A further consideration of this diagram will show that the frequency of oscillation ω will be such that $\omega < \omega_o$ where ω_o corresponds to the frequency calculated from $\omega_o^2 LC = 1$.

One further point must be considered in circuit design and that is the equivalent series resistance of the circuit $L.C.R.$ The tube cannot operate efficiently unless this circuit has the proper resistance value. The curves shown in Figure 25 were taken with a 4"×12" tube working into a pure resistance (see Figure 7). As can be readily seen, the curves are relatively flat but show a slight maximum at about 1,500 ohms. Numerous tests have shown that best results are obtained when $\frac{I_L^2 R}{I_{c_1}^2} = 1{,}500$ approximately.

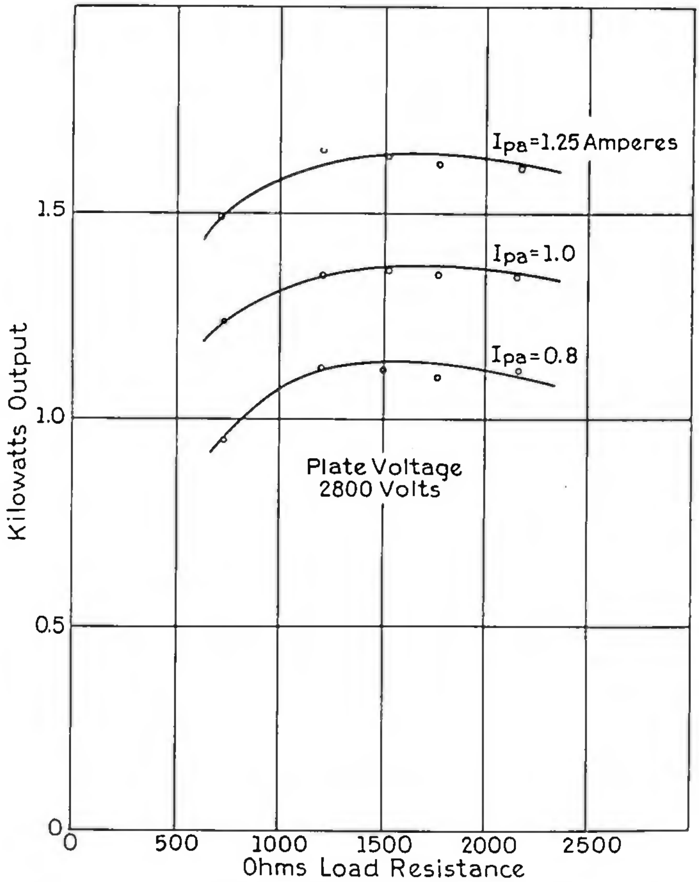


FIGURE 25—Plate Resistance of 4″×12″ Magnetron

As an example the detailed calculation of a circuit will be given An output of 10 kw. is desired at a frequency of 15,000 meters and the available direct voltage is 10,000 volts.

The tube is a 4″×12″ magnetron and has a filament rating of 22 volts and 17.5 amperes. (This corresponds to an 0.020″ diameter tungsten filament running at 2,500° K., and will give an emission of 4 amperes with a life of about 1,000 hours.) The safe continuous plate dissipation is 5 kw.

The control coil L will be assumed to have an inductance of 1.0 millihenry and wound 2 turns per cm. with cable suitable to carry 40 amperes at this frequency.

Referring now to Figure 22 on the curve for $I_e = 4$ amperes, it is found that the angle $\theta_1 = 50°$ corresponds to an output of 10 kw. and a loss of 4.45 kw. The filament loss is 0.385 kw., giving a total loss of 4.84 kw., which is well within the tube rating. From Figure 21 we find that the average plate current is 1.445 amperes. Since the plate supply is 10,000 volts, the total plate input is 14.45 kw., which checks the loss output figures.

Since the wire of the control coil is rated at 40 amperes, we must have $R=6.25$ ohms. The $R I_L$ drop then becomes 250 volts, and since 15,000 meters corresponds to $\omega=125{,}000$, we have $\omega L I_L=5{,}000$ volts. This gives $E_c=5{,}006$ volts. The angle a is given by $\tan a=\frac{R}{\omega L}$ or $\tan a=0.05$ and $a=2°\ 51.'7$.

Since the equivalent series resistance of the circuit must be 1,500 ohms, we have $I_{c_1}{}^2 R'=I_L{}^2 R$ from which $I_{c1}=2.582$ amperes

By the sine rule $\qquad \frac{I_c}{\sin a}=\frac{I_L}{\sin \beta}=\frac{I_c}{\sin \gamma}$

and applying this $\beta=129°\ 19'$, $\gamma=47°\ 59'.3$, and $I_c=38.315$ amperes. Since $I_c=C\,\omega\,E_c$, we have $C=0.06123$ mf.

As a check value on these values, we may calculate the equivalent series resistance of the L, C, R circuit from the formula

$$R'=\frac{R}{m^2 R^2 \frac{C}{L}+(m^2-1)^2}$$

where R is the actual resistance in the circuit, L the inductance, C the capacity, and m the ratio of the actual frequency to the resonant frequency.

In this case $R=6.25$ ohms, $C=0.06123$ mf., $L=1.0$ millihenry, and $\omega_o=127{,}800$ since $\omega_o\sqrt{LC}=1$. This gives $m=0.9781$ and $m^2 R^2 \frac{C}{L}+(m^2-1)^2=0.004163$ from which $R'=1{,}501.3$ ohms.

For a current of 4 amperes thru the tube, Figure 10 shows the necessary voltage to be 1,300 volts, which is then the value of V_e. This gives $V=8{,}700$ volts, but as the vector diagram deals with root-mean-square values we have for e_p the value 6,152 volts.

In Figure 24 it is seen that $E_{c1}=\sqrt{(\omega L I_L)^2+(e_p-R I_L)^2}$. Now $\omega L I_L=5{,}000$ volts and $e_p-R I_L=5{,}902$ volts, which gives $E_{c_1}=7{,}735$ volts. This value E_{c_1} must be produced by the current I_{c_1} flowing thru C_1, hence $I_{c_1}=C_1\,\omega\,E_{c_1}$ from which $C_1=0.00267$ mf.

For the choke coil current we have $I_{choke}=I_{c_1}\sin\gamma$ or $I_{choke}=1.914$ amperes. The voltage across the choke coil being e_p in value or 6,152 volts, the choke coil must then have an inductance of 25.72 millihenrys.

There finally remains the calculation of the polarizing field necessary. The angle θ_1 has been determined as 50°, so that $\theta_2°=80°$. The magnetic field must therefore become of such a value as to prevent electrons from reaching the anode at this time. The plate voltage is given by $V_o-V\cos 80°$, which is 8,500 volts. Referring now to Figure 26, it is seen that the magnetic field necessary at this voltage is 121 gausses. Using the formula $H = 0.4\,\pi\,N\,I$, the current constant of the control coil is found to be 2.5 gausses per ampere, and as $I_L = 40$ amperes (root-mean-square), $H = 141$ gausses. At the time $\theta_2 = 80°$, $H \cos \theta_2 = 24.5$ gausses. This gives then for the polarizing field $H_o = 145.5$ gausses.

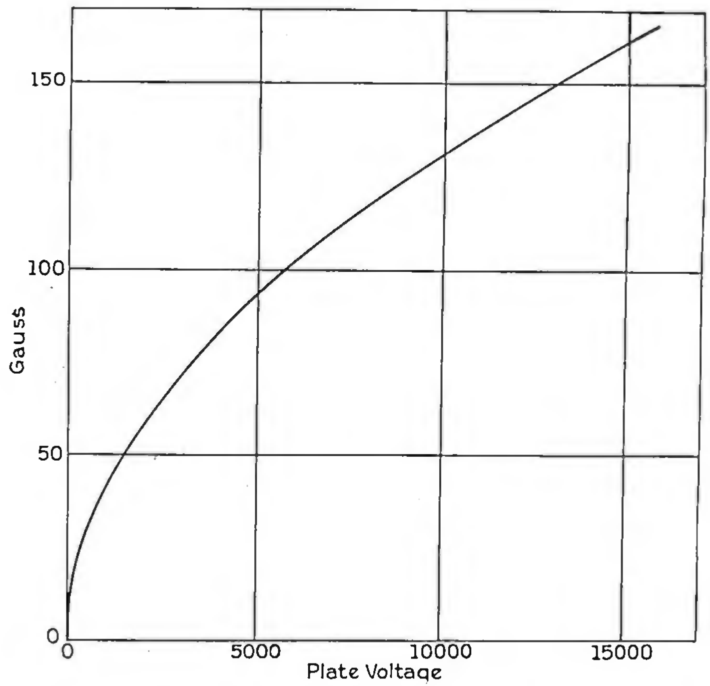


FIGURE 26—Critical Field for 4″×12″ Magnetron.
$V = 0.0221\, r^2 H^2$

By proper design of the coils the field can be conveniently furnished by the average plate current. In order to do this, the filament transformer mid-tap is connected to one terminal of the coil system and the other terminal grounded. It is then necessary to shunt the coils with sufficient capacity to by-pass the alternating component of the plate current. If sufficient copper is used in the coils the RI drops will be low and the loss correspondingly small. This scheme has the advantage of automatically adjusting itself, but it suffers from the lack of flexibility.

Some form of forced ventilation between the control coil and the glass tube is necessary in the large sizes. In order that a 4″×12″ tube may dissipate 6 kw. continuously at the anode, a half horsepower blower furnishes sufficient air.

Tests

Numerous tests have been carried out at both high and low frequency, and several oscillograph films taken. In Table II will be found a few typical results. These tests were made at different times and with different tubes. The wave length was about 12,000 meters, and the tubes were self-excited. Under the heading, "calculated efficiency," the calculations were based on a value of 4 amperes for filament emission since the filaments were run at a temperature such as to give this value.

TABLE II

V_o Volts	I_{pa} Amps.	Input Kw.	Output Kw.	Loss Kw.	Efficiency Percent	Calculated Efficiency Percent
3,000	1.0	3.0	1.55	1.45	52	51
5,000	1.0	5.0	3.25	1.75	65	65
5,000	1.45	7.25	4.45	2.80	61.3	56.8
7,000	1.1	7.7	5.10	2.60	66.2	66.6
7,500	1.4	10.5	6.80	3.70	64.8	67.5
9,000	1.3	11.7	8.05	3.65	68.8	69.3

As will be readily seen, the results obtained agree as well as can be expected with the calculated performance. In order to have a permanent record a few films were made at lower frequency. Figure 27 was taken with the tube non-oscillating, that is, with the tube directly across the generator, and there was no load on the tube. Curve A is the 40-cycle control current of 6.2 amperes thru a coil giving 8.8 gausses per ampere. The maximum control field is thus 77.5 gausses. The permanent polarizing field was 60 gausses. Curve B shows the current thru the tube. By measurement on the film, current begins to flow when the control field is at a value of 13 gausses below the zero line, but as this zero line corresponds to 60 gausses the true field is 47 gausses. The theoretical value of field is found to be 46 gausses (see Figure 26) for 1,200 volts, which was the voltage applied. In curve C is shown the generator voltage. The oscillatory character of the voltage is explained by fact that a capacity of a few microfarads was placed across the generator terminals. The object of this was to hold the voltage constant and prevent damage to the generator due to the transient produced by the sudden starting and stopping of the plate current. Since the generator armature has inductance, the capacity formed a resonant circuit with this inductance and shock excitation caused the oscillations. On measurement it will be found that the plate current in curve *B* rises to a maximum in a time angle of considerably less than 30°, but it must be remembered that there was no load on the tube. The effect of the resistance of the working circuit is to make this rise in current take a longer time.

Figure 28 is from a film taken with the tube oscillating at 500 cycles. For convenience of measurement the tube was excited from a 500-cycle generator and curve A shows this control current. The zero line corresponds to a polarizing field of 100

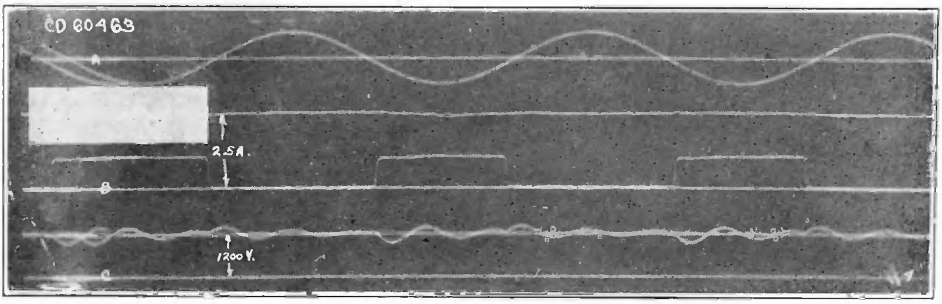


FIGURE 27—Characteristic of 4″×12″ Magnetron, Non-oscillating, Taken by Oscillograph

gausses. The control current of 23 amperes thru a coil giving 2.68 gausses per ampere gives a peak value of 87 gausses. Curve *B* is the plate current rising to a maximum of approximately 3 amperes in a time angle of about 30°, remaining practically constant and then falling to zero again in the same angle. Curve *C* shows the plate voltage which will be noted to be nearly a sine wave. The calibration line corresponds to 2,600 volts. Measurement on the film shows that the tube

	Volts	Gausses	Gausses (Calc. *H* from Figure 26)
begins to open at........	2,170	61	61.5
is entirely open at.......	1,700	33.5	54.5
begins to close at........	1,950	59	59.5
is entirely closed at......	2,250	94	62.5

It is important to notice that the plate current begins to flow and starts to stop at the time when the field and voltage arrive simultaneously at the proper values. The adjustment of the circuit was not particularly good and the plate voltage does not fall quite low enough for the proper utilization of the emission. Thus the output was low, the loss high, and the efficiency low, however the principal features are clearly brought out.

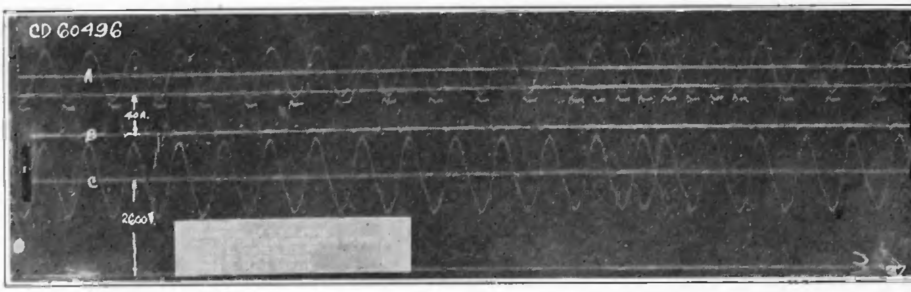


FIGURE 28—Characteristic of 4″×12″ Magnetron Oscillating at 500 Cycles (approx.), Taken by Oscillograph

CONCLUSION

Space does not permit a complete discussion of all the factors which may affect tube operation. A brief mention will be made of a few rather obvious conditions which may exist and their general effect on the system. If the plate voltage remains too high while current flows thru the tube, the plate loss is increased and the output decreased. If the plate voltage falls too low, the power output is decreased, but the efficiency may increase over a limited range. If with properly adjusted values of voltage and current the phase relations become disturbed, then some plate current is drawn at too high voltage and the loss is increased. In this case the output may be maintained but the efficiency falls off.

Of course greater efficiency could be obtained by properly deforming plate voltage and plate current so as more nearly to approach "square" waves. Practical ways of producing these results are not very simple and the gain is apt to be offset by the difficulties encountered.

If the tube is separately excited, the conditions outlined in the paper can be accurately obtained. When the tube is self-excited slight departures may occur, but as shown by experiment these deviations do not seem to be sufficient to cause any appreciable error in the calculations.

There is a limitation to the magnetron at the very high frequencies, and it arises from the difficulty of producing the necessary alternating magnetic field. In order to have very high frequency the inductance must be small; in other words, a very few turns of wire and hence excessively large currents are required to produce the magnetic field.

The magnetron has the advantage of very simple construction and can be made in almost any desired size and the efficiency of operation compares favorably with radiotrons of comparable output.

The writer wishes to acknowledge his indebtedness to Dr. A. W. Hull for his advice and criticism thruout the course of this work, to Mr. E. F. Hennelly for his co-operation in the design and production of tubes, and to Mr. E. W. Kellogg and Mr. D. C. Prince for helpful suggestions.

Research Laboratory,
General Electric Company,
Schenectady, New York.

References

(1) A. W. Hull, "The Magnetron," "A. I. E. E. Journal," volume XL, September, 1921.

(2) A. W. Hull, "The Axially-Controlled Magnetron," "A. I. E. E. Journal," volume XLII, October, 1923.

(3) I. Langmuir, "The Effect of Space Charge and Residual Gases on Thermionic Currents in High Vacuum," "Phys. Rev.," N. S., volume II, number 6, December, 1913.

(4) I. Langmuir and K. B. Blodgett, "Currents Limited by Space Charge Between Coaxial Cylinders," "Phys. Rev.," N.S., volume XXIII, number 4, October, 1923.

(5) A. W. Hull, "The Effect of a Uniform Magnetic Field on the Motion of Electrons Between Coaxial Cylinders," "Phys. Rev.," N. S., volume XVIII, number 1, July, 1921.

(6) A. W. Hull, "The Measurement of Magnetic Fields of Medium Strength by Means of a Magnetron," "Phys. Rev.," N. S., volume XXII, number 3, September, 1923.

SUMMARY: As an introduction, details of tube design are discussed, together with a partial list of the sizes studied. A resumé of the general theory of magnetic control is then given.

The first part of the paper is taken up with the application of the magnetron as an amplifier at 8,000 meters wave length. The circuit is described and the results of tests on tube impedance, design of control coils, the variation of amplification with anode voltage, design of polarizing field coils, and description of a four-stage amplifier are given.

The second part is concerned with the use of the magnetron as a generator. Since the magnetron is a rather unfamiliar tube, the circuit and necessary apparatus are described in considerable detail. The conditions necessary for efficient operation are then discussed. Based on observed wave shapes of anode voltage and anode current, formulas suitable for circuit design are developed, and the complete calculation of a typical circuit given. The results of tests at various voltages are then compared with calculated performance and representative oscillograms shown. In conclusion, a few factors which may cause departure from theoretical results are briefly discussed.

NOVEL CURRENT SUPPLY SYSTEM FOR AUDIONS*

By

Charles V. Logwood

(De Forest Radio Telephone Company, Jersey City, New Jersey)

Never in the history of mankind has invention been stimulated to such an extent as it has by the three-electrode vacuum tube invention of Dr. Lee De Forest. This invention is used in a combination of three industries, namely, the long distance telephone, radio communication, and radio broadcasting, which have grown to gigantic proportions in the last decade. The minds of thousands of trained engineers are daily applied to the task of discovering new application of the established properties of the audion. We find methods of accomplishing desired results described in many publications in dealing with its use in new combinations and in data on the circuits interlinking the input and output branches of the audion device and interlinking audions and their circuits to one another. In any case, we must deal with the power supply to the audion itself. This paper is therefore not entirely concerned with the audion alone. Engineers working with audions have from time to time developed new and important discoveries and applications of standard uses of other devices to the problem of supplying the audion with the power for heating a hot cathode as well as a power supply for the plate circuit.

Both of these power supplies must be constant in their voltage because otherwise causes independent of the controlling forces present in the grid circuits would cause fluctuations in the output circuits of the audion as, for example, when the voltage was being varied at the source supplying the power to heat the filament. This change would cause changes in the plate circuit current detrimental to successful operation. If the plate circuit supply were likewise of a type having inconstant voltage, the variations would cause a disturbance in the output circuit.

The usual source of constant power supply is a storage battery. This device imitates the properties of a condenser of very

* Received by the Editor, October 13, 1924. Presented before The Institute of Radio Engineers, New York, November 5, 1924.

However, under certain conditions the amplifier tubes can be lit on alternating current and yet very little hum is heard in the telephones. A simple method is shown in Figures 1 and 2.

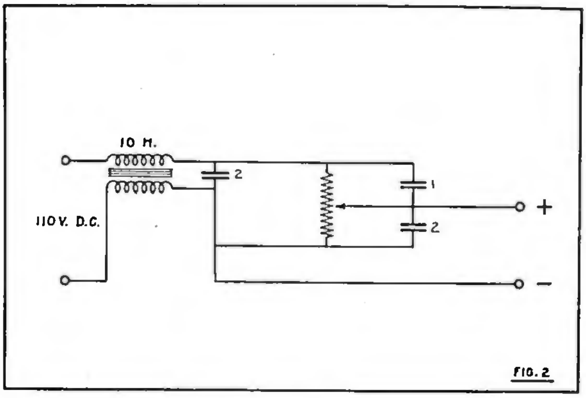


Figure 2

Attention is directed particularly to Figure 2. The device which is included in this circuit was supplied to the Navy Department in the year 1916.[1] The source of current was the ships mains. The filter coil was a double winding affair with an open core. One section of the winding was in the negative lead and the other in the positive lead. Across the output terminals of this filter coil was connected a three-terminal potentiometer bridged by proper condensers. The variable contact of the potentiometer leads to the receiving set. The potentiometer was made of hard graphite of about 12,000 ohms resistance. The potential delivered to the receiving set was regulated by this variable contact. The type of filter coil in Figure 2 is shown more completely in Figure 3.

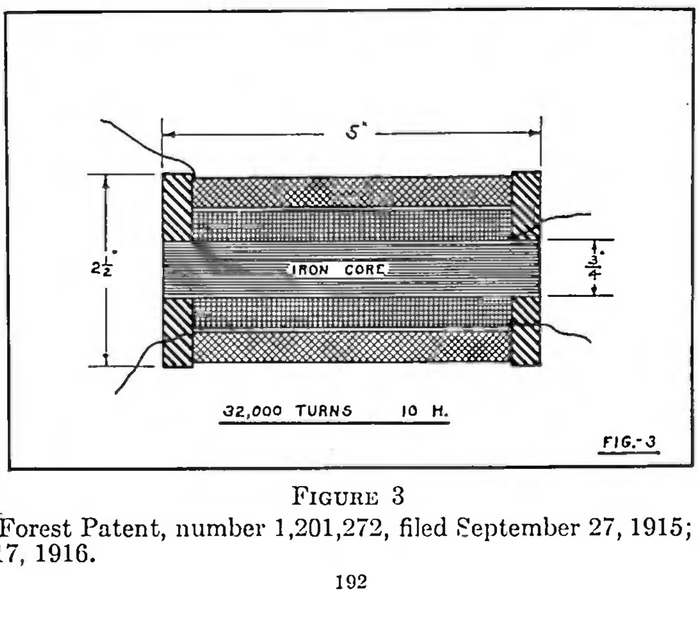


Figure 3

[1] Le Forest Patent, number 1,201,272, filed September 27, 1915; patented October 17, 1916.

The two windings in each section are the same, the size of the wire being number 34 double cotton covered. A considerable number of filter sets were delivered and, as far as I am aware, they gave excellent results. The coil dimensions were approximately 4 inches long and 2½ inches in diameter. The open core was of soft iron and was 1 inch in diameter.

The first set made was, I believe, delivered to Dr. Goldsmith at the College of the City of New York. One can see even at that time that scientific men foresaw its usefulness, and it was at Dr. Goldsmith's request that he obtained a "B" battery substitute.

As far as I am aware, I never heard of such a circuit being called a filter before that time. I had heard of wave filters in 1914, and presume the name started from that. I recall Eccles' book of December, 1915, showing wave filter circuits. I recognize Campbell's work on wave filters, and believe he has done more to help other inventors than the inventors realize. It is thru the applications of his theories that telephone and telegraph systems have reached the present state of perfection.

Coming back to the circuits that are more than everyday types, I call the attention to Figure 4.

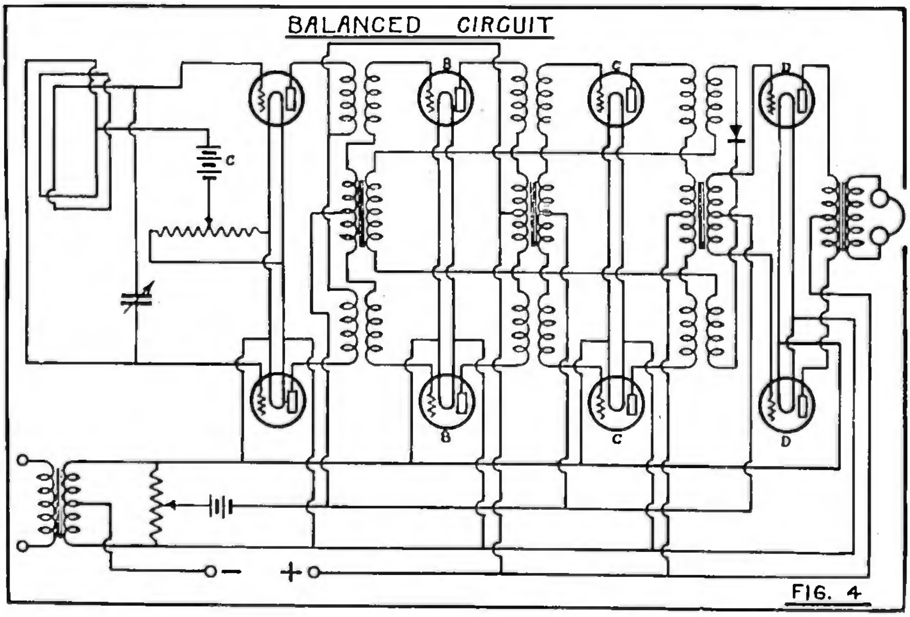


FIGURE 4

This circuit includes 8 De Forest DV-2 amplifier tubes, one crystal detector, 6 radio frequency transformers, 4 audio frequency transformers, 3 step-up transformers, and one step-down transformer. The step-down transformer was the output transformer for the telephones. The three input transformers were balanced type. The "B" battery supply is rectified alternating current, but the filaments were lit with alternating current. Power was delivered from a six-volt step-down transformer.

The general scheme is the "reinforced" or so-called "reflex" method. The balanced circuits are used to oppose changes of induced grid voltage, so that alternating current variations in the filament circuit will not be relayed thru the audio frequency or input transformers. When the tubes are all standard and have similar characteristics this circuit enables good reproduction thru a loud speaker, but at its best the alternating current hum is heard in telephone receivers. Details of this circuit can be obtained on request. Any source of "B" battery can be used in this circuit.

THERMO JUNCTIONS

This method of converting alternating to direct current is a most interesting one and should lead to much investigation. It is a simple method yet it is an expensive method of obtaining direct current power. I do not recall any investigation that has held my attention so steadily as this subject. I tried almost all of the common metals one can purchase in quantity in the process of my investigations and I have decided that molybdenum and advance are about as high in efficiency as any other combination. Next came iron and advance, nichrome and advance, and copper and advance. In Figure 5 I show the table in millivolts per junction.

TABLE OF JUNCTION VOLTS
AT RED HEAT

	Molybdenum-advance	Iron-advance	Copper-advance
Milli-volts	100	60	68

Current depends upon cross section of conductor and difference in temperature of hot and cold junctions.
Resistance includes meter resistance and 6 ft. leads.

FIGURE 5

THERMO ELECTRIC VALUES
See Eccles, 1916, "Wireless Telegraphy and Telephony"

Lead as zero lower limit	18°	Upper Limit	416°
Zinc	373°		
German Silver	175°		

The current thru the hot junction is from the metal of the lower to that of the higher thermo-electric value.

	Microvolts per 1°C.		Microvolts per 1°C.
Iron	$+17.34-.0487\,t$	Silver	$+2.14+.015\,t$
Steel	$+11.39-.0228\,t$	Gold	$+2.83+.0102\,t$
Plat. Ir. alloy 10% Ir.	$+\ 5.96-.0134\,t$	Copper	$+1.36+.0095\,t$
Plat. Soft	$-\ .61-.011\,t$	Lead	
Plat. Hard	$+\ .26-.0075\,t$	Tin	$-\ .43+.0055\,t$
G. S.	$+12.07-.0512\,t$	Aluminum	$-\ .77+.0039\,t$
Zinc	$+\ 2.34+.024\,t$	Palladium	$-6.25-.0359\,t$
		Nickel to 170°C.	$-22.04-.0512\,t$

(Refer to Eccles' book, cited above, for further data.)

In carrying out the early experiments I had a Weston direct current ammeter with two heavy binding posts. These posts were about 1½ inches apart between centers. I connected the free ends of the junction to each post. Then I would heat the junction until the color was a cherry red. The resistance of the meter was about 0.05 of an ohm and the junction resistance was approximately the same when red hot at the junction end.

I found that the current forced thru by the thermo potential would reach as high a value as 7 amperes for a single junction. I did not take into consideration, however, the cooling of the cold ends by the meter itself until I had made up a battery of junctions containing ten or more. Immediately after I got the hot junctions red hot, the current was no higher than 1 ampere. At first this led me to believe I had reversed junctions; finding this not to be so, I proceeded to cool the cold ends. The more metal cooling surface I added, the greater became the difficulties.

This problem looked possible, but I could not find a way to cool the junctions unless I used a fan or water. This arrangement was then no better than a storage battery.

The next step was to be satisfied with lower potentials and to multiply the number of junctions. The results were just as disappointing as before.

In order to keep the bulk down to reasonable dimensions, I crowded the junctions together and heated them electrically. The more I heated them, the greater became the heat conduction and reflection, thus always keeping the potential lower than I expected.

In Figure 6 I show the first complete 6-volt generator delivering 1 ampere. The power consumed from the line was about

400 watts and I considered it much too high. In this figure is shown the method of getting more heat to the hot junctions than is possible by any other method except that shown in Figure 8

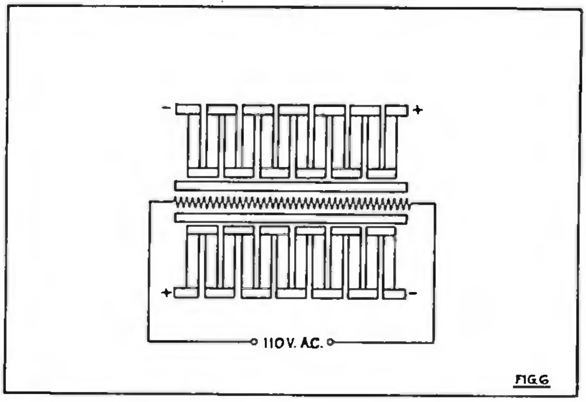


FIGURE 6

A rod of soapstone approximately 6 inches long had been turned down to about 1½ inches diameter with a ¾-inch hole running thru it.

Into this hole I inserted a resistance coil or unit made of nichrome resistance wire, bringing out the ends of the wire at each end of the tube. Two brass plates were fitted on each end and were held together with stay rods separated about $\frac{3}{8}$ inch apart. When rows of junctions were laid in between these stay rods and insulated by mica so that no short circuit would occur, each row of junctions were joined together in the proper polarity order. It is obvious that the hot ends of the junctions would rest on the surface of the soapstone. Soapstone has one redeeming feature, and that is, retaining its heat for an almost unbelievable length of time. I believe this method would have succeeded had I been able to find a way of preventing carbonization of the soapstone. If the resistance touched the walls of the soapstone it would invariably short-circuit the turns and burn out.

A very good method of making the junctions for this type of thermo generator is shown in Figure 6A, alternate strips of molybdenum and advance being laid side by side in a holder. Across the ends, from one side to the other, are laid advance strips. In order to weld these securely, the spot welder was used with a hydrogen jet. Whenever the weld was made a blast of hydrogen prevented oxidation. If the hydrogen was not used, an iron flux was used instead. This was a very good method for welding these widely different strips of metal. When the welds were all made, the sections were cut as shown, the result being a series of junctions.

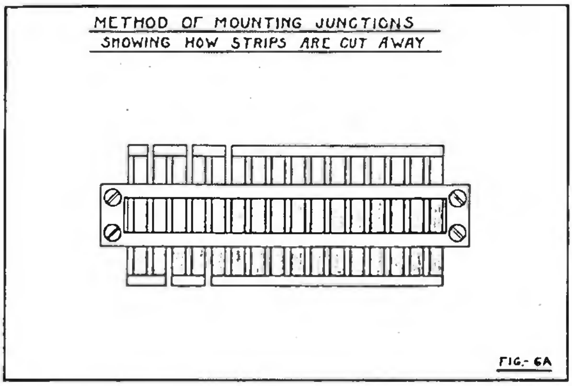


FIGURE 6A

In previous efforts, I had a great many disappointments, because ordinary spot welding would not hold the weld. After this device was constructed and tested, I proceeded in another direction (see Figure 7). This apparatus gave better results than the one in Figure 6 because it was heated by a gas flame and the rising heated air would draw the cool air up with it around the cool ends of the junctions. With a much smaller number of junctions, I could get 8 volts and 1 ampere. This scheme was more economical than the electrical one as it was found to consume only a moderate amount of gas. The more I experimented with this device, the more convinced I became that it is going to be worked out in time.

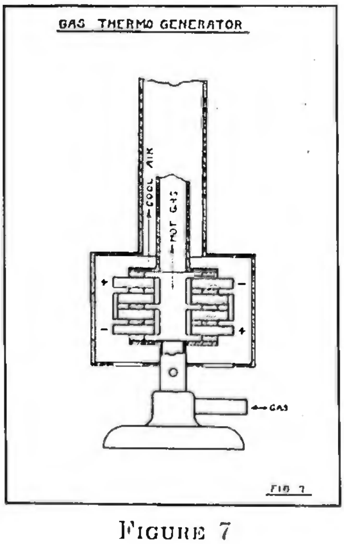


FIGURE 7

Figure 8 shows an induction method which I have worked out, and this, I believe, will eventually lead to the desired results. The drawing in Figure 8 will show some of its general features, but a detailed description is also necessary. Each hot junction is made of copper, and is a complete short-circuited turn. There are 20 of these rings separated by mica insulation. From these rings radiate 16 spokes as in a wheel; 8 are copper and 8 are of another metal such as advance or copel. The copper spokes are welded to the brass ring of its section. The advance spokes connect to the next brass ring. It is obvious, then, that the junction is made at the point where the advance connects to the copper ring. Since the ring is heated by the short circuit, it is directly connected to the junction. The outer ring is split, so that it will not weaken the field unnecessarily.

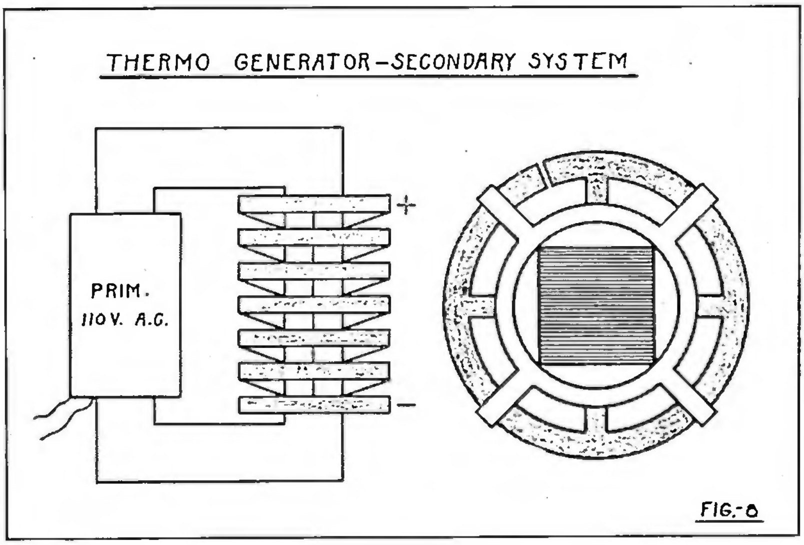


FIGURE 8

RECTIFIERS

Coming to the next step in current supply system I refer again to Figure 2. Here we see one of the early filter circuits. This circuit was the forerunner of Figure 9. Here we have two valves, a condenser, and a transformer, the transformer having two secondaries and one primary winding. It will be noticed that the neutral point of the plate supply is grounded. Connected to this rectifier circuit is a filter system, which embodies the circuit in Figure 2. The constants are noted in the corner of the figure. This is very suitable for operating a detector and two stages of audio frequency amplification.

Figure 10 shows the first of the "B" battery substitutes. It consists of two rectifier tubes, a transformer, and filter systems.

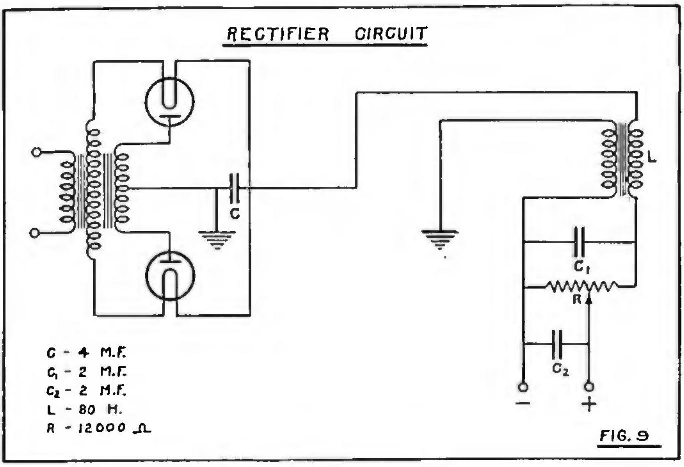


FIGURE 9

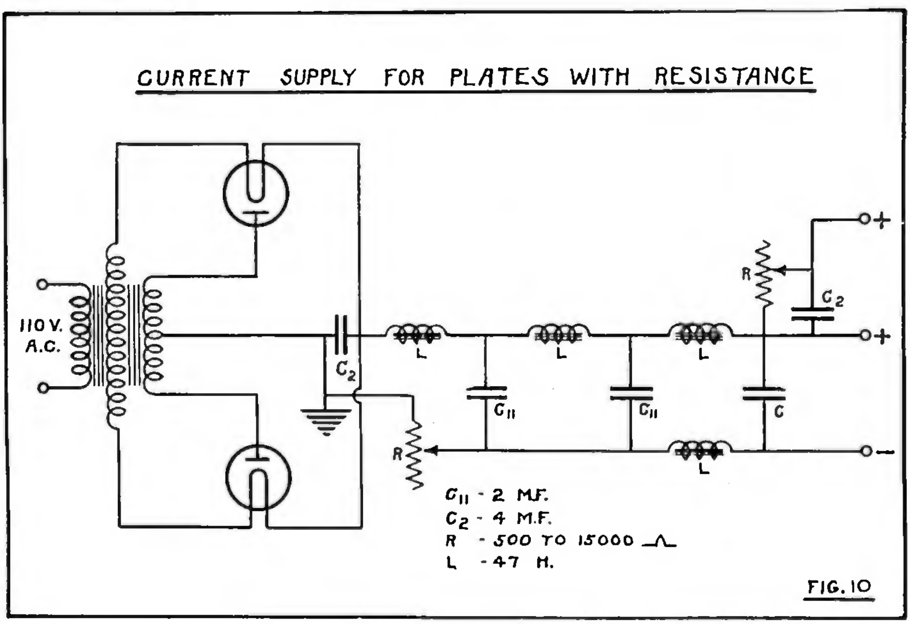


FIGURE 10

It will be noticed that the inductance coils of this circuit are fairly high in value. I found after months of hard work that the line conditions varied considerably, aside from variations in the fundamental frequency itself, and it was not until I combined resistance with capacity and inductance that I was able completely to eliminate all hum even in the most delicate detector adjustments. Many different receiving sets were set up so that comparisons could be made. The simplest filter circuits, such as shown in Figure 10A, were used on circuits that were of the type of neutrodyne, super-heterodyne, straight radio frequency detector and audio frequency stages, but the simple filter circuits would not deliver sufficiently smooth current to a standard De Forest reflex circuit.

Figure 10R is a single-wave rectifier system utilizing two rectifier tubes. It will be noticed that the plate of the second rectifier is in series with the positive side of the rectified current source. This gives a smooth clean current supply entirely free from alternating current hum.

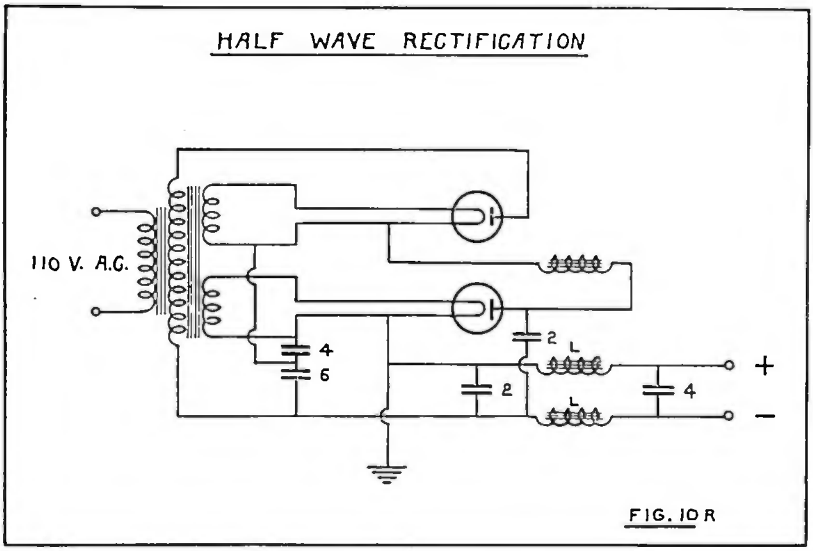


FIGURE 10R

By this time, I had tried the following types of supply on the De Forest reflex circuits:

A. Double filament type.
   This is exceedingly quiet with the audion filaments grounded.
B. Electrolytic single rectification. Best results were obtained by grounding filaments of the audions.
C. Single rectification utilizing tuned filter inductance. Best results with positive line grounded.

This rectifier filter circuit, shown in Figure 10, is efficient and reliable.

The rectifier tube was developed for the circuit, and has proven after months of constant use to be very satisfactory. Each rectifier will successfully pass 40 milliamperes without taking up more than 10 percent of the total emission available. It will be noted that three of the filter coils are in series with the positive leg and one in series with negative line.

It makes little difference where the plate supply circuit is grounded, but for complete elimination of singing I advise grounding the neutral terminal. If it is desirable to ground the receiver, it is advisable to put a ½ microfarad condenser in series with the receiver ground. A reduced voltage tap is obtained by a high resistance "Bradleystat" (carbon compression rheostat). Shunted across this resistance is a by-pass condenser.

The potentials across the tank condenser C_2 is about 160 volts at a load of 30 milliamperes. The potential across plates and filaments drawing 30 milliamperes is about 125 volts. The no-load voltage across the tank condenser is 260 volts. The terminal alternating voltage is 200 volts. The two rheostats shown in Figure 10 are 10,000 ohm "Bradleystats," consuming 1 to 5 watts.

In Figure 11, I show a more complete rectifier system. One transformer is used. There are two distant rectifier circuits. An auto transformer is made to deliver power to one set of rectifier tubes, and the other coil, a secondary winding, supplies another pair of rectifier tubes. It will be noted that the same

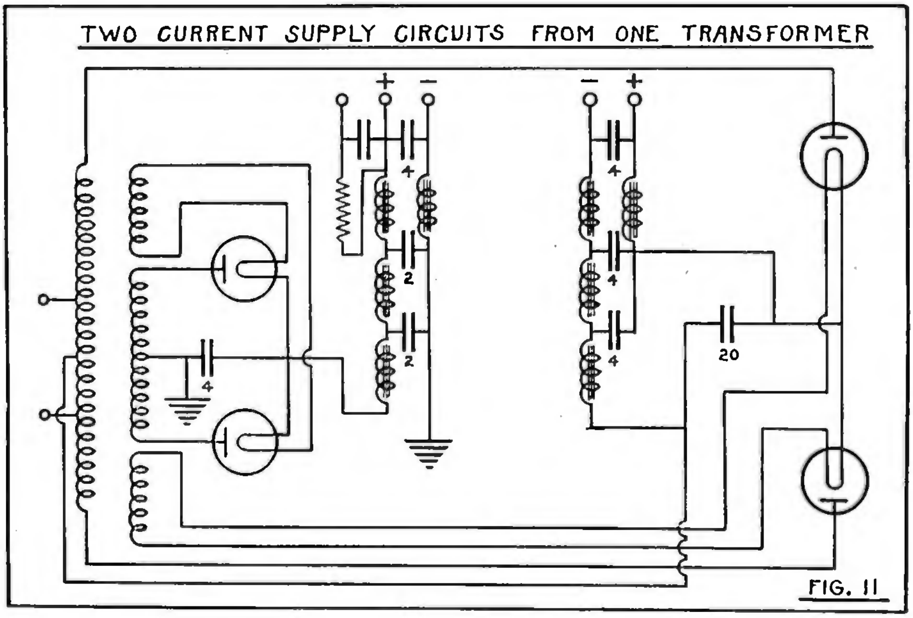


FIGURE 11

connections are used in Figure 11 as in Figure 10, while the other filter circuit has somewhat similar conditions. This circuit was developed for the purpose of supplying "A" and "B" battery voltage to the special receiving circuit shown in the next figures.

We shall next consider the circuit of Figure 12. This circuit is similar to the one shown in Figure 11 in part, but contains certain other necessary adjuncts. Rectified current is obtained from two rectifier tubes delivering at full load about 0.3 of an ampere. This current goes to light the filaments of four standard DV-2 tubes which have all been put in series. It is better to connect them in this way as the necessary power is then more easily obtained from the rectifier tubes. There is connected across the terminals of the rectifier circuit a resistance of approximately 3,000 ohms. In order to obtain proper grid bias it is necessary to have a variable contact on this potentiometer. Plate current is obtained either from a rectifier or from "B" batteries. But the primary object is to light the filaments.

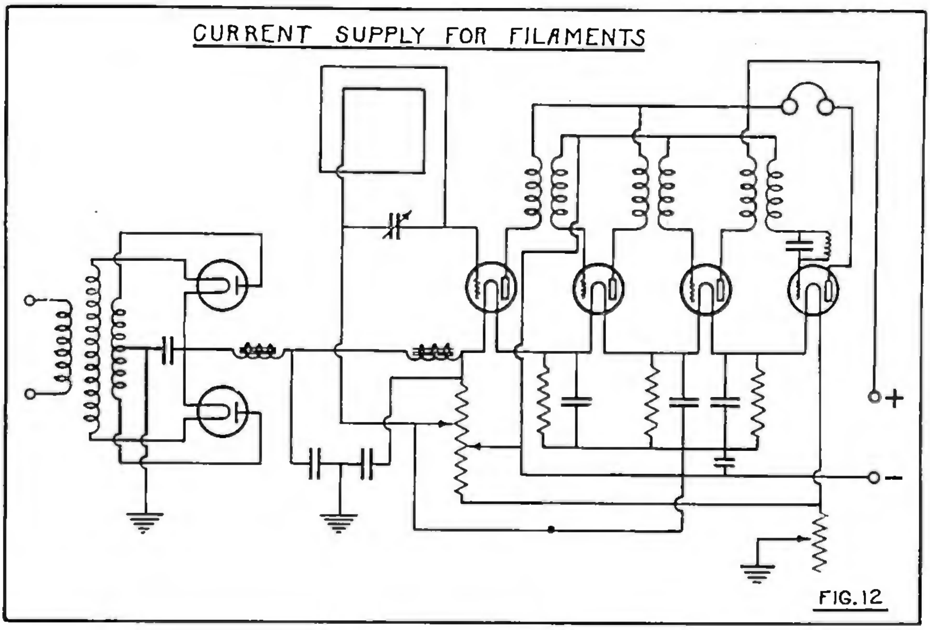


FIGURE 12

It will be noted that starting from one end of each filament is an 800-ohm resistance, all these resistances being connected in common at one end. Across these resistances are 1 or 2 micro-farad condensers so that the audio frequency will be distributed equally over the filaments. A condenser connects the grid bias side of the system.

This circuit works very well and gives promise of producing a good system. No disturbances are heard in the receivers. Ground connections are necessary for eliminating ripple.

RADIO FREQUENCY FILAMENT SOURCE

There is no doubt that many engineers have tried to utilize radio frequency energy to light the filaments principally because it is so easy to get enough current to light them this way.

Consider the circuit shown in Figure 13. This is not an unsuitable circuit; in fact, it worked better than any other circuit I have tried when using radio frequency energy to light the filaments. However, I found I had a great deal of trouble ahead of me as soon as I tried to tune in for stations. The problem was to find the proper frequency to put thru the filaments. I discovered that the detector was where one fell into most of the trouble. So I shielded the detector and used a separate battery on the filament. Of course, this was not entirely a substitute for batteries, but in these days dry batteries last a long time on one tube consuming only 60 milliamperes. The first frequency used to light the filaments was very high. I found that a frequency of 7,500 kilocycles (40-meter wave length) was useable, but as the frequency was diminished it became more difficult to get results. At first I assumed I would have to make the filament frequency the same as that of the received wave, but that gave too much trouble. There resulted a group of squeals with every twist of the dial.

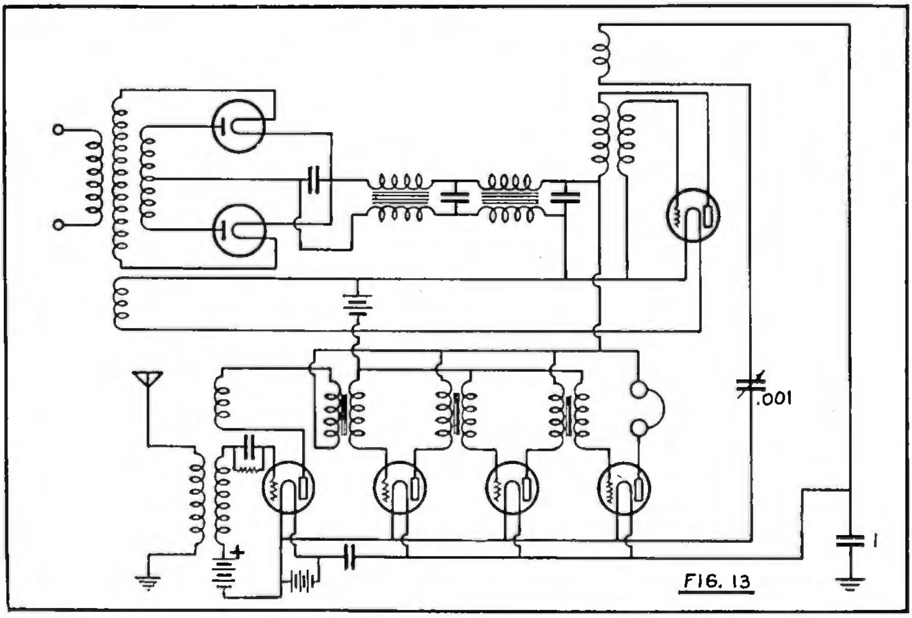


FIGURE 13

Figure 13 will enable one to follow the scheme. I found that the oscillator tube can be a DV-2 as this will supply enough current for 4 DV-3 De Forest tubes. The circuit of Figure 13 is a detector and three stages of audio frequency amplification utilizing regenerative couplings on the detector tube.

Figure 14 is another circuit with which I had considerable success. This scheme was in general a push and pull oscillator;

the rectifier tubes were constructed with grids. The two pancake choke coils in the secondary terminals were to keep the radio frequency out of the transformer. Coupled to the push-pull oscillator is an absorbing circuit which includes the filament circuit. The circuit is tuned to the oscillator frequency, and a separate battery is supplied to light the detector filament. A stopping condenser is inserted to prevent the battery from lighting the filaments of the other tubes. It is very necessary to ground the filaments so that all hum is avoided. A filter circuit is tapped on the tank condenser. All irregular noises are thus ironed out. The generated energy goes to supply the plates of the receiving circuit.

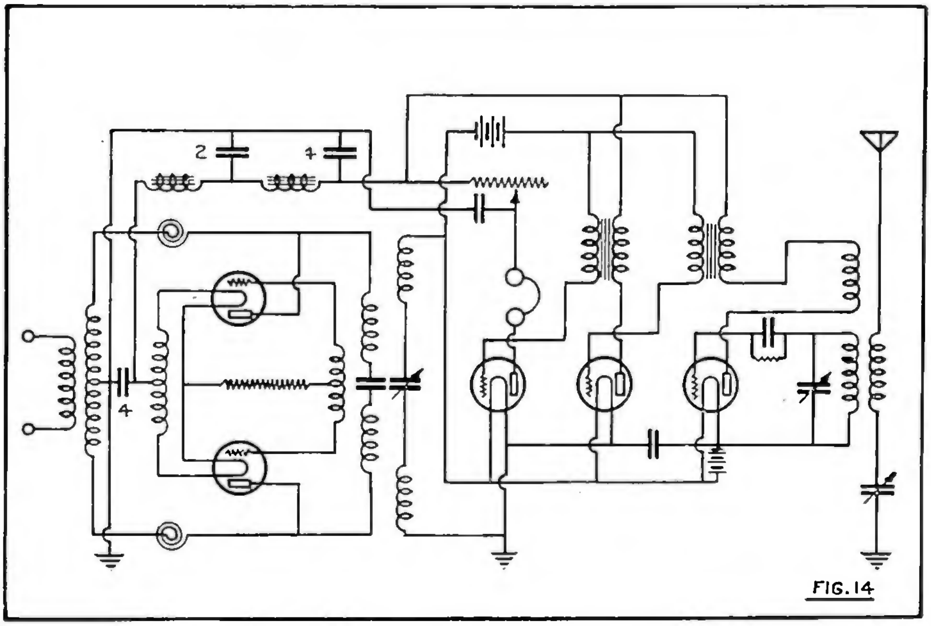


FIGURE 14

After these tests were completed, I found that in comparison with a standard storage battery, this arrangement was possibly 50 percent as efficient. There is no doubt some disturbing factor which I have made no great effort to locate.

Of course, there is no doubt that there is considerable "paralysis" or blocking, due to effect of the radio frequency voltages acting on the space charge within the tubes. Further than this information, I cannot determine exactly why the arrangement works at all since we know well that such rapid reversals set up opposing forces within the tube.

The detector was my stumbling block. The amplifier was prejudicially affected by the radio frequency currents used, because when I substituted a storage battery supply, the amplification was noticeably increased.

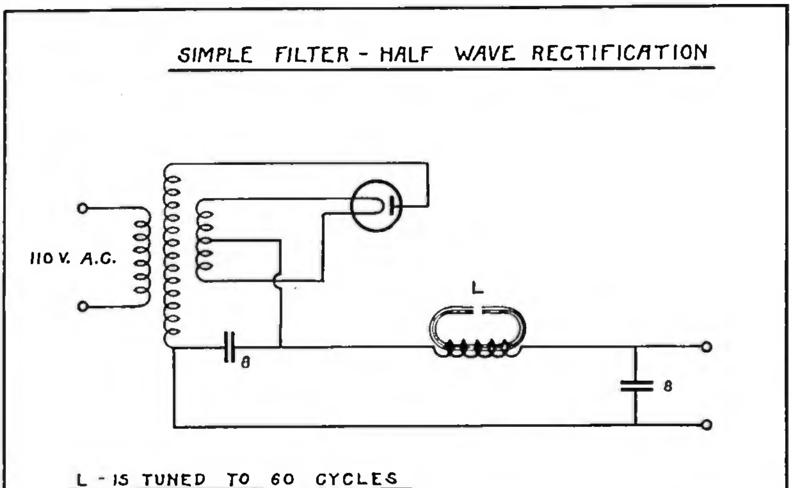


FIG.

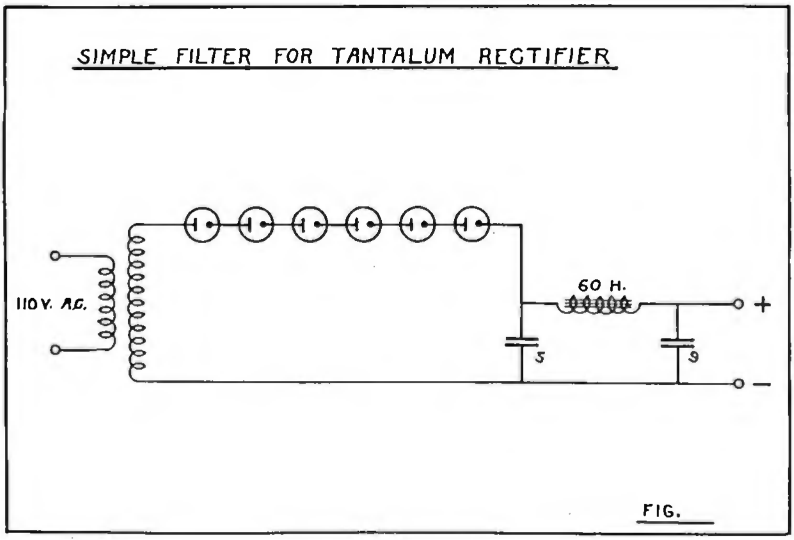


FIG.

I shall now describe an entirely different idea in current supply devices, and one which is indeed very attractive. It will deliver both "A" and "B" voltages constantly. The efficiency is fair. It consumes about 200 watts from the line and will deliver 50 to the receiving circuit. Lengthy tests have not been carried on to any great extent, but even from the time it was first tested it convinced our engineers that it had great merits. The plate voltage is fairly constant, and the device will deliver 150 volts and up to 50 milliamperes with real reliability. In tests made, I have found that there is no ripple in the plate circuit, but the filament supply gave us some concern until the proper filter was found.

While at this time we cannot tell much about its life, we presume it will turn out to be satisfactory in this respect. Owing to the continued development of this outfit by the manufacturer, we are prevented from giving full details.

The outfit is a miniature motor-generator set. Its speed is 6,000 revolutions per minute. There are 24 bars on the commutators. The fields are excited by the high voltage side, and the motor is universal for 110 volt alternating or direct current. The commutator ripple has a frequency of 2,400 cycles per second, and this frequency is easily filtered out with proper condensers and impedances. The bearings are sleeve wick lubricated, which probably is better than ball bearings. They need but little attention when once the cups are filled with oil. The motor is cooled by a fan attached on the shaft. The plate voltage across the commutator is 150 volts. The filament supply is 8 volts. No commutator sparking disturbance, due to the power line, is heard in the receiver. The little device is also a fine outfit for charging storage batteries as it has the two separate voltages.

I should like to see a perfected "A" battery substitute supply that will light the filaments as well as a motor generator can be made to do, and without having to change the accepted multiple connection of filaments. The filter on the low voltage side would be a very big affair if we tried to make it do as well as the "B" battery substitute. If we found we needed a 20-henry choke coil and suitable condenser to smooth out the ripple from a Tungar rectifier, we would have to use a bulky outfit. I do not know whether there are any electrolytic "A" battery substitutes on the market at this time, but I believe the problem is just as great as when rectifier tubes are employed to rectify the alternating current supply. It would be interesting to hear from anyone concerning secondary emission tubes, such as Dr. Hull proposed some time back.

SUMMARY: There are considered various forms of "A" and "B" battery substitutes such as rectified and filtered alternating current generators, thermo electric devices, radio frequency current generators, electrolytic rectifiers, and motor generators.

A METHOD OF MEASURING RADIO FREQUENCY BY MEANS OF A HARMONIC GENERATOR*

By

August Hund

(Radio Laboratory, Bureau of Standards)

Introduction

Harmonics of an electron tube generator have been used for radio-frequency measurements[1] for several years. The well-known system for measuring a radio frequency in terms of an audio frequency, devised by Abraham and Bloch[2] and employing their multi-vibrator is perhaps the best example of such use of harmonics.

It is the purpose of this paper to describe briefly an arrangement which employs a simple type of harmonic generator the fundamental of which is an audio-frequency alternating current. The generator is rich in harmonics of sufficient power to produce appreciable currents in a wavemeter which is coupled to it and tuned to resonance with frequencies which are integral multiples of the fundamental. The arrangement is a convenient one for primary frequency standardization since the fundamental frequency produced by the harmonic generator can be checked during the measurement against the frequency of a standard tuning fork by means of a visually indicating instrument. A large number of harmonics can be utilized since decidedly sharp settings are made possible by the use of another visual indicator. The visual indicators lighten the labor of the observer since it is found easier to take a large number of settings with the eye than by ear.

Description of the Method

The arrangement for primary frequency standardization is shown in Figure 1. The heavy line portions are the essential parts

*Published by permission of the Director of the Bureau of Standards of the United States Department of Commerce. Received by the Editor, October 16, 1924.

[1] "Radio Instruments and Measurements," Bureau of Standards Circular Number 74, pages 100–104 ; 1918.

[2] "Comptes Rendus," volume 168, page 1105 ; June, 1919.

of the system. The visual beat indicator is a portable galvanometer, with 1 milliampere for full scale deflection. It is used for keeping the fundamental frequency f of the harmonic generator exactly at the value of the frequency of the standard tuning fork generator. The pointer will stand still when the two frequencies are exactly alike. This will also happen when the

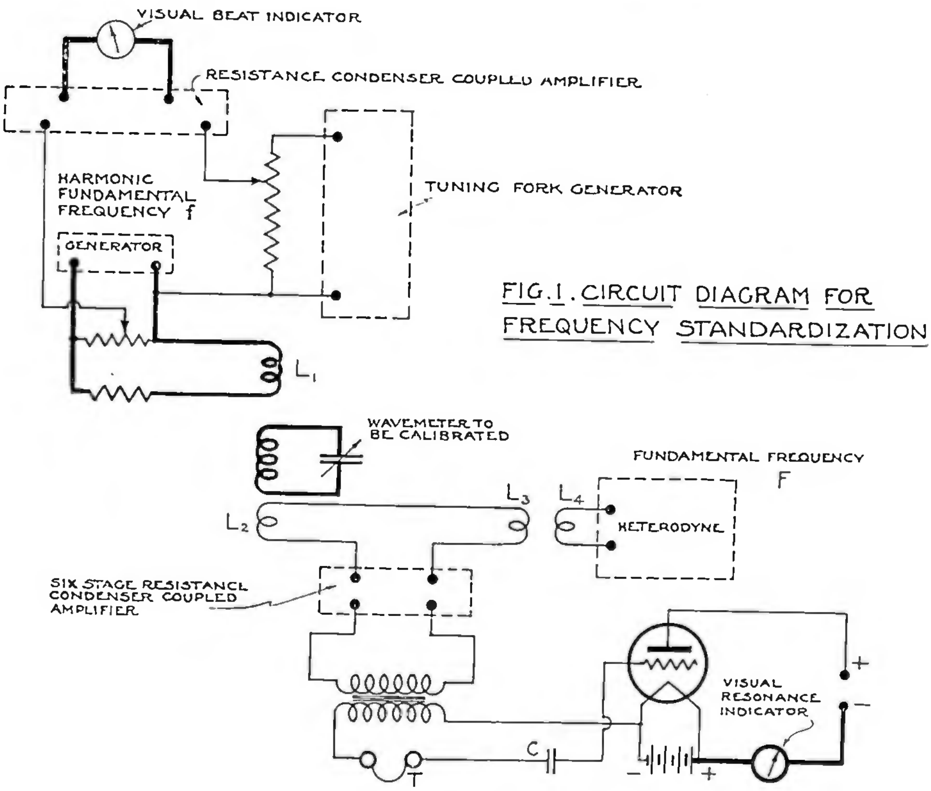


FIGURE 1

two frequencies are very different, but such a shift of frequency is not likely to happen during the measurement and after having the fundamental frequency f adjusted. The visual indicator of resonance will indicate a sharp minimum whenever the wavemeter is tuned to the fundamental frequency f or any integral multiple of it. The procedure of measurement is briefly as follows :

(1) The fundamental frequency f of the harmonic generator is varied until the fundamental alternating current is in synchronism with the current produced by the standard fork generator. The zero beat indicator will then stand still and the least change in the frequency will cause the pointer to swing[3]

[3] Two swings per second, for instance, mean that the fundamental is off by two cycles. The pointer will, of course, also stand still when the harmonic generator is adjusted to $2f$, $3f$, and so on.

to and fro. The frequencies of all possible currents have then the form $(a \times f)$ if a denotes whole numbers such as 1, 2, 3, 4, and so on.

(2) The heterodyne is set to certain fundamental frequency F which is in the neighborhood of the frequency range to be used in the calibration.

(3) While the wavemeter is varied, a series of beat notes will be heard in the telephone receiver T which produce at the same time minimum deflections on the resonance indicator. The telephone receiver is used as a rough guide and the settings are made by means of the visible indications. The minimum deflections will occur whenever

$$a \cdot f = b \cdot F$$

if $b.F$ stands for all possible frequencies of the heterodyne and b denotes integer numbers such as 1, 2, 3, 4 . . . . . This shows that a minimum indication is obtained whenever the wavemeter is set to a frequency which is an integral multiple a of the fundamental frequency f of the harmonic generator. Beats can also occur between harmonics of the harmonic generator and harmonics of the heterodyne, which is expressed by factors a and b. The factor b can be made equal to unity by choosing a rather loose coupling between the heterodyne and the six-stage amplifier. Such a precaution is, however, not necessary.

(4) Knowing approximately the fundamental frequency F of the heterodyne driver it is easy to determine the particular harmonic frequency $a \times f$ to which the wavemeter is tuned. The simplest way, however, is to substitute the wavemeter by one the calibration of which is known approximately. (Example : Suppose the fundamental frequency $f = 1$kc. (kilocycle per second) and the approximate frequency is found to be $a.f = 21.13$kc., then the true setting is 21 kc., since a must be a whole number).

When the precautions above mentioned are followed, this method may be used to obtain resonance settings on a wavemeter up to the 100th harmonic. It has been found possible to obtain as high as the 360th harmonic of a 1,000-cycle fundamental frequency, but this requires much skill and does not appear useful in actual wavemeter standardization work. For the higher frequencies it is preferable to use a tuning fork of higher fundamental frequency f, or to employ an additional harmonic generator and measure its fundamental frequency f' against a certain harmonic $(a \times f)$ by another zero beat indicator in the same way as f is checked against the fork driver. An an example, suppose the fundamental frequency f of the first harmonic generator is adjusted to the frequency of the tuning fork, which let us assume to be $f = 1$ kc. The fundamental frequency f' of the second harmonic generator may be adjusted by another zero beat indicator to the 20th harmonic of f, that is, $f' = 20$ kc. A calibration of a wavemeter at 500 kc. would then require only the 25th harmonic of the second harmonic generator instead of the 500th harmonic of f.

Practical Hints and Description of Apparatus

(I) The *harmonic generator* is shown in Figure 2. It makes use of the fact that a circuit of this type produces strong harmonics and especially when much inductance with pronounced distributed capacity is used in the grid and plate circuits and a crystal rectifier in the output branch. In order to accomplish this a hard rubber tube, one-half inch in diameter and five inches in length was used as a core for a coil with 48,000 turns of wire. Using wire, about Number 30, American wire gauge, and winding the coil in the ordinary way will give pronounced coil capacity. Taps were taken off every 3,000 turns as indicated in the figure, giving enough sections of different inductance to produce distorted audio currents ranging from about 10 cycles per second to 15 kilocycles per second. An ordinary air condenser connected from the plate to the grid gives a means for varying the frequency gradually within a small range. A tube capable of giving from 2 to 10 watts power is sufficient for the measurement. Two tubes connected in parallel can also be used. The entire generator should be shielded by copper foil with the output coil outside of the screen.

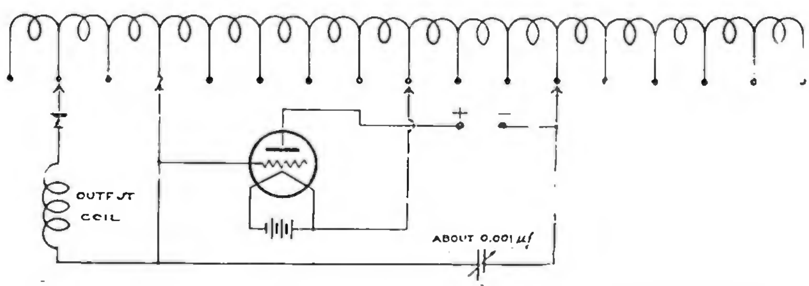


FIGURE 2—Diagram of Connections for the Harmonic Generator

(II) The 6-*stage amplifier* (Figure 3) is used for amplifying the beat effects between the current of frequency *a.f* to which the wavemeter is tuned and the current produced by the heterodyne. It acts normally as an audio-frequency repeater since the beat notes are usually within the audible range of frequencies. It operates as a radio-frequency amplifier when no heterodyne is used. This is only possible for comparatively low frequencies (not much higher than the 20th harmonic of f). It seems therefore best to use the heterodyne for all settings. The entire arrangement is surrounded by a shielding of copper foil. If possible the " B " battery should be within the shielding, otherwise a by-pass condenser should be used within the screen and across the terminals leading to the " B " battery.

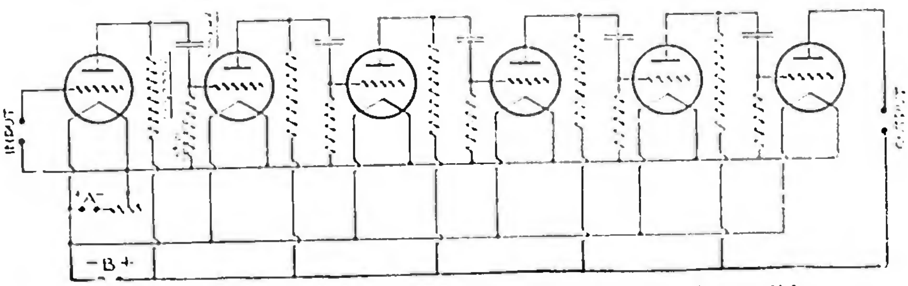


Figure 3—Six-Stage Resistance Condenser Coupled Amplifier

(III) The *amplifier* leading to the visual beat indicator is likewise resistance-condenser coupled and shown in Figure 4.

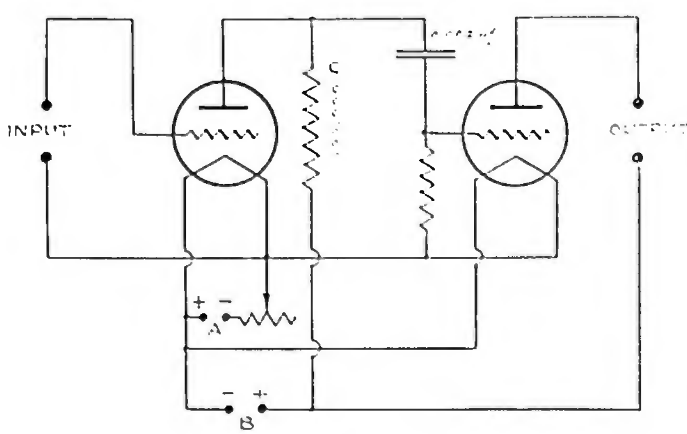


Figure 4—Resistance Coupled Amplifier for Zero Beat Indicator

(IV) The circuits leading to the *visual resonance indicator* are shown in Figure 1. An ordinary audio-frequency transformer is employed for coupling the output branch of the 6-stage amplifier to the circuit with the visual resonance indicator. It was found that the resonance settings can be made sharper when a dip method is used. Such an indication is obtained when a grid condenser of about 0.0001 μf. is employed without a leak in the detector circuit. When the different beat notes affect the detector tube the microammeter in the plate circuit will show a sharp dip. If the frequency measurement is carried out in a laboratory where many outside disturbances affect the grid, the telephone receiver T (Figure 1) indicates the presence of interfering voltages. Under such circumstances the use of a grid leak is advantageous.

(V) The *tuning fork generator* provides the fundamental frequency in terms of which the measurement is made. It is therefore essential to use a standard fork the frequency of which is constant and known. It seems best to use a fork employing an electron tube drive of such a type that the circuits can produce alternating current only when the fork is vibrating at its own natural frequency. For most work a fork having a frequency of about 1,000 vibrations per second is convenient. A fork giving about 100 vibrations per second would have the advantage of giving more points on the wavemeter to be calibrated, but the disadvantage of not giving calibrations at frequencies as high as can be obtained with a 1,000-cycle fork.

(VI) The *heterodyne* is an ordinary electron tube generator covering a range of frequencies from about 10 to 1,500 kc. Copper foil is used for shielding the entire apparatus except the coil L_4 (Figure 1) which couples to the 6-stage amplifier. A tube giving about one-tenth of a watt radio frequency power will do.

(VII) The inductances of the *coupling coils* L_1, L_2, L_3 and L_4 shown in Figure 1 depend on the range of frequency used, while the shape of coils L_1 and L_2 depends, besides, on the shape of the coil used in the wavemeter. A loose coupling to the wavemeter is essential. The best distance between L_1 and the wavemeter, L_2 and the wavemeter, and between L_3 and L_4 is found by trial for which case it is convenient to use the telephone receiver T as well as the resonance indicator because the relative positions of the coils may be so much off that the indicator will not respond at all. The coils L_3 and L_4 are made to slide in a box which is covered with copper foil.

(VIII) The *zero beat indicator* in Figure 1 can also be replaced by a cathode-ray oscillograph (the hot-cathode type is convenient). The usual way of using this apparatus applies the two voltages E_1 and E_2 coming from the harmonic generator and fork generator, respectively, to the two deflection condensers of the oscillograph. Synchronism is then recognized by a stationery pattern (Lissajous figure) on the fluorescent screen of the cathode-ray tube. Another way is partly indicated in Figure 5. The current coming from the fork generator produces a circle on the screen of the cathode-ray tube. The battery between the hot cathode and the anode of the oscillograph is connected

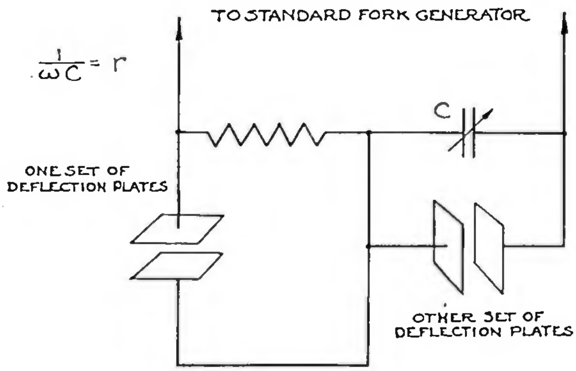


FIGURE 5—Zero Beat Indicator, Using a Cathode Ray Tube

in series with the output of the harmonic generator. If the fundamental frequency of this generator is not exactly the same as the frequency of the fork, the diameter will increase and decrease at the rate of the frqeuency difference.

Department of Commerce,
Washington, D.C.
September 2, 1924

SUMMARY: An improved method has been developed for standardizing a wavemeter by means of the harmonics produced by a simple type of harmonic generator the fundamental of which is an audio-frequency alternating current. The arrangement is adapted to primary frequency standardization since the fundamental frequency can be checked during the measurement against the frequency of a standard tuning fork by means of an instrument using visual indication. A large number of harmonics (up to 100 and higher) can be utilized since very sharp settings are made possible by the use of a visual resonance indicator.

AN ELECTROMETER METHOD FOR THE MEASUREMENT OF RADIO FREQUENCY RESISTANCE*

By

P. O. Pedersen

(Fellow, A.I.E.E. Fellow, I.R.E. Professor in The Royal Technical College, Copenhagen)

Introduction

To determine the resistance of a conductor for direct current is one of the simplest electrical measurements and can be carried out with a very high degree of accuracy. The case is entirely different when measuring the effective resistance for radio frequency current.

To determine this resistance is still a rather difficult matter and cannot be done with any high degree of accuracy, altho the development of suitable generators for the production of continuous radio frequency current has resulted in considerable improvement.

The older methods[1] practically all rested on the fundamental investigations of *V. Bjerknes* on resonance in simple and coupled circuits[2]. Measurements were generally carried out in the way that the circuit to be investigated was set in oscillation by means

*Received by the Editor, October 16, 1924.

[1] E. Nesper: "Die Frequenzmesser und Dämpfungsmesser der Strahlentelegraphie," pages 165-238. (Leipzig, 1907.)

[2] V. Bjerknes: (a) "Dämpfung schneller electrischer Schwingungen," 'Wied. Ann," 44, page, 14, 1891.

(b) "Ueber den zeitlichen Verlauf der Schwingungen im primären Hertzschen Leiter," "Wied. Ann.," 44, page 513, 1891.

(c) "Ueber electrische Resonanz," "Wied. Ann.," 55, page 121, 1895.

of a spark-discharge, and the oscillations then investigated in an auxiliary circuit loosely coupled to and in resonance with the circuit under test. As indicator in the auxiliary circuit there was generally used either a quadrant electrometer the deflection of which is proportional to the time integral of the square of the potential difference or, and in most cases, a radio frequency ammeter the deflection of which is proportional to the square of the current.

Most of the newer methods[3] are based upon the use of continuous oscillations which originate in a generator circuit and by means of suitable coupling arrangements act upon the test circuit—namely, the circuit under test—and in this case the measurements are carried out directly in the test circuit.

Figures 1 and 2 show the principles of the two methods now nearly always used. In both figures, *G H F* stand for generators of continuous radio frequency current, while *S* indicates coupling arrangements, *C* variable air-condensers, *A* ammeters for radio frequency currents, and *r* variable resistances of which the values of the various settings are accurately known.

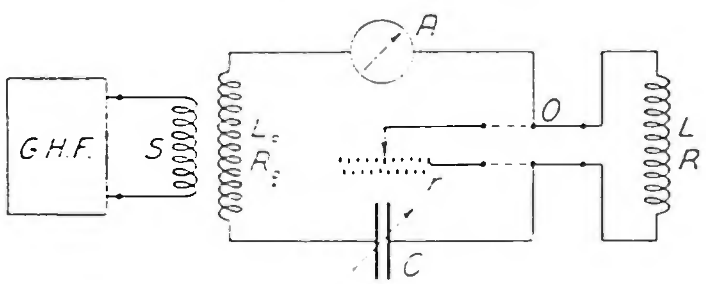


FIGURE 1—The Substitution Method

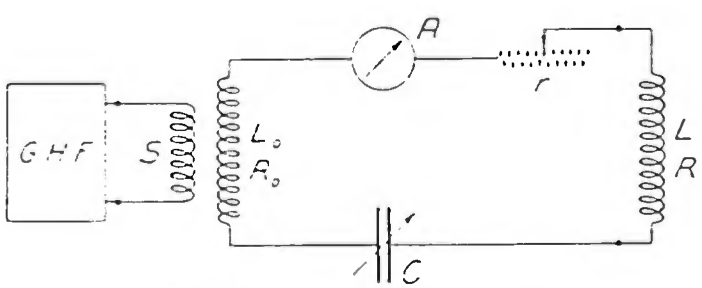


FIGURE 2—The Added-Resistance Method

3 (a) J. H. Dellinger: "The Measurement of Radio Frequency Resistance," PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, New York, volume 7, pages 27-60, 1919.

(b) "Radio Instruments and Measurements," "Bureau of Standards Circular," Number 74, Washington, 1920.

(c) H. Armagnat et L. Brillouin: "Les mesures en haute frequençe," Ecole Supérieure d'Electricité, Section de Radiotélégraphie," Paris, 1924.

Figure 1 shows the substitution method. The effective radio frequency resistance of the wire coil L is measured in the following manner: With the switch O in the position shown, the condenser C is varied until the circuit $C\ L_o\ A\ O\ L$ is in resonance with the generator-circuit, which is the case when the reading, A_{max}, of the ammeter is a maximum. Next the switch O is changed over to the position shown in broken lines and then the circuit $C\ L_o\ A\ O\ r$ is brought into resonance with the generator circuit. The reading A_{max}' of the ammeter will in this case generally be different from the reading A_{max} first determined; but by varying the value of r we may arrange that $A_{max}'=A_{max}$. In that case we have $R=r_o$ where r_o is that value of r for which the reading is the same in both cases.

Figure 2 shows the added-resistance method. For a given value r' of r the circuit $C\ L_o\ A\ r\ L$ is brought into resonance, just as described above, and the corresponding reading A_{max}' is taken. This is repeated for a value r'' with a corresponding reading A_{max}''. We then have the total resistance of the circuit $R^o=R_o+R$ determined by

$$R^o=\frac{r''\ A_{max}''-r'\ A_{max}'}{A_{max}'-A_{max}''}. \tag{1}$$

In carrying out these measurements, the following difficulties and sources of errors are, among others, encountered:

1. The emf. must not vary during a test. This requirement is, however, often difficult to fulfil, especially when using the method of added resistance where the reaction of the test circuit on the generator circuit varies with the different settings of the resistance.

2. The coupling should be loose and must not vary during a test. This is often difficult to attain, especially with the substitution method where the coupling between the generator circuit and the auxiliary circuit often will be partly of electrostatic nature, and this part of the coupling may vary in an uncontrollable manner when throwing over from the coil under measurement ($L\ R$) to the known resistance (r).

3. The readings are quite difficult to make and take a comparatively long time.

For circuits having some $0.3-1.0$ ohms, one must be very careful in order to obtain a mean-error not over 2 percent, and in many cases the errors surely reaches 10 percent or even considerably more.

In several respects it would be an advantage to have to deal only with the test circuit itself and its oscillations, as in that case no difficulties would arise from the coupling between the test and the auxiliary circuit or the generator circuit.

For oscillations in a single circuit containing the condenser C, the inductance L, and the resistance R (see Figure 4, heavy line circuit), the current i is given by

$$\left.\begin{array}{l} i=\frac{h^2}{\kappa} V_o C\, \varepsilon^{-\kappa t} \sin \nu t = \\ \frac{V_o}{\sqrt{\frac{L}{C}-\frac{R^2}{4}}} \cdot \varepsilon^{-\frac{R}{2L}t} \sin\left(t\sqrt{\frac{1}{LC}-\frac{R^2}{4L^2}}\right), \end{array}\right\} \quad (2)$$

where $\kappa=\frac{R}{2L}$, $h^2=\frac{1}{LC}$, $\nu=\sqrt{h^2-\kappa^2}$ and where V_o is the potential of the condenser at the beginning of the oscillatory discharge. Figure 3 represents a current curve obtained according to formula (2).

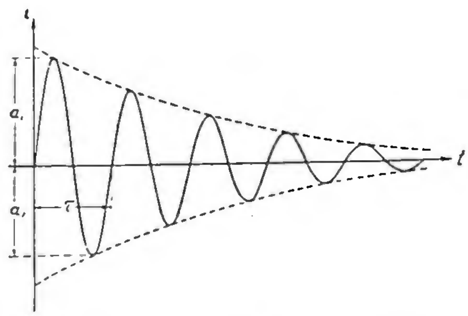


FIGURE 3—Curve of Oscillations

For feebly damped oscillations, formula (2) may, to a close approximation, be written:

$$i=V_o\sqrt{\frac{C}{L}} \cdot \varepsilon^{-\kappa t} \sin ht = V_o\sqrt{\frac{C}{L}} \cdot \varepsilon^{\frac{R}{2L}t} \sin \frac{t}{\sqrt{CL}}. \quad (2, 1)$$

If the effective resistance R of the circuit is to be determined only by means of the oscillations in the circuit itself, without any auxiliary circuit, this must be done by utilizing in some way or other the natural constants of the oscillations. There are here several possibilities. If, for example, $\frac{a_1}{a_2}$ is the ratio between the maxima of two successive amplitudes in opposite directions (see Figure 3), then we have

$$\frac{a_1}{a_2}=\varepsilon^{\frac{\pi}{2}R\sqrt{\frac{C}{L}}},$$

or

$$R=\frac{2}{\pi}\sqrt{\frac{L}{C}}\log_e \frac{a_1}{a_2} \quad (3)$$

Knowing the value of L, C and the ratio $\frac{a_1}{a_2}$, R may be calculated.

This method was used by E. Rutherford[4] and J. Zenneck.[5] By the former, the ratio $\frac{a_1}{a_2}$ is determined in a very ingenious manner by means of the magnetic influence of radio frequency current on magnetically saturated steel needles, while the latter uses a Braun-tube for the determination of the ratio between the successive maximum amplitudes of the condenser potential.

Both of these methods are, however, rather inconvenient and inaccurate. Neither of them is suitable for feebly damped circuits.

There is another way, however, to utilize the constants of the current curve for the determination of R, which leads to a method having considerable advantages as compared with the methods so far used.

This method has been developed in the Laboratory of Telegraphy and Telephony of the Royal Technical College, Copenhagen, and the principle underlying it has previously been published elsewhere.[6]

1. Theory of the New Method

We will consider the arrangement shown in Figure 4. The condenser C, assumed for the present to be without leakage, is charged to the potential V_o when the key N is in the position ac. If now the key is changed over to the position ab, then the charge of electricity CV_o will be discharged thru the circuit shown in heavy lines and the value of the current as a function of time is given by formula (2).

The potential difference between A and B is then $L\frac{di}{dt}$, and the time-integral D_0 of the square of this potential from $t=0$ to $t=\infty$ is then

[4] E. Rutherford: "A Magnetic Detector of Electrical Waves and Some of Its Applications," "Phil. Trans.," A, volume 189, page 1, 1897.

[5] J. Zenneck: "Verfahren, um die Dämpfung elektrischer Schwingungen sichtbar zu machen," "Ann. d. Phys.," Volume 7, page 801, 1902.

[6] P. O. Pedersen: (a) "Metode til Bestemmelse af den effektive Modstand i højfrekvente Svingningskredse," "Vid. Selsk. Math.-fys. Medd.," IV, 5, 1922, Copenhagen.

(b) "A Method for the Measurement of Radio Frequency Resistances," "Wireless World and Radio Review," page 135, April 29, 1922.

(c) "En ny Metode til Bestemmelse af den effektive Modstand i Højfrekvente Svingningskredse," "Ingeniøren," pages 185-196, April 19, 1924.

$$D_o = \int_o^\infty \left(L \frac{d\,i}{d\,t} \right)^2 \cdot dt = \frac{V_o^2}{4\kappa} = V_o^2 \frac{L}{2R}, \tag{4}$$

or

$$R = \frac{L}{2\,D_o} V_o^2 = \frac{L}{2\beta P_o} V_o^2 \tag{4, 1}$$

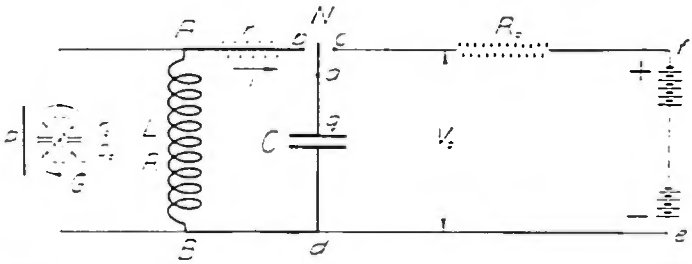


FIGURE 4—Schematic Representation of the Arrangement. The test-circuit is shown in heavy lines. G is a Quadrant-Electrometer connected up as shown and resting on a grounded plate P (see also Figure 5). The one terminal (e) of the battery is also grounded.

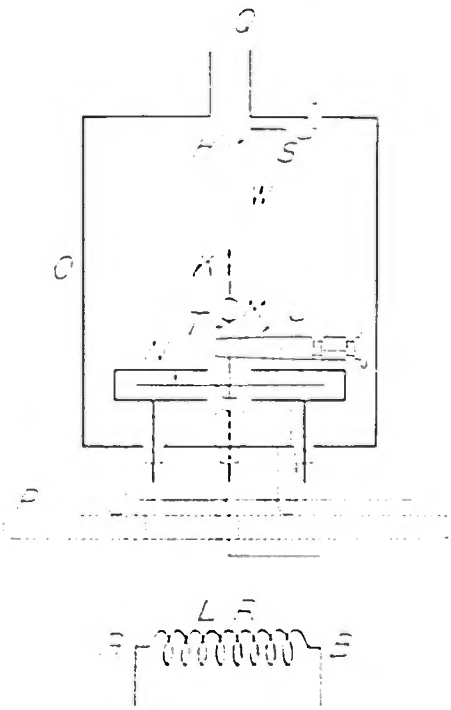


FIGURE 5.—The Quadrant Electrometer G. The needle N carried by the aluminum wire T with the attached mirror M, is suspended by means of the quartz fiber Q. Connection is effected thru the stout wire S and the thin Wollaston wire W—S being insulated from the cover by an amber bushing. The cover is connected to earth over the plate P. U is a clamping arrangement for the needle.

The quantity D_0 may be measured, for example, by means of a quadrant electrometer G inserted between A and B in such a manner that one pair of oppositely placed quadrants and the needle are connected to one of these points while the other pair of quadrants is connected to the other point as shown in Figures 4 and 5.

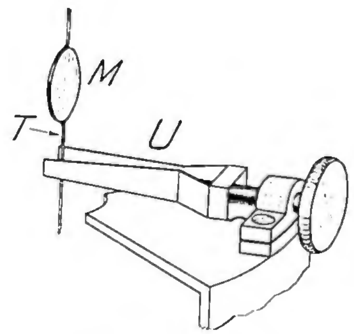


FIGURE 5b—Details of clamping arrangement. The tweezer-form spring U is made of phosphor-bronze and is opened and closed by means of a conical-pointed screw in such a way that on closing, the wire T with needle and mirror is raised a little by the spring

The throw P will then be proportional to D. The determination of the ballistic constant β will be discussed later on.

If the values V_o, L, β, and P_o are known, equation (4, 1) gives the value of R.

If V_o and L are kept constant and an extra resistance r is inserted in the circuit (see Figure 4) we have—if P_r is the value of the throw corresponding to the resistance $R+r$,—

$$R+r=\frac{L}{2\beta P_r}\cdot V_o^2, \qquad (4, 2)$$

and from this and equation (4, 1)

$$\frac{R+r}{R}=\frac{P_o}{P_r} \text{ or } R=r\frac{P_r}{P_o-P_r} \qquad (5)$$

By means of two measurements—one with and one without the added resistance r in the circuit—R may be determined without knowing the values of V_o, L or the ballistic constant β of the galvanometer.

2. INVESTIGATION OF THE VARIOUS POSSIBLE SOURCES OF ERROR

If the condenser has any leakage, it will lose some of its charge in the time interval from the moment N breaks its connection at c till it makes connection at b (see Figure 4). If the leakage of the condenser is considerable and if the said time interval is not very short, a considerable error may be caused thereby. As will be shown in the following, various difficulties are encountered in constructing the key N in such a way that the above-mentioned time interval will be very short. The difficulty resulting from this, may, however, be entirely eliminated by using the test arrangement shown in Figure 6.

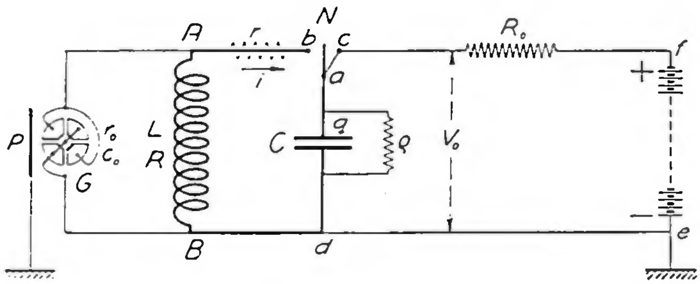


FIGURE 6—Schematic View of Test Arrangement for Oscillating Circuits Containing a Condenser Having a Leakage, ρ ohms

Here the terminals a and c are connected together so that the terminals of the condenser C having a leakage of ρ ohms are permanently connected to the terminals e and f of the battery. The discharge is then started immediately when the contact ab is made, and at the beginning of the discharge the condenser has the charge V_oC—assuming that $\rho \gg R_o$, where R_o is a large resistance inserted in the lead cf.[7]

The logarithic decrement δ of an oscillating circuit having a series resistance R and a condenser shunted with ρ ohms is known to be:

$$\delta = \pi\sqrt{\frac{C}{L}}\left(R + \frac{1}{\rho} \cdot \frac{L}{C}\right). \tag{6}$$

By connecting the terminals of the battery permanently to the condenser the decrement is accordingly increased to:

$$\delta' = \pi\sqrt{\frac{C}{L}}\left(R + \frac{1}{\rho} \cdot \frac{L}{C} + \frac{1}{R_o} \cdot \frac{L}{C}\right), \tag{7}$$

and consequently the effective resistance of the circuit, owing to the permanent connection between condenser and battery, is increased by the amount

$$r^o = \frac{1}{R_o} \cdot \frac{L}{C} \tag{8}$$

[7] If a very large leakage-free condenser is at hand (see part 4), the arrangement of Figure 4 may be used even for a leaky condenser C, provided that the leakage-free condenser is inserted in series with the leaky condenser.

By the measurement under discussion, there is directly determined the total resistance

$$R^o = R + \frac{1}{\varrho} \cdot \frac{L}{C} + \frac{1}{R_o} \cdot \frac{L}{C}. \tag{9}$$

In order to derive the actual equivalent resistance

$$R' = R + \frac{1}{\varrho} \cdot \frac{L}{C} \tag{10}$$

of the circuit itself, the correction r^o determined by means of formula (8) should be deducted from the resistance R^o determined by the throw of the galvanometer.

In order to keep this correction small, it is advisable to give R_o a rather high value. On the other hand it is necessary that $R_0 \ll \varrho$ in order that the condenser potential may, to a close approximation, be put equal to V_o. (The resistance R_o should be inserted in the lead $c\,f$, and not in $d\,e$. In the latter case, the zero position of the electrometer would be displaced during a measurement, since the potential of the two quadrants and the needle before the discharge would be very nearly zero, but during the discharge would be almost equal to V_o).

The correction calculated according to (8) would, for two reasons, be a little too large. Firstly, the resistance R_o will always have a little inductance, and consequently its impedance is larger than R_o. Secondly, R_o will not be perfectly free from capacity and this capacity added to the capacity between the leads $c\,f$ and $d\,e$ (see Figure 6) will increase the capacity of the oscillating circuit. As the frequency of the oscillations is thereby reduced, the effective resistance of the circuit will also be reduced a little. In general, however, both of these corrections will be exceedingly small.

In the measurements on leaky condensers described in the earliest publications (6, *a* and *b*) large choke coils and large resistances were inserted in both of the battery leads, and therefore no correction was made for the additional damping caused by the battery leads. There is no doubt, however, that it is more rational—as was done by Nancarrow and Cohen[8]—to dispense with the choke coils and to correct for the increase in damping. For the reason stated above, it is better, however, to insert the resistance in one of the battery leads only, connecting the free end of the battery with the key—and not in both battery-leads as shown in Figure 2 of the paper of Nancarrow and Cohen.

[8] F. E. Nancarrow and I. J. Cohen, "High Frequency Resistance Measurement," "Post Office El. Eng. Journal," volume 16, pages 71-81, April, 1923.

In the case shown in Figure 6, an additional current will flow thru the inductance L as long as $a\,b$ is closed. The value of this current is V_o/R_o, and if we call the ohmic resistance of L, r', then the result will be a potential difference $V_o\frac{r'}{R_o}$ between the points A and B. This potential difference will, in normal manner, act upon the quadrant electrometer, but is so small that its influence is negligible. If, for instance, $V_o=500$ volts, $R_0=50{,}000$ ohms, $r'=1$ ohm, and if the key is closed 10 seconds, then the corresponding value of $(\text{potential})^2\times\text{time}=1\times10^{-3}$ volts² seconds. The value corresponding to the oscillations is generally more than 20 volts²×seconds. The error caused by the direct current thru L is therefore quite unimportant. The resistance r should, of course, not be inserted between the two points A and B to which the quadrant-electrometer is connected.

The preceding considerations and corrections apply only to the measurement of condensers having so great a leakage that the arrangement shown in Figure 6 must be applied.

A further number of possible sources of error found when applying this method of measurements must be considered—and this even in those cases where the more simple arrangement shown in Figure 4 may be used.

In the derivation of formula (4), only the inductance L has been considered, but not the effective resistance of the coil. It is very easily seen, however, that the error arising from this—for all circuits which are not extremely highly damped—is of no importance.

Furthermore there is the possibility that the appreciable resistance r_o of the lead to the electrometer needle in connection with the capacity c_o between the needle and the two quadrants and the opposing pair of quadrants, respectively, may cause a not insignificant error, partly by increasing the damping of the circuit and partly by reducing the potential of the needle.

The first-mentioned error causes an increase R' of the effective resistance, which, to a close approximation, may be determined by:

$$R'=r_o\frac{c_o^2}{C^2},\tag{11}$$

as c_o is so small that practically the entire voltage drop is across c_o. This is easily seen from the following: If the potential v between A and B is given by (see Figure 4)

$$v=V_m\sin\omega t,\tag{11, 1}$$

then the current thru the condenser C and the inductance L is determined by

$$i = \omega V_m C \cos \omega t \qquad (11, 2)$$

while i' thru the electrometer lead under these conditions is given closely enough by

$$i' = \omega V_m c_o \cos \omega t \qquad (11, 3)$$

The loss of power in the oscillating circuit is consequently equal to $\frac{1}{2} \omega^2 V_m{}^2 C^2 R$ and in the electrometer $\frac{1}{2} \omega^2 V_m{}^2 C_o{}^2 r_o$. The total loss is therefore

$$\tfrac{1}{2} \omega^2 V_m{}^2 (C^2 R + c_o{}^2 r_o) = \tfrac{1}{2} \omega^2 V_m{}^2 C^2 (R + R')$$

where R' has the value determined by (11). The capacity of the needle does not necessarily exceed 5 cm. and the resistance r_o of the needle-lead may be about 200 ohms, while the condenser C will often be over 10,000 cm. If $c_o = 5$ cm., $r_0 = 200$ ohms, and $C = 10{,}000$ cm., then $R' = 0.00005$ ohms—a quite negligible increase in the effective resistance of the circuit.

The fraction η of the potential difference lost in the needle lead is, according to (11, 3), determined by

$$\eta = \omega c_o r_o = \frac{c_o r_o}{\sqrt{LC}} \qquad (12)$$

If—as above—$r_o = 200$ ohms, $c_o = 5$ cm. $= 0.55 \times 10^{-11}$ farad, and $\omega = 1 \times 10^6$ then $\eta = 0.0011$. This correction is also quite negligible in all cases where the frequency does not substantially exceed the above value.

Equations (11) and (12), on the other hand, show the importance of as small a value as possible of the resistance r_o in the needle lead; but if the suspension wire for this reason is made short and thick, the electrometer will be too insensitive.

This difficulty was overcome by the arrangement shown in Figure 5a. The suspension wire is a quartz fibre Q, and the electrical connection is affected thru the stout wire S carrying a Wollaston wire W. The core of the Wollaston wire is a 0.004 mm. thick platinum wire and the silver coating is removed only from the middle part of the wire and retained at both ends. Originally we made two hooks of the stout ends of the wire and used the hooks as connections to the wire S and to the needle N, respectively.

While this connecting arrangement gave a perfectly satisfactory results in the tests described in the above-mentioned publications,[9] later investigations have shown that it is not always

[9] See note 6 *a* and *b*.

reliable. High contact resistances may appear between the hook H and the wire S and between the hook K and the vertical aluminum wire T carrying the needle N, and finally between the wire T and the needle N itself. These resistances may vary erratically and introduce considerable errors in the measurements. Similar observations were made by Nancarrow and Cohen (see note 8), who eliminated this difficulty by using a thin metal wire for both suspension and connection wire for the needle. The said authors were satisfied with the results thereby obtained and find this electrometer method very convenient and superior to other methods in accuracy.

We were not, however, quite satisfied with the said suspension arrangement which had some drawbacks, partly owing to the fact that the elastic properties of a thin metal wire are not nearly as close to the ideal as those of a thin quartz wire. Using metal wire the zero position of the needle will vary more or less from throw to throw and the throws will not be absolutely constant. Using quartz wire, the zero position does not move and—as we shall see later on—the throws are exceedingly regular. We, therefore, rearranged the suspension arrangement as shown in Figures 5a and 7, where the quartz wire Q carries the needle while the Wollaston wire W makes the connection having its two stout ends H' and K' soldered to the connecting wire S and to the carrier wire T of the needle, respectively. The electrical and mechanical connection between T and the needle N itself—made of aluminum foil—is secured by using the design shown in Figure 7. With this arrangement perfectly satisfactory results have been obtained and we prefer this design to the one used by Nancarrow and Cohen, at least where accuracy is essential.

3. The Discharging Key

One more source of error has to be considered, namely, the losses in the discharging key N (see Figures 4 and 6). At the beginning, great difficulties were encountered here. We first tried an ordinary discharge-key, but the throws of the electrometer were too small—as small as 1-20th of the value to be expected—and very irregular. This, no doubt, was caused by the closing-spark at b. Numerous arrangements were tried in order to effect a good and sure contact instantaneously. We may here mention that we tried polished copper and steel hammers making contacts against polished copper or steel plates, the impact being made with great velocity. None of the various meth-

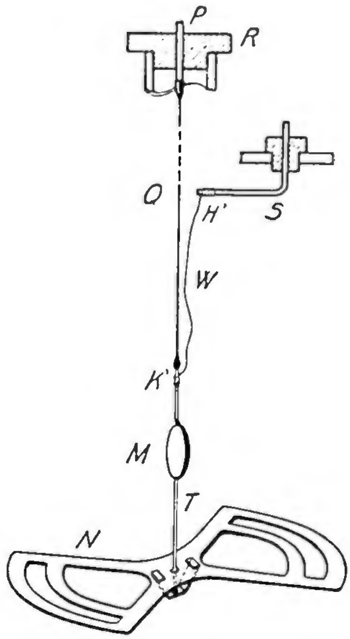


FIGURE 7—New Method for suspension of the needle and for providing electrical connection. (Compare Figure 5a.) In the tests described below, the quadrant electrometer had a quarts wire 90 mm. in length and 0.01 mm. thick. The Wollaston wire was about 50 mm. long and 0.004 mm. thick. The needle was made of aluminum foil 0.02 mm. thick.

ods where the contact was made between solid bodies gave the desired results. We next tried to make contact between a perfectly clean surface of mercury and a clean polished rod of metal with a rounded end (using steel, tungsten, or platinum) and large constant throws were thus obtained—provided that a perfectly clean mercury surface was prepared prior to each single discharge.

This leads to the conclusion that the contact should be made between volumes of mercury in vacuum, and this method when finally adopted gave perfectly satisfactory results. At the beginning we used the mercury lamp shown in Figure 8, where the contact is effected simply by tipping over the complete lamp, which causes a coherent stream of mercury to run from the one branch to the mercury in the other branch. In the following this key is called key I. In this key the contact-making jet is comparatively long and of course does not always have the same

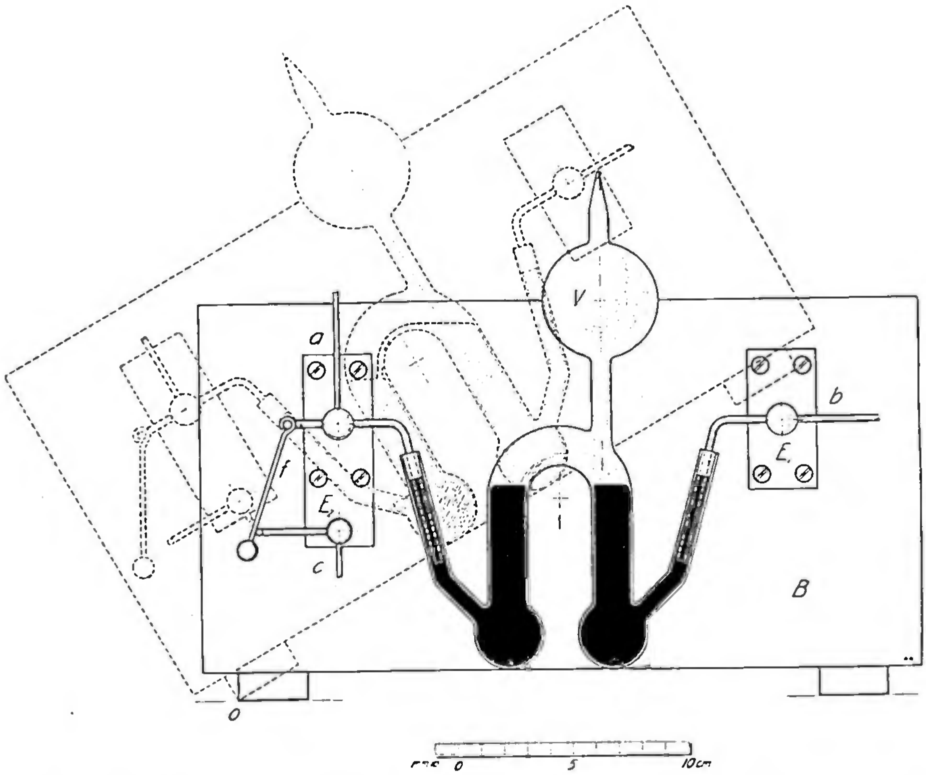


FIGURE 8—Key I. Mercury lamp used as discharging key. The connecting wires *a*, *b*, and *c*. corresponds to the connections denoted by the same letters in Figures 4 and 6. Using the arrangement of Figure 6, *a* and *c* are directly connected, thus shunting out the interrupter *f*. This is also the case with the keys shown in Figures 9-11. E_1 and E_2 are ebonite pieces. Similar lettering is used in Figures 9-11

cross-section. This may introduce an error of say 0.002 ohms while the total resistance of the key is about 0.016 ohms. In order to reduce this error we designed the key shown in Figure 9, having a very short jet.

The key is mounted on a wooden panel *B* revolving about the axis *O*. When the key is at rest, it takes the position shown in full lines, and in this position *b* is disconnected while *a* is in connection with *c*. Pushing the shaft *M* downward, the key is turned over to the position shown in broken lines, and the connection between *a* and *c* is broken before connection is made between *a* and *b* by bringing into contact the two volumes of mercury. When employing the arrangement Figure 6, *a* and *c* are directly connected and the interrupter *f*, thereby put out of operation.

A third type or key is shown in Figure 10.

If the handle *M* is brought up by a quick movement into the position shown in broken lines, the mercury drops from the bulb *V* down into the other end of the key, thus making contact between the two volumes of mercury—that is, contact is produced between a and b. The purpose of this key was to investigate whether it was of any importance to make the contact between the mercury volumes with great rapidity.

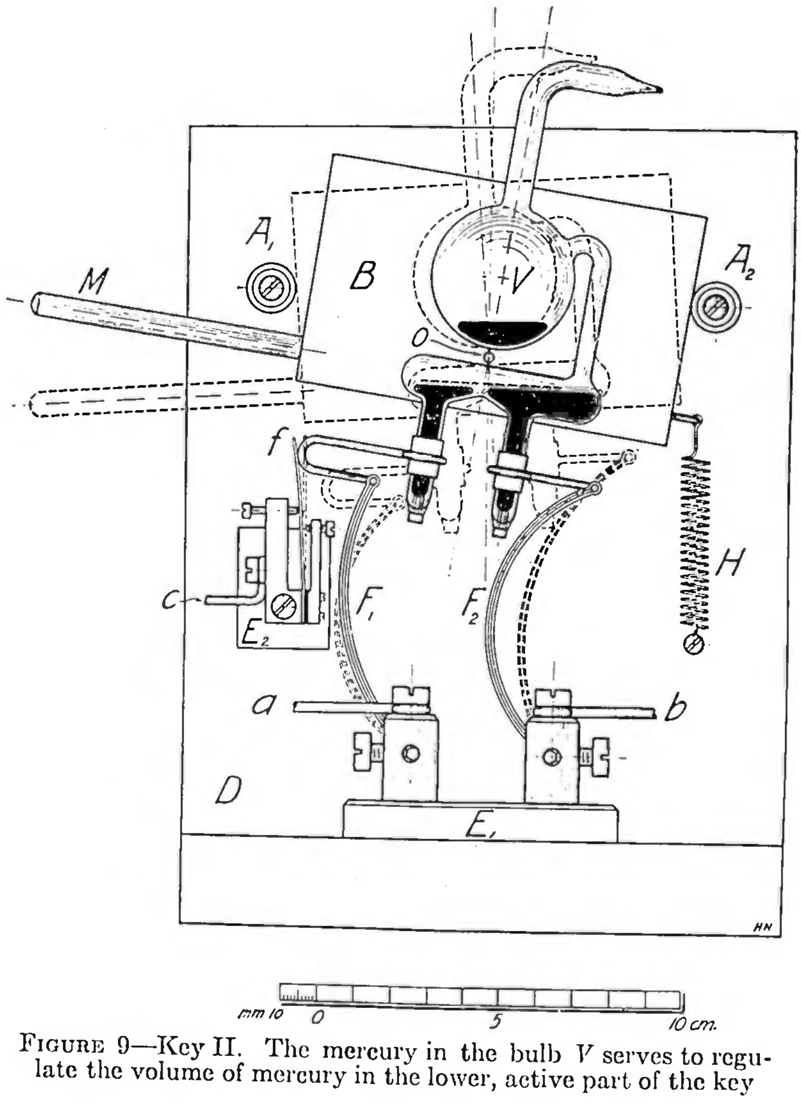


FIGURE 9—Key II. The mercury in the bulb V serves to regulate the volume of mercury in the lower, active part of the key

Beside these keys we have also tried one of the same design as was used by Nancarrow and Cohen[10] but mounted similarly to our own keys, as appears from Figure 11. This key was filled with hydrogen, while the keys I, II, and III, were evacuated to a pressure of not exceeding 0.0001 mm. of mercury.

With these four keys—and several others—a series of comparative measurements have been made, using the arrangement

[10] The key itself was delivered by A. C. Cossor, Ltd., London, and was the same type as used by Nancarrow and Cohen.

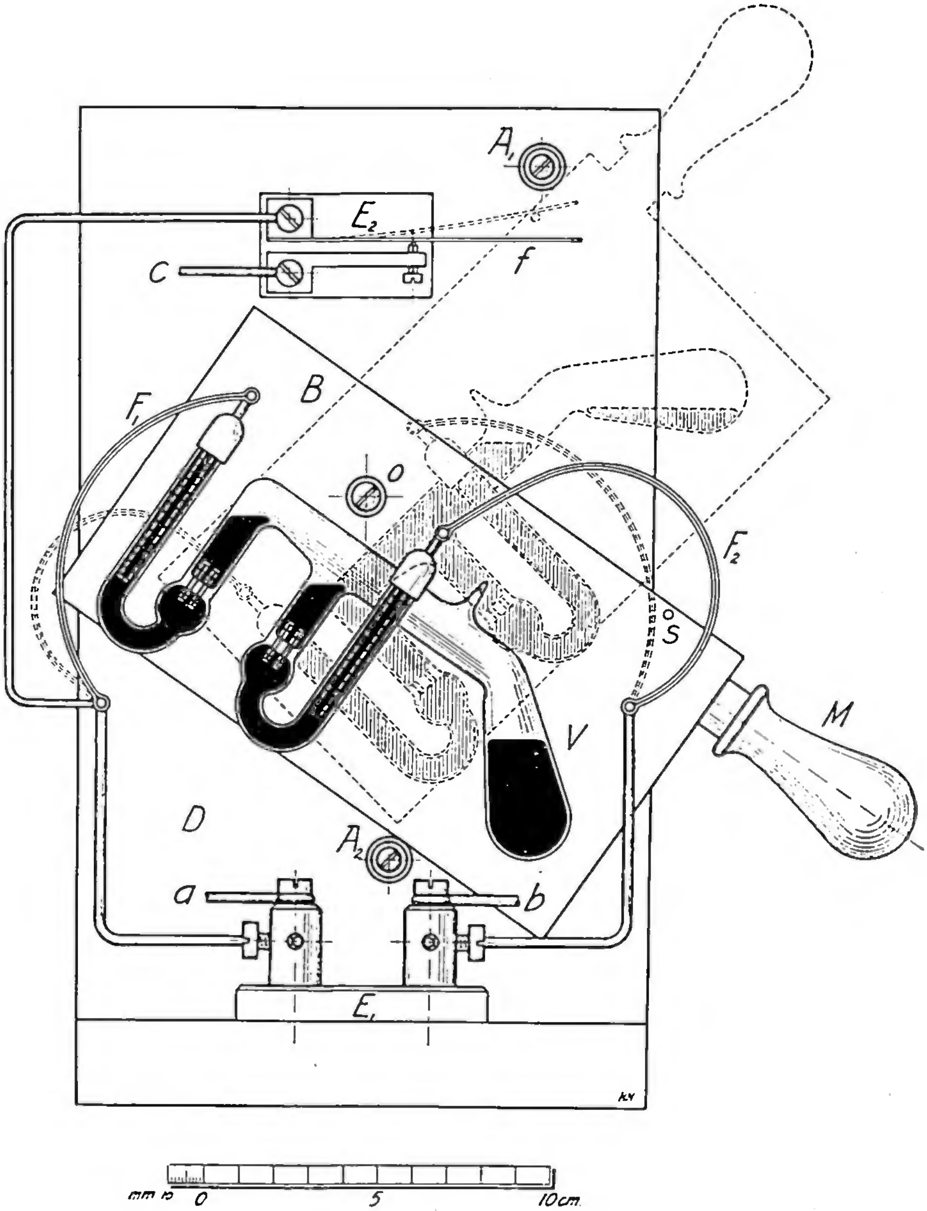


FIGURE 10—Key III

shown in Figure 4. With the same oscillating circuit and a constant value of V_o the throw of the quadrant electrometer for the various keys has been measured.[11] Ten readings have been taken for each of the keys, the mean value of which is shown in Table 1, where also is shown the mean error of the difference between the single throws and the mean value.

Column 4 of the table further shows the total resistance of the circuit ($R = R^o +$effective key resistance)—calculated on the

[11] The distance between mirror and scale was about 3 meters.

basis of the throw given in column 2. The resistance given for key II was determined in a special series of tests which will be mentioned below.

Column 5 shows the direct current resistance R' of the keys when closed. Column 6 shows the resistance $R°$+the "spark resistance" R_g of the key. We have accordingly $R°+R_g=R-R'$. Column 7 shows finally the difference between the "spark resistance" of key II and the same resistance of the other keys. Later on we shall see that this resistance for key II may, to a close approximation, be taken to be zero.

TABLE 1

Comparison of Various Keys. (V_0=450 Volts)

1	2	3	4	5	6	7
KEY	Throw Mean Value mm.	Mean Error %	Total Resistance of the circuit R Ohms	D. C. Resistance of the Key R' Ohms	The Circuit Resistance—"Spark Resistance," Calculated from Columns 4 and 5 $R_o+R_g=R-R'$ Ohms	"Spark Resistance"
I Fig. 8—Vacuum...	420.6	0.17	0.5099	0.016	0.4939	—0.0002
II Fig. 9—Vacuum...	416.7	0.047	0.5147	0.0210	0.4937	0
III Fig. 10—Vacuum...	422.4	0.058	0.5078	0.0132	0.4946	—0.0009
IV Fig. 11—Hydrogen (English key).	348.7	0.075	0.6151	0.0200	0.5951	—0.1014

Keys I, II, and III have practically no spark resistance while the hydrogen-filled, English key has a little over 0.1 ohm.

The table further shows that key II has the smallest mean error—less than ½ part per thousand. Least satisfactory in this respect is the key which was originally used—number I—but this, as mentioned before, is surely due to the relatively long "mercury thread" by means of which the connection is established between the two volumes of mercury.

Key II gives the most constant throws, has practically no spark resistance, and is exceedingly convenient to use. This type of key is no doubt the best one, and so far it has not shown any disadvantages whatever.

Besides these keys we have tried various others, and we have further tried various gas pressures in key II—using air as well as hydrogen. The result of these investigations may be summarized thus: As long as the mercury is perfectly clean, the spark resistance is very small, at least for pressures above 10 mm.

of mercury and below 0.1 mm. pressure. Between these two limits the spark resistance can, on the other hand, reach quite considerable values when, at the same time, the closing spark becomes very luminous.

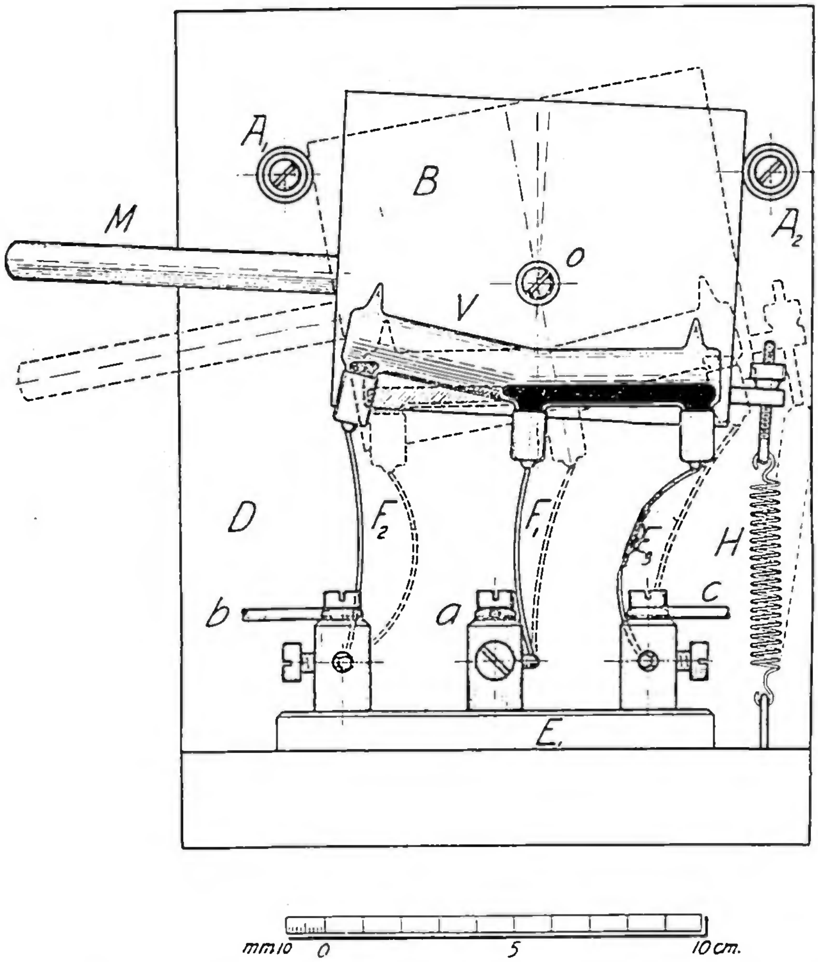


FIGURE 11—Key IV. Filled with Hydrogen and of same design as was used by Nancarrow and Cohen

If the key contains oxygen the mercury surface rapidly becomes dirty owing to oxidation produced by the contact sparks, and the result of this is a high and variable spark resistance. In this state, the key is useless. The key bulb must therefore be completely emptied of oxygen, either by pumping or by washing with hydrogen. However, keys containing hydrogen at considerable pressures show some spark resistance. The best way is to clean with hydrogen and then exhaust the bulb as far as possible. Treated in this manner the keys have—according to our experience—an unlimited life. In such a key, the closing spark for $V_o=400$

volts and $C = 25{,}000$ cm. is very faint and hardly visible in complete darkness.

Recently Professor J. T. McGregor Morris called my attention to a very interesting paper throwing much light on this question (J. T. Morris: "On Recording Transitory Electrical Phenomena by the Oscillograph," "The Electrician," June 7, 1907). In this paper it was shown that with the generally used contact-making devices, a permanent contact is not made instantaneously but only after several contacts have been made and broken. For an ordinary tapping key contact, this intermediate state lasts for about 0.023 seconds, for instance, with four intermediate makes and breaks. With a mercury pool and a needle point contact, the permanent contact is completed in from 0.002 to 0.001 of a second with one or two intermediate breaks.

This makes it perfectly clear why it is impossible to use the ordinary telegraph key as a discharge key in this method of measurement, and all the information given in the above-mentioned paper indicates that a contact-making device consisting of either a clean butt-ended metal rod and a clean mercury surface or between two clean mercury masses would make a permanent contact at once and could thus be used for the discharge key in question with good results.

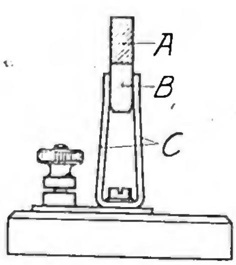


FIGURE A

It was also shown by the author of the above-mentioned paper that the intermediate breaks just after making the initial contact were due to rebounding of the contact pieces, and he overcame this difficulty—at least for the purpose he had in mind—by use of a modified knife blade contact of a form as shown in Figure A, corresponding to Figure 5 of cited paper. On the brass blade A of the switch an extension B of ebonite was fitted, having exactly the same width as the blade itself. To quote the paper: "As the ebonite extension was already in the jaws of the switch before the switch was tripped, when the brass entered the jaws of the switch it quickly glided in without any jar at the moment of electrical contact. As far as the records taken with this form of switch contact go, it appears to work absolutely instantaneously, but certainly within 0.0001 of a second. Needless to remark, the contacts must be moderately clean, and an ordinary working pressure of jaws is necessary."

This indicates a possibility of using this modified knife blade contact—we call it type A key—for our discharge key and we therefore made such a key, and current oscillograms were taken for this key, for an ordinary telegraph key, and for the mercury-mercury key number II. In agreement with the above-mentioned paper, we found that the ordinary tapping key contact gave intermediate breaks while key A and the mercury-mercury contact gave smooth starting curves for the current, thus indicating that they made permanent contact at once.

We therefore tried key A as a discharge key in our method of measurement with the following results:

Key	Readings mm.	Remarks
Mercury-mercury	205, 205, 205, 205	
Key A	29, 81, 113, 59, 33 145, 48	Key closed directly by hand
	182, 188, 198, 168 201, 203, 202, 204, 203, 199, 204, 198, 202, 201, 200	Key closed by means of quick blow from a wooden hammer

It thus appears that the key A worked very rapidly was much better than the ordinary tapping key and, in some cases, came very close to the mercury key. But this latter key is far more constant and is much more convenient to use than key A, as it is necessary every now and then to grind the two sides of key A in order to get rid of small projections between the ebonite and the brass. This key also has to be kept very clean; otherwise it became far inferior to the mercury key. We therefore prefer the mercury key.

4. Carrying Out of Measurements

The method described above can be used in various ways for the determination of the radio frequency resistance of an oscillating circuit at its natural frequency, and consequently for determination of radio frequency resistance of inductances, condensers, etc., at any desired frequency.

We shall commence with a treatment of the first-mentioned problem. If the condenser of the oscillating circuit is practically without leakage, then the arrangement shown in Figure 4 is employed. With the extra resistance r inserted in the oscillating circuit we have—as shown in part 1—

$$R+r=\frac{L}{2\beta P_r}V_o^2=\frac{K_o}{P_r} \tag{4, 2}$$

where P_r is the throw of the quadrant electrometer with the total resistance $R+r$ in the circuit while K_0 is a constant as long as the potential V_o, the inductance L, and the ballistic constant β of the electrometer are kept constant.

Taking two measurements, one with $r=0$ and one with $r=r$, the resistance of the circuit itself is determined by

$$R=r\frac{P_r}{P_o-P_r}. \tag{5}$$

In order to check the accuracy of these measurements, various values of r may be inserted and the resistance R determined for each value by means of equation (5). In Table 2, there is recorded a series of such measurements.

TABLE 2

KEY II, DIAGRAM FIGURE 4, RESISTANCES IN OHMS

The added resistances $r=$	0.1	0.5	1.0	1.5	2.0	Mean value of R
R calculated by means of equation (5)	0.501	0.499	0.499	0.500	0.499	0.4996

Using the arrangement shown in Figure 6, where the condenser of the oscillating circuit is permanently connected to the battery during the measurements, the resistance of the circuit—as stated in paragraph 2—is increased by the resistance r^o determined by

$$r^o=\frac{1}{R_o}\cdot\frac{L}{C} \tag{8}$$

where R_o is the resistance of the conductor between the free terminal of the battery and the discharging key.

In Table 3, there is recorded an example of a series of such measurements taken on the same circuit as dealt with in Table 2.

TABLE 3

KEY II, DIAGRAM FIGURE 6, RESISTANCES IN OHMS

The added resistances $r=$	0.5	1.0	1.5	2.0	Mean value of $(R+r^o)$
$R+r^o$ calculated by means of equation (5) $=$	0.608	0.609	0.609	0.610	0.6090

According to Tables 2 and 3, the correction r^o should have the value of $0.6090-0.4996=0.1094$ ohms. The correction calculated by means of equation (8) is 0.1146 ohms ($L=1.34\times 10^{-3}$ hy., $C=1.11\times 10^{-7}$ farad, $R=105{,}000$ ohms). The correction calculated is thus 0.0052 ohm greater than that measured. As stated in paragraph 2, the correction thus calculated is a little too large, and the agreement is therefore quite satisfactory.

The measurements recorded in Tables 2 and 3 were carried out with key II. For comparison there is recorded in table 4 a series of measurements on the same circuit but using key IV.

TABLE 4

Key IV, Diagram 4, Resistances in Ohms

The added resistance r =	0.1	0.3	0.5	1.0	1.5	2.0	Mean value of R
R calculated by means of equation (5) =	0.499	0.500	0.502	0.502	0.501	0.503	0.5011

Comparing with Table 2, we find that key II is a little better than key IV, but even the latter gives sufficient accuracy for practical use.

For these measurements there was used as the "added resistance" the rheostat shown in Figure 12, which is variable in steps of 0.1 ohm from 0.1 to 2.0 ohms. The resistance is made of a single constantan wire provided with taps soldered on at suitable intervals.

The exact adjustment of the individual values was done by carefully scraping away some of the wire.

For measuring radio frequency resistances above 5 ohms, we used as the added resistance radio frequency rheostats of higher resistances. This method may conveniently be used for measuring the radio frequency resistances of coils up to several hundred ohms.

In carrying out the measurements on highly damped coils, that is, coils for which R/L has a high value, it will often be preferable to insert another coil (L_1) into the oscillating circuit, (L_1) having a great inductance and a small but known radio frequency resistance. The throws of the electrometer may thereby be considerably increased.

To measure an unknown radio frequency resistance x having no inductance or capacity, we simply insert this resistance instead of the known resistance r in Figure 4. If beforehand we have determined in the way set forth above, the resistance R of the circuit itself, then, by means of equation (4, 2), we may find the constant $K_o = P_o R$. We then have

$$x = \frac{K_o}{P_x} - R \tag{13}$$

where P_x is the throw of the electrometer after having inserted the resistance x in the circuit.

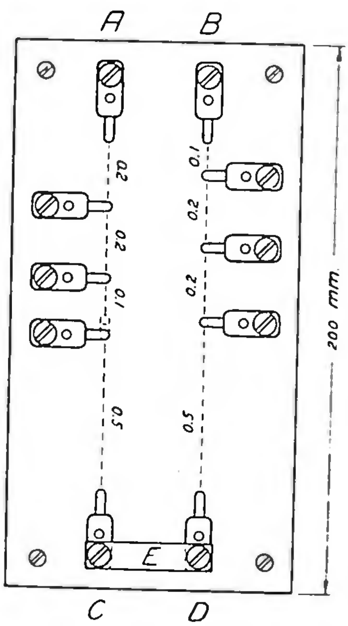


FIGURE 12—Rheostat used as "added resistance" in these measurements and made of a single 0.3 mm. Constantan Wire

To measure the difference in radio frequency resistance of various condensers having equal capacity, we successively insert various condensers into the oscillating circuit and determine the corresponding throws $P_{c(n)}$ of the electrometer. Having previously determined the constant K_o we then have

$$R_{c(n)} = \frac{K_o}{P_{c(n)}} \tag{14}$$

The condenser, denoted by (n), has then an effective resistance at the applied frequency of $(R_{c(n)} - R_{c(m)})$ ohms more than the resistance of the condenser (m).

If one of the condensers is to be considered as leakage-free, and if we denote this by (o), then the resistance $r\ (n)$ of the condenser (n) is given by

$$r_n = R_{c(n)} - R_{c(o)} \tag{15}$$

We have found that carefully made condensers, using pure ruby-colored mica as dielectric, and with plates made of not too thin copper foil, with a perfectly clean surface, do not show any more loss in dry air than an air condenser of the same capacity.[12] Such mica condensers may, therefore, be considered as being without loss. But it is very essential that the air be dry, for if this is not the case, the mica condensers will show a considerable loss. It is therefore necessary to embed the condensers in paraffine or to use some other suitable means of keeping them dry.

In the following Table 5, giving the results of measurements of radio frequency resistance of some condensers, condenser number (o) is considered free of loss.

TABLE 5

COMPARISON OF THE EFFECTIVE RESISTANCES OF DIFFERENT CONDENSERS AT FREQUENCY OF ABOUT 15,000. ($C=100{,}000$ cm.)

Index (n)	Throw $P_{e(n)}$ mm.	Total Resistance of Circuit $R_{e(n)}$ Ohms	Resistance of Condenser R_n ohms	Dielectric Material: Material	Dielectric Material: Thickness mm.	Thickness of Copper Foil mm.	Remarks
0	437.7	0.4735	0.0000	Ruby-colored Mica	0.110	0.06	Copper foil carefully cleaned of grease and oil
1	399.4	0.5189	0.0454	"	0.112	0.06	Copper foil not cleaned
2	412.5	0.5000	0.0265	"	0.200	0.05	Preparation unknown
3	406.7	0.5071	0.0336	Green-colored Mica	0.135	0.06	Copper foil carefully cleaned of grease and oil
4	96.5	2.1373	1.6638	Celluloid	0.117	0.06	

If loss-free condensers or condensers of a known loss are used the method here described is very convenient for the determination of radio frequency resistances of any coil or condenser at any desired frequency, but it is hardly necessary to dwell any longer upon this point. We will therefore consider here only one application of the method, namely the determination of radio frequency resistances of dielectric materials. The arrangement shown in Figure 13 is used for this purpose. In parallel to the variable condenser C is placed an air condenser C'. Between the plates of the latter is placed a sheet (p) of the material to be investigated. The thickness of this sheet is denoted by d cm. If the

[12] Air condensers will generally show even a little higher loss owing to longer connections. It is very essential that the different condensers should be treated alike, especially with regard to temperature and humidity of the air. By breathing on a condenser one may materially increase its effective resistance

The described method of measurement is so sensitive that the influence of variations in humidity and temperature of the air on the effective resistance of oscillating circuits is easily observed. The throws of the galvanometer will, for example, generally have different value when the door of the test room is open from the value when it is closed.

material shows any perceptible conductivity for direct current, it is appropriate to place two very thin mica sheets e (0.02–0.05 mm.) between the sheet p and the condenser plates as shown in Figure 13. This also makes it unnecessary to have the battery permanently connected to the condenser and renders needless the correction mentioned in paragraph 2.[13]

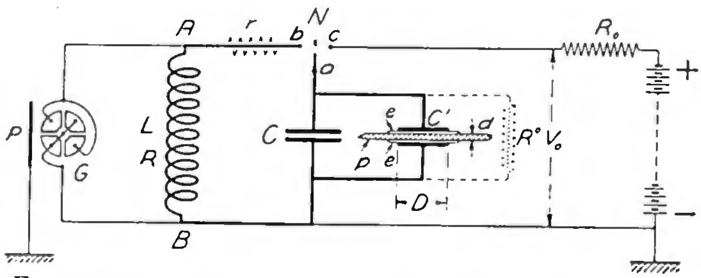


FIGURE 13—Arrangement Used for Determination of Radio Frequency Resistances of Dielectric Materials

The measurements are carried out as follows: The radio frequency resistance of the oscillating circuit without the test sheet in C' is determined in the usual manner by $R = r \dfrac{P_r}{P_o - P_r}$. Next the sheet p is introduced into C' and the capacity of C is reduced until the total capacity has the same value as before. If the throw of the electrometer is now P', then the increase of the radio frequency resistance—R'—caused by the sheet p is determined by

$$R' = R \frac{P_o - P'}{P'} = r \frac{P_r}{P_o - P_r} \cdot \frac{P_o - P'}{P'} \tag{16}$$

This increase of resistance may be imagined, for instance, as a resistance—R^o—shunted across the condensers C and C' and, according to formula (6) or (8), paragraph 2, R^o is determined by

$$R^o = \frac{1}{R'} \cdot \frac{L}{C_1}, \tag{17}$$

where C_1 is the total capacity.

---

[13] The introduction of these mica-sheets is, however, permissible only if the following relation is satisfied:

$$\frac{n \varepsilon \varrho d}{t} \cdot \frac{1}{18 \times 10^{11}} \gg 1,$$

where n is the frequency, ε the dielectric constant of the mica, t the total thickness of the mica sheets (cm.) and ϱ the specific resistance of the dielectric material while d is the thickness of the sheet p. If the above relation is not satisfied, a considerable part of the potential drop across the condenser C' will be found across the mica sheets. This introduces an error which, under unfavorable conditions, may be very considerable. In such cases the arrangement shown in Figure 6 must be applied.

If the thickness d of the sheet is small compared with the diameter D of the plates in the air condenser C', then the resistivity ρ of the test plate p at the applied frequency is determined with sufficient accuracy by

$$\rho = R^o \frac{F}{d} \text{ [Ohm per cm}^3\text{]} \tag{18}$$

where $F = \frac{\pi}{4} D^2$ is the area of the air condenser.

5. Determination of the Ballistic Constant of the Electrometer

In the investigations treated above, there is an uncertainty in one regard. In table 1, paragraph 3, we have arbitrarily put the "spark resistance" of key II as equal to zero. The measurements so far considered, give us only the difference between the spark resistances of the various keys. The fact that, in spite of considerable differences in design, the three evacuated keys show very little difference in "spark resistance" makes it probable that this resistance is very small in all of them—but it is not a proof. Such proof can be produced only by an independent determination of the ballistic constant of the electrometer.

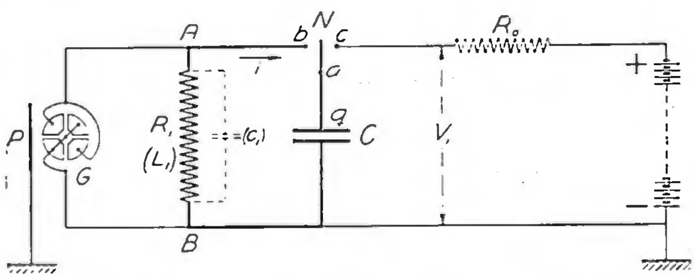


FIGURE 14—Arrangement for Determination of the Ballistic Constant of the Electrometer

For this purpose we have used the arrangement shown in Figure 14 where R_1 is a fairly large resistance—which is, as far as possible, without capacity or inductance—and C_1 is a good leakage-free mica condenser. If C_1 is charged by means of the key N to the potential difference, V_1, and then discharged thru the resistance R_1 by throwing the key N over into the position $a\ b$, the potential difference between the points A and B will vary during the discharge. The time integral (B) of this difference squared is easily calculated beforehand.

In order to evaluate the influence of a small inductance in R_1, we will carry out the calculations under the assumption that, beside the resistance R_1, there is an inductance L_1, assuming the circuit C, L_1, R_1 to be aperiodic.

If we denote the initial value of the potential difference across the condenser by V_o, and introduce the following abbreviations

$$\kappa_1 = \frac{R_1}{2 L_1} \text{ and } h_1^2 = \frac{1}{L_1 C},$$

then we have

$$\left. \begin{aligned} v_1 = \frac{V_1}{2\sqrt{\kappa_1^2 - h_1^2}} \{ & (\kappa_1 + \sqrt{\kappa_1^2 - h_1^2})\, \varepsilon^{(-\kappa_1 + \sqrt{\kappa_1^2 - h_1^2})t} \\ & + (-\kappa_1 + \sqrt{x_1^2 + h_1^2})\, \varepsilon^{-(\kappa_1 + \sqrt{\kappa_1^2 + h_1^2})t} \end{aligned} \right\} \quad (19)$$

from this we get

$$B = \int_o^\infty v_1^2 \, dt = \frac{1}{4} V_1^2 \frac{4\kappa_1^2 + h_1^2}{\kappa_1 h_1^2} = \frac{1}{2} V_1^2 \left(R_1 C + \frac{L_1}{R_1} \right). \quad (20)$$

Using the arrangement of Figure 14, R_1 will generally not be less than 10,000 ohms and C generally not less than 0.1×10^{-6} farad. The last term inside the parenthesis in equation (20) is then negligible in comparison with the first, and we may therefore, to a close approximation, put

$$B = \frac{1}{2} V^2{}_1 R_1 C \quad (20, 1)$$

If the resistance R_1 has a capacity C_1, as indicated by the broken lines of Figure 14 (but without resistance in the connecting wires), this capacity will instantaneously be charged at the beginning of the discharge to the potential difference $V_1 \cdot \frac{C}{C + c_1}$ C also will have this potential. In this case, we get

$$B_1 = \frac{1}{2} \left(V_1 \frac{C}{C + c_1} \right)^2 \cdot R_1 (C + c_1) = \frac{1}{2} V_1^2 \frac{C^2}{C + c_1} R_1 \quad (22)$$

From this it follows, by comparison with (20, 1),

$$\frac{B_1}{B} = \frac{C}{c_1 + C} \quad (23)$$

For good resistances, this correction also is quite negligible.

Finally we have to consider the influence of the loss which is caused in this case by the making of the contact at b. Here we find, just as is set forth above, that if an ordinary discharge key is applied at N, the throws of the electrometer G are too small and somewhat irregular. Even if the conditions are here far less unfavorable than when discharging thru the oscillating circuits of Figures 1 and 4, yet such a key is inapplicable. Using key II, the throws are perfectly constant, and as only a single closing of the current is effected, we can surely consider in this case the resistance of the key to be negligible in comparison with the large resistance R_1. We can therefore without hesitation apply the arrangement of Figure 14 to the determination of the ballistic constant. All that is required is to calculate the value B by means of equation (20, 1) and to measure the throw P of the electrometer; we then have

$$B = \beta P, \tag{24}$$

where β is the ballistic constant.

Having in this manner determined the value of β we can, by means of formula (4, 1) in paragraph 1, namely

$$R = \frac{L}{2\beta P_o} \cdot V_o^2 \tag{24, 1}$$

determine the resistance R of the circuit.

In this manner the resistance of a certain circuit was determined to be 0.684 ohms while a determination according to the method using added resistance described in paragraph 4 gave a resistance of 0.683 ohms—an agreement which is quite satisfactory. We can therefore, without hesitation, put the resistance of key II as equal to zero.

6. Concluding Remarks

The method offers among others the following advantages:

(1) Much greater accuracy than the methods hitherto applied, especially for feebly damped circuits.

(2) The method is simple, convenient, and quick.

(3) No special generator for radio frequency oscillations is required, and there is therefore no complication arising from tuning or coupling.

As a slight disadvantage, it may be mentioned that the quadrant electrometer requires a fairly stable support, while on the other hand it is safely transportable with the clamping device shown in Figures 5*a* and *b*.

In working out this method I have had excellent assistance from Mr. J. P. Christensen, Mr. Chr. Nyholm, Mr. B. B. Rud, Mr. Kay. Christiansen, Mr. Nørregaard, and Mr. J. Egelund-Nielsen.

Part of the expenses have been defrayed from a grant received from the "H. C. Orsteds Fond for teknisk-videnskabelig Forskning," founded by The Great Northern Telegraph Company.

Telegraph and Telephone Laboratory
of The Royal Technical College,
Copenhagen, September, 1924.

SUMMARY: The author criticizes the existing methods for the measurement of radio frequency resistance and describes a new electrometer method, where a quadrant electrometer is put across the inductance in an oscillatory circuit. The condenser of this circuit is charged to the voltage V_o and discharged thru the inductance by means of a special key.

The throw of the electrometer will then be proportional to $V_o^2 - L/2R$. The theory of the method is given and it is shown how to eliminate the different possible sources of error. With this method the radio frequency resistance of even a very feebly damped circuit may be determined with an error well within one part in a thousand, and this determination may be made in a few seconds.

NOTE ON TELEPHONE RECEIVER IMPEDANCE*

By

E. Z. Stowell

(University of Nebraska)

Some time ago the writer made a series of measurements of telephone receiver impedance to radio frequencies at the Bureau of Standards Radio Laboratory. It is believed that the results will be of interest.

The method employed was that of resistance variation, using the circuit of Figure 1. In the circuit *L* is a standard inductor, a single-layer solenoid on a polygonal frame ; *C* is a variable standard air condenser, with a vernier condenser in parallel; *R* is a pure resistance which can be discontinuously varied; a thermocouple *T* and a galvanometer *G* for direct current indicated resonance. The entire circuit was enclosed in a grounded copper cage, with the exception of the galvanometer. The leads to the

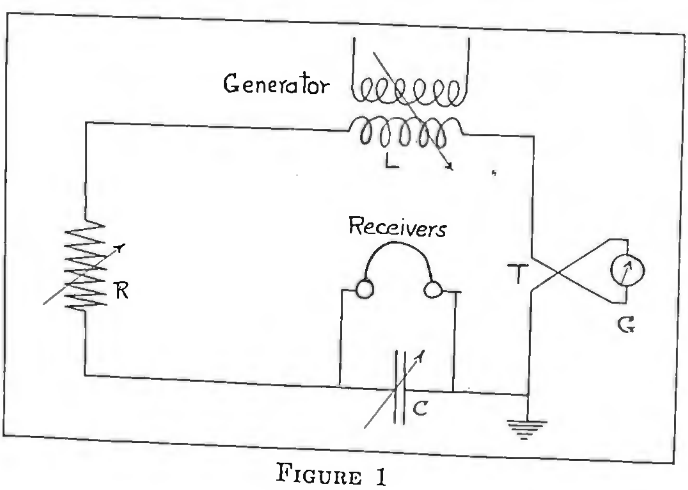


Figure 1

galvanometer were enclosed in grounded lead sheath. On the side of the cage next the coil the screen was widened sufficiently to permit of the introduction of an emf. from the output coil of a 250-watt electron tube oscillator.

The resistance of the circuit was determined as follows:

*Received by the Editor, October 24, 1924.

The source and the measuring circuit were both tuned to the desired frequency and the galvanometer reading noted. Then one of the standard resistors R was introduced into the circuit from outside the cage. The circuit remained in tune, and the galvanometer was again read. Assuming (1) that the applied emf. was constant, and (2) that the galvanometer deflections were proportional to the square of the current, the resistance of the circuit originally was

$$r = \frac{\Delta r}{\sqrt{\frac{d_1}{d_2}} - 1}$$

where Δr is the extra resistance introduced by the standard resistor, d_1 and d_2 being the deflections before and after the introduction of Δr.

Suppose the resistance of the measuring circuit to be measured in this manner. The telephone receivers, suspended horizontally in an auxiliary grounded cage, are introduced in parallel with condenser C from without. In general the telephones not only add resistance to the circuit, but detune it as well. The circuit is again tuned by the condenser, the change in capacity being noted and the resistance again measured as described above. The resistance and reactance of the inserted phones are now known from these relations :

$$\left.\begin{aligned} R &= \frac{\Delta}{\left(\frac{\delta}{C_1}\right)^2 + (\Delta C_2 \omega)^2} \\ X &= \frac{1}{C_2 \omega}\left[1 + \frac{\frac{\delta}{C_1}}{\left(\frac{\delta}{C_1}\right)^2 + (\Delta C_2 \omega)^2}\right] \end{aligned}\right\} \begin{aligned} \Delta &= R_2 - R_1 \\ \delta &= C_2 - C_1 \end{aligned}$$

where C_1 and R_1 are the capacity and resistance in the circuit without the headset, the insertion of which changes them to C_2 and R_2, respectively. C_1 and C_2 of course include the capacity of the inductor L. ω is 2π times the applied frequency.

Observations were made on about 50 pairs of telephones, comprising 14 makes, at 8 isolated frequencies between 6,000 cycles/sec. and 1,000,000 cycles/sec., Mr. C. T. Zahn collaborating. The results for a typical pair of telephones now on the market are given in Figure 2.

It is seen that a pair of receivers behaves electrically like a wave trap, or parallel resonance circuit. The receivers have an electrical natural frequency quite distinct from the natural frequency of the diaphragm; in the case shown, it occurs at 12,000 cycles/sec. At this frequency, the resistance suffers an enormous increase. Above this frequency, the telephones behave like a condenser with rather large dielectric loss.

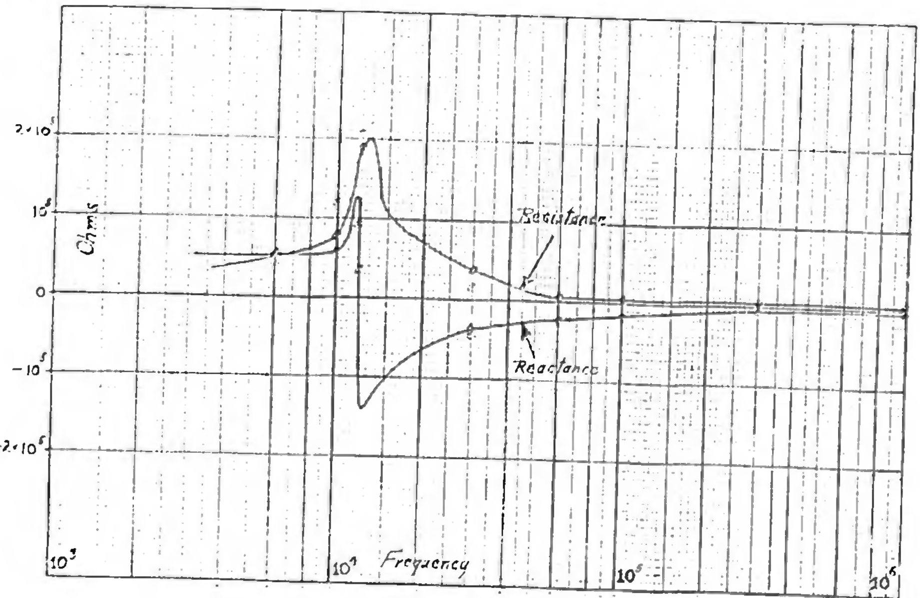


FIGURE 2

It appears that the receivers have some characteristics in common.

1. Their natural frequency falls in the range from 9,000 to 15,000 cycles/sec. with occasional exceptions.
2. Their resistance at the natural frequency is of the order 100,000 to 200,000 ohms.
3. At frequencies above 50,000 cycles/sec. the telephones may be considered a condenser of the order of 10^{-10} farad.
4. Their resistance above 50,000 cycles/sec. is inversely proportional to frequency and may be calculated from the relation

$$R = \frac{\psi}{C\omega}$$

where ψ is the constant phase difference and C the capacity of the phones. ψ varies with the make from 0.04 to 0.10; 0.06 is an average value.
5. At frequencies of the order of 1,000,000 cycles/sec., receivers differ very little among themselves, and little change is produced in the impedance by removing the electromagnets, indicating that the capacity of the

leads furnishes the major portion of their impedance. At these frequencies all the receivers examined act like condensers of capacity very nearly 10^{-10} farad.

With regard to the precision involved in these measurements: the ratio of probable error of the impedance to the impedance itself is about 0.04 or 4 percent at low frequencies; at resonance about 10 percent for the resistance and 50 percent for the reactance, due to the rapid change in the latter; above resonance, about 5 per cent and decreasing as the frequency mounts.

The data for any given pair of telephones, as for example those of Figure 2, can be explained fairly satisfactorily by assuming a symbolic circuit for them as in Figure 3. Here L is

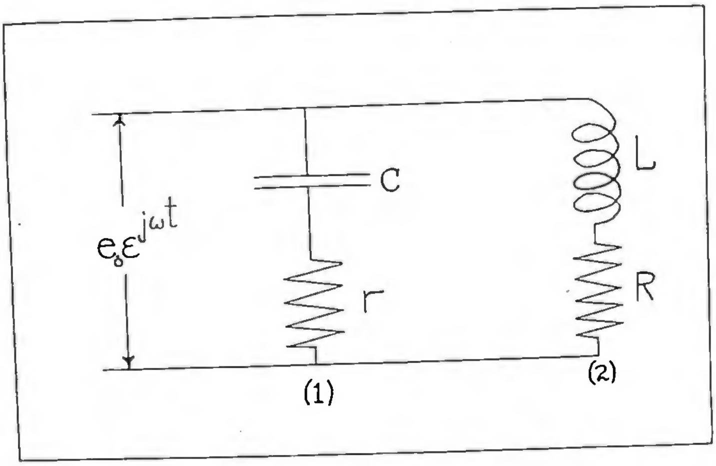


FIGURE 3

the direct current inductance of the electromagnets of the order of a few henrys ; C is the capacity of the leads of the order of 10^{-10} farad; R the resistance of the electromagnets which increases in a complicated manner with the frequency, and r is the resistance of condenser C, and inversely proportional to frequency. It can be shown that if these four quantities are known, the resistance and reactance of the telephones at any angular velocity ω are

$$R = \frac{r\,(R^2+L^2\,\omega^2)+R\left(r^2+\dfrac{1}{C^2\,\omega^2}\right)}{(R+r)^2+\left(L\,\omega-\dfrac{1}{C\,\omega}\right)^2}$$

and

$$X = \frac{L\,\omega\left(r^2+\dfrac{1}{C^2\,\omega^2}\right)-\dfrac{1}{C\,\omega}\,(R^2+L^2\,\omega^2)}{(R+r)^2+\left(L\,\omega-\dfrac{1}{C\,\omega}\right)^2}$$

In Figure 2 the crosses are values computed from these formulas; where none appear, they fall so close to the observed points that they were omitted for clearness.

Acknowledgment is due Director Burgess of the Bureau of Standards for his courtesy in allowing publication of this material.

Brace Laboratory of Physics,
University of Nebraska.

DISCUSSION* ON "ON THE RADIATION RESISTANCE OF A SINGLE VERTICAL ANTENNA AT WAVE LENGTHS BELOW THE FUNDAMENTAL"

AND

"ON THE OPTIMUM TRANSMITTING WAVE LENGTH FOR A VERTICAL ANTENNA OVER PERFECT EARTH"

By Stuart Ballatine

By

Balth. van der Pol, D.Sc. (Member)

(Physicist, Philips' Incandescent Lamp Works, Eindhoven, Holland)

In the two above-mentioned papers, which appeared on pages 823 and 833, respectively, of Volume 12 of these Proceedings, the writer first calculates the radiation resistance of a vertical antenna loaded at the bottom only so that a current distribution over the antenna results with a current node at the top. The writer finds (formula (19) page 829), the radiation resistance to be a function of a single variable $a = \frac{2nl,}{\lambda}$ this variable being determined by the ratio of the antenna length l to the wave length λ. The function is composed of the well-known integral sine and integral cosine functions. Further it is shown by the writer, that, when the antenna is excited at a wave length below the fundamental, the vertical distribution of the radiated energy, as represented by polar diagrams, is in certain circumstances markedly different from the distribution obtained from an antenna oscillating at its fundamental wave length. Finally it is suggested that important information concerning upper atmospheric reflection may be obtained by exciting an antenna in such a way that no energy is radiated in a horizontal direction, but at an elevated angle only. Any energy thus reaching a distant receiver must then be necessarily reflected and thus important data concerning the "Heaviside layer" might be obtained.

I may be allowed to point out that seven years ago I investi-

*Received by the Editor, January 2, 1925.

gated exactly the same question. The results of this research were published in the "Proceedings of the Physical Society of London," XXIX, page 269 (1917), and in the "Jahrbuch für drahtl. Telegraphie," XIII, page 217 (1917). In my paper, however, the problem was tackled in a somewhat more general way than in Dr. Ballantine's investigations, loading of the antenna at the top as well as at the bottom being considered. The radiation resistance, instead of being a function of the ratio of the antenna length to the wave length only, was found also to depend upon the boundary conditions at the top of the antenna, it being different, depending on whether a capacity at the top, in the form of a horizontal wire, is present or not.

In fact Dr. Ballantine's formula (19), page 829, for the radiation resistance in ohms:

$$R_{loop} = 60\Big[\cos^2 a \,.\, S_1(2a) - \frac{1}{4}\cos 2a \;\; S_1(4a) - \frac{1}{2}\sin 2a\Big\{S_1(2a) - \frac{1}{2}S_1(4a)\Big\}\Big] \qquad (1)$$

is a special case of my more general formula (29), on page 279 of the "Phys. Soc. Proceedings (London)," which in the present notation reads

$$R_{loop} = 60\Big[\sin^2\eta \,.\, S_1(2a) + \frac{1}{4}\cos 2\eta \,.\, S_1(4a) + \frac{1}{2}\sin 2\eta\Big\{S_2(2a) - \frac{1}{2}S_2(4a)\Big\} + \frac{\cos^2\zeta}{2}\Big(\frac{\sin 2a}{2a} - 1\Big)\Big] \qquad (2)$$

where:

$$\cos\zeta = \frac{I_{top}}{I_{loop}}$$

$$\cos\eta = \frac{I_{bottom}}{I_{loop}}$$

$$\eta + \zeta = a = \frac{2\pi l}{\lambda}$$

$$S_1(x) = \log x + 0.577216 - C i(x)$$

$$S_2(x) = S i(x).$$

For, with $\frac{I_{top}}{I_{loop}} = 0,\ \zeta = \frac{\pi}{2}$ and $\eta = a - \frac{\pi}{2}$, and (2) is reduced to (1).

In my paper the vertical distribution of the radiated energy is also fully considered and depicted in seven drawings. It was also suggested there that, in order to get information about the higher atmosphere, it was feasible to send waves upwards at an inclined angle by exciting an antenna at a higher harmonic.

Recently very important experiments along these lines have been carried out,[1] in England, France, and Germany, and, up to the present, cases have been reported where at great distances better reception was obtained when the transmitting aerial was excited at a higher harmonic than when it was oscillating at the fundamental frequency.

Stuart Ballantine (by letter): I wish to thank Dr. van der Pol for calling our attention to his important paper, and for his courtesy in sending me privately copies of it and of the foregoing discussion. Upon examination I find that he has covered practically the ground of my first paper and also independently suggested the usefulness of the specially-excited antenna for Heaviside layer experiments. His mathematical exposition, addressed to mathematical-physicists, is somewhat more prolix than my own (in the ratio of forty-eight to seventeen lines), and is unfortunately not carried to a numerical conclusion, which, of course, is the part of real interest to most of us. I remember having spent about three days deriving the formulas (19) for the radiation resistance, whereas the numerical computations for Figure 3 consumed nearly three weeks. The sine-integral and cosine-integral tables were not complete and I had to build them up with the aid of the asymptotic formula. As to the second paper, on the optimum transmitting wave length of the ideal vertical antenna, I do not find any references in Dr. van der Pol's article to this subject. In view of this I do not now think that the publication of my papers is such an unfortunate duplication as I had been obliged to think after first glancing thru Dr. van der Pol's paper; nevertheless, I must express regret at not having sooner discovered his work, in order that I could have added a reference to it commensurate with its importance and priority.

The superior generality which Dr. van der Pol claims for his investigation seems to me of more academic than practical significance. I see no way of making the current at the free-end of the antenna different from zero which does not involve the connection of additional structure. If this is done, of course, the problem is changed and becomes that of a complex antenna. There seems to be a mistake in this part of Dr. van der Pol's paper, for he adds a horizontal section without taking any further account of it than its effect on the current distribution over

[1] R. Mesny, "l'Onde électrique," III, page 99 (1924).
A. Meisner, "Jahrb. d. drahtl. Tel. u. Tel.," XXIV, page 884 (1924).

the vertical portion. Over a perfectly conducting plane earth the horizontal part will contribute only a horizontal component of electric force, so that as far as a vertical receiving antenna on the horizon is concerned it is sufficient to consider only the vertical field produced by the vertical section with its altered current distribution. But if the radiated power is to be calculated, it is necessary to know the field intensities in all points of the surrounding surface and the contribution of the top section to these intensities must be computed. Also the radiations of the two sections cannot be considered separately since the principle of superposition fails for the energy. Dr. van der Pol does not specify that the finite current at the end of the vertical antenna is due to a top section, but he vaguely refers to such a section and gives in formula (31) an expression for the radiation resistance *"of a flat-top antenna without any load at the bottom."* If he really means this, the formula is, of course, inadequate, and if he does not, it is an abstract generalization. For the same reason only three of the energy distribution diagrams given seem of actual importance. These are Figures 1, 8, and 10. Figure 8 corresponds to Figure 3 of my second paper, characterizing the special Heaviside-layer transmitter.

It should be mentioned that the possibility of eliminating the direct radiation along the earth is not confined to a special excitation of the vertical antenna; a horizontal section can be added provided the earth be of sufficiently good conductivity. In this case a current distribution in the vertical part of the type shown in Dr. van der Pol's Figure 6 (reproduced below), would produce no vertical electric force on the horizon. Over earth of imperfect conductivity this would not be true, for as H. von Hoerschlemann[1] has shown, the horizontal section is then capable of producing a vertical electric force on the horizon by the induction in the earth of vertical current components which are not symmetrical about the lead-in.

I had read in "l'Onde électrique," after my paper had been submitted for publication, some fragmentary accounts of the preliminary experiments of Commandant Mesny. I hope that this work will be systematically and diligently pursued. In this connection I may say that my colleague, Mr. R. W. Seabury, of Boonton, New Jersey, is erecting at the seashore a special transmitter of the type described in the last section of my second paper, with which we hope to be able to make some careful experiments over sea-water.

[1] H. von Hoerschlemann: "Jahr. d. draht. Teleg.," volume 5, page 14 (1912).

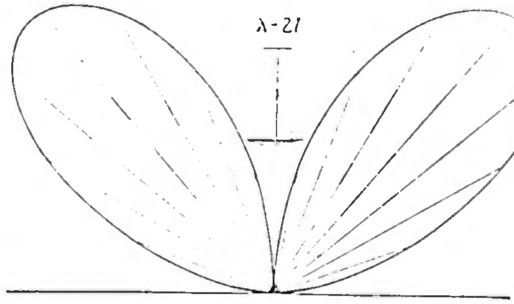


FIGURE 6—Reproduced from Dr. van der Pol's paper in the "Proceedings of the Physical Society of London," 24, 269

It was discovered some time ago by American amateurs experimenting with unusually short wave lengths that the transmission of certain short waves during the day was surprisingly good. This has been popularly attributed to the wave lengths employed, due I suppose to some esoteric predilection of the Heaviside reflecting mechanism for these wave lengths. I believe that a better explanation can be based on the probability that most of these short waves were produced by antenna systems which had previously been designed to operate at wave lengths four times as long, that is to say, fifty-meter waves were being produced by antennas, the fundamentals of which were in the neighborhood of two-hundred meters. In this case the energy would be radiated up into the air and if, according to modern speculation, the Heaviside-layer is a better reflector by day than by night, the superior long-distance transmission could be readily explained. It would thus seem that the optimum transmitting wave length, while being definitely indicated in normal circumstances, would in the presence of celestial reflection depend upon many things, the height of the reflector, the distance of the receiver, and so on, and would therefore dodge specification. For perfect earth it is 0.39 of the fundamental (idealized case considered in my paper); for ordinary earth it approaches the half-fundamental (as I shall show in a forthcoming paper); and for Heaviside-layer transmission it could be anything but would most likely be somewhere near the quarter-fundamental. All of these wave lengths are substantially below the fundamental, in a region of which I believe we have been too neglectful.

DIGESTS OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

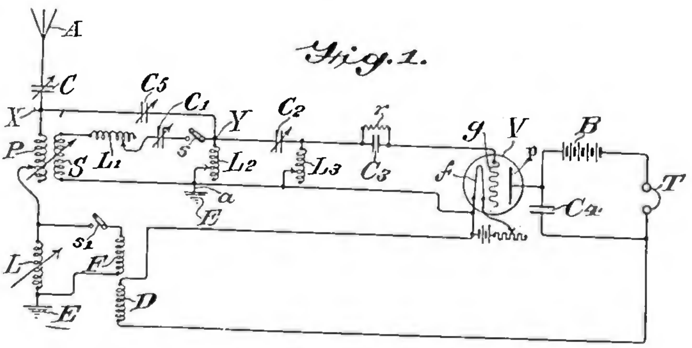
Issued January 6, 1925–February 24, 1925

By

John B. Brady

(Patent Lawyer, Ouray Building, Washington, D. C.)

1,521,777—D. G. McCaa, filed July 10, 1923, issued January 6, 1925. Assigned to the Electric Apparatus Company, Parkersburg, Pennsylvania, a corporation of Pennsylvania.



Number 1,521,777—Radio System

Radio System, having a circuit arrangement for eliminating interference or other disturbances. The frequency of the energy which it is desired should be excluded or reduced in effect and represented by oscillations set up by static, atmospherics or other natural electricity, is caused to differ from the frequency of the energy which it is desired shall be received, and the undesired oscillations are neutralized by an opposing and substantially equal potential caused by the received undesired oscillations, leaving the desired oscillations to effect the desired signals with substantially no disturbance by the undesired oscillations. When the undesired radio frequency oscillations are artificially produced as by transmitters emitting oscillations of frequency differing from the desired oscillations, their disturbing effects are similarly eliminated or reduced. The desired oscillations, prefer-

*Received by the Editor, March 7, 1925.

ably first amplified, are utilized to change the reactance of a circuit or path in which both the desired and undesired signals are received to materially increase the ratio of amplification of the undesired oscillations to the amplitude of the undesired oscillations. Similarly, with regard to undesired oscillations artificially produced and having a frequency different from the desired oscillations, the desired oscillations, preferably first amplified, effect a change of reactance of a circuit in which both the desired and undesired oscillations are received to render the circuit or path resonant to the desired oscillations and de-tuned or non-resonant with respect to the undesired oscillations. A local source of radio frequency oscillations, having a frequency differing from the desired oscillations, is utilized to effect a variation of reactance whereby the desired oscillations are caused to partake of maximum amplitude in a certain part or branch of said circuit of path and thereby increase the ratio of the effect of the desired oscillations to the effect of the undesired oscillations in the ultimate signal-translating instrument.

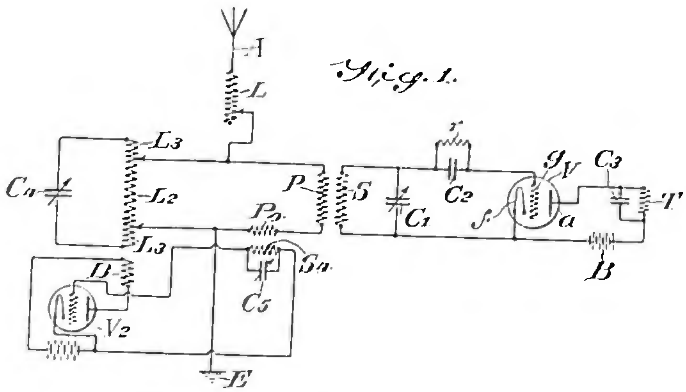
1,522,020—A. Maurer, filed January 29, 1924, issued January 6, 1925.

Table for Radio Apparatus, in which a loop is pivotally mounted beneath the table top and arranged to be operated by an extended shaft from the front of the table. The shaft has a rotatable dial on the extremity thereof and is gear-connected with the loop so that rotation of the shaft operates to position the loop in the desired plane.

1,522,070—T. H. Nakken, filed November 3, 1920, issued January 6, 1925. Assigned to Naamlooze Vennootschap Nederlandsche Lumingtron Maatschappli, Rotterdam, a Company of Netherlands.

Means for Transforming Light Impulses Into Electric Current Impulses, by means of electron emission from a photoelectric body. The photoelectric body is enclosed within a tube exhausted of air. A cathode is provided in the tube for emanating electrons. The photoelectric body is subjected to the action of a variable exterior source of light and is provided in an electric circuit in which the intensity of current will be varied in accordance with the variations in the source of light. The tube is provided with a plate and a control electrode or grid whereby the exposure of the photoelectric body to the electron discharge may be controlled.

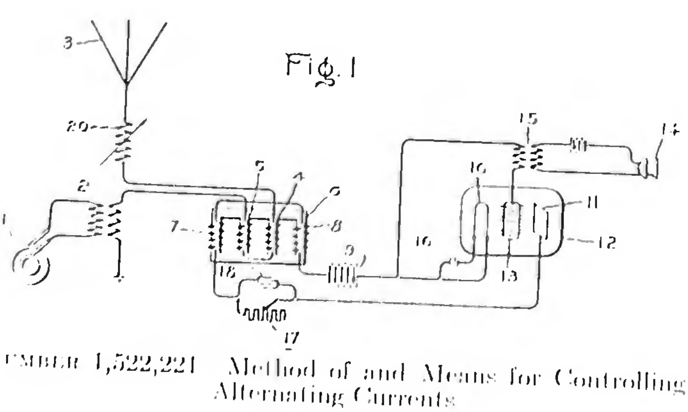
1,522,136—D. G. McCaa, filed July 29, 1924, issued January 6, 1925. Assigned to The Electric Apparatus Company, Parkersburg, a corporation of Pennsylvania.



Number 1,522,136—Receiving System

Receiving System, having a means for eliminating or reducing the effects of electrical disturbances in the reception of signals. The desired signal and the disturbing effects are divided between reactive paths, one of which is employed for effecting the translation of the desired signals, and with another of which is associated means for impressing thereon a part of the energy of the desired signals previously amplified, to cause a change of reactance, and thereby withholding from the signal-translating path the effects of the undesired oscillations to greater degree than the effects of the signal-representing or desired oscillations.

1,522,221—E. F. W. Alexanderson, filed November 20, 1914, issued January 6, 1925. Assigned to General Electric Company, a Corporation of New York.



Number 1,522,221—Method of and Means for Controlling Alternating Currents

Method of and Means for Controlling Alternating Currents in transmitting systems for radio telephony, wherein large amounts of energy may be controlled by the small current variations produced by sound waves in an ordinary telephone transmitter, in such a way that the sound waves may be faithfully reproduced in suitable receiving apparatus at a distant point. The patent describes the Alexanderson magnetic amplifier. A reactance is connected in the antenna circuit. A second circuit including a magnetizing winding is inductively related to the reactance in such a manner that the impedance of the antenna circuit may be varied by varying the current flowing in the magnetizing winding. A third circuit is provided, having means therein for producing a variable current and means for amplifying and reproducing in the second circuit the energy variations of the current in the third circuit, the amplifying means being capable of producing materially greater energy variations than can be produced with an ordinary telephone transmitter.

1,522,286—H. P. Clausen, filed February 3, 1920, issued January 6, 1925. Assigned to Western Electric Company, Incorporated, a Corporation of New York.

Method and Apparatus for Mounting Filaments in electron tubes, which consists in attaching a pair of resilient wires to the ends of the filaments and securing the wires at an angle to an intermediate portion of a pair of lead-in wires within the tube. The lead-in wires are bent to flex the resilient wires to provide tension in the filament. In this manner there is no tendency for the filament to sag over against the grid during the expansion due to heating of the cathode.

1,522,305—M. Latour, filed July 14, 1920, issued January 6, 1925.

Radio Receiver, in which the received signals control the luminous condition of a thermionic filament which may be used to make an impression upon a photographic band at a radio receiving station. The incandescence of the lamp filament is controlled by the received signaling energy for setting into operation a photographic process.

1,522,308—H. F. Lowenstein and E. E. Clement, filed August 14, 1922, issued January 6, 1925. Assigned to Edward F. Colladay, Washington, D. C.

Radio Receiving Apparatus, which may be supervised in its operation by an operator at a radio switchboard connected by line wire with the subscribers' station.

1,522,357—E. E. Clement, filed August 14, 1922, issued January 6, 1925. Assigned to Edward F. Colladay, Washington, D. C.

RADIOPHONE SYSTEM, wherein a central high power station is employed for transmission on different wave lengths. A plurality of sub-stations is provided for receiving the radio signals from the central station. Wire circuits inter-connect the central station with the sub-stations for supplying power for operation of the radio receiving sets.

1,522,358—E. E. Clement, filed August 14, 1922, issued January 6, 1925. Assigned to Edward F. Colladay, Washington, D. C.

RADIO ADVERTISING SYSTEM, which includes a combination line wire and radio communication system. The system so associates radio transmitting and receiving apparatus with a telephone trunk line that the radio operator can reach the subscriber over two paths, that is, by line wire and by space radio. The subscriber can talk to the radio operator while listening to the broadcasting, while the radio operator can connect the subscriber by line wire to the space radio system for broadcasting the conversation.

1,522,360—E. E. Clement, filed February 29, 1924, issued January 6, 1925. Assigned to Edward F. Colladay, Washington, D. C.

RADIO BROADCAST SELECTING AND DISTRIBUTING SYSTEM, in which a central station has wire connections with the subscribers' stations and supplies an unmodulated periodic current by line wire to the subscribers' stations for use as a heterodyne for incoming signaling waves. A master oscillator at the main station serves as the local source of oscillations for each of the subscribers.

1,522,361—E. E. Clement, filed February 29, 1924, issued January 6, 1925. Assigned to Edward F. Colladay, Washington, D. C.

RADIO BROADCAST SELECTING AND DISTRIBUTING SYSTEM, wherein a centralized receiving station collects energy from a distant transmission station and re-transmits the same to subscribers within a local area. The power for each of the subscriber sets may be supplied from the central station.

1,522,362—E. E. Clement, filed March 22, 1924, issued January 6, 1925. Assigned to Edward F. Colladay, Washington, D. C.

Subdivided Service System of Radio Broadcast Distribution, where the central station transmits to a plurality of subscribers' stations either by currents over a line telephone circuit or space radio, the power for tha radio receiving sets being supplied from the lines. Switching means are provided for changing the tuning of the receiver when connections are changed from the antenna or line wire circuit.

1,522,581—L. Espenschied, filed August 16, 1922, issued January 13, 1925. Assigned to American Telephone and Telegraph Company, New York.

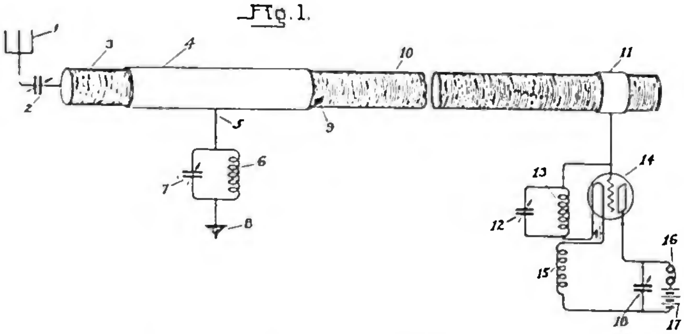
Radio Broadcasting System, in which the receiving stations are enabled to have a positive indication at all times as to whether or not they are in connection with and ready to receive from the central broadcasting station. The purpose of such an arrangement is to afford a broadcasting subscriber, who may be sending out information of a business character or otherwise, a greater measure of assurance that the receiving stations to which he desires to transmit are actually receiving the information sent out. A second purpose is to give the subscriber at the receiving station definite information as to the condition of receptivity of the radio transmission channel. A break in this transmission channel may be due to some defect in the receiving station itself or some defect in the transmitting station, but in any case, it is desirable that the receiving subscriber shall be notified as to the condition of the channel. Such assurance on the part of the broadcaster is especially needed in the case of emergency alarm services as, for example, when a broadcasting station may be employed to transmit fire alarms to a number of designated receiving stations, or where police information is broadcast from a central station to a number of correlated "pick-up" points. The invention briefly consists in sending out continuously carrier waves from the broadcasting station and employing these at each of the receiving stations to operate an indicator or alarm device; in other words, to establish normally channels between the broadcasting station and all the receiving stations involved and to operate these channels on the closed circuit basis, whereby the receiving station always definitely knows, as by the holding up of a signal, that it is in proper connection with the central station.

1,522,745—A. Press, filed June 17, 1920, issued January 13, 1925. Assigned to Westinghouse Electric and Manufacturing Company, Pennsylvania.

BALANCED ANTENNA SYSTEM, in which ground currents are substantially eliminated. The radio apparatus is connected between a grounded antenna system and circuits are provided there-between to balance out resultant current to ground.

1,522,807—L. Cohen, filed January 15, 1922, issued January 13, 1925.

Fig. 1.



NUMBER 1,522,807—Electrical Signaling

ELECTRICAL SIGNALING receiving apparatus for reducing the interference arising from static disturbances. A wave-coil is employed in the receiving system. A portion of the wave-coil is enclosed in an adjustable metal tube which is electrically connected to a point on the wave-coil and grounded thru tuned circuit. The receiving apparatus is also connected in a circuit which is adjustably connected with the wave-coil. Points along the wave-coil are selected for a condition of maximum reception.

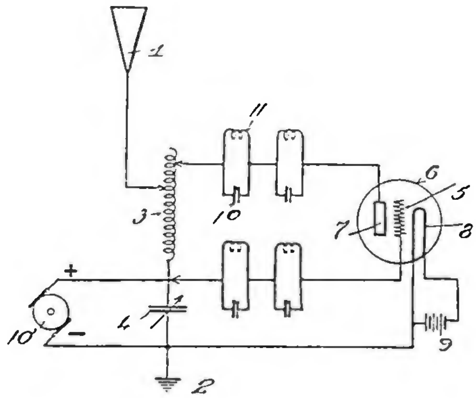
1,522,882—J. H. Hammond, Jr., filed March 16, 1912, issued January 13, 1925.

METHOD OF AND SYSTEM FOR SELECTIVE ENERGY TRANSMISSION and reception, wherein the receiving station has a pair of local antenna circuits responsive respectively to high frequency undamped radiant impulses of different periodicities. A circuit is connected between the antenna circuits and is tuned to the difference between the periodicities of the received impulses for selectively observing the signals.

1,522,883—J. H. Hammond, Jr., filed June 16, 1917, issued January 13, 1925.

POLYPULSE SYSTEM OF CONTROL of the movements of a body in which a gyroscope is arranged to stabilize the body. The gyroscope is controlled by devices which respond to different frequencies radiated from a distant station whereby the direction of movement of the body may be governed.

1,523,011—W. E. Garity, filed September 23, 1920, issued January 13, 1925. Assigned to De Forest Radio Telephone and Telegraph Company, New York, a corporation of Delaware.

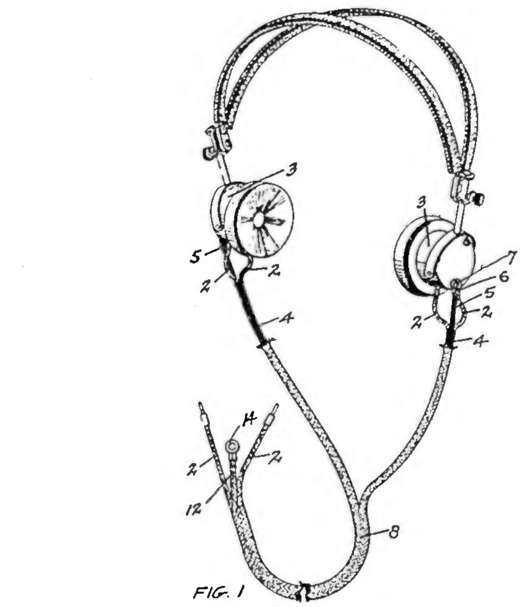


NUMBER 1,523,011—Continuous Wave Transmitting System

CONTINUOUS WAVE TRANSMITTING SYSTEM, wherein parasitic currents or harmonics of the fundamental frequency are suppressed. The transmitting system includes an electron tube operating circuit, wherein a plurality of rejector circuits are provided and each tuned to a frequency to be suppressed. The rejector circuits are connected in circuit with the grid and plate electrodes of the oscillator.

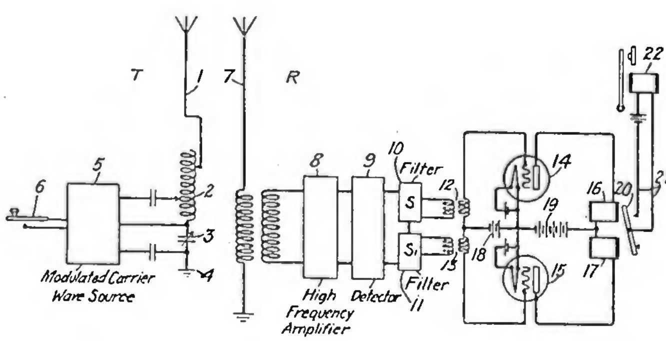
1,523,051—G. W. Carpenter and W. L. Carlson, filed June 18, 1924, issued January 13, 1925.

TELEPHONE HEADSET for use with sensitive multistage electron tube amplifiers, wherein the conductors leading to the telephone headset are shielded by a tubular webbing of a metallic tinsel and textile threads. The forming of the shield with textile threads and metallic tinsel provides an extremely flexible conductive covering for the telephone cords and permits the headset to be conveniently used in connection with the amplifier.



NUMBER 1,523,051—Telephone Headset

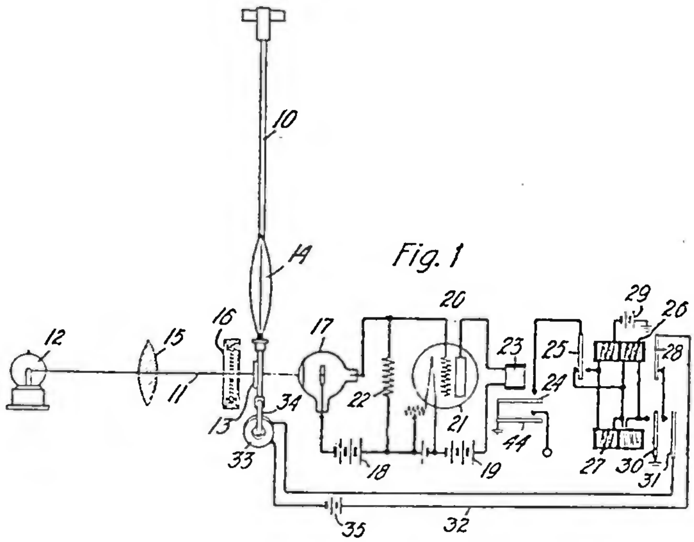
1,523,111—H. J. Fisher, filed December 5, 1923, issued January 13, 1925. Assigned to Western Electric Company, Incorporated, New York.



NUMBER 1,523,111—Signaling System

SIGNALING SYSTEM for radio telegraph operation, wherein a carrier wave is modulated by two different frequencies and the modulated and unmodulated components are transmitted to a distant station at which the corresponding components are combined to provide currents of the modulating frequencies which are selected, detected, and used to energize separate windings of a polarizing relay. The relay is employed to operate a suitable apparatus for observing the signals.

1,523,149—E. B. Wheeler, filed November 15, 1923, issued January 15, 1925. Assigned to Western Electric Company, a corporation of New York.



NUMBER 1,523,149—Means for Control of Electric Impulses

MEANS FOR CONTROL OF ELECTRIC IMPULSES in accordance with the swinging of a pendulum. The system comprises a relay for closing an electric circuit which relay may be operated by energy from a thermionic amplifier arranged to be controlled by the action of a beam of light impressed upon a photoelectric cell connected in the input circuit of the amplifier. In order to cause the relay to produce a succession of electrical impulses which shall be of equal duration and separated by equal intervals, an oscillating pendulum provided with an opaque body is arranged so that the opaque body intercepts the light beam impressed upon the photoelectric cell. This interception takes place preferably at the midpoint of the oscillation of the pendulum. It is thus evident that the light beam is twice intercepted for each oscillation of the pendulum. The relay is thereby caused to produce two pulses for each oscillation of the pendulum.

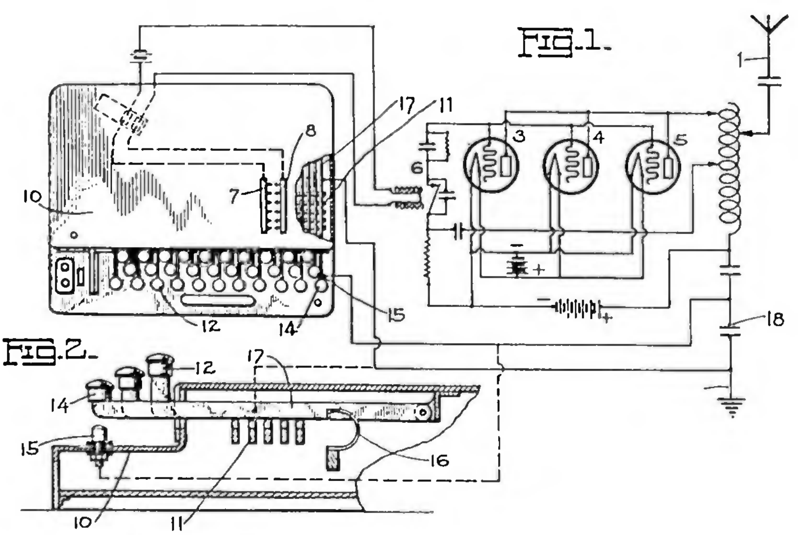
1,523,193—A. Gudheim, filed November 21, 1921, issued January 13, 1925.

AUTOMATIC FILAMENT CONTROL FOR RADIO APPARATUS, where separate rheostats are connected in each of the filament circuits and provided with a cam for operating a jack which controls the circuits to the filaments of the several tubes and insures a connection between the telephones and the last active tube in the system.

1,523,280—C. D. Palmer, filed January 29, 1921, issued January 13, 1925.

Radio Antenna for Aircraft arranged to be used either as a loop antenna or as a trailing wire antenna as may be desired. A switch is provided convenient to the operator which may be operated to connect a looped conductor on aircraft electrically as a closed circuit in the radio system or as a trailing wire balanced against the engine frame as a counterpoise for radio operation from aircraft.

1,523,377—J. B. Brady, filed August 14, 1923, issued January 13, 1925. Assigned to Morkrum Company, Chicago, Illinois, a corporation of Maine.



Number 1,523,377—Radio Telegraph System

Radio Telegraph System employing automatic printers for automatic transmission of telegraph signals from a central radio station to any number of outlying receiving stations. Means are provided for automatically starting and stopping automatic printers located at the outlying receiving stations by signals from the central station. In this manner news may be dispatched from a central radio transmitting station to the outlying printer receiving stations by preceding the printer signals with a starting signal which automatically controls the motor circuit at selected receiving stations for automatically placing the apparatus in condition for the reception of selected printer signals.

1,523,399—V. L. Chamberlin, filed February 1, 1924, issued January 20, 1925.

Detector Rod Support, in which the selecting wire is carried upon a standard having universal movement for reaching any part of the crystal. The standard consists of two ball members spaced by a tubular member with the ball members connected together under tension by a coil spring. The selecting wire may be moved to a point on the crystal for obtaining maximum sensitivity.

1,523,400—V. L. Chamberlin, filed February 1, 1924, issued January 20, 1925.

Crystal Holder for a detector which consists of a U-shaped member formed of spring metal and having inturned upper ends. A crystal support is provided within the U-shaped member and may be vertically adjustable therein for properly securing the crystal within the U-shaped member.

1,523,401—V. L. Chamberlin, filed February 1, 1924, issued January 20, 1925.

Detector Tip for a crystal detector which consists of a cylindrical cap with a fine detector wire extending from the closed end thereof. A conical coiled spring extends from the end of the cap about the detector wire and fits close about the detector wire for supporting said wire intermediate its ends.

1,523,430—W. A. Knoop, filed November 20, 1923, issued January 20, 1925. Assigned to Western Electric Company, Incorporated, New York.

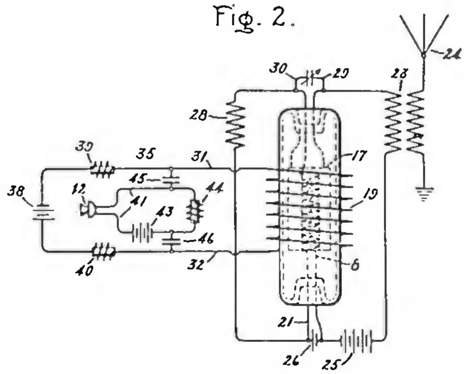
Mounting for Vacuum Tubes for eliminating noises in amplification systems due to shock vibration of the tube elements. The tube is provided with such a resilient support that vibrations may be damped. The tube base has a body attached thereto which projects into a pot containing a damping fluid. The body is immersed in the fluid and tends to prevent movement of the tube under mechanical vibration for suppressing noises in amplification circuits in which the tube may be connected.

1,523,536—A. E. Greene, filed September 4, 1923, issued January 20, 1925.

Electrical Condenser of the variable plate variety in which the stationary plates are held in spaced relationship by means of a shearing pressure on the edge portions of the plates. A pair of supporting members is provided, forming the condenser frame and slotted tubular members are positioned between the supporting members. Slotted members are located within the said slotted tubular members and arranged to exert a shearing pressure on the edge portions of the stator plates for maintaining the stator plates in spaced relationship.

1,523,777—A. W. Hull, filed May 21, 1920, issued January 20, 1925. Assigned to General Electric Company, New York.

Fig. 2.



NUMBER 1,523,777—Electron Discharge Device

ELECTRON DISCHARGE DEVICE, wherein an electron current is subjected to the conjoint action of a variable magnetic field. The usual tube construction is shown, including a filament, grid and plate. A grid circuit is provided for controlling an electron stream and in addition to this a winding for the development of a magnetic field is provided and arranged in the control circuit for affecting both electrostatic and electromagnetic control of the electron stream.

1,523,778—A. W. Hull, filed November 15, 1921, issued January 20, 1925. Assigned to General Electric Company, New York.

ELECTRON DEVICE AND METHOD OF OPERATING tubes of the magnetron class. The magnetron of this invention utilizes an axial magneto-strictive effect. A cathode is provided having a current-carrying capacity sufficiently high to conduct currents capable of producing a magnetic field, whereby electron current may be varied or even entirely interrupted. The cathode is surrounded by a cylindrical plate which may be connected in any desired utilization circuit.

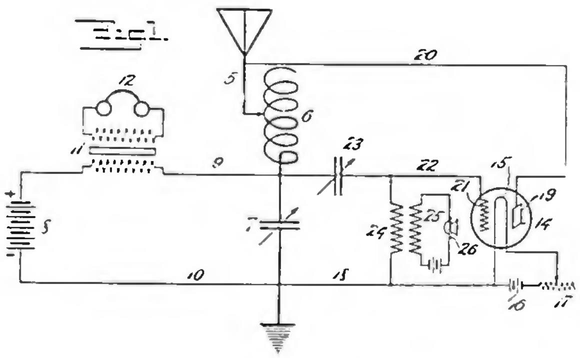
1,523,893—R. C. Pitard, filed December 15, 1923, issued January 20, 1925.

Grid Condenser formed by an electrical conductor adapted to embrace a portion of the tube with a dielectric material interposed between the conductor and the tube. The metal collar of the electron tube is made use of as one of the plates of the grid condenser. The other plate consists of a ribbon of metal secured around the base of the tube but separated therefrom by a dielectric sheet.

1,523,957—R. E. Hall, filed August 13, 1919, issued January 20, 1925. Assigned to Hall Research Corporation of Delaware.

Telephone Call and Method Therefor, for summoning an operator to a receiving station by means of a signal from the transmitting station. A special form of gaseous jet relay is provided for closing a call circuit. The relay is actuated by the transmission of a particular note from the transmitting station, resulting in the tripping of the relay at the receiving station and the closing of a call circuit.

1,524,413. M. W. Sterns, filed January 28, 1920, issued January 27, 1925.



Number 1,524,413—Radio Telephone System

Radio Telephone System, in which the same tube circuit functions as a transmitter and receiver. The circuit is arranged for simultaneous transmitting and receiving. A grounded aerial circuit is provided with a tuning inductance connected thereto and a divided secondary circuit across one portion of which the input circuit of the tube is connected and across the other portion of which the output circuit is connected. A telephone modulator is inductively connected to the grid and filament circuits of the tube while the receiving device is connected in the output circuit of the tube.

1,524,645—M. Latour, filed August 19, 1921, issued January 27, 1925.

RECEIVING APPARATUS FOR ELIMINATING STATIC, in which a pair of loop antennas are provided with a detector connected with each antenna and having a portion of their output circuits each common to a source of direct current. A resistance is provided in the output circuit of each detector and connections from the indicating apparatus to a point in each resistance are provided, enabling the circuits to be adjusted for the reception of signals substantially free of disturbances from static.

1,524,646—M. Latour, filed December 5, 1923, issued January 27, 1925.

CONNECTION OF RADIO FREQUENCY ALTERNATORS FOR RADIO SIGNALING, in which the driving motors for the alternators are coupled together with circuits for maintaining the machines in step. A pair of alternators is shown adapted to be operated in parallel with a pair of motors connected in parallel for driving the alternators. The currents in the driving motor circuits are balanced and a supplemental circuit is provided for compensating for changes in load of the alternators for maintaining the alternators in step.

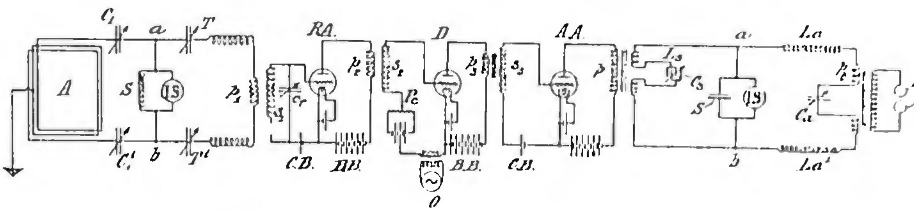
1,525,049—S. Ruben, filed June 28, 1923, issued February 3, 1925.

ELECTRON DISCHARGE TUBE construction including an evacuated vessel with an electron emission element therein and a cooperating anode. An element composed of an insulating material is interposed between the electron element and the plate. A pair of electrically conductive plates are arranged in a plane approximately parallel to the anode. The electron emission element is disposed in conductive relation to the conductive plates. By this arrangement of elements the electron stream is deflected from its normal direct path and is forced to traverse an electrostatic field in a direction approximately 45 degrees to that of the field in the space between the pair of conductive plates.

1,525,110—F. K. Vreeland, filed August 6, 1919, issued February 3, 1925.

AUDIO FREQUENCY SELECTIVE SIGNALING SYSTEM, wherein the circuit connected with the detector system includes a baffle circuit and an intensity selective or other energy dissipating means which operates directly on the audio frequency currents to exclude those currents not desired from the observing circuit. The patent sets forth the differences in characteristic between the stray impulses which are very abrupt and transitory and signaling impulses which are sustained. The strays when they constitute serious interference have an intensity or amplitude which is greater than that of the signaling impulses. The baffle circuit in the audio frequency amplifier separates the signal currents from the strays and also dissipates the strays of greater intensity than the signals, permitting the signals to be received substantially clear of static disturbances.

Fig. 3.



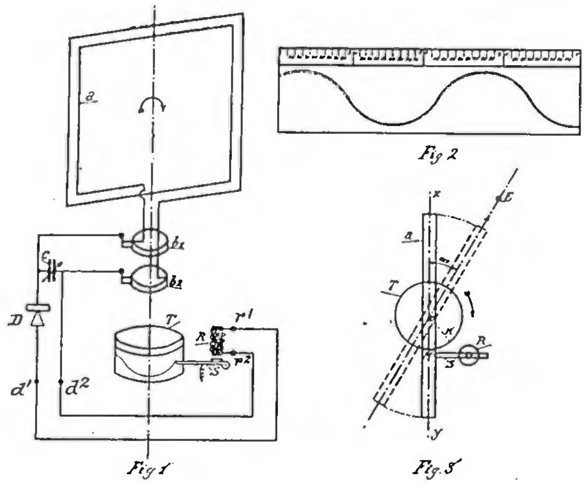
NUMBER 1,525,110—Audio Frequency Selective Signaling System

1,525,159—H. M. Wohltman and M. Hirschfeld, filed April 24, 1922, issued February 3, 1925.

CRYSTAL DETECTOR, designed to have all parts easily accessible and replaceable and in which the entire surface of the crystal may be utilized and delicate adjustment made there-against. A glass tube is provided having a large bore in one portion thereof in which the crystal is arranged to be inserted and a smaller bore in the other portion thereof thru which the contacting wire may be inserted to impress a point on the crystal. The crystal may be readily changed in position to enable the contacting wire to reach all points thereof.

1,525,177—R. B. Goldschmidt and R. Braillard, filed May 24, 1920, issued February 3, 1925.

DIRECT READING RADIOTELEGRAPHIC COMPASS, in which a loop collector is rotated about a vertical axis in order to receive maxima and minima of signal intensity. The loop frame carries a cylindrical drum on which is mounted a chart against which an inscribed pencil may be moved automatically to inscribe a curve characteristic of the received signals. In this manner the characteristics are made both visible and audible.



NUMBER 1,525,177—Direct Reading Radiotele graphic Compass

1,525,182—H. C. Hayes, filed July 7, 1923, issued February 3, 1925.

SOUND TRANSMITTER AND RECEIVER, in which a pair of annular magnets are positioned adjacent each other with a set of annular pole pieces on each of the magnets. The diaphragm consists of a magnetic annular ring which is acted upon by the annular pole pieces. The structure is designed to eliminate distortion in loud speaker reproducers.

1,525,308—A. J. Kloneck, filed November 28, 1916, issued February 10, 1925.

SIMULTANEOUS SIGNALING AND RECEIVING SYSTEM, in which a ground to antenna circuit is provided for transmitting while an antenna to antenna circuit is provided for receiving the antennas being common for both circuits. A circuit arrangement is provided between a pair of antennas for receiving signals while eliminating local disturbances from the local transmitter which may be simultaneously operating on an antenna to ground circuit.

1,525,302—R. Knopp, filed June 19, 1922, issued February 3, 1925. Assigned to Frank J. Quigan, Incorporated, Brooklyn, a firm of New York.

ELECTRIC CONDENSER of variable adjustment in which a movable plate may be shifted axially of a central shaft with respect to a stationary plate for varying the capacity therebetween. Cams are provided which are rotatable face to face for securing fine adjustment of capacity.

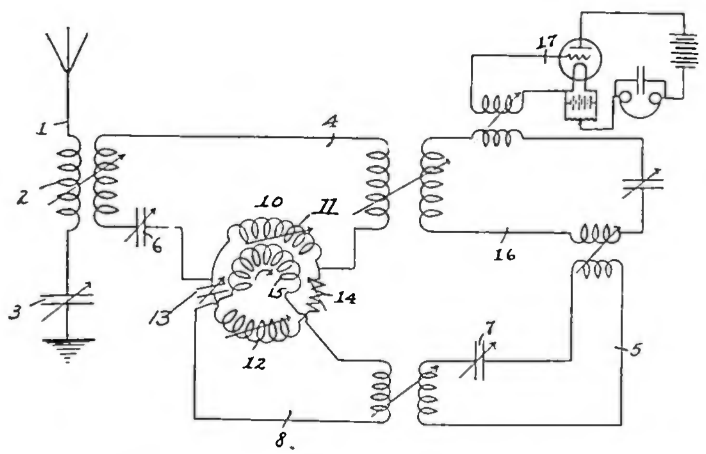
1,525,350—H. Zuckerman, filed December 4, 1920, issued February 3, 1925.

Vacuum Spark Gap, wherein the gap is located within an exhausted tube, each gap being provided with heat radiating flanges with an insulating rod extending between the gaps for maintaining the faces in spaced relation. The electrodes are supported by U-shaped members extending from the base of the receptable.

1,525,431—T. H. Phillips, Jr., filed October 17, 1917, issued February 3, 1925. Assigned to Elmer A. Sperry, of Brooklyn, New York.

Remotely Controlled Selective System for radio control of circuits from a distance. The patent describes a mechanical arrangement of switches which may be operated by distinct signals from a transmitting station to close selected circuits at a receiving station.

1,525,526—J. Weinberger, filed March 3, 1921, issued February 10, 1925. Assigned to Radio Corporation of America, a corporation of Delaware.



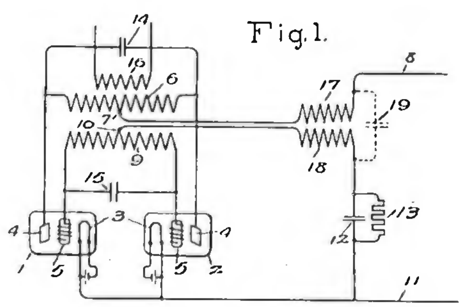
Number 1,525,526—Radio Receiving System

Radio Receiving System, in which relatively strong interference may be overcome while permitting the reception of desired signals. Two intermediate circuits are coupled to the receiving circuit for eliminating interfering currents from the antenna. One of the intermediate circuits has a relatively high ratio of signal current to interfering current. The other intermediate circuit is tuned to the interference and has a relatively high ratio of interfering current to signal current. The intermediate circuits are arranged to oppose the intermediate currents while retaining the signal currents.

1,525,778—C. A. Hellmann, filed April 17, 1922, issued February 10, 1925.

VARIABLE CONDENSER of the rotary plate variety, wherein the two sets of elements are of unequal angular extent. Either the rotary or the stationary plates may be greater than 180 degrees in angular extent, while the other set of plates is less than 180 degrees. The object of the invention is to provide a variable condenser in which variation of capacity may be had over an angle of rotation exceeding 180 degrees and approaching as near to 360 degrees as may be desired in any particular case. The specification describes a great many modifications of the invention.

1,525,827—D. C. Prince, filed December 14, 1923, issued February 10, 1925. Assigned to General Electric Company, New York.



NUMBER 1,525,827—Production of Alternating Currents

PRODUCTION OF ALTERNATING CURRENTS by a pair of electron tubes operating in a push-pull circuit 180 degrees out of phase. A pair of three-electrode electron tubes are provided with an inductive winding having its terminals connected to the anodes of each of the tubes and an intermediate point connected to a source of direct current thru an inductance. A second inductive winding is provided which is inductively related to the first winding and has its terminals connected to the control electrodes of the tubes. An intermediate point of this last-mentioned inductive winding is connected to the cathodes thru a second inductance. The inductances are coupled to each other for the production of alternating currents by the tube system.

1,525,844—W. C. White, filed July 3, 1920, issued February 10, 1925. Assigned to General Electric Company, New York.

VACUUM TUBE APPARATUS, in which an electron current between two electrodes of an electron tube is controlled by means of a magnetic field. A stream of electrons is produced between a cathode and plate electrode of an electron discharge device. The velocity of this stream is caused to be greatly decreased as the electrons approach the plate electrode. By producing a magnetic field in the region adjacent to the plate electrode which acts upon these slowly moving electrons, it is possible by means of a comparatively weak magnetic field to produce a substantial variation in the electron current received by the plate electrode.

1,525,941—C. V. Logwood, filed April 21, 1920, issued February 10, 1925. Assigned to De Forest Radio Telephone and Telegraph Company, New York, a corporation of Delaware.

RADIO SIGNALING SYSTEM, in which a source of high frequency oscillations is modulated in accordance with the signals to be sent in such manner that the modulating signal current increases the power transmitted rather than decreases the same. A pair of electron tubes are provided for supplying oscillating currents to the antenna. The grid electrodes are charged with opposite potentials and condensers are provided for building up and storing energy which may be supplied to the antenna additively to the normal supply of energy thereto, whereby the modulating signal current increases the power supply.

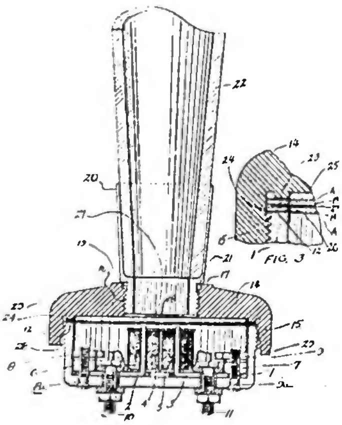
1,526,311—M. C. Batsel, filed January 25, 1921, issued February 17, 1925.

RADIO TRANSMISSION SYSTEM, in which a coupling system is provided between the oscillator and the radiating circuit which will keep the current in the amplifier system within safe values when the radiating system is untuned to the frequency of the oscillating circuit, but which will have the correct impedance when the two systems are tuned to the same frequency for the desired output.

1,526,408—F. W. Young, filed August 24, 1921, issued February 17, 1925. Assigned to Western Electric Company, Incorporated, a corporation of New York.

CARRIER WAVE RECEIVING SYSTEM, in which de-modulators of different kinds may be used without substantial change in the receiving circuit. The invention is directed to a circuit arrangement in which either a crystal detector or a tube detector may be used at will without substantial change in the receiving circuit. The tube socket is so arranged that it may receive a crystal detector support and switches are provided for adapting the circuit to a crystal rectifier instead of a tube rectifier.

1,526,626—C. E. Brigham, filed March 13, 1924, allowed February 17, 1925. Assigned to C. Brandes, Incorporated, of New York City.



NUMBER 1,526,626—Electromagnetic Sound Reproducer

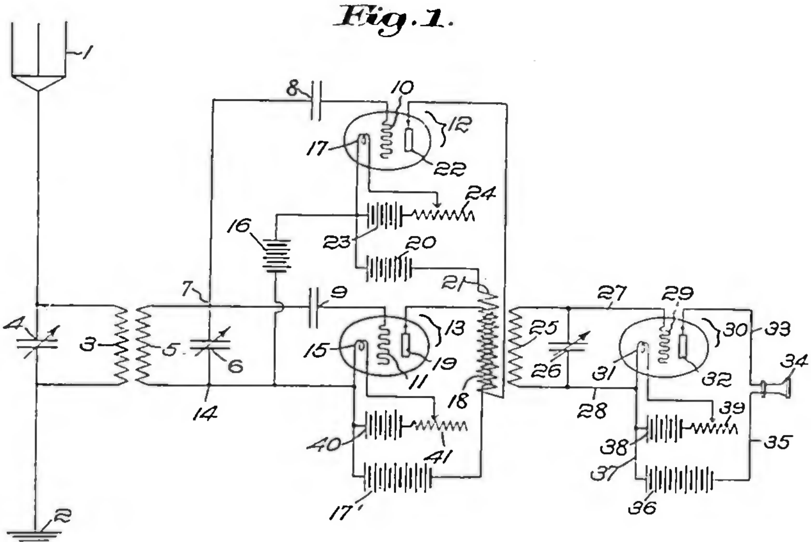
ELECTROMAGNETIC SOUND REPRODUCER for radio reception, in which a diaphragm is resiliently supported at its periphery for operation by an electromagnetic operating mechanism. The diaphragm is supported by a pair of relatively thin rings, one positioned on one side of the diaphragm and the other positioned on the opposite side of the diaphragm. The rings are composed of layers of dissimilar material formed integral with each other and remain in permanent adjustment with respect to the electromagnetic sound reproducer. This patent covers the Brandes Table Talker.

1,526,664—W. Dubilier, filed October 6, 1923, issued February 17, 1925. Assigned to Dubilier Condenser and Radio Corporation, New York, a corporation of Delaware.

ELECTRICAL CONDENSER of fixed capacity, in which the plates are clamped by the metallic sheet which wraps about the stack and forms one of the armatures of the condenser. The clamp serves as both a compression element and as a conducting plate.

1,526.852—J. H. Hammond, Jr., filed August 20, 1917, issued February 17, 1925.

Fig. 1.



NUMBER 1,526,852—Means for and Method of Limiting Interference in Radio Signaling

MEANS FOR AND METHOD OF LIMITING INTERFERENCE IN RADIO SIGNALING, by providing circuits for limiting the effect of high potentials on the detector. The receiving system includes an oscillatory circuit and a primary and secondary detector, both controlled by the oscillatory circuit. A pair of circuits are controlled by the detectors which operate upon another detector, in the output circuit of which the observing instrument is connected. The detectors are arranged to be responsive in different degrees to impulses having a given intensity.

1,527,228—J. C. Schelleng, filed December 29, 1923, issued February 24, 1915. Assigned to Western Electric Company, Incorporated, New York.

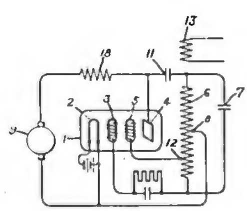
METHOD OF HARMONIC OR SUB-HARMONIC FREQUENCY PRODUCTION by a circuit arrangement utilizing an oscillator for producing a complex wave the fundamental frequency of which is normally approximately that of the desired sub-harmonic frequency and having a harmonic approximately equal to the reference frequency. The current of the reference frequency is caused to coact with the current of the harmonic frequency in the oscillation circuit of the oscillator. The effect of such coaction on the oscillator is to pull it into step with the frequency of the impressed current, that is, to cause the reference and harmonic frequencies to become identical. The fundamental frequency is thus correspondingly automatically adjusted to exact sub-harmonic relationship with the reference frequency. The production of the unmodulated carrier may be accomplished by means of the present invention by combining the received side bands, selecting the resulting component of double carrier frequency and causing it to operate upon a local oscillator in the manner described above to produce the first even sub-harmonic, that is, the desired carrier frequency.

1,527,578—D. H. Sheriff, Jr., filed March 5, 1923, issued February 24, 1925.

Variable Condenser, designed for the securing of fine or critical adjustment after the usual rotative adjustment has been made. The plates are formed so that one set may be rotated with respect to the other set and then one set may be moved out of and into parallelism with the other set of plates to effect fine adjustment of capacity.

1,527,703—D. C. Prince, filed April 8, 1922, issued February 24, 1925. Assigned to General Electric Company, New York.

Fig. 1.



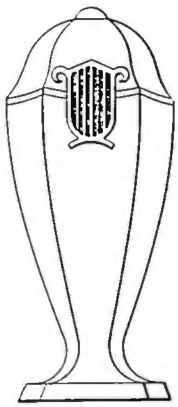
Number 1,527,703—Electron Discharge Apparatus

Electron Discharge Apparatus, in which losses incident to the operation of electron tube discharge devices are eliminated. Losses which occur by reason of secondary emission are prevented by interposing a supplemental grid between the control electrode and the plate. If, when current is flowing to the plate, this extra grid is made slightly negative with respect to the plate no secondary electrons can escape from the plate and the control grid may be made positive enough greatly to reduce the space charge losses without introducing compensating grid losses.

1,527,896—S. L. Miller, filed June 7, 1922, issued February 24, 1925.

Radio Cabinet, designed to facilitate the quick and easy positioning therein of the radio apparatus. The front side of the cabinet is open. A panel is provided having a sub-base at its lower portions slidable in the base of the cabinet. The cabinet is provided with a plurality of openings in its rear side through which binding posts carried by the slidable sub-base may be projected for completing connections with the apparatus from the exterior of the cabinet.

Design 66,668—Stephen Bourne, filed November 26, 1924, allowed February 24, 1925. Assigned to C. Brandes, Incorporated, of New York City.



NUMBER 66,668—
Design for a Loud
Speaker for Radio
Reproduction

DESIGN FOR A LOUD SPEAKER FOR RADIO REPRODUCTION, in which the sound is directed upwardly in a vase-like amplifying horn and outwardly to the listener-in.