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CONTENTS

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, or Chicago.

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INSTITUTE ACTIVITIES

Standard Report

The Standards Committee of THE INSTITUTE, Ralph. H. Bown, chairman, is making good progress with the revision of the 1922 Standardization Report. It is expected that the work will be completed this Fall so that pamphlet publication of the Report may be possible early in the coming year.

Institute Sections

By authorization of the Board of Direction at its July, 1925, meeting, President Dellinger appointed a Sections Committee charged with the duty of investigating and developing the technical activities of present Sections, and of reporting upon by-law revisions which will enable the Board of Direction to administer more effectively the affairs of the Sections. The Committee is made up of Mr. Donald McNicol, chairman, and Messrs. Melville Eastham, J. V. L. Hogan, Leslie McMichael, H. M. Turner, G. Y. Allen, C. M. Jansky, Jr., J. C. Jensen, G. W. Pierce, A. H. Taylor, Montford Morrison, J. F. Dillon and C. E. Williams.

Increase in Membership

The Membership Committee, L. E. Whittemore, chairman, in a campaign carried on in June and July, last, succeeded in obtaining applications from about three hundred radio engineers and workers who desire to become associates of THE INSTITUTE. Thruout the Fall and Winter months the campaign shall be continued with a view to doubling the membership within the year.

Affiliation With A. A. A. S.

THE INSTITUTE recently became affiliated with the American Association for the Advancement of Science.

National Electric Code

THE INSTITUTE is now a member of the National Fire Protection Association, whose Electrical Committee originates the provisions of the National Electric Code. THE INSTITUTE OF RADIO ENGINEERS is represented on the Electrical Committee. Revisions of the Code are made and published annually. INSTI-

TUTE members should study the Section of the National Electric Code governing radio installations and forward to the Secretary any suggestions which would make for betterment of the wiring regulations covering radio and storage battery installation.

Chicago Section

The initial meeting of the Chicago Section of THE INSTITUTE was well attended and the first papers presented were of a high order. The speakers were Professor E. W. Bennett and Assistant Professor L. J. Peters, of the University of Wisconsin. Mr. Montford Morrison is chairman of the Section; L. R. Schmidt, secretary, and William W. Harper, treasurer.

New York Meetings

Growth in membership and in influence of THE INSTITUTE are reflected by the increasing interest being taken in the New York meetings. At recent meetings it has been necessary to use the large auditorium of the Engineering Societies Building in order properly to accommodate the audience. It is expected that in the near future attendance at meetings will exceed five hundred.

A NEW PHENOMENON IN SUNSET RADIO DIRECTION VARIATIONS*

By

L. W. Austin

(For Special Laboratory Radio Transmission Research)

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

The observations on the deviations preceding sunset[1] have been continued. The phenomena, it will be remembered, are as follows: The apparent direction of the long-wave stations, New Brunswick and Tuckerton, to the northeast of Washington, begins to shift toward the east two or three hours before sunset. This deviation reaches a maximum of 10° to 15° roughly an hour before sunset. The bearing returns to normal before sunset and then usually shifts to the west and passes into the irregular night deviations.

The remarkable thing about this phenomenon is its uniformity, the only variations from day to day being differences in the amount of deviation and the exact time when the bearing returns to its correct value. It seems to occur with regularity only with stations at certain distances, not over 300 km. and not less than 100 km. As the only stations suitable for these observations lie to the northeast of Washington, attempts have been made to interest observers in taking observations in other directions. Work covering only two or three days by Mr. Englund at Cliffwood, New Jersey, indicated that Annapolis, about 270 km. to the southwest, showed deviations first to the west and later to the east, that is, in the opposite sequence to those observed on the northerly stations at Washington.

According to Eckersley's theory,[2] deviation is due to an indirect wave reflected or refracted from the Kennelly-Heaviside layer, which comes down with its magnetic field non-parallel to the earth's surface, thus having a vertical component which cuts

*Published by permission of the Director of the Bureau of Standards of the United States Department of Commerce. Received by the Editor, June 12, 1925.

[1]Proceedings of The Institute of Radio Engineers, 13, page 3; 1925.
[2]"Radio Review," 2 page 60; 1921.

the top and bottom of the radio compass coil and produces an emf. which destroys the true minimum and requires turning the compass coil to bring the electromotive forces again into balance. If we could assume that the conducting layer is horizontal, and that there is a regular reflection, it should be possible to restore the bearing to the true direction by rotating the frame carrying the compass coil around a horizontal axis at right angles to the line joining the stations. Then, at the vertical angle which restores the true horizontal bearing, the compass coil should be at right angles to the direction of the indirect wave, and from the assumptions should enable the height of the reflecting layer to be determined by triangulation. This experiment has been tried but failed to restore the true bearing. It did, however, show a new series of phenomena which, while not so far explained, show apparently the same regularity of sequence as the before-sunset deviation already described. It has been frequently noticed that the rotation of the normal axis of the compass coil around a horizontal axis at right angles to the true direction of the sending station frequently produces a great sharpness of minimum at a certain vertical angle. It is now found that the angle for the sharpening of the minimum apparently varies regularly with the changes in bearing deviation during the before-sunset period. The "sharp minimum" vertical angle starting at 0° to 20° increases with the deviation of the horizontal bearing until at about an hour before sunset, just before the horizontal bearing deviation has reached a maximum, it reaches 50° to 80°. Then, as the horizontal bearing returns toward the true direction, the vertical "sharp minimum" angle decreases rapidly so that before the horizontal bearing has become correct, the vertical angle has returned to zero and gone up to 50° to 80° on the other side, that is, with the main axis of the compass coil tipped forward.

Figure 1 shows the double axis compass coil and Figure 2 a typical set of curves. A few points in regard to the curves are worthy of notice. The sharp minimum vertical angle always begins to rise some time before the bearing of the station begins to shift. The vertical angle, so far as has been observed, always returns to zero at the same moment that the easterly bearing deviation begins to drop. The vertical angle curve cuts the axis again nearly at the same time that the westerly deviation starts to decrease. The negative maximum of the vertical angle always nearly coincides with the passage of the bearing thru its true value in going from the easterly to the westerly deviation.

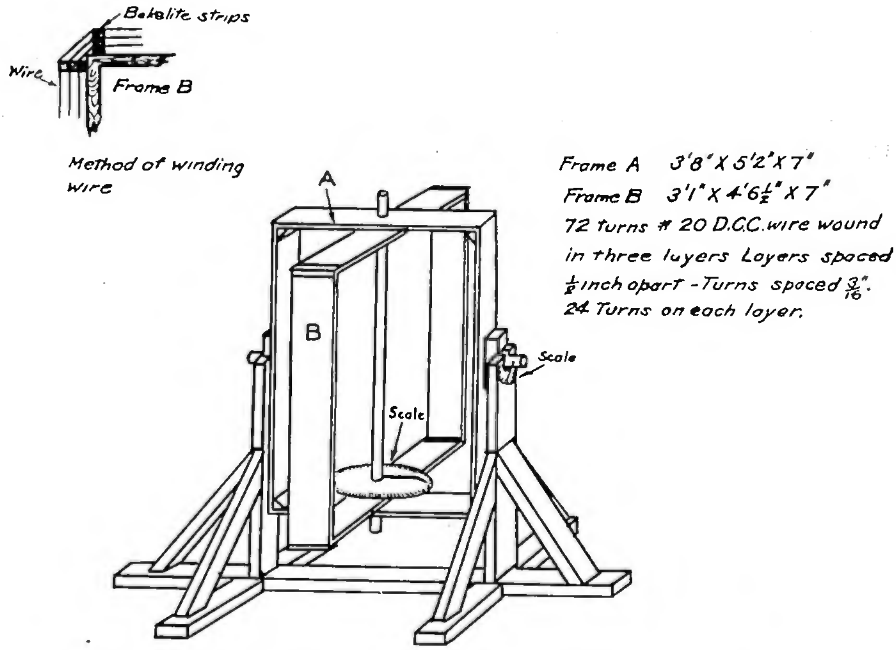

FIGURE 1

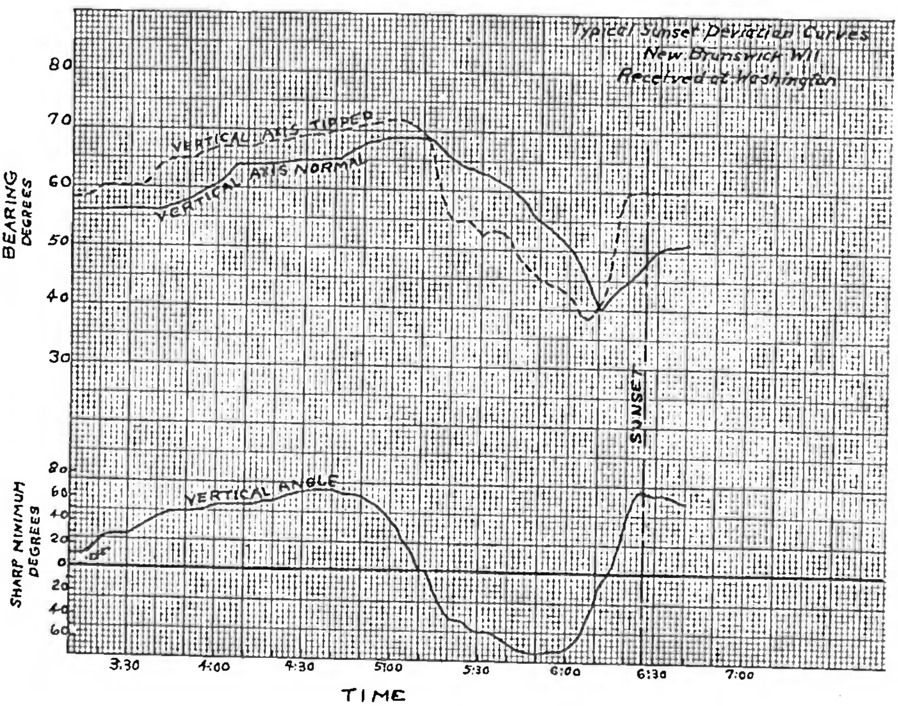

FIGURE 2

Enough observations have been made to convince us that we have a perfectly regular natural phenomenon apparently occurring daily, which is probably connected with the deionization of the atmosphere as the sun sinks toward the west. It seems probable that similar deviations take place after sunrise, but these have not as yet been investigated. As it may be a long time before the physical processes involved are understood, I am publishing the observed facts for others to verify and, if possible, explain.

RECENT COMMERCIAL DEVELOPMENT IN SHORT WAVE TRANSMITTERS AND RECEIVERS*

By

S. E. Anderson, L. M. Clement, and G. C. De Coutouly

(Western Electric Company, New York)

Introduction

In view of the recent activity in the use of the very short wave lengths, that is, below 100 meters, it may seem somewhat tardy to present a paper describing a transmitter and receiver recently built for the United States Coast Guard covering the wave length range between 100 and 200 meters (1,500 to 3,000 kc.). When the complete title of the paper is taken into consideration, however, the authors hope that the matter presented will be of interest, as commercial development always follows somewhat behind the development of the laboratory.

The paper deals with the development of the radio receiver and transmitter for telephonic and interrupted continuous wave telegraph transmission for communication between small vessels and between them and shore stations. The sets must be designed to give satisfactory communication over distances of 50 miles for telephony and 100 miles for interrupted continuous wave telegraphy. One wave length only will be used for communication and this equipment will be operated by persons not familiar with radio. The controls on the receiver, therefore, will be locked and the transmitter will be adjusted to a single frequency. In order to insure absolutely reliable communication the selectivity of the receiver must be good and the transmitting frequency must be held within very close limits.

The system consists of two main parts—the 50-watt coupled oscillator circuit type of transmitter and the double detection type (super-heterodyne) receiver.

The primary power source is a 200 ampere-hour storage battery which supplies the filaments of the transmitter and the plate circuit dynamotor. A standard telegraph key is used to con-

* Presented before The Institute of Radio Engineers, New York, December 17, 1924. Received by the Editor, January 13, 1925.

trol the telegraph feature of the transmitter while a hand set is used for telephony. Separate dry or storage batteries are used to operate the radio receiver.

The Transmitter

The operating conditions demand that the transmitter be simple to operate, rugged, and efficient in order to insure minimum drain on the storage battery. The frequency stability requirements are very severe as it is necessary to maintain the transmitter frequency constant for variations in the supply voltages and change in antenna constants due to service conditions. The most serious cause of variation is due to changes in the antenna capacity caused by the rolling of the vessel, which may be as great as 45° from the vertical. The range requirements of 50 miles for telephone and 100 miles for telegraph signals are considered to be satisfactorily met by a 50-watt transmitter as a result of some preliminary tests made by the Coast Guard people. The power output requirements of the set expressed in terms of the antenna constants and antenna current demand that it deliver at least two amperes into a 12-ohm antenna of 0.0003 microfarad capacity having a natural wave length of 116 meters.

Electrical Design

The transmitter circuit is made up of three major parts—the oscillator circuit, the modulator circuit and the speech input circuit. The circuit diagram of the transmitter is shown in Figure 1. The negative grid biasing potentials for all tubes are obtained by means of a system of resistances properly inserted in the plate circuit. Keying for interrupted continuous wave telegraph transmission is obtained by the use of a 15,000-ohm resistance (R_{13} on the diagram) which is connected between the minus 18-volt terminal and the ground. The key short-circuits this resistance when it is depressed, which removes the high negative potential applied to the grids of the tubes.

The completed transmitter is shown pictorially in Figures 2, 3, and 4. In consists of a single unit brass frame 33″ high, 16½″ wide, and 18″ deep. The upper part of the front panel supports all of the meters which are necessary for observation of the performance of the different parts of the circuit. At the bottom of the front panel the switches for the control of the filaments and the motor-generator are located. The necessary connections to the set are made to a terminal strip which is accessible thru

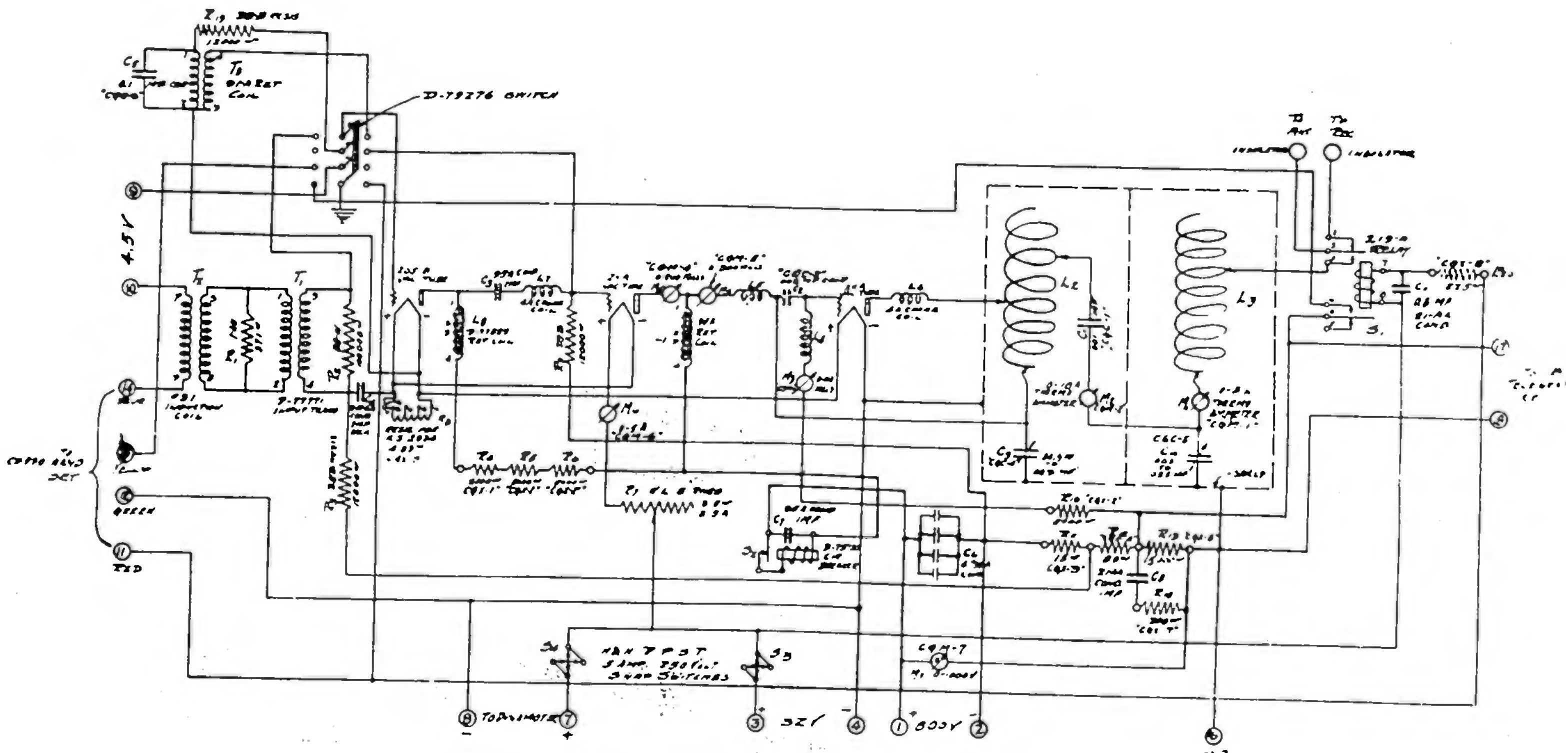

FIGURE 1—Schematic Circuit of Complete Transmitter

a door at the bottom of the transmitter. The equipment in the transmitter as shown in the photographs is mounted in three separate sections. In the first section from the bottom audio frequency coils and resistance units for the speech input and modulator circuit are mounted.

The second section from the bottom is divided into two compartments—the front containing the two power tubes as well as the speech input amplifier tube with their accessories. The back is entirely shielded from the rest and contains the primary tuning inductance, the primary tuning condenser and the grid coupling condensers. The third section located at the top of the set is also

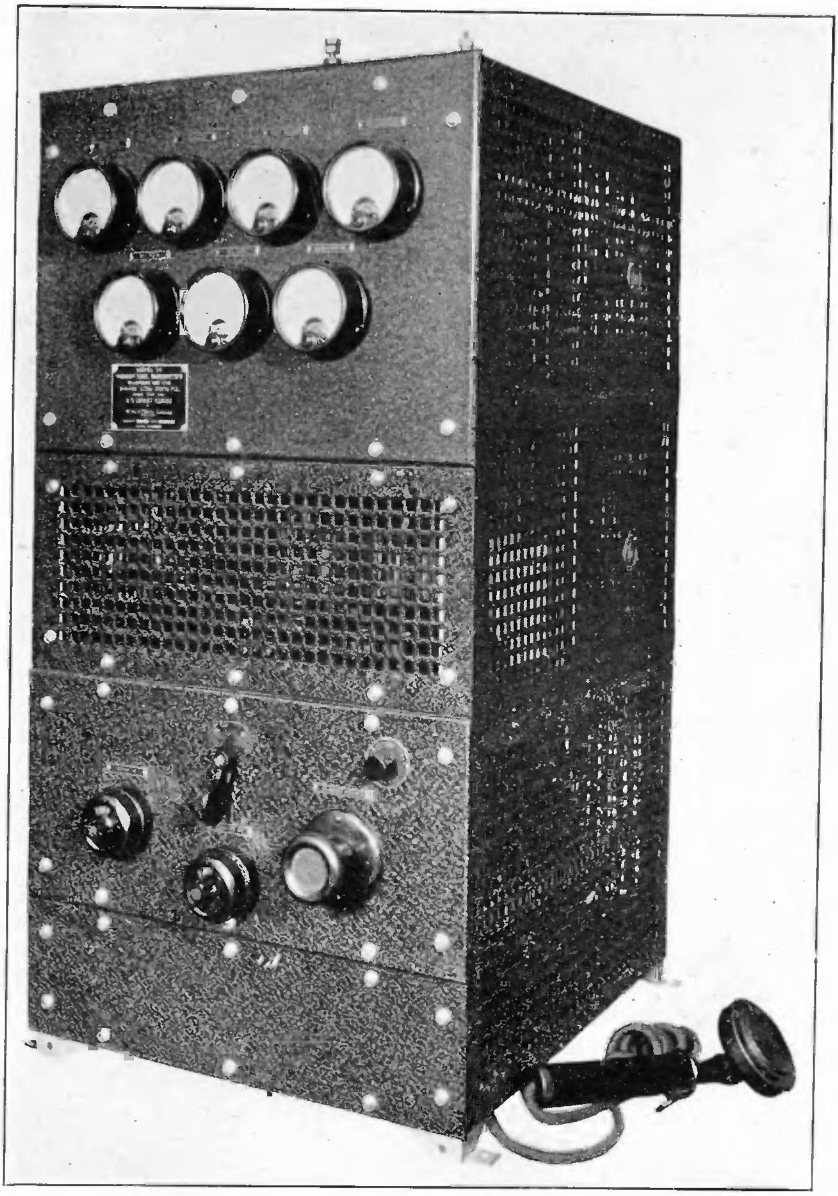

FIGURE 2

divided into two parts, the front containing the plate voltage meter resistor and the antenna relay and the second containing the antenna loading coil and the antenna coupling condensers. This compartment is also entirely shielded from

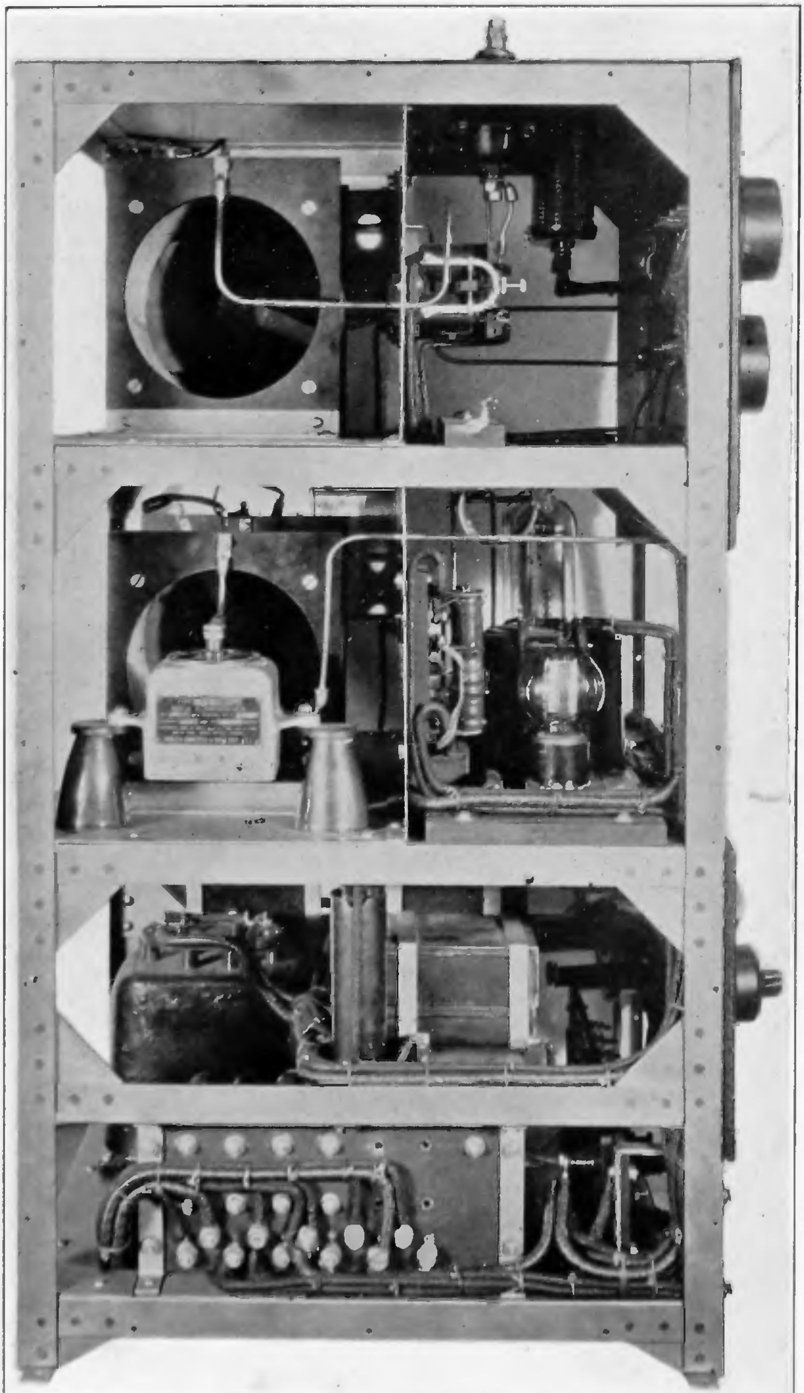

FIGURE 3

the rest of the circuit. The control switch for telephone or interrupted continuous wave telegraph transmission is mounted at the center of the front panel. When the set is operating as a telephone transmitter the push button provided on the hand set connects the transmitter to the antenna and

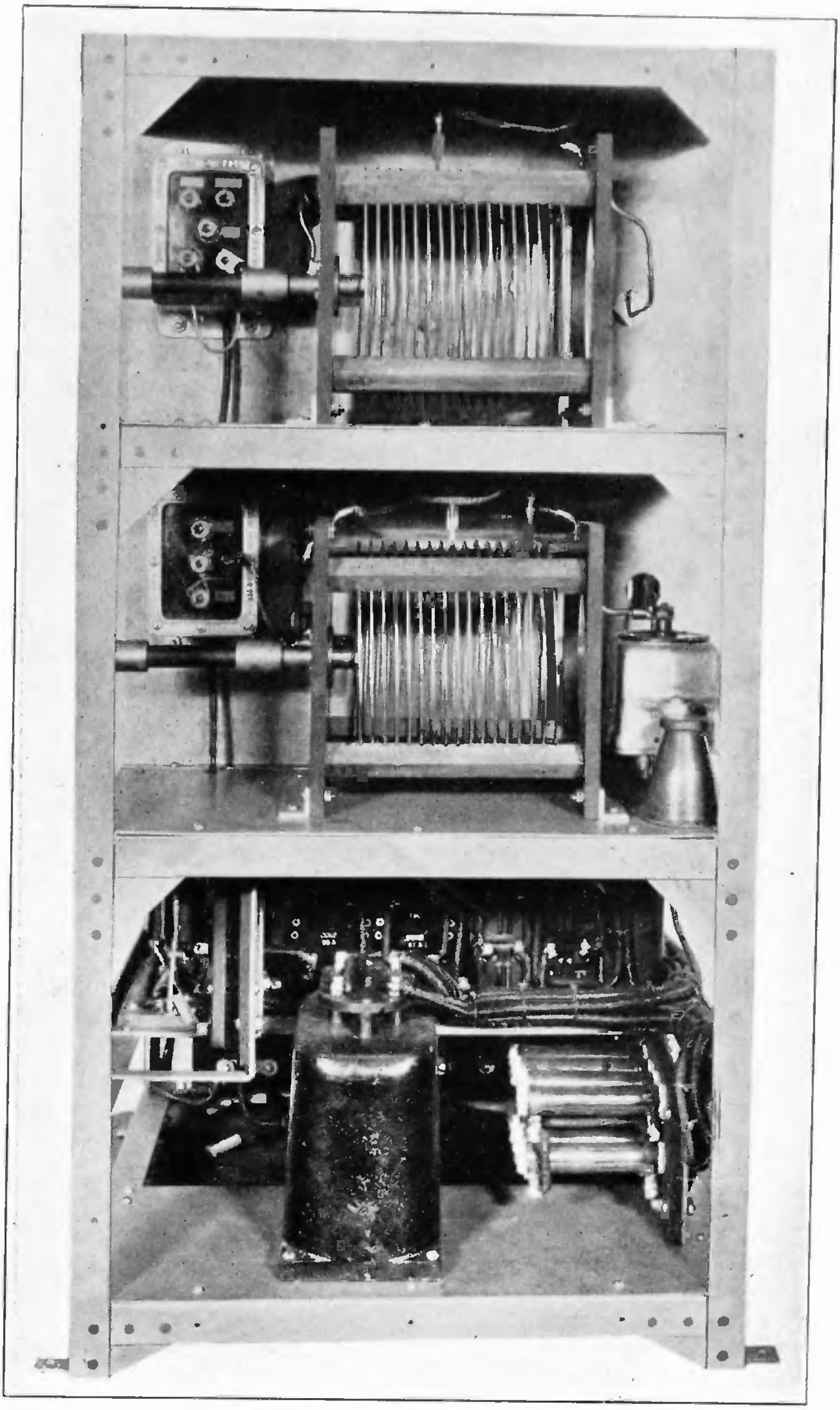

FIGURE 4

starts the oscillations when it is pressed. With the control switch in the interrupted continuous wave position the telegraph key is connected in circuit and oscillations are started when the key is pressed. The filaments of the tubes are controlled by means of an ordinary snap switch which is shown on the photograph, Figure 2. A second snap switch controls the plate dynamotor which supplies the plate voltage to the plates of the tubes only after the filaments of the tubes have been turned on. A filament rheostat is also provided to adjust the filament current to the proper value.

The antenna and primary coils are provided with a fine continuous adjustment of their inductance so that the circuits may be adjusted to any frequency within the range of the transmitter. The fine adjustment is obtained by means of a sliding contact on the last turn of the inductance. It can be set in any position from the outside of the transmitter by means of a screwdriver. No fine adjustment knobs were provided, as the transmitter is to be set at the desired frequency, and it will remain constant for a long period of time.

One of the first problems to be considered was the choice of the type of transmitter circuit which would best give the degree of frequency stability required. With this end in view, both the simple oscillator circuit and the coupled oscillator circuit were studied.

The change of antenna capacity for a 45° roll of the vessel from the vertical was calculated by well-known formulas and found to be approximately 3 percent of the total antenna capacity. The frequency change due to a 3 percent variation in antenna capacity was then computed for the simple tuned oscillator circuit and for the capacity coupled oscillator circuit.

The calculated frequency change for the case of the simple oscillator for a 3 percent increase in antenna capacity was found to be approximately 8,000 cycles at an operating frequency of 2,300 kilocycles.

In the case of the capacity coupled oscillator circuit the circuit constants were determined for the resonance condition of the double tuned capacity circuit with an antenna of 0.003 microfarad capacity. These constants were calculated so that the circuit resonated at the desired frequency F_1. Assuming that the change of frequency due to the antenna capacity variation was of the second order with respect to the change of frequency in the primary circuit due to the change of the introduced reactance from the secondary into the primary, the reactance introduced by the secondary into the primary after the antenna capacity change was calculated as if the circuit was still resonating at the desired frequency F_1.

The frequency at which the primary circuit resonates after the antenna capacity change was obtained by calculating the frequency determined by the primary inductive reactance in series with the reactance of the grid and primary tuning capacities and the value of reactance introduced from the secondary circuit after the antenna capacity change. This gives a new value F_2 for the frequency which was then substituted back into the equations for the secondary circuit in order to calculate more accurately the change of apparent reactance introduced into the primary circuit by the secondary. By means of several approximations the final change of frequency is approached, and the difference between it and the original frequency F_1 gives the change due to the changed antenna capacity. The frequency change was found, in this case, to be about 3,100 cycles per second when the coupling between the primary and secondary circuits was of the critical value (critical coupling).

The simple type oscillator did not meet the frequency stability requirements, and accordingly the capacity coupled oscillator circuit was chosen. The coupled oscillator circuit does not radiate harmonic frequencies of the fundamental to any great extent, and this alone is enough to justify its use.

The laboratory model and later the completed commercial transmitters were tested for frequency stability due to changes in plate potential supply voltage and change in antenna capacity.

As the change of frequency due to change in the antenna capacity and to the variations of plate and filament voltages due to the discharge of the battery was very small in comparison with the frequency at which the transmitter operated, the following method for measuring this frequency change was used: The continuous wave emitted by the transmitter placed in the telephone position by means of the transfer switch, not modulated by the voice, was received with a heterodyne receiver which was set to give a certain beat frequency for a given condition of the transmitter. The frequency of this beat note was measured by means of an auxiliary standard calibrated oscillator by the "zero beat" method. The setting of the transmitter was then changed to simulate the changed condition, and the frequency of the heterodyne beat note in the receiver was again measured by means of the calibrated audio frequency oscillator. The difference between the two readings of that oscillator gave the difference in frequency between the two conditions of the transmitter. The following results were observed:

For a variation of plate potential caused by a change in storage battery voltage from 33 (fully charged) to 28 volts (nearly discharged) with the filament kept at a constant value, the frequency change was of the order of 0.007 percent. It may, therefore, be said that the frequency of the transmitter is practically independent of the variations of plate voltage and storage battery voltage likely to occur in practice. The same method was used to measure the change of frequency due to a change of antenna capacity. For an antenna capacity change of from 300 to 310 micro-micofarad (3 percent) the change of frequency was found to be about 2,500 cycles per second when the antenna coupling capacity was chosen so that the required antenna power was obtained. During the test the antenna capacity was varied from 300 micro-microfarads to about 500 micro-microfarads. It was noticed that the frequency of the transmitter first increased with the antenna capacity and then decreased as the antenna capacity was further increased and approached a value after which no further decrease occurs. This series of observations at first could not be easily explained, but upon a mathematical investigation it was found to follow the theory.

Design of Radio Frequency Oscillator Circuit

The double-tuned self-excited oscillator output circuit is shown in Figure 1. It consists of a closed inductance-capacity oscillating circuit coupled to the antenna circuit by means of a large capacity which is common to both circuits. L_2 and C_1 are the primary tuning inductance and capacity, respectively, with L_2 variable by taps. C_{10} is the antenna coupling condenser and C_9 the grid coupling condenser. The circuit is grounded at the point common to condensers C_9 and C_{10}. The direct current plate voltage is applied to the oscillating tube thru the primary inductance L_2 in order to eliminate a radio frequency plate feed choke coil. The power delivered by the vacuum tube to the primary circuit is controlled by means o" the plate tap. The antenna circuit is composed of an antenna loading coil L_3, variable by taps, and in series with the antenna ammeter and the antenna coupling condenser C_{10}.

The values of the various circuit constants of the Coast Guard transmitter were calculated in two steps from the knowledge of the antenna and tube characteristics and the $\omega L/R$ assumed from previous experimental data. First, by means of primary calculations the tuning and coupling capacity to be used in the primary closed oscillating circuit was determined from considerations of tube impedance and frequency. The second step of the caluclations was based upon the knowledge of the antenna coupling and primary capacity which had been obtained in the preliminary calculations. The values of the primary and secondary inductance were calculated as well as the effective resistances of the primary and secondary circuits and the currents and voltages in all branches of the circuits.

Basis of All Calculations

The resonance conditions that hold in practice for the calculation of double tuned capacity coupled circuits are:

$$\text{1st—}X_3=0$$

$$\text{2nd—}X_1'=0$$

X_3 being the reactance of the secondary circuit considered as a separate unit from the primary and X_1' being the apparent reactance opposed by the entire double-tuned circuit to the vacuum tube.

It is known that the plate-to-filament impedance of any vacuum tube is essentially a pure resistance at the frequency considered, and for this reason the load circuit should be adjusted to look like a pure resistance for best efficiency. This explains why the condition $X_1'=0$ has to be considered as one of the resonance conditions for that type of circuit. If these two conditions obtain, the reactance introduced into the primary by the secondary is equal to zero and the resistance introduced into the primary is equal to

$$R'=\frac{X_c^2}{R_3}$$

where X_c is the reactance of the coupling condenser at the frequency considered and R_3 is the effective resistance of the entire secondary circuit, that is to say, the sum of the antenna resistance proper and the resistance of the antenna loading coil at the operating frequency. The resonance conditions $X_1'=0$ may be written in the following form:

$$X_1'=X_1-\frac{X_1^2\,X_2'}{Z_2'^2}$$

where X_1 is the coupling reactance between the tube and the primary circuit, X_2' the apparent reactance of the secondary, and Z_2' the apparent impedance of the secondary.

However, $$X_2' = X_2 - \frac{X_c^2 X_3}{Z_3^2}$$

and as $X_3 = 0$, X_2' is equal to X_2. The resonance relation $X_1' = 0$ may be therefore written

$$X_1 - \frac{X_1^2 X_2}{R_2'^2 + X_2^2} = 0$$

This is equivalent to $X_2^2 = X_1 X_2 + R_2'^2 = 0$, as X_1 can never be equal to zero. This last equation in connection with equation $X_3 = 0$ enables all the circuit constants to be calculated.

As a first approximation in the calculations X_2 may be considered as strictly equal to "0" as its value.

$$X_2 = \frac{1}{2}(X_1 - \sqrt{X_1^2 - 4 R_2'^2})$$

is so small that it can be neglected. The current amplitude in the secondary circuit may, therefore, be calculated by the formula

$$I_3 = \frac{X_1 X_c E}{R_1 R_2' R_1'}$$

where X_1 is the reactance of that portion of the primary inductance coil between the low point of the coil and the plate tap at the operating frequency. E is the amplitude of the effective driving electromotive force. R_2' is the apparent resistance of the secondary circuit:—

$$\left(R_2' = R_2 + \frac{X_c^2}{R_3}\right)$$

and R'_1 is the apparent resistance opposed to the vacuum tube of the entire double tuned capacity coupled circuit:—

$$\left(R_1' = R_1 + \frac{X_1^2}{R_2'}\right)$$

where R_1 is the impedance of the plate-to-filament circuit of the vacuum tube for alternating currents. This impedance is sufficiently independent of the frequency, so that it may be taken as a basis of calculations.

In order that the double tuned capacity coupled oscillating circuit be stable in operation, the coupling between the primary and the secondary should be very loose. If the coupling is tight, there are two frequencies at which this kind of circuit may oscillate, one of which is determined by the primary and the other by the secondary. The circuit should always be operated at or near the critical coupling value, for which the relation between the coupling reactance and the primary and secondary effective resistance is $X_c^2 = R_2 R_3$.

Experimental Development of the Transmitter

An experimental model of the transmitter was set up in the laboratory taking care that the relative position of all apparatus, the constants of which were calculated in accordance with the method described, was such as to simulate as nearly as possible the exact dispositions of apparatus chosen for the final transmitter. The circuit constants were adjusted to the values which had been determined by the theoretical design. The theoretical calculations were, in general, fully verified by measurement except for a few minor modifications which had to be made in the values of the antenna coupling capacity. These minor modifications were due to the fact that the coils utilized had more resistance than correspond to the assumed $\omega L/R$ in the theoretical calculations. This increase in resistance was caused by the additional losses due to the proximity of the shields to the coils. The performance of the audio frequency speech input amplifier and oscillator circuit was found to be in accordance with the theoretical considerations.

Audio Frequency Characteristics of the Transmitter and Percentage of Modulation

The frequency characteristic of the transmitter was determined by feeding into the input of the set at the two terminals where the microphone transmitter is connected a number of audio frequency currents at a level corresponding to the energy level furnished by the microphone transmitter, the transmitter being adjusted for telephone transmission. The value of the audio frequency input current was chosen so that no current was taken by the grid of the modulator tube. The output of the modulator tube was measured for each input frequency by means of a peak voltmeter placed across the modulator plate choke coil. The frequency characteristic is shown in Figure 5. It is seen that this characteristic is practically flat between 100 cycles and 2,000 cycles and does not vary widely over a much larger range. It is, therefore, evident that the quality of audio frequency transmission of the Coast Guard transmitter is excellent for practical telephone conversation.

Percentage of Modulation

The percentage of modulation was determined by an oscillograph in the ordinary way. An oscillogram was taken of the rectified wave when the transmitter was set for telephony and interrupted continuous wave. The two oscillograms, Figure 6,

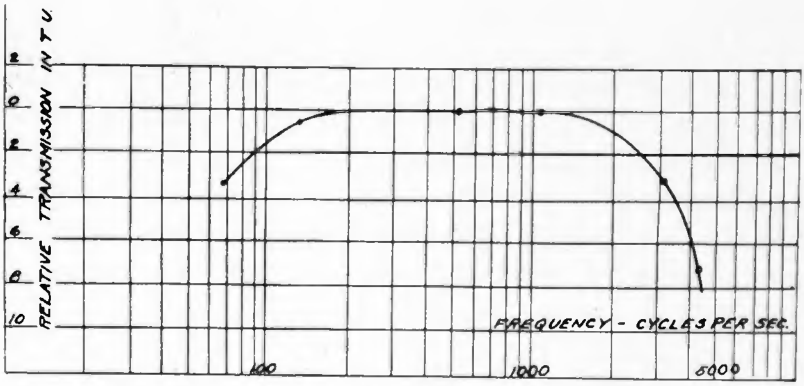

FIGURE 5—Frequency Characteristic Coast Guard Transmitter Model T-1

show that the percentage of modulation was 41 percent at an input audio frequency of 264 cycles and that the modulation of the carrier wave for the interrupted continuous wave telegraph position was complete. The effect of inertia of the moving element probably accounts for the peaks which appear below the zero line. The tone received, however, is very clear.

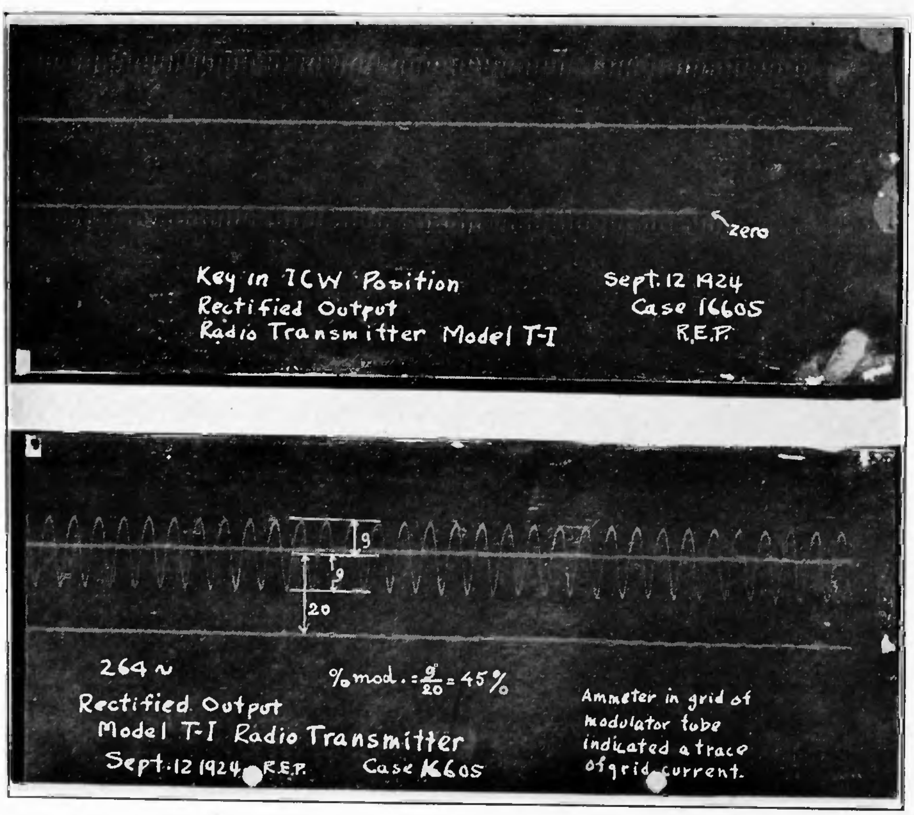

FIGURE 6

Radio Receiver

The double detection (super-heterodyne) type of receiver is used because the required sensitivity and selectivity could be obtained only with this type of receiver. It is designed to cover a frequency range of 1,500 to 3,000 kc. (200 to 100 meters) and for the reception of telephone and interrupted continuous wave telegraph signals. In addition, a second oscillator operating at the intermediate frequency is provided for the reception of continuous wave telegraph signals. The development of this receiver involved the solution of a number of difficult problems in order to meet the rigid requirements imposed. In brief, it had to be sensitive (voltage amplification in excess of 5,000); selective against signals differing widely from the desired transmitter frequency but capable of receiving signals when the carrier frequency did differ from time to time not more than 5 kc. from the specified frequency. Its adjustment had to be simple and locks had to be provided so that it could be set and placed in operation by the turning of only the filament switch. Figures 8, 9, and 10 show the arrangement of the apparatus in the receiver and its general appearance. It is thoroly shielded by the brass panel shelf and the shielded box.

The complete receiver circuit (Figure 7) may be divided into the following parts:

Radio Frequency Input Circuit.
Radio Frequency Oscillator Circuit.
Modulator or First Detector Circuit.
Intermediate Frequency Amplifier Circuit.
Detector (Second) and Audio Frequency Circuits.
Intermediate Frequency Oscillator Circuit.

Choice of Intermediate Frequency

Taking into consideration the fact that the intermediate frequency selectivity is of no value in differentiating between two signals, the carrier frequencies of which differ by twice the intermediate frequency, a moderately high intermediate frequency would naturally be chosen. With too high an intermediate frequency the amplification obtainable is considerably reduced and the regenerative effects due to interstage coupling of one form or another are greatly increased. If too low a frequency is used, the tuning of the secondary circuit and that of the oscillator will differ by only a small percentage of the carrier frequency, and the tuning of the two circuits will not be independent of each other.

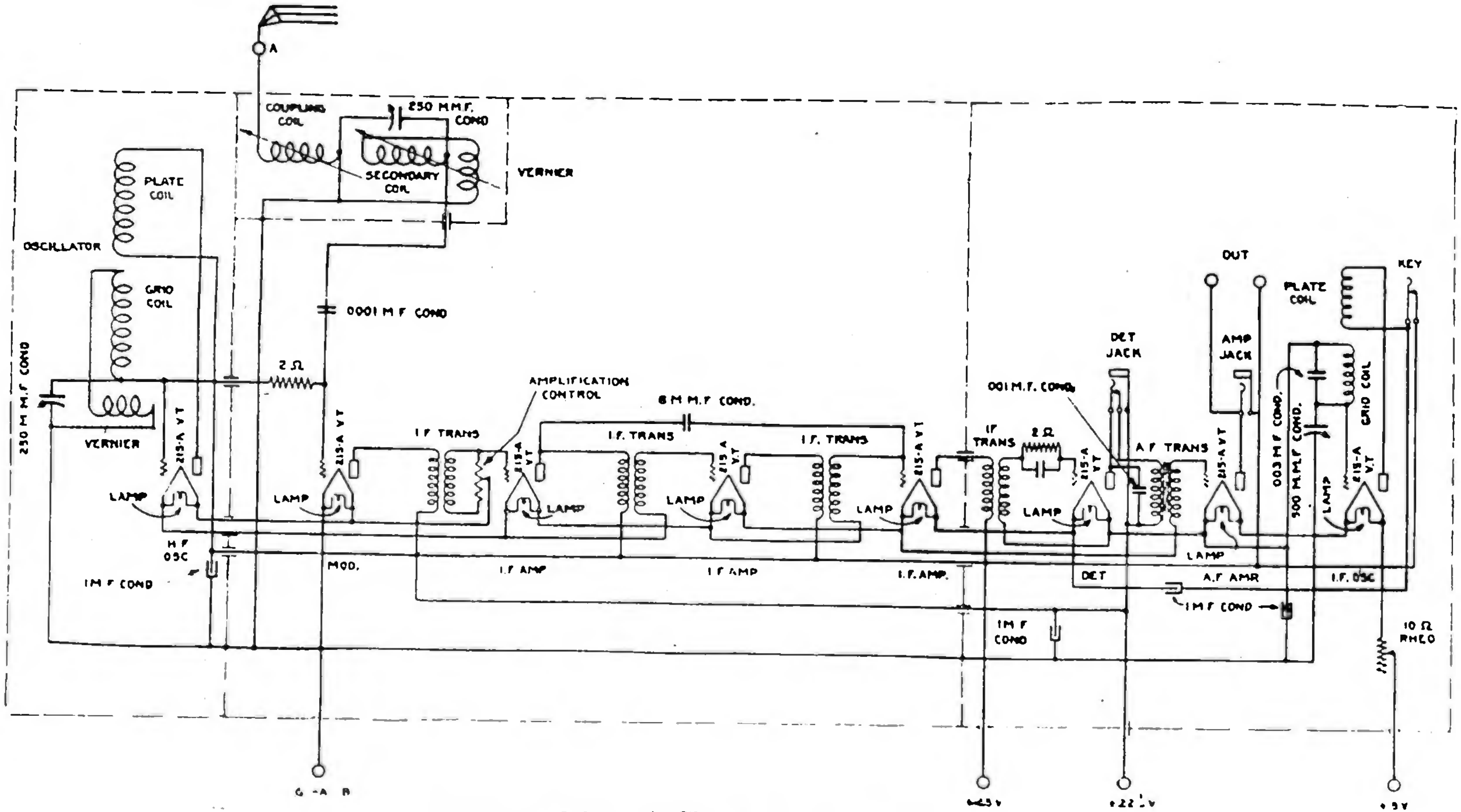

FIGURE 7—Schematic Circuit of Complete Receiver

The 50 kc. frequency used was chosen because satisfactory intermediate frequency transformers had been developed for this frequency, the required amplification could readily be obtained, and such an amplifier requires no stabilizing adjustment in order to prevent a tendency toward internal oscillation.

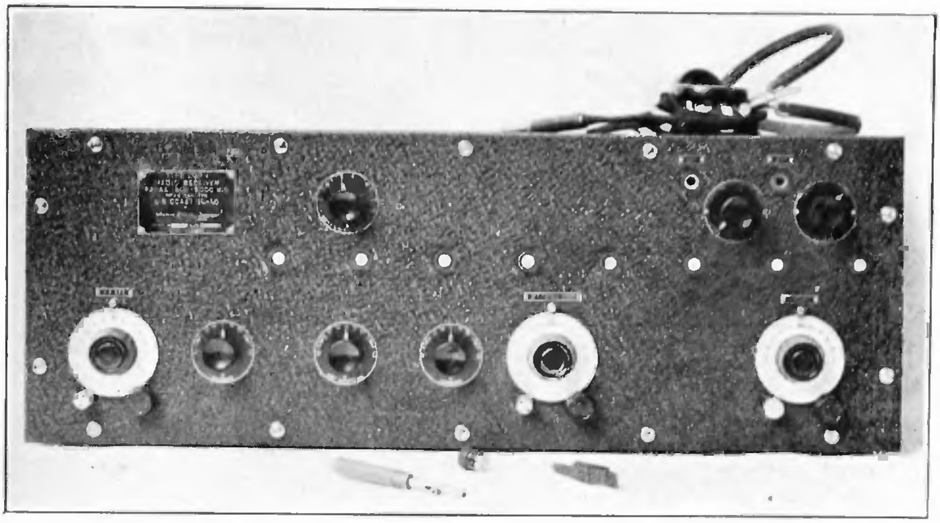

FIGURE 8

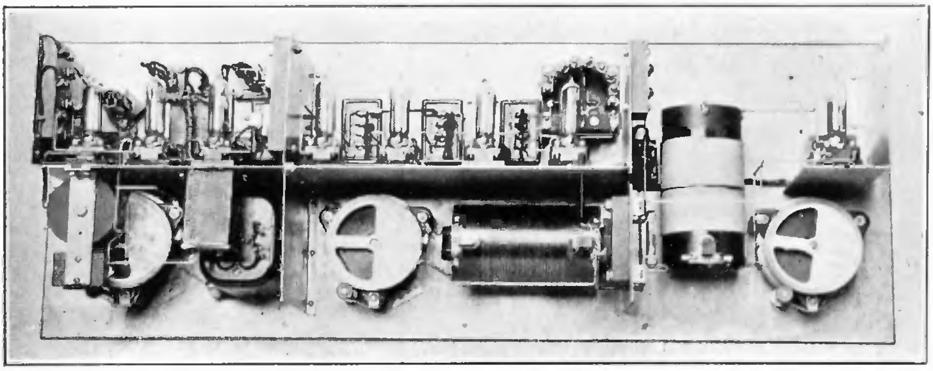

FIGURE 9

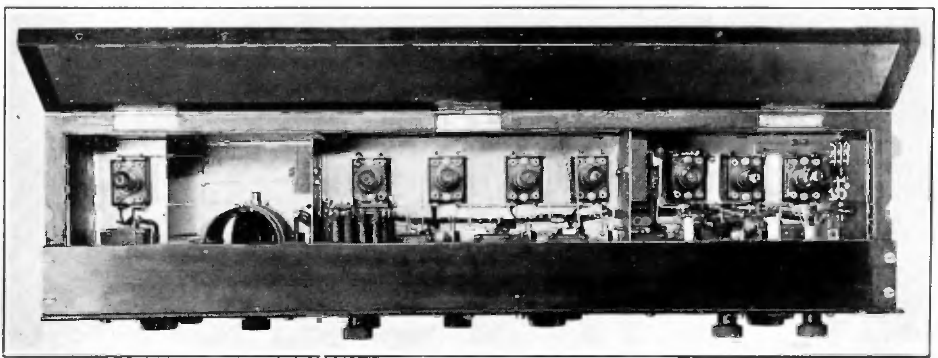

FIGURE 10

Radio Frequency Input Circuit

The radio receiver is designed to operate in connection with an antenna, but it is desired not to tune the antenna circuit in order to eliminate the additional tuning control. The radio frequency circuit, therefore, is of the simplest possible type, as shown in the schematic of the complete receiver. A small coupling coil is connected directly between the antenna and ground, the mutual inductance between this coil and the secondary circuit being adjustable. On account of the fact that if more than critical coupling is used, no additional signal strength is obtained and the selectivity of the secondary circuit is seriously impaired, the coupling coil was made of such size that the maximum coupline between the antenna and the secondary was not greatly in excess of critical coupling. The coupling coil is mounted at the low potential end of the secondary coil, and as one end of each is connected to the ground the capacity coupling between them is reduced to a minimum. The secondary coil is wound with bare copper wire spaced by its own diameter on a thin walled tube. This insures a coil of very low radio frequency resistance and, in fact, this is found to be practically as low as that obtained with the best types of cellular windings without any supporting dielectric. A "vernier" adjustment is provided by means of a small coil mounted at the opposite end of the secondary from the antenna coupling coil, but connected in the low potential side of the tuned circuit in order to have one terminal of the "vernier" coil at ground potential. The use of the inductance "vernier" has many advantages over the use of a separate plate on the variable condenser. With the latter the capacity of the separate plate may be 1/10 or 1/20 of the total capacity of the condenser, but when the condenser is adjusted to some point near its minimum capacity, the capacity of the "vernier" may be considerably greater than that of the condenser and its adjustment correspondingly critical. With the inductance "vernier," on the other hand, the percentage change in inductance and in the resonant frequency is nearly constant over the entire range of the receiver. The "vernier" was so designed that the total variation was equivalent to about 10 percent of the condenser setting for the major portion of its range. The adjustment of a "vernier" of this type is no more critical at the higher frequency end of the receiver range than at the lower.

Radio Frequency Oscillator Circuit

The tuned grid inductively coupled oscillator circuit was used so that the tuning condenser is placed across only the grid coil. One side of it is thus at filament or ground potential with consequent elimination of the effect of the hand on the frequency of the oscillator. The inductance "vernier" is used in series with the grid coil and is mounted at the high potential end of the coil. The oscillating coils are so designed that the reading of the scale of the oscillator condenser for a frequency 50 kc. below that of the incoming signal is practically the same as the scale reading of the secondary circuit of the receiver over the entire tuning range.

Modulator or First Detector Circuit

Because the grid condenser and grid leak type of modulator requires a much smaller input on the grid for maximum efficiency than the negative grid bias type of detector, it is employed in this receiver. The circuits used for the frequency changing system consisting of the oscillator and modulator are illustrated in the schematic of the complete receiver, Figure 7. The condenser and grid leak combination is chosen for maximum efficiency, which is obtained with a capacity of 100 micro-microfarads and a 2-megohm resistance leak.

The grid leak serves both as a grid leak for the modulator tube and as a means of coupling the modulator tube to the oscillator. With this circuit the adjustment of the secondary circuit has almost no effect on the frequency of the oscillator except when the secondary circuit is made resonant with the oscillator frequency, which is not the operating condition. The oscillator is carefully shielded from the remaining portion of the receiver in order to prevent any interaction between it and the secondary circuit.

Filament Circuit

The vacuum tubes used in this receiver each require a filament current of 250 milliamperes at approximately 1 volt. When employing a number of tubes of this particular type it is advantageous to connect their filaments in series, so that grid biasing potentials may be obtained by the drop in potential across certain portions of the filament circuit. In a receiver having high amplification, connecting the filaments in series presents some additional problems because of the coupling thus introduced between the grid circuits of the various tubes. This coupling is reduced to a satisfactory point in this receiver by the use of a number of high capacity by-pass condensers properly located.

The filament circuit is laid out from the standpoint of obtaining the desired grid biasing potentials with the simplest possible filament circuit.

Detector and Audio Frequency Amplifier Circuits

The second detector is of the grid leak and grid condenser type because it has been found, by careful measurement, that the efficiency of the grid leak type of detector when using W. E. 215-A vacuum tubes is considerably greater than that of the negative grid bias type of detector up to inputs much greater than are likely to be obtained in practice. The disadvantage of the grid leak type of detector is that the output level obtainable is considerably lower than that from the negative grid bias type of detector. When one step of audio frequency amplification is provided, however, the output level obtainable from the receiver is ample for headphone operation. The detector and the audio frequency amplifier form a couplet which operate very well together, as the relative output levels are such that overloading occurs at about the same point in both tubes.

A by-pass condenser of the order of 0.001 microfarad is provided in the detector plate circuit in order to keep the output circuit of low impedance to the carrier frequency. In addition to obtaining an increase in detector efficiency, the condenser by-passes radio and intermediate frequencies which may be amplified by the audio frequency circuits and help to cause overloading of succeeding tubes. From the standpoint of detector efficiency an even larger capacity would have been advantageous, but it would have resulted in too great an attenuation of the higher audio frequencies.

Intermediate Frequency Oscillator

The intermediate frequency oscillator is of the tuned grid inductively coupled type and is so arranged that it may be turned off by means of a key in the plate supply. High efficiency in this oscillator was not desired nor was it necessary because of the fact that it operates at the frequency of the amplifier. The problem was not to obtain sufficient output from the oscillator, but to reduce the coupling from this oscillator to the detector to such a value that the detector would not be seriously overloaded. The by-pass condenser connected as shown reduced the input to the second detector from the intermediate frequency oscillator to about 0.5 volt at the grid of the second detector, which is approximately the value for maximum signal strength.

The capacity of the variable condenser was made only a small portion of the total tuning capacity as it was desired to have a frequency adjustment of only four or five thousand cycles.

It has been found that having this oscillator adjustable over a range of this order of magnitude is of value in differentiating between signals from two stations very close together in carrier frequency, as the radio frequency adjustments of the receiver may be set for the optimum strength of the desired station and the intermediate frequency oscillator adjusted so that the beat notes of the desired and undesired station may be most advantageously adjusted.

The coupling between the intermediate frequency and radio frequency oscillators is reduced to the lowest possible degree in order that the harmonics of the intermediate frequency oscillator will not beat with the fundamental of the radio frequency oscillator when it is adjusted over its operating range. With the intermediate frequency oscillator turned on, beat notes will occur for only two settings of the high frequency oscillator condenser corresponding to the frequencies 50 kc. above and below the carrier frequency.

Intermediate Frequency Amplifier

Prior to the development of the receiver being described, a very satisfactory intermediate frequency transformer had been developed. The frequency characteristic of one of these transformers is shown in Figure 11. This characteristic covers only the operating range, but it is also very important that audio frequencies and radio frequencies be not transmitted by the intermediate frequency transformer. It was found that when four of these transformers were used in an intermediate frequency amplifier, the characteristic obtained was quite different from the fourth power of the characteristic of a single transformer. This is to be expected, because the input impedance of a vacuum tube is a function not only of the grid to filament capacity but it is also affected by the make-up of its plate circuit. The input impedance of a grid leak detector tube is also very different from the input impedance of an amplifier tube.

A satisfactory over-all characteristic was obtained by balancing out some of the interstage coupling capacity. The balancing capacity is not only used to stabilize the amplifier and to reduce any tendency toward internal oscillation, but its proper adjustment determines the shape of the amplifier characteristic. The amplification of the receiver is controlled by means of a potentiometer. The total resistance of this potentiometer is closely related to the value of the balancing capacity. The proper combination of these two values results in the desired characteristic. The potentiometric gain control shown is adjustable in ten steps having a voltage amplification ratio between them of approximately 2.5 to 1. The over-all amplification of the receiver for various steps of this amplification control is shown in Figure 12. The selectivity is greatest when the maximum amplification is used. This is a very desirable characteristic, as when a signal is so weak as to require the maximum amplification of the receiver a high degree of selectivity is desirable. The selectivity of the receiver is intentionally made considerably less than might be obtained in order to be able to receive signals when the carrier frequency changes slightly or is not absolutely accurately set by all transmitters.

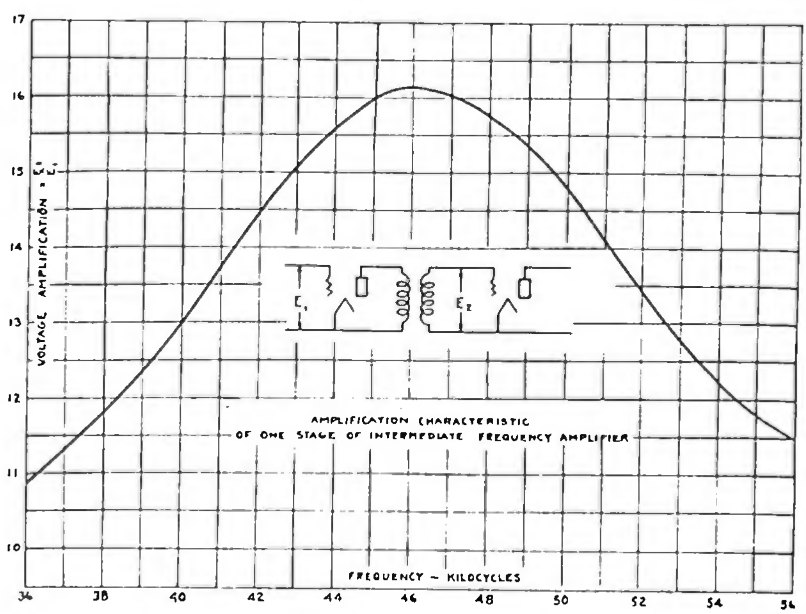

FIGURE 11

MEASUREMENT OF THE INTERMEDIATE FREQUENCY AMPLIFIER

For the measurement of the over-all intermediate frequency amplification, the circuit shown in Figure 13 is used. The input resistance R_1 assumes different values in accordance with the intermediate frequency amplification to be measured. The current thru the input resistance is kept constant at 1 milliampere. For measuring the amplification obtained on the two upper steps of the amplification control, the input resistance R_1 consists of a short straight piece of high resistance wire having

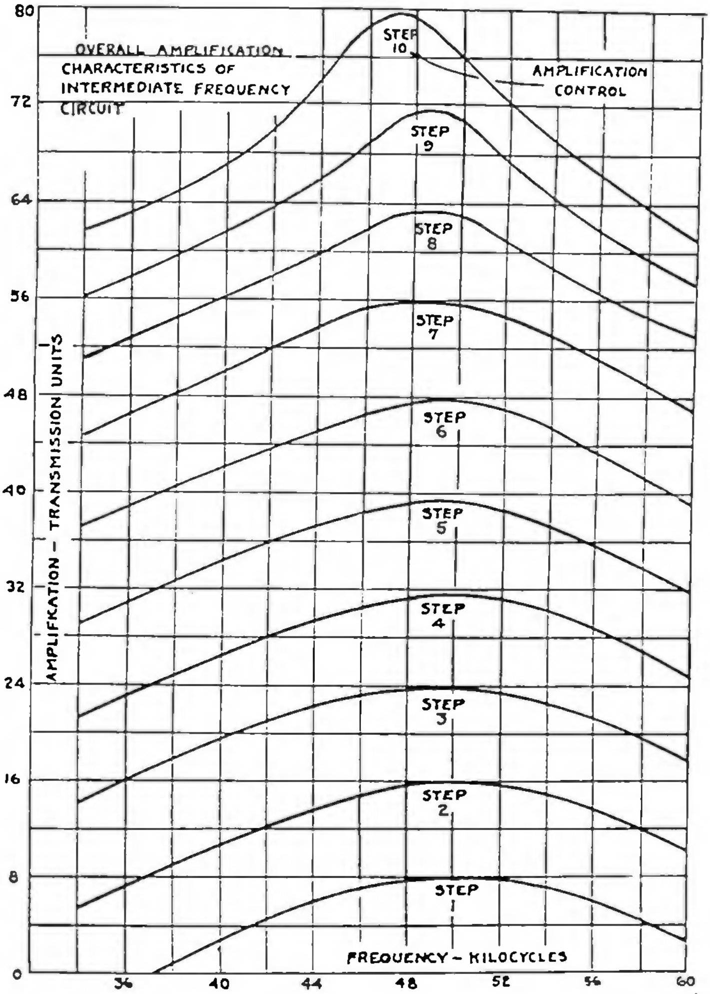

FIGURE 12

a resistance of 0.1 ohm mounted directly in the base of the short circuiting switch, this being the only practical way of eliminating undesirable pick-up. With a voltage amplification of 10,000, this means that 1 milliampere flowing thru this resistance will give an input of 1 volt to the grid of the second detector. When the amplification is reduced to 2,000 or less, resistance boxes may be used for the input resistance provided that precautions are observed to make all of the leads as short and direct as possible. It is essential that the input voltage to the receiver consist only of the drop across a definitely known resistance and that the current measured by the thermocouple should be the entire current thru this resistance and no other. The second detector, including its condenser and grid leak, is calibrated by connecting it directly across resistance R_1, which for this purpose consists of a variable resistance box having negligible inductance and capacity at 50 kc. A complete calibration curve of the detector up to a voltage input corresponding to a change in the plate current of 200 microamperes is usually made. When measuring the amplification of the receiver, the current thru the input resistance is adjusted to the same value of 1 milliampere and the change in the detector plate current noted. This is most conveniently done by the use of a differential meter in which the normal space current of the detector is neutralized by a current from a separate battery flowing thru the proper resistance (see Figure 13). As the amplification is decreased by using the lower steps of the amplification control, the input resistance R_1 is increased so that the input voltage to the grid of the second detector is of the order of 0.5 to 1.0 volt. In all of these measurements it is very essential that the oscillator be thoroly shielded from the receiver so that with the switch across the resistance R_1 closed, no change in the plate current of the second detector may be noted when the oscillator is turned on and off, even tho the maximum amplification of the receiver is used. This method was used in measuring the frequency characteristic of the receiver.

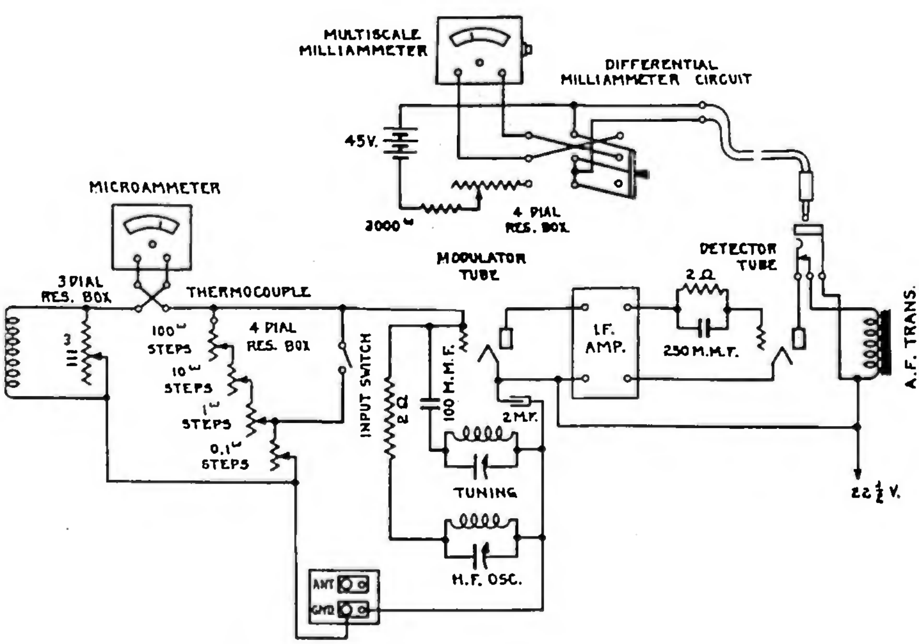

FIGURE 13

CONCLUSION

The transmitter and receiver meet the requirements and show what may be expected if the design is based on the results of intelligent co-ordination of theoretical and laboratory work. The practical operation of the system shows that the range over water is considerably in excess of requirements, which seems to indicate that the shorter wave lengths will be very satisfactory for this class of service.

The authors wish to express their thanks to Messrs. P. H. Betts, A. W. Saunders, and A. E. Lanz for their valuable assistance in the preparation of this paper.

SUMMARY: This paper describes the transmitter and receiver recently developed for use by the United States Coast Guard. This apparatus is for operation on wave lengths between 100 and 200 meters. In describing the development of the transmitter a short summary of the various circuit considerations is included. The actual transmitter finally developed is also described together with its operating characteristics.

In considering the radio receiver the various problems to be met in the design of a radio receiver of this character are dealt with at some length. The frequency characteristics of the radio receiver, as developed, are shown, and the method of determining them is described in detail.

The transmitter and receiver performed very satisfactorily under conditions considerably more severe than will be met in actual service.

DESIGN OF TELEPHONE RECEIVERS FOR LOUD SPEAKING PURPOSES*

By

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I. Introduction

The development of telephone receivers to handle without serious distortion the relatively large amounts of power required for loud speaking purposes has presented many difficulties. The simple receiver of bi-polar construction sufficed as long as it had to take care of the small amount of power used in ordinary telephone practice, but considerable modification, if not a complete change of design, became necessary when loud speakers came into existence.

At the present time three types of magnetic driving mechanisms are employed for loud speakers: (1) The moving iron or electromagnetic type; (2) The moving coil or electrodynamic type, including all those forms in which conductors carrying primary currents are displaced in a steady magnetic field; and (3) The induction or eddy current type, including all those in which conductors carrying secondary or induced currents are displaced in a steady field.

The present paper will deal only with the moving iron or the electromagnetic type of driving element. This is by far the most common. It is also the least expensive, probably because its steady flux is readily supplied by permanent magnets instead of electromagnets. It depends for its operation upon the variation in pull of an electromagnet or system of electromagnets upon an iron armature or diaphragm. Several types of electromagnetic constructions will be discussed, and then a detailed consideration of the design of a new type recently developed will be given.

Simple Bi-polar Receiver

The familiar two-pole receiver is shown in Figure 1. Many

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papers and books have been written describing its operation and characteristics. The reader is referred to A. E. Kennelly's "Electrical Vibration Instruments," which covers the subject very thoroly and which gives a complete bibliography. A few relations showing first order effects will here be given to show the limitations of this type of element for loud-speaking telephones.

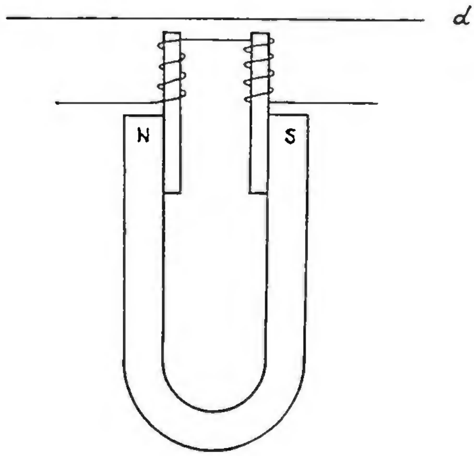

FIGURE 1—Simple Receiver

If Φ is the steady component of flux crossing the air gaps and $\phi \sin \omega t$ represents the superposed alternating component of flux due to a sine wave of current in the windings, the pull on the diaphragm will be proportional to

$$(\Phi+\phi \sin \omega t)^2=\Phi^2+2\,\Phi\,\phi \sin \omega t+\phi^2 \sin^2 \omega t$$
$$=\Phi^2+2\,\Phi\,\phi \sin \omega t+\phi^2\left(\frac{1-\cos 2\,\omega t}{2}\right)$$
$$=\Phi^2+\frac{\phi^2}{2}+2\Phi\,\phi \sin \omega t-\frac{\phi^2}{2}\cos 2\,\omega t$$

It is seen that the pull is made of three components: (1) a steady component $\left(\Phi+\frac{\phi^2}{2}\right)$; (2) a single frequency component $(2\,\Phi\,\phi \sin \omega t)$ and (3) a double frequency component $\frac{\phi^2}{2}\cos 2\,\omega t$.

The steady component produces no undesirable effect, but the double frequency pull gives rise to an extraneous overtone which is quite objectionable. It is seen that if ϕ is small compared to Φ the double frequency term will be negligible compared to the single frequency term. In loud speakers, however, ϕ has to be large in order to produce sufficient variation of force, and this in turn requires that Φ shall be much larger, in order to make the single frequency component of force predominate.

In the simple receiver the limit to the amount of steady flux that can be employed is determined by the saturation of the diaphragm. Increasing the thickness of the diaphragm allows the use of more steady flux and, therefore, makes the device capable of handling more power without the double frequency distortion referred to above. This procedure is objectionable, however, because it increases the mass and rigidity of the diaphragm, both of which are undesirable because of the non-uniformity of response they cause. Increase in power is, therefore, incompatible with good quality of response in the simple receiver.

Another source of distortion inherent to the simple receiver when used for loud-speaking purposes is the unsymmetrical displacement of the diaphragm away from and toward the poles with respect to its mean position. This is shown in Figure 2 as a static characteristic of displacement against current in the coils. For the large displacements necessary in loud-speaking receivers, this non-linear distortion is very objectionable because of the extraneous overtones it causes.

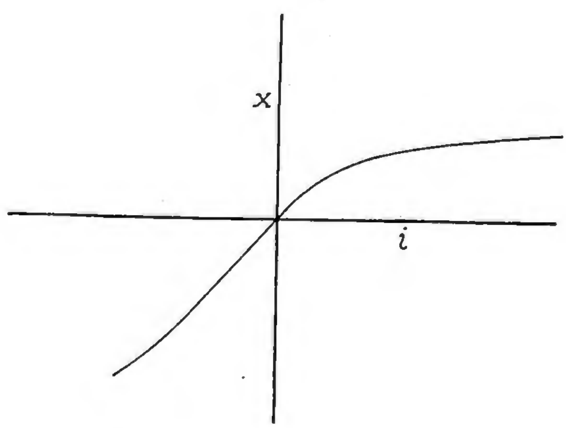

FIGURE 2—Static Characteristic of Simple Receiver

It may be said, however, that bi-polar receiver constructions are being employed with fair success for loud speakers when only a moderate amount of output is required. Fairly large diaphragms are employed so that the displacements do not have to be as great for a given amount of power as with smaller diaphragms.

BALANCED ARMATURE UNIT

To overcome the disadvantages inherent to the simple receivers, the four-pole balanced armature receiver was developed. Two constructions are shown in Figure 3, the operation of the two being the same. When current passes thru the coil (or coils) poles 1 and 4 are strengthened, while 2 and 3 are weakened (or *vice versa*), causing the armature to be pulled in the direction of the stronger pair of poles. When in its normal position, the armature carries little or no steady flux. The steady flux may, therefore, be large without saturation of the armature. It is not, however, to be inferred that with this construction there is no limit to the steady flux but saturation of the poles. If the field is too strong, the armature will not stay in its mid-position. This can be shown as follows: Suppose the armature is rotated slightly clockwise. Poles 1 and 4 will now have a greater pull on the armature than poles 2 and 3 because of the reduced air gap. If the difference between these two forces is not less than the restoring force called into play by the deflection of the moving system, the armature will be pulled over to poles 1 and 4. The armature is continually being deflected from its mid position, and so the strength of the poles can not exceed a certain value without causing instability. This limit, however, is much higher than in the simple receiver where diaphragm saturation is involved.

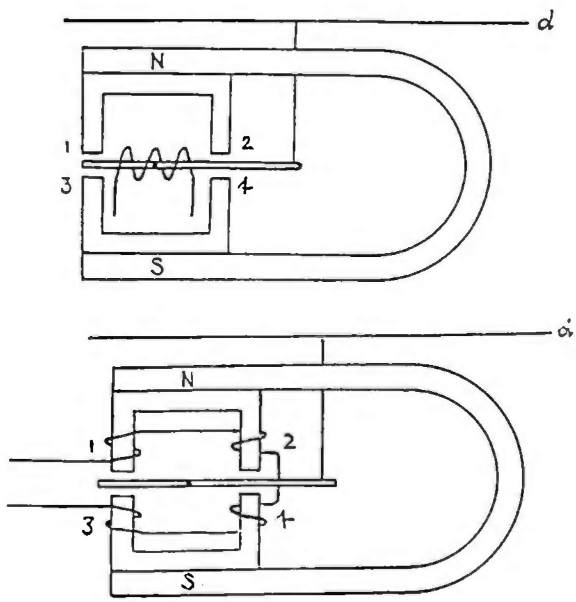

FIGURE 3—Balanced Armature Receivers

The chief advantage of a strong field in this type of receiver is that the sensitivity is greater. The double frequency component of force, so objectionable in the simple receiver, is not present in this type if the armature is closely balanced. That there is no double frequency pull may be shown as follows: The pull caused by poles 1 and 4 is proportional to

$$(\Phi+\phi \sin \omega t)^2$$

and the pull of poles 2 and 3 is proportional to

$$(\Phi-\phi \sin \omega t)^2$$

where Φ represents the steady component of flux and $\phi \sin \omega t$ the superposed alternating flux. The resultant rotating force (F) is given by the difference between the above expressions.

$$(\Phi+\phi \sin \omega t)^2-(\Phi-\phi \sin \omega t)^2$$
$$=(\Phi^2+2\ \Phi\phi \sin \omega t+\phi^2 \sin^2 \omega t)-(\Phi^2-2\ \Phi\ \phi \sin \omega t+\phi^2 \sin^2 \omega t)$$
$$=4\ \Phi\ \phi \sin \omega t$$

It is seen that the steady component and the double frequency component of pull both disappear, leaving only the single frequency.

Because of the four-pole arrangement, the deflections of the armature are symmetrical with respect to its mean position. That is, the static characteristic of displacement against current is as in Figure 4, where the range of linearity is roughly double that of the simple receiver having the same air gap clearance.

The fact that the balanced armature receiver will stand larger variations of flux without double frequency distortion, and larger diaphragm displacements without the other type of non-linear distortion mentioned, and the fact that it allows greater steady fields without saturation of the moving part, makes it much better suited for loud-speaker work than the simple receiver.

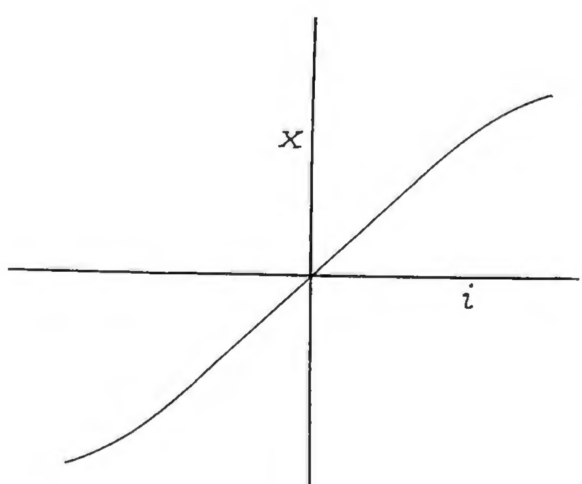

FIGURE 4—Static Characteristic of Balanced Receiver

The chief disadvantage of the balanced armature unit is its complicated vibrating system. The diaphragm has several resonances, and also the armature has one or more in the audible range unless made very heavy. The result is that the two coupled mechanical systems give rise to a rather bad anti-resonance, which is difficult to smooth out. If the balanced principle could be employed without the use of an armature, not only this disadvantage would be overcome, but a receiver with a lighter vibrating system would be obtained. Such a receiver has been developed and has been termed the balanced diaphragm type. The body of the paper will be concerned with the details in the design of this new loud-speaking receiver.

II. Balanced Diaphragm Receiver

The construction of the balanced diaphragm receiver is shown in Figures 5 and 6. Two pairs of poles are disposed on opposite sides of the disphragm in such a way that the steady flux passes across the air gaps without going lengthwise thru the diaphragm. Essentially the construction consists of two simple bi-polar receivers actuating a common diaphragm. Normally both pairs

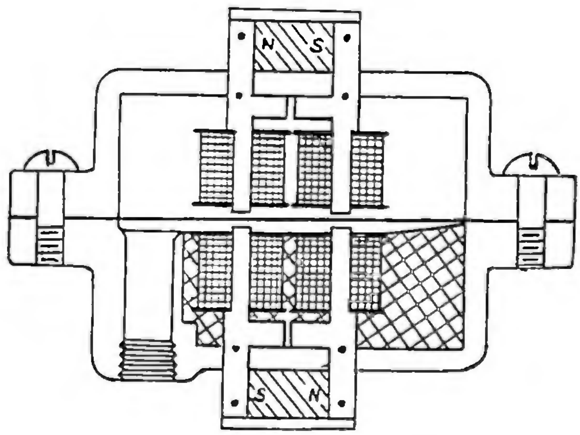

Figure 5—Balanced Diaphragm Receiver

of poles pull equally on the diaphragm. The windings are so connected that current will strengthen one pair (say 1 and 2) and weaken the other, or *vice versa,* causing a force on the diaphragm in the direction of the stronger pair of poles. In the construction shown, two short blocks of high coercive force magnet steel are used for supplying the steady flux. These are placed outside the case for ease of magnetizing. The bridge or shunting tath below the coils on each half of the receiver is of low reluctance compared to the main gaps, and allows the varying flux component an easy path around the high reluctance permanent magnet. This leakage path is, of course, a shunt to the steady

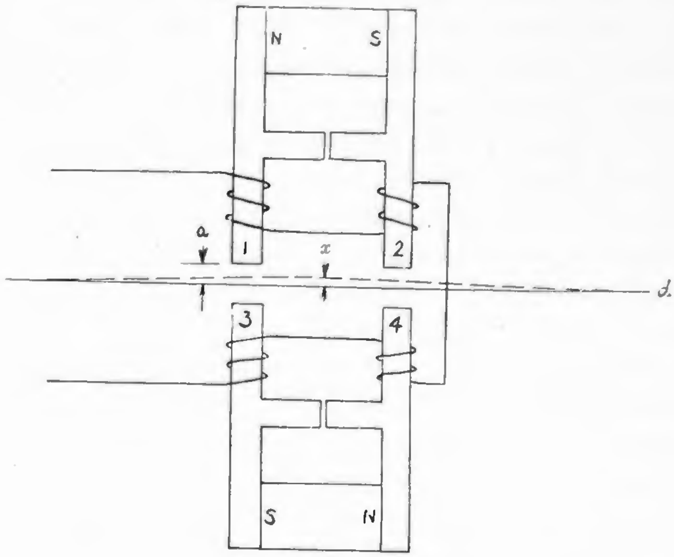

Figure 6—Balanced Diaphragm Receiver

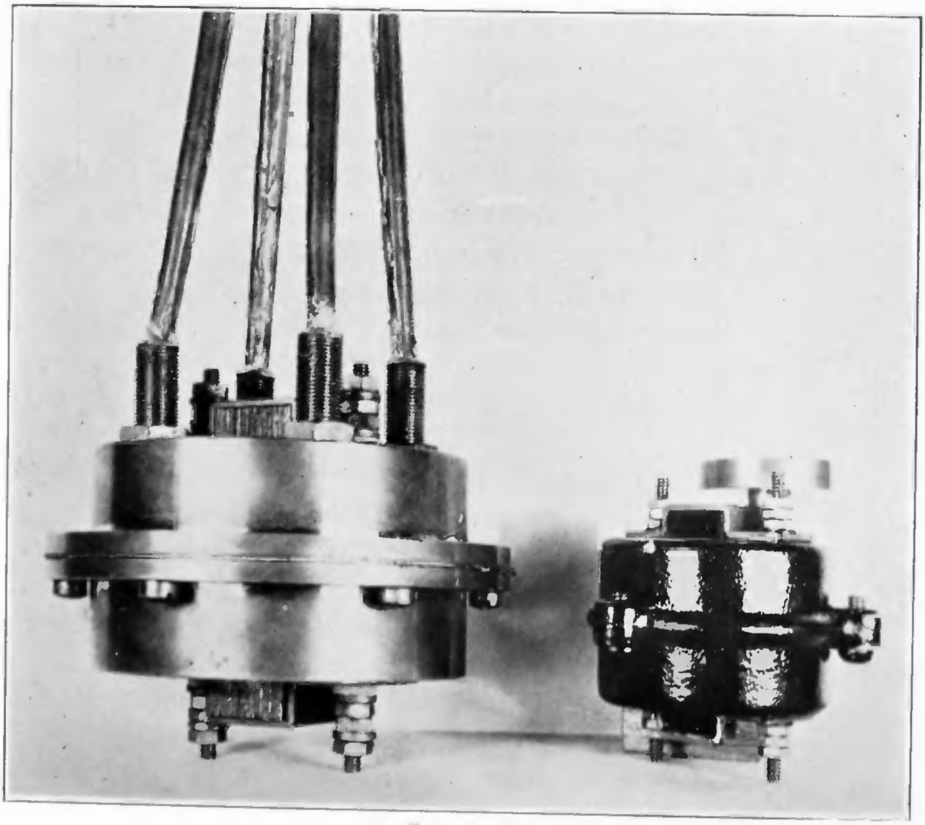

Figure 7

flux and requires that the magnet section be large enough to supply both the leakage flux and the useful flux. The poles are built up of T-shape laminations riveted together at the lower ends where there is little or no variation of flux. Because of the pole construction the sound outlet is off center as shown. Wax is used to fill up the one-half of the receiver so that the air chamber next to the diaphragm and ahead of the orifice is small. This space is usually made approximately conical in shape with an altitude of from ten to twenty mils. The advantages of the balanced diaphragm construction are the same as those given in the discussion of the balanced armature with the added feature that no armature is employed to obtain those advantages.

Figure 7 shows two sizes of the balanced diaphragm loud-speaking receiver, one for use in the home and one for power work. Design information has been worked out whereby different sizes of receivers having the greatest possible sensitivity may be obtained without resorting to the cut-and-dry method. The various constants for the receiver will now be determined and the details in designing a receiver given.

The following notation will be used:

A = Pole area (cm.^{2})
a = Air gap length (cm.)
x = Deflection diaphragm at center (cm.)
$\dot{x}$ = Velocity of diaphragm at center (cm./sec.)
M_o = Mmf. due to one permanent magnet (gilberts)
M = Mmf. due to current i in one pair of coils (gilberts)
i = Current in windings (amperes)
n = Number of turns per pair of coils
B = Flux density in air gap (gausses)
A_d = Diaphragm area (cm.^{2})
t = Diaphragm thickness (cm.)
e = Young's modulus for diaphragm material (dynes/cm.)
δ = Density of diaphragm material (gm./cm.^{3})
f_o = Resonance frequency of diaphragm if not in the presence of magnetic field (cycles/sec.)
f_r = Resonance frequency in presence of magnetic field
m = Equivalent mass of vibrating diaphragm, referred to acceleration at center (gm.)
r = Damping, referred to velocity at center of diaphragm, dynes/(cm./sec.)
S = Stiffness of diaphragm not in presence of magnetic field, referred to deflection at center (dynes/cm.)

S_m = Magnetic reduction of stiffness (dynes/cm.)
L = Inductance of receiver (henrys)
K = Force factor or force per unit current in windings (dynes/ampere)

Referring to Figure 6, suppose the current at any instant is flowing so as to increase the strength of poles 1 and 2 and decrease 3 and 4, and that the diaphragm is displaced a distance x which is practically the same at the poles as at the center. Then, neglecting all reluctances excepr those of the main air gaps

$$B_{12} = \frac{M_o + M}{2(a-x)}$$

$$B_{34} = \frac{M_o - M}{2(a+x)}$$

The resultant force on the diaphragm

$$F = \frac{1}{8\pi} B_{12}^2 \,.\, 2A - \frac{1}{8\pi} B_{34}^2 \cdot 2A =$$

$$= \frac{A}{16\pi}\left[\left(\frac{M_o+M}{a-x}\right)^2 - \left(\frac{M_o-M}{a+x}\right)^2\right]$$

$$= \frac{A}{16\pi}\left[\frac{M_o+M}{a-x} - \frac{M_o-M}{a+x}\right]\left[\frac{M_o+M}{a-x} + \frac{M_o-M}{a+x}\right]$$

$$= \frac{A}{16\pi}\left[\frac{2(a\,M + x\,M_o)}{a^2-x^2}\right]\left[\frac{2(a\,M_o + x\,M)}{a^2-x^2}\right]$$

If x is small compared with a, and M small compared with M_o

$$F = \frac{A}{4\pi}\,\frac{(a\,M + x\,M_o)\,(a\,M_o)}{a^4}$$

$$= \frac{A\,M_o}{4\pi a^2} M + \frac{A\,M_o^2}{4\pi a^3} x \qquad (1)$$

The force acting on the diaphragm is made up to two components, one proportional to and in phase with the mmf. due to current in the coils, and one proportional to and in phase with the displacement of the diaphragm. This, of course, neglects the effect of eddy currents and hysteresis in the poles and diaphragm. The first term determines the force per unit current or force factor

$$K = \frac{F_i}{i} = \frac{A\,M_o}{4\pi a^2}\,\frac{M}{i}$$

$$= \frac{A\,M_o}{4\pi a^2} \times 0.4\pi n$$

$$= \frac{A\,M_o\,n}{10\,a^2} \text{ dynes per ampere.} \qquad (2)$$

The force proportional to x is in effect a reduction of diaphragm rigidity since it is opposed to the restoring force. This reduction of stiffness is

$$S_m = \frac{F_x}{x} = \frac{A\,M_o^2}{4\,\pi\,a^3}\text{ dynes/cm.} \tag{3}$$

These two quantities are important, and will be referred to constantly thruout the paper.

The problem in design is, of course, to secure the largest value of K for a receiver having a specified impedance. From equation (2) it is seen that increasing the steady magnetomotive force M_o will accomplish this, but from equation (3) we see that there is a limit to M_o because of the instability of the diaphragm when S_m is greater than the diaphragm rigidity. Likewise, to increase A or reduce a will increase K, but there is a limit here because of the corresponding increase of S_m. Hence the upper limit of S_m is a quantity which partially determines the greatest value of K.

It will now be shown that for operation in a given tube circuit the inductive reactance of the receiver should equal the tube impedance at the frequency where the power is to be optimum. It is not meant by this that the frequency response curve is to show a maximum at this frequency, but that conditions are to be so chosen that the greatest response capable of being obtained at this frequency results. In all receivers of the electromagnetic type the inductive reactance predominates at the higher frequencies (where the optimum is usually desired), and so this will be considered as the whole impedance. If $\mu\,e_g$ is the effective voltage acting in the plate circuit, R_p being the tube impedance

$$i = \frac{\mu\,e_g}{\sqrt{R_p^2 + \omega^2 L^2}}$$

It was seen in the first part of the paper that the pull on the diaphragm is proportional to the first power of the variable component of flux in the air gaps. This is given by

$$F \propto \phi \propto \frac{L\,i}{N} \qquad N = \text{total turns in series}$$

But

$$L \propto N^2$$

$$F \propto \sqrt{L}\,i$$

Substituting the above value of i

$$F \propto \mu\,e_g \sqrt{\frac{L}{R_p^2 + \omega^2 L^2}}$$

This is maximum if

$$\omega L = R_p \tag{4}$$

We have then the two determining conditions: (1) for a given diaphragm the magnetic reduction of rigidity must be less than the diaphragm rigidity; and (2) for operation in a given tube circuit the inductance is fixed by the relation that the inductive reactance should equal the tube impedance at the frequency where the optimum is to be obtained. It will now be shown that if, in the design of a receiver, these two quantities are obtained in the values prescribed, the force factor K will be independent of the pole area or air gap length. This neglects the effects of iron saturation. We have

$$S_m = \frac{A\,M_o^2}{4\,\pi\,a^3} \tag{5}$$

$$L = 2\left(\frac{0.4\,\pi\,n^2\,A}{2\,a}\right)10^{-8} \tag{6}$$

$$K = \frac{A\,M_o\,n}{10\,a^2} \tag{7}$$

From (5) $$A\,M_o = \sqrt{4\,\pi\,a^3\,A\,S_m}$$

From (6) $$n = \sqrt{\frac{10^8\,La}{0.4\,\pi\,A}}$$

Substituting in (7)

$$K = \frac{\sqrt{4\,\pi\,a^3\,A\,S_m}}{10\,a^2}\sqrt{\frac{10^8\,L\,a}{0.4\,\pi\,A}}$$

$$= \sqrt{10^7\,L\,S_m} \tag{8}$$

This conclusion may be seen also in a qualitative way, for if the air gap is increased or the pole area is reduced, the turns must be increased to give the same inductance and the permanent mmf. must be increased to give the same magnetic reduction of rigidity. Both of these increases compensate for the reduction of K due to the greater gap or smaller pole area.

The importance of the foregoing conclusion will be evident in the design of receivers of this type. The procedure is simply as follows:

1. Select a diaphragm large enough to radiate the amount of power required and of the correct thickness to give the desired resonance frequency. This latter should be calculated higher than the frequency desired because of the reduction of rigidity due to the magnetic field, which usually may be 50 percent of the intrinsic diaphragm stiffness.

2. Fix the air gap at a convenient value, say at least four times the maximum displacement of the diaphragm.

3. Choose a convenient pole area, taking into account only the requirement that the poles shall not be saturated to the point where their reluctance is comparable to that of the air gaps.

4. Use the strongest permanent magnet that will still allow the diaphragm to remain in its mid position with stability.

5. Calculate the number of turns to give the required inductance. Equation (8) predicts that variations in the dimensions, which were chosen more or less arbitrarily, will not affect the sensitivity of the resulting receiver. Thus the design of such receivers is made quite simple, and with a degree of assurance that the greatest possible sensitivity will be obtained.

III. Diaphragms and Horns

Before dealing with an actual design, some of the properties of diaphragms and horns should be reviewed. It can be shown that if a loud speaker is to operate between the limiting frequencies f_1 and f_2, its resonance frequency should be roughly

$$f_r = \sqrt{f_1 f_2} \tag{9}$$

Rayleigh gives the following approximate formula for the fundamental resonance frequency of a circular diaphragm clamped around its circumference:

$$f_o = 1.48 \frac{t}{A_d} \sqrt{\frac{e}{\delta}} \tag{10}$$

where $\sqrt{\frac{e}{\delta}}$ is the velocity of sound in the metal, usually about 5.10^5 cm./sec. Hence

$$f_o = 7.4 \cdot 10^5 \frac{t}{A_d} \tag{11}$$

It can be shown that the equivalent mass of vibration of a clamped diaphragm for its fundamental mode is roughly one-fourth its total mass. From these last two relations, then, the rigidity may be calculated, using

$$f_o = \frac{1}{2\pi} \sqrt{\frac{S}{m}} \tag{12}$$

If the reduction of rigidity due to the presence of the steady magnetic field is of the order of 50 percent of the intrinsic diaphragm stiffness, the actual resonance frequency of the system will be

$$f_r = \frac{\sqrt{2}}{2} f_o$$

From equation (10) it is seen that the ratio of diaphragm thickness to area must be constant for a receiver having a given resonance frequency. The mass of the diaphragm (and hence its equivalent mass) will, therefore, vary as the square of the area. From equation (12) the rigidity will also vary as the square of the area because of the constant ratio of S to m. The magnetic reduction of rigidity may, therefore, be greater for large diaphragms. Referring to equation (8) for the force factor of a receiver, it might be thought that since K is larger when large diaphragms are used, the over-all sensitivity of large loud speakers would be greater. Such would be the case if a horn providing the same acoustic load on the diaphragm were employed, but with heavier and stiffer diaphragms it is necessary that this loading due to the horn be increased so as to give the same degree of uniformity in response over the frequency range. The loading or radiation damping required for a given degree of uniformity is proportional to the mass or to the stiffness of the diaphragm.[1]

If, as indicated in the paper referred to, the radiation damping r is large compared to other losses in the diaphragm, the power radiated at the resonance frequency will be

$$W \propto \frac{K^2}{r}$$

But $$K \propto \sqrt{S_m} \propto A_d$$

and $$r \propto m \propto A_d^2$$

Hence W is constant. Thus it may be reasonably expected that all sizes of the balanced diaphragm receiver, if fitted with properly designed horns so as to give the same uniformity of response, will have the same over-all sensitivity.

In the paper referred to, the following approximate formula for radiation damping or loading is given

$$r = 4.6 \frac{A_d^2}{A_o} \qquad (13)$$

where A_o is the initial area of the horn. It is seen that if A_o is held constant, the radiation damping will vary with the diaphragm area in just the right manner to give the same uniformity of response independent of diaphragm size.

The power that a diaphragm radiates using a properly designed horn is proportional to the square of its area and to the square of its velocity. If it is assumed that the maximum allowable deflection of a diaphragm is proportional to its diameter

[1] See paper "The Function and Design of Horns for Loud Speakers," by C. R. Hanna and J. Slepian, "Journal A. I. E. E.," March, 1924.

(hence to the square root of its area), then since the velocity at a given frequency is proportional to the deflection, the greatest power output from a given diaphragm will be proportional to the cube of the area. That is,

$$W \propto \dot{x}^2 \cdot A_d^2$$
$$\dot{x} \propto x \propto \sqrt{A_d}$$
$$W \propto A_d^3$$

This is significant in the design of power loud speakers, for if the diameter of a diaphragm is doubled, the amount of power it can be made to radiate without serious distortion will be increased 64 times. The distance range varying as the square root of the power will be increased eight times. The large size unit shown in the photograph has a 3-inch diaphragm, and is capable of radiating about a watt of sound in speech and music. Altho this may seem small, a watt of sound is probably all that a fifty-piece band can produce. It is almost incredible that a 3-inch diaphragm moving not more than four or five thousandths of an inch will produce as much sound as a good-sized band, but such is the case. This is accounted for by the large radiation resistance or damping imposed on the diaphragm by a properly designed horn. Such sounds have been heard with great loudness about a half mile away and because of the logarithmic character of the ear's impression of intensity, could probably have been heard distinctly over two miles distance if there were no obstructions in the way.

For several reasons it has not been found desirable to employ diaphragms larger than 3 inches in diameter. First, the volume of the air chamber immediately above the diaphragm cannot be kept sufficiently small without making the height of the space less than a practicable value. (In the paper referred to it was shown that unless this volume is small, the radiation at the higher frequencies is materially reduced, because of the fact that the air is compressed in the space instead of being forced into the horn.) Second, because of the greater length of path across the surface of the diaphragm to the outlet, space resonances occur at frequencies within the working range unless several outlets are distributed over the diaphragm surface in such a way as to keep the effective length of path small. With large diaphragms the number of outlets required necessitates that each one shall be excessively small if the total outlet area is prescribed according to information given in the paper on horn design referred to above. There are four outlets in the large receiver shown in Figure 7, each one being 3/16 inch in diameter.

Diaphragms 1½ to 2 inches in diameter have been found large enough to radiate all the sound necessary for home use. The smaller of the two receivers shown in the photograph has a 1¾-inch diaphragm.

IV. Details of Receiver Design

Suppose a power loud speaker with the following characteristics is required:

1. Maximum power output of 1 watt at 500 cycles.
2. Frequency range 50-4,000 cycles.
3. Impedance of proper value for 5,000-ohm tube.

If a 3-inch diaphragm ($A_d = 45.6$ cm.^{2}) is employed and the total orifice area is equivalent to a ⅜-inch diameter hole, the radiation damping imposed on the diaphragm by a properly designed exponential horn will be

$$r = 4.6 \frac{A_d^2}{A_o} = 13{,}500 \text{ dynes}/(\text{cm.}/\text{sec.})$$

The maximum deflection at 500 cycles in order to radiate 1 watt or 10^7 ergs per second is obtained as follows:

$$\frac{1}{2} \dot{x}^2 r = \frac{1}{2} (\omega x)^2 r = W$$

$$\frac{1}{2} (2\pi \cdot 500 \cdot x)^2 \, 13{,}500 = 10^7$$

$$x = 0.0123 \text{ cm.} = 0.0048 \text{ inch}$$

The air gap should be approximately four times this or 0.020 inch. The resonance frequency of the diaphragm should be

$$f_r = \sqrt{50 \times 4000} = 450 \text{ cycles.}$$

If the magnetic reduction of rigidity is half the intrinsic diaphragm stiffness, f_r will be $\frac{\sqrt{2}}{2} \cdot f_o$, so that the resonant frequency of the diaphragm when not in the magnetic field should be

$$f_o = 450\sqrt{2} = 635 \text{ cycles.}$$

The thickness of the diaphragm is obtained from equation (11)

$$635 = 7.4 \cdot 10^5 \frac{t}{45.6}$$

$$t = 0.0392 \text{ cm.} = 0.0154 \text{ inch, or say } 0.015 \text{ inch.}$$

The actual value of f_o for $t = 015$ inch is 620 cycles/sec.

The equivalent mass of the diaphragm for the fundamental mode of vibration taking $\delta = 7.8$ is

$$m=\frac{1}{4}(45.6\times 2.54\times 0.015)7.8=3.4 \text{ gm.}$$

From equation (12) the stiffness may be calculated

$$S=(2\pi f_o)^2\, m=(2\pi\ .\ 620)^2\times 3.4$$
$$=51.3\times 10^6 \text{ dynes/cm.}$$

The magnet and pole construction should be designed so as to give a magnetic reduction of stiffness about half the above, of

$$S_m=25\times 10^6 \text{ (say)}$$

The actual resonance frequency in the field will be

$$f_r=\sqrt{\frac{51.3-25}{51.3}}\times 620=445 \text{ cycles/sec.}$$

The pole area is the only other arbitrarily chosen value. Let each pole be 3/16 inch $\times$ 5/8 inch and later we shall determrine whether the steady flux required to give the above value of S_m saturates the poles or not.

$$A=3/16\times 5/8\times 6.45=0.756 \text{ cm.}^2$$
$$a=0.020\times 2.54=0.0508 \text{ cm.}$$

From equation (3)

$$M_o=\sqrt{\frac{4\pi a^3 S_m}{A}}=\sqrt{\frac{4\pi(0.0508)^3\, 25.10^6}{0.756}}$$
$$=233 \text{ gilberts.}$$

The density of the steady flux in the poles will be

$$B_o=\frac{M_o}{2a}=\frac{233}{2\times 0.0508}=2{,}300 \text{ gausses}$$

which is sufficiently low.

The bridge or leakage path should have a reluctance of about one-fourth that of the two main air gaps. A path 3/16 inch $\times$ 3/4 inch in area and 0.0125 in length has this reluctance. The density of flux in the bridge gap will be

$$B_s=\frac{233}{0.0125\times 2.54}=7{,}350 \text{ gausses}$$

which is also sufficiently low. The total flux delivery from the magnet must be five times that in the main poles or

$$\Phi_m=5\ B_o\ A=5\ .\ 2{,}300\ .\ 0.756$$
$$=8{,}700 \text{ maxwells.}$$

Each magnet of the receiver must deliver 8,700 lines at 233 gilberts mmf. The problem of designing a permanent magnet capable of delivering a certain flux at a gven magnetomotive force is not difficult if the hysteresis loop for the particular steel is had. With cobalt, tungsten, or chromium steels, the flux density in the steel for the most economical magnet should be from 5,000 to 6,000 gausses. At this density the mmf. per centimeter length of magnet is from 120 to 160 gilberts for cobalt steel, and 40 to 50 gilberts for tungsten or chromium steel. Suppose a sample of cobalt steel when worked at a density of 5,000 gausses supplies 150 gilberts mmf. per centimeter length. For the particular application where 8,700 maxwells at a magnetomotive force of 233 gilberts are required, the length of magnet

$$l_m = \frac{233}{150} = 1.55 \text{ cm.} = 0.61 \text{ inch, say } 5/8 \text{ inch}$$

and the area

$$A_m = \frac{8700}{5000} = 1.74 \text{ cm}^2.$$

A magnet ¾ inch × ¾ inch in section has 1.81 cm.^2 area, which is approximately correct. If tungsten or chromium steel is used, the length should be about 3½ times the above, and because of the greater leakage or fringing, the section should be greater, especially at the center of the magnet where the total flux is greater. Cobalt steel magnets for applications of this kind are usually about ¼ or 1/5 as large as magnets of other steels. The receiver construction is also simplified if the magnet is short enough to go between the poles as shown in Figure 5. This is a factor which usually determines the area of the poles of the receiver. For example, if, with the pole area chosen, the value of M_o had been greater than that which could be obtained with a convenient length of magnet, the area of pole could be increased and the required value of M_o thereby reduced.

The remaining problem is to determine the proper windings. If at 3,000 cycles the response is to be as great as possible for that frequency, the inductance at that frequency is obtained from

$$\omega L = R_p$$

$$L = \frac{5000}{2\pi \cdot 3000} = 0.266 \text{ henry.}$$

In most laminated pole receivers tested, it has been found that the inductance decreases with frequency, approaching a limiting value of about half the low frequency inductance. This limit is usually reached below 3,000 cycles, and so the low frequency inductance of the receiver should be about double the above or

$$L_o = 0.5 \text{ henry (approx.)}$$

The number of turns per pair of poles may be calculated from

$$L_o = 2\left(\frac{0.4\,\pi\,n^2\,A}{2\,a}\right)10^{-8}$$

$$0.5 = 2\left(\frac{0.4\,\pi\,n^2 \cdot 0.756}{2\times 0.0508}\right)10^{-8}$$

$$n = 1{,}640 \text{ turns.}$$

With reasonable winding space, the ohmic resistance of the receiver is always small compared to the tube impedance, and so its value does not concern us, excepting as the windings might heat with the relatively large amounts of power employed. The loud speaker is usually in the secondary circuit of a transformer for insulation from the high voltage used in power amplifiers, and hence carries only the voice currents. Because of the great fluctuations of intensity, the average power in speech and music is usually so low compared to the peak value as to cause little or no heating of the windings or cores. So a size of wire is chosen which will allow the proper number of turns in a convenient winding space, and the matter of resistance forgotten. In the receiver here designed, 820 turns of number 36 wire can be conveniently wound on each pole if the winding section is 3/8 inch long by about 3/16 inch thick.

The principal dimensions and characteristics of the receiver will be tabulated:

Diaphragm 0.015 inch thick by 3 inch diameter.

$f_o = 620$ cycles/sec.

$m = 3.4$ grams

$S = 51.3\times 10^6$ dynes/cm.

$S_m = 25\times 10^6$ dynes/cm.

$f_r = 445$ cycles/sec.

$a = 0.020$ inch

$A = 3/16$ inch $\times$ 5/8 inch

$M_o = 233$ gilberts

Leakage path 3/16 inch $\times$ 3/4 inch by 0.0125 inch long

Total flux delivery from magnet, 8,700 maxwells

Magnets, cobalt steel, 3/8 inch $\times$ 3/4 inch $\times$ 5/8 inch long.

Inductance 0.5 henry at low frequencies

$n = 1{,}640$ turns per pair poles

Number 36 wire in space 3/8 inch $\times$ 3/16 inch

The force per unit current in the windings is given by equation (8)

$$K = \sqrt{10^7\,L\,S_m} = \sqrt{10^7 \cdot 0.5\times 25 \cdot 10^6}$$

$$= 11.2\times 10^6 \text{ dynes/ampere.}$$

This latter is the direct current force factor and will be found to decrease to a limiting value of about half with increase in frequency for most laminated pole receivers. With solid poles the percentage decrease in force factor is greater and the rate of decrease is more rapid with increase in frequency. Laminations of silicon steel 0.014 inch thick have been used with good results.

Details in the mechanical design of the receiver will not be discussed except to say that the diaphragm must be rigidly clamped with no metal to metal contacts. Paper, cloth, or rubber washers are used on each side of the diaphragm to prevent rattling. In the large size receivers rubber dam 7 to 10 mils thick has proven the best for washers. The air gaps should of course be accurate within close limits and the diaphragm flat if the full benefit of the balanced construction is to be obtained.

V. Experimental Work

By means of motional impedance diagrams some of the predicted characteristics of receivers can be checked experimentally. The equations for force factor and reduction of stiffness are found to give results which agree closely with those obtained by experiment. These equations are

$$K_o = \sqrt{10^7 L_o S_m}$$

$$S_m = \frac{A M_o^2}{4\pi a^3}$$

A receiver having the following principal dimensions was used in the test:

Diaphragm—0.007 inch thick × 1¾ inch diameter.
Poles 3/32 inch × 5/16 inch. $A = 0.189$ cm.^{2}
Air gap 0.0125 inch. $a = 0.0318$ cm.

The equivalent mass of the vibrating diaphragm, assuming it to be one-fourth its total mass, is $m = 0.54$ gm.

The magnetomotive force of the permanent magnet in each half of the receiver, as determined by measuring the pull on a thick iron armature at a known distance from the main poles was found to be

$$M_o = 107 \text{ gilberts.}$$

Using a vacuum tube oscillator and an alternating current bridge, the resistance and reactance of the receiver were measured at different frequencies and are plotted in Figure 8. The smooth asymptotic curves are the estimated resistance and reactance if the diaphragm were not permitted to move. The differences

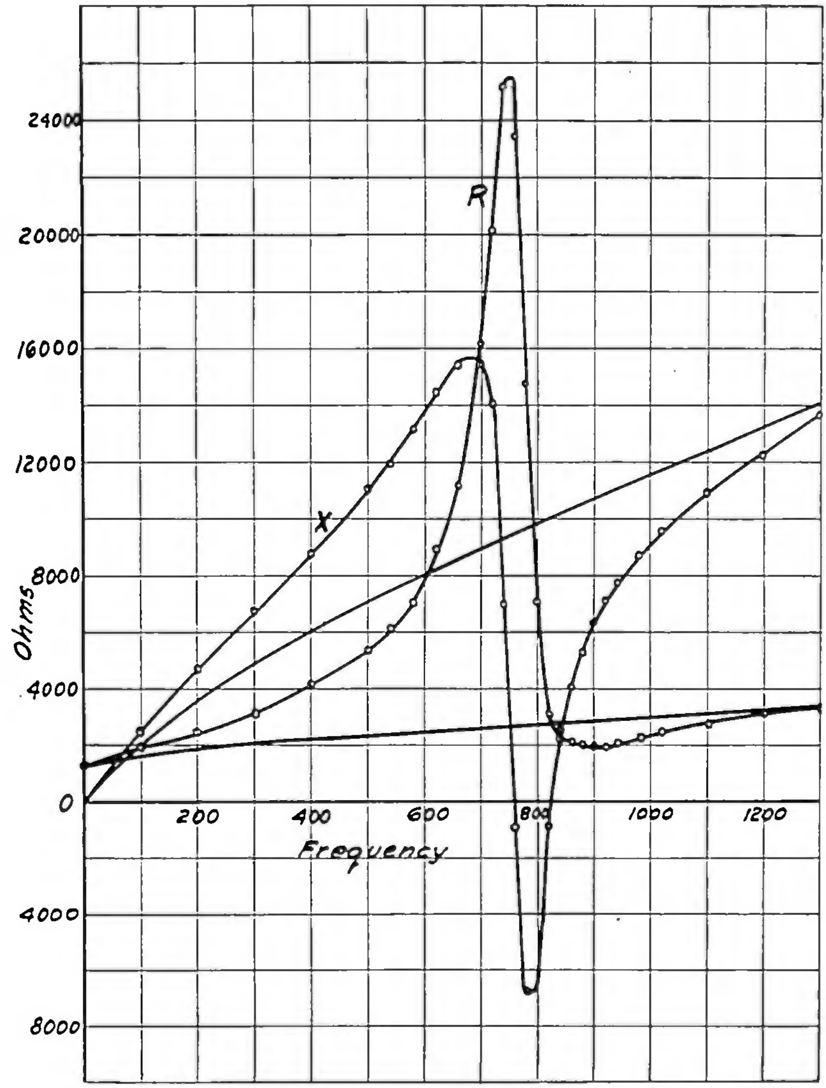

FIGURE 8—Resistance and Reactance Curves

between the values on the actual curves and the asymptotic curves are the motional resistance and the motional reactance. These two values may be plotted as a vector, the arrow of which will be found to describe a circle as the frequency is varied. This motional impedance circle for the receiver tested is shown in Figure 9. The resonance frequency of the diaphragm is 760 cycles, where the motional impedance vector is maximum.

The damping constant r of the receiver diaphragm is obtained from the logarithmic decrement

$$\Delta = \frac{r}{2\,m} = \pi(f_2 - f_1)$$

when f_1 and f_2 are frequencies corresponding to the extremities

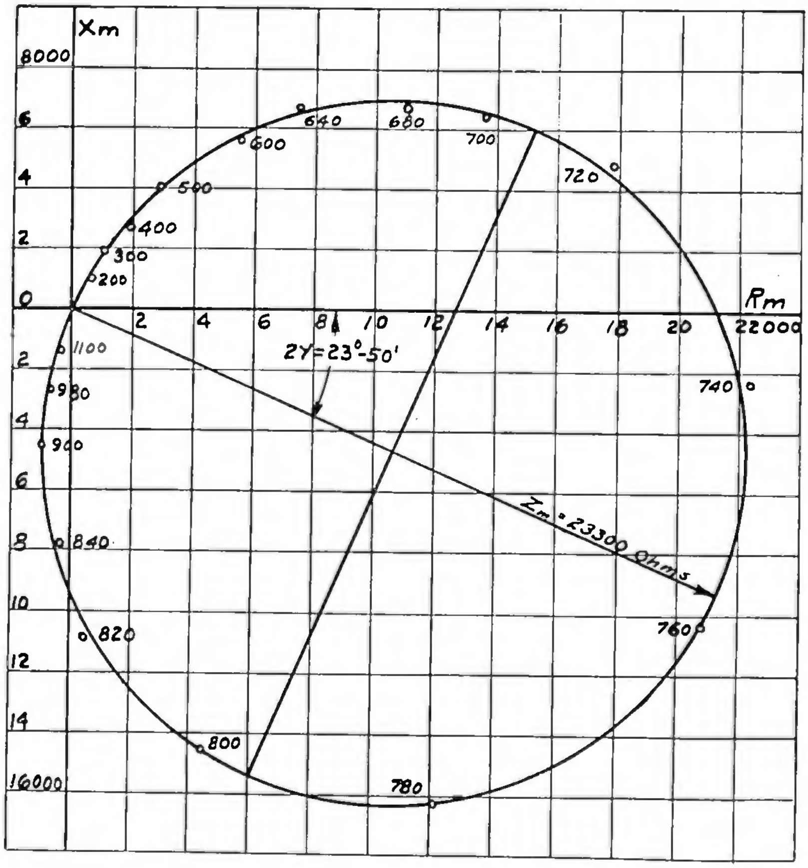

FIGURE 9—Motional Impedance Locus

of a diameter perpendicular to the principal diameter of the circle.

$$\frac{r}{2\times 0.54} = \pi \cdot 85$$

$$r = 288$$

The force factor K of the receiver at the resonance frequeency is determined by the diameter Z_m of the motional impedance circle and the value of r.

$$Z_m = \frac{10^{-7} K^2}{r}$$

$$23{,}300 = \frac{10^{-7} K^2}{288}$$

$$K = 8.2 \times 10^6$$

K is a vector quantity which lags behind the current in the receiver windings by an angle γ equal to half the depression angle of the motional impedance circle. The value of γ for the receiver under test is 11° 55′ at 760 cycles. The vector K is plotted in Figure 10.

Since K is reduced principally by eddy currents as the frequency is raised, its value for direct current may be obtained by noting the effect of eddy currents on the receiver resistance and reactance. As the frequency is raised, the effective resistance (diaphragm clamped) increases because of eddy current losses, and the reactance is less than it would be if the eddy currents did not flow. The angle of lag θ of the eddy currents behind the voltage which produces them is given by the anti-tangent of the ratio of this decrease in reactance to the increase in resistance.* The phase of the eddy currents is the same as that of the force which they produce. So if a line is drawn from the tip of the vector K at an angle θ with the vertical (which is the phase of the voltage causing the eddy currents since it is in quadrature with the main current), the direct current force factor is determined by the point where this line cuts the horizontal line.

In the receiver tested the decrease in reactance of the receiver is 5,700 ohms, and the increase in resistance 1,340 ohms at 760 cycles. θ is therefore the anti-tangent of 4.25 or 67°. K_o, the direct current force factor, is found to be 15.2×10^6 dynes per ampere. The locus of K as the frequency is varied is a semi-circle, as shown in Figure 10, points corresponding to other frequencies being determined by drawing lines from K_o at an angle (with the vertical) corresponding with the phase angle of the eddy currents for each frequency. Several points on the semi-circle are shown.

The results of the test will be tabulated below:

$f_r=760$ cycles.
$m=0.54$ gms.
$r=288$ dynes per (cm./sec.)
$S=m\ (2\pi\ f_r)^2=12.3\times10^6$ dynes/cm.
$K=8.2\times10^6$ dynes/amp. at 760 cycles.
$\gamma=11°\ 55'$
$K_o=15.2\times10^6$ dynes/amp. (d.c. force factor).
$L_o=3.18$ henrys at low frequencies.

The receiver was dissembled and thicker spacers placed in it so as to increase the air gap to a value sufficiently great to prevent the magnetic field from affecting the diaphragm stiffness. By means of a motional impedance test, the resonance frequency was found to be 910 cycles instead of 760 cycles. The intrinsic diaphragm stiffness

$$S_o=0.54\ (2\pi\cdot910)^2=17.6\times10^6\ \text{dynes/amp.}$$

* See paper "Theory of Magneto Mechanical Systems," by R. L. Wegel, Journal A. I. E. E.," October, 1921.

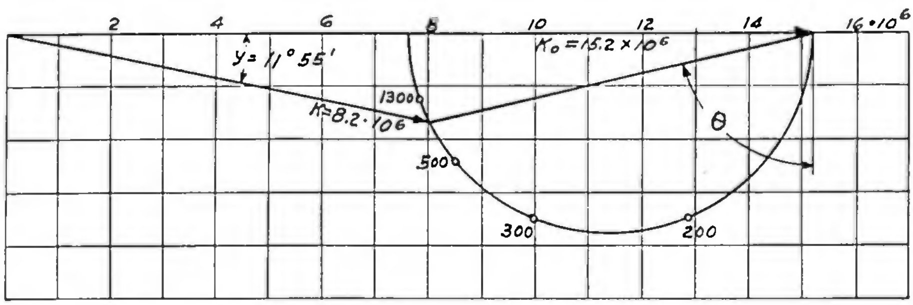

FIGURE 10—Force Factor Diagram

The reduction of rigidity due to the magnetic field in the case of the normal air gap is therefore

$$S_m = 17.6\times10^6 - 12.3\times10^6 = 5.3\times10^6$$

the predicted value

$$S_m = \frac{AM_o^2}{4\pi a^3} = \frac{0.189\times1072}{4\pi\,(0.0318)^3} = 5.4\times10^6$$

which is in close agreement with the experimental value.

The predicted value of the force factor for direct currents

$$K_o = \sqrt{10^{-7}L_o S_m} = \sqrt{10^{-7}\times3.18\times5.3\times10^{-6}}$$
$$= 13.0\times10^{-6} \text{ dynes/amp.}$$

This checks reasonably well with the value 15.2×10^6 determined experimentally

The force factor of this receiver is considerably greater than that of any simple receiver of equal inductance. This is accounted for by the balanced construction which allows the use of greater steady flux without diaphragm saturation.

VI. CONCLUSIONS

The balanced diaphragm type of receiver has all the advantages of the best types of electromagnetic receivers with the added feature that its vibrating system is just a simple diaphragm.

A determination of the characteristics of this type of receiver points to a direct method of design, with a degree of assurance that the greatest possible sensitivity will be obtained for a given application. The force factor, which is a measure of the sensitivity of the receiver, depends only on the inductance of the receiver, which is fixed by the characteristics of the tube circuit, and the allowable magnetic reduction of diaphragm rigidity, which is determined by the characteristics of the diaphragm.

The amount of power that a diaphragm can radiate without serious distortion is roughly proportional to the cube of its area. Receivers with moderately large diaphragms are, therefore, capable of radiating sufficient power for great distances out of doors. Various sizes of receivers having equal inductance and fitted with horns which cause each to have the same uniformity of response to different frequencies, all have the same over-all sensitivity.

Research Laboratory, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pennsylvania.

January 13, 1925.

SUMMARY: A discussion of the advantages and disadvantages of various present day electromagnetic receivers is given. A new type, called the balanced diaphragm receiver, is described and the details of design worked out.

AMPLIFICATION OF WEAK CURRENTS AND THEIR APPLICATION TO PHOTO-ELECTRIC CELLS*

By

G. Ferrié, R. Jouaust, and R. Mesny

(Paris, France)

In several instances, particularly in steller photometry, it is often necessary to measure very weak currents of the order of magnitude of 10^{-12} ampere. Galvanometers cannot detect currents of this nature, and consequently very sensitive electrometers are needed.

Tubes may be considered electrometers in which slight variations of the grid potential are manifested by considerable variations in the filament plate current. Thus the tube will act as a rugged and very sensitive electrometer which naturally can also be employed for measuring very weak currents.

Several attempts to develop this idea have been made by Kunz,[1] Pike,[2] and Meyer, Rosenberg and Lank.[3] Recently[4] we have applied the processes described below to the same problem.

A photo-electric cell constructed by Rougier[5] was employed.

This cell (Figure 1) is placed in a glass bulb having a diameter of 5 to 6 centimeters, equipped with tubulations for the passage of the wires which connect its electrodes to the voltage supply battery. The inside of the bulb is silvered, excepting for an aperture *A* which admits the luminous rays. On the silver plating opposite the aperture, at *K H*, is placed a hydride of potassium deposit electrically connected to the terminal *C* by means of a platinum wire. The anode *P* is ring-shaped in order not to inter-

*Received by the Editor, October 16, 1924. Translated from the French.

[1] J. Kunz: "Amplification of Photo-electric Current by an Audion," "Phys. Rev.," 10, 1917, page 205.

[2] C. E. Pike: "Amplification of Photo-electric Current by an Audion." "Phys. Rev.," 13, 1919, pages 102-108.

[3] E. Meyer, H. Rosenberg, and Lank (Zurich): "The Measurement of Photo-electric Currents by Means of Tube Amplifiers," "Arch. des Sc. Phys. et Nat.," 2, 1920, pages 260-262.

[4] G. Ferrié, R. Jouaust, R. Mesny: "Amplification of the Current of Photo-electric Cells and Its Use," "Comp. Rendue de l'Ac. des Sc.," 177, November 5, 1923, page 847.

[5] G. Rougier: "The Photo-electric Cells and Their Use for Photometry," "Revue d'opt. th. et exp.," 2, 1923, pages 133-166 and 365-383.

cept the light. The photograph (Figure 2) illustrates the dimensions of the cell.

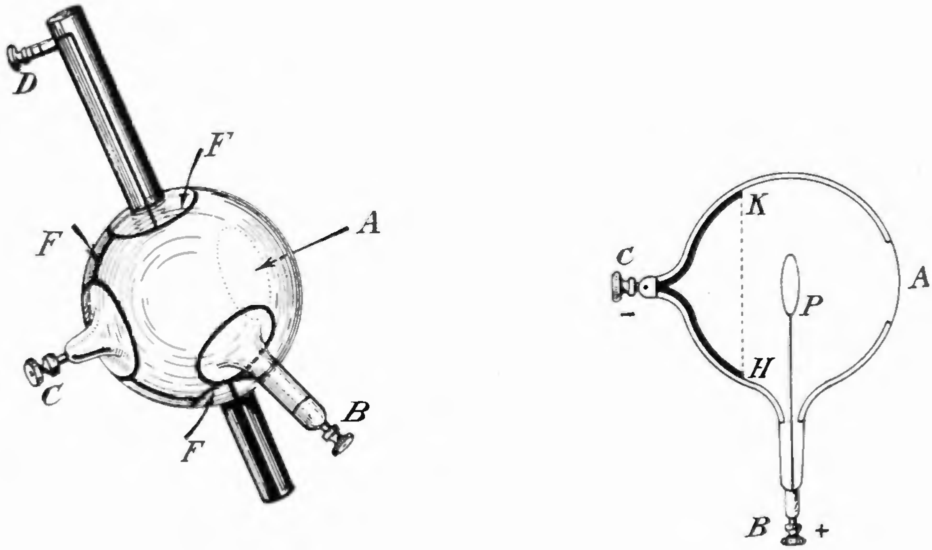

FIGURE 1

On the exterior surface are pasted sheets of tin foil F, serving as a guard ring for the prevention of weak currents due to the conductivity over the surface of the cell. These currents are superimposed on the photo-electric currents which are to be measured.

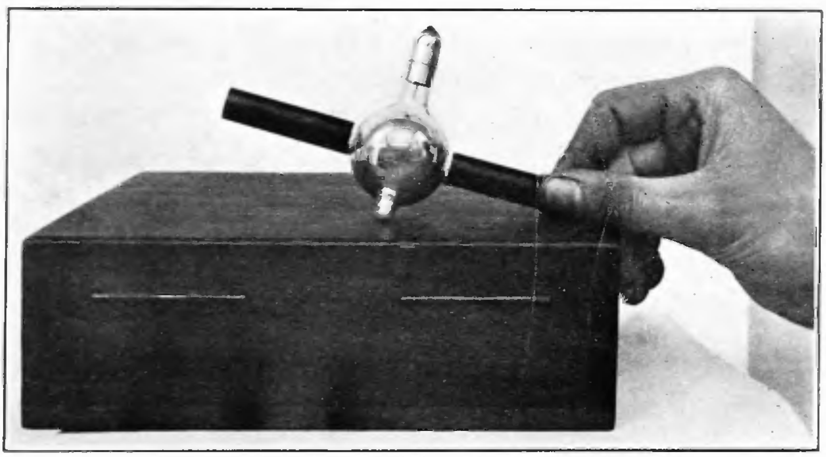

FIGURE 2

The connections which have been employed are as follows:

1. The anode of the cell is connected to the grid of a tube having three electrodes, the negative pole of the filament being connected to the positive pole of the battery, the negative pole

of which is connected to the alkaline deposit. As usual, a continuous difference in potential is applied between the plate and the filament of the tube (Figure 3).

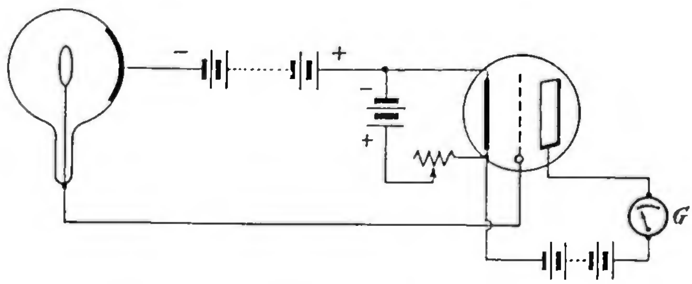

FIGURE 3

The emission of electrons, which takes place when the alkaline deposit is illuminated, gives a negative charge to the grid; as a result the filament plate current is reduced.

In order to obtain good results, the capacity between the grid and the various parts of the tube should be low. Moreover, since the grid must be highly insulated, it is well to employ tubes having "horns," and it is also necessary to select them carefully. Very few of the ordinary tubes are likely to give good results. With a tube having the dimensions of the ordinary receiving tubes we have obtained an amplification of 1,000, the variation of the filament-to-plate current being 1,000 times the intensity of the photo-electric current. An amplification of 10,000 was obtained with a 50-watt tube operating at 1,000 volts.

This connection is analogous to a method employed by Kunz and Rosenberg.

2. The difficulty in finding tubes with three electrodes having the necessary qualities has induced us to try another more complicated but also more reliable method (Figure 4).

A disc *D*, equipped with grooves, rotates at a great speed between the cell and the source of light. Thus the photo-electric current becomes a current of musical frequency corresponding to a rather high note.

The primary of the input transformer of an audio frequency amplifier, *A*, with three tubes is inserted in the circuit of the photo-electric current.

The amplified difference of potential, available at the output of this amplifier, is applied between the filament and the grid of a modulator tube *M*, in the plate circuit of which no steady electromotive force is inserted. But the plate-to-filament gap of this

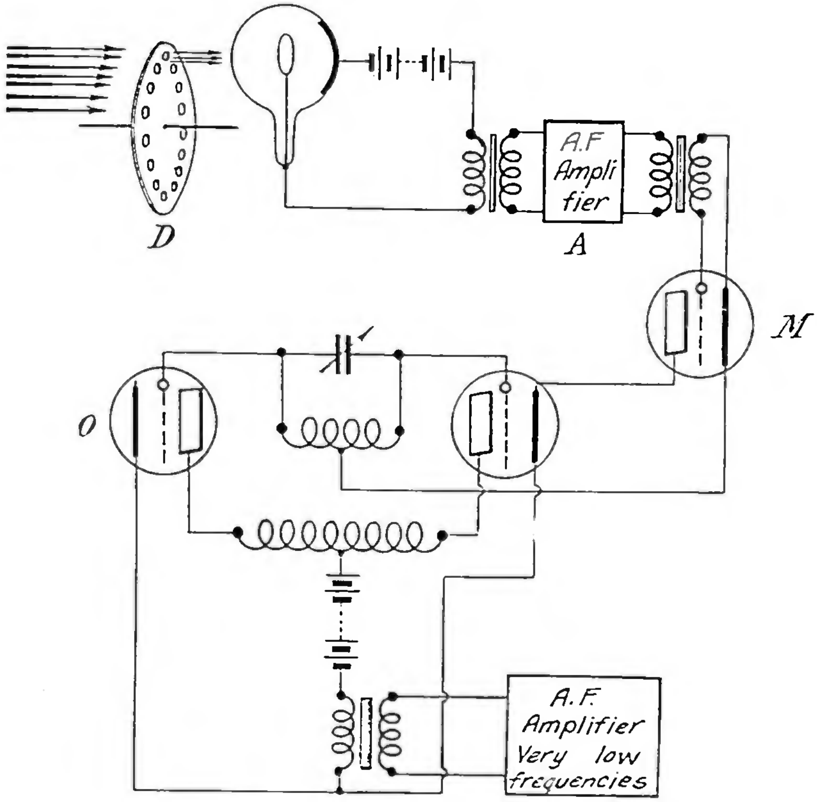

FIGURE 4

modulator tube is inserted in the grid-to-filament circuit of a small continuous wave generator *O*.

This generator was of the two-tube variety with a symmetrical connection (push-pull), and produced oscillations at a wave length of approximately 50 meters. When this apparatus is adjusted up to its maximum operating effectiveness, every variation of potential difference between the filament and the grid of the modulator tube (which causes variations of the filament-to-plate resistance of this tube) induces marked changes in the intensity of the oscillations produced; these variations in their turn produce variations in the plate-to-filament current of the oscillator. A further amplification can be obtained by conducting the latter variations to the terminals of an amplifier of very low frequency.

In this way amplifications of the order of 10^6 have been obtained.

By means of this process we have tried to register the photoelectric current due to the light of the stars; however, numerous difficulties are to be overcome in this respect. Nevertheless, experiments have been conducted under Jules Baillaud by using the observatory of Paris equatorial telescope having an opening of 28 cm.

3. Finally, we have employed tubes with two grids in order to obtain a very powerful amplification with a single tube, thus eliminating the difficulty of selecting the tubes. For this reason we bore in mind the following considerations relative to tubes having only one grid:

When the cell is not illuminated, the grid collects a few of the electrons emitted by the filament. On the other hand, it receives a certain number of positive ions produced by the ionization due to the dissociation by impact of traces of gas remaining in the tube. Its potential, calculated with reference to that of the filament, has such a value that an equal supply of electricity is produced by the positive ions and by the electrons.

When the cell is illuminated, the electrons emanating from the cathode will charge the anode and the grid connected to it. The potential of the latter, which is already slightly lower than that of the filament, will be reduced; this reduction will necessarily increase the number of positive ions received by the grid; but the number of positive ions which can be received by the grid per unit of time is limited. If the illumination is intense, the number of electrons produced by the cathode of the cell per unit of time may be greater than this maximum number of positive ions. Then the negative charge of the grid will increase gradually, its potential will decrease and finally reach such a value that all electron emission from the filament is checked, that is, the plate current is interrupted.

If the illumination is weak, however, another state of equilibrium will take place such that the positive electricity supplied by the ions will be balanced by the negative electricity supplied by the electrons coming from the filament and the cell. In this way the plate current is reduced. Obviously, under these conditions any obstacle to the formation of positive ions in the tube will give greater effective significance to the variations of the plate current produced by a given illumination of the cell.

For this reason we have replaced the tube with three electrodes employed originally by a tube with two grids of the usual commercial type.

The exterior grid was connected to the anode of the cell, and a potential difference of 6 volts applied between the filament and the interior grid (Figure 5).

Under these conditions the interior grid assists in the emission of electrons. The voltage applied to the plate can be reduced, and was actually brought down to about 15 volts, a value slightly smaller than the ionization potentials of gases. In this way fewer positive ions were produced than in the ordinary tubes where the voltage between the filament and the plate was approximately 40 volts.

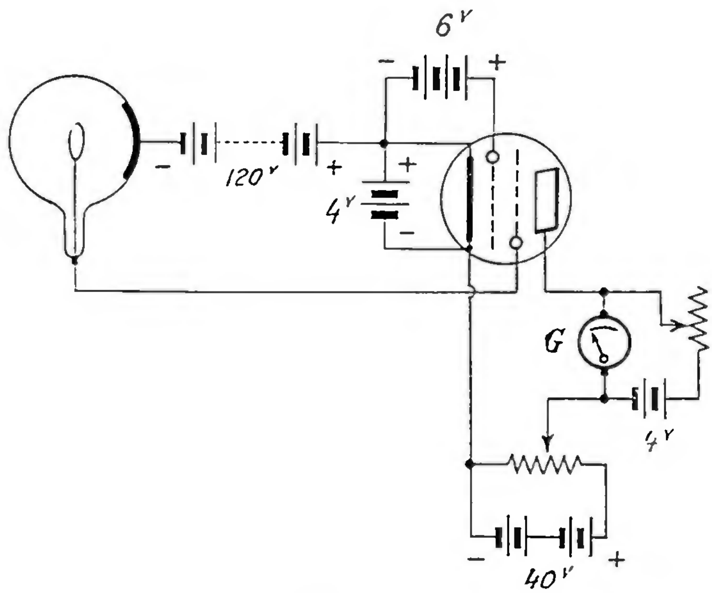

FIGURE 5

We have also proved that when the plate voltage of the tube is regulated accurately by means of a potentiometer, an amplification much superior to that obtained with the ordinarily better tubes can be produced. Any two-grid tube on the market can be used for this purpose.

We have looked into the possibility of applying this arrangement to stellar photometry, and with the aid of Jules Baillaud, experiments have been conducted at the observatory in Paris on the same equatorial telescope as mentioned above.

The cell, the tube with two grids, and the batteries which keep the first grid positive, were enclosed in a box covered by a grounded metal screen. This box was fastened to the photographic equatorial in such a way that the sensitive coating of the cell was slightly behind the focus. This box is shown in Figure 6 above the head of the observer. The arrangement has been chosen in order to make the luminous energy thus received operate on a large surface of potassium.

Carefully insulated wires were connected to the terminals of the filament heating storage batteries at convenient points, to the terminals of the batteries which were intended to act on

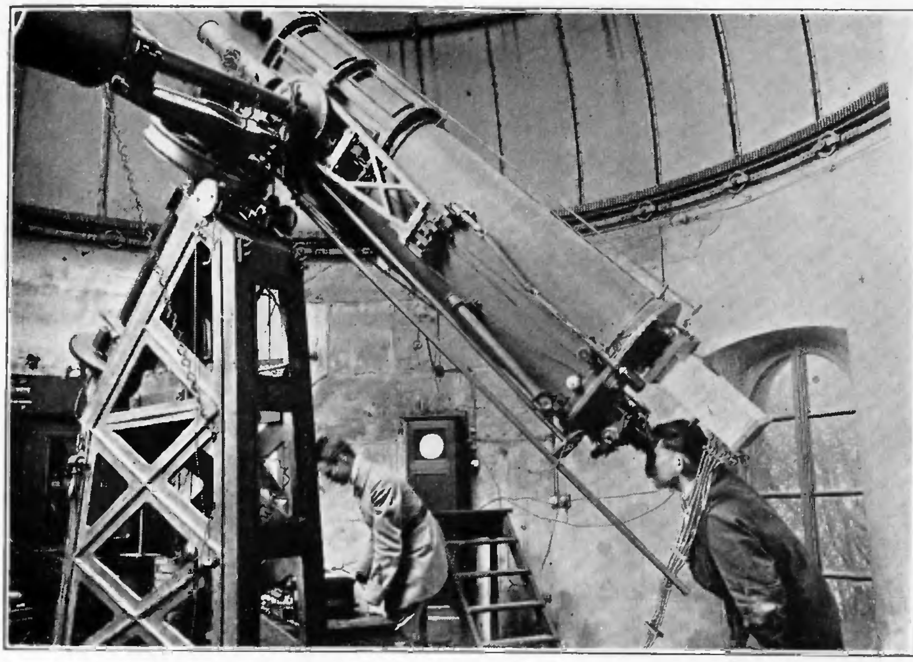

Figure 6

the cell, and to those batteries required to produce the necessary steady voltage in the tube between the filament on the one hand and the plate and the first grid on the other. A potentiometer made possible the regulation of this voltage. A sensitive galvanometer in the plate circuit of the tube was balanced for the normal plate current. The assembly of this apparatus is illustrated in Figure 7.

Under these conditions the star Capella gave a variation of the plate current of 3.5 micro-amperes, β of the constellation Bootis 1 micro-ampere, and ζ of the same constellation 0.3.

Let us consider the results obtained in previous experiments with rather casual arrangements. One might hope that an apparatus which is very carefully constructed with respect to insulation will have greater sensitiveness. This apparatus is now being built. It will make possible the direct utilization of the tube as an electrometer or as a ballistic galvanometer. It will also include a particular device to be explained in greater detail.

In view of what has been said above, it seems very difficult, despite the opinion of Rosenberg, to admit the proportionality between the variation of the plate current and the quantity of luminous energy received by the cell. Besides, even if this proportionality existed, the constant of proportionality would be subject to variations from one experiment to the other.

A standardization device has been provided, based on the following principle: after each experiment a quantity of variable luminous energy is imparted to the cell. This quantity of luminous energy can be varied in a well-known way and regulated so as to obtain the same variation of the plate current as that produced by the observed star.

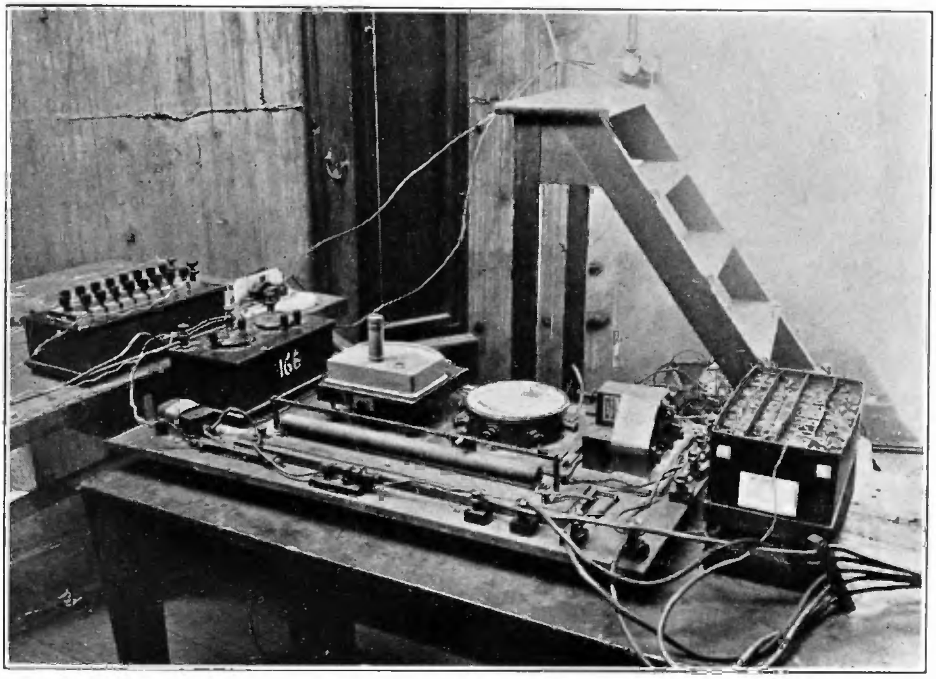

FIGURE 7

The practical utilization of this principle is easily understood: An electric lamp, the voltage of which is regulated accurately at its terminals will illuminate the part of the potassium layer which is influenced by the light of the star during an experiment.

Neutral glasses and absorbing glass wedges make it possible to vary continuously the luminous flux which arrives at the cell in this way.

4. In conclusion, another process should be mentioned which may yield a still greater sensitivity. A well-insulated condenser with a capacity of a few electrostatic units (c. g. s.) is placed in series with the cell, and the latter is subject to unknown illumination during a given time. Then the condenser is discharged by connecting one of its terminals to the filament and the other to the exterior grid of the tube (Figure 8).

An abrupt change in the plate current will then take place. In this way, by exposing the cell for 10 seconds to an illumination which can produce a permanent variation of the plate cur-

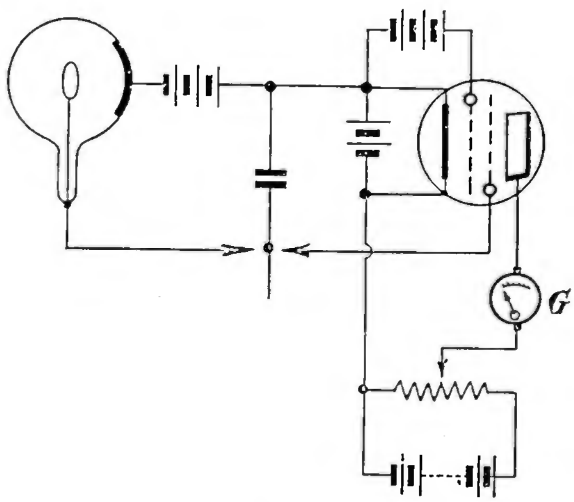

FIGURE 8

rent of 2 micro-amperes, we have obtained on the same measuring apparatus a deflection corresponding to a plate current change of 25 micro-amperes.

We will continue to study this new method of operation which also makes it possible to transform the light energy into telephone signals, when the luminous intensity is sufficient to allow a discharge of the condenser at least 15 or 20 times per second. It is only necessary to connect the arrangement in question to an ordinary amplifier for low frequency currents.

According to the above, it should be possible to use the properties of photo-electric currents for determining the instant when a star has a given position in the field of an instrument, and particularly the instant when it passes a meridian.

Naturally it may be possible to register on the same apparatus the time indicated by an astronomical pendulum and the photo-electric current produced by the observed star acting on the cell.

As long as the star is concealed by the micrometer, the photo-electric current will be reduced. Thus it is possible to observe the instant when the image of the star comes into contact with the micrometer cross thread, and the instant when it is entirely disclosed. Thus the personal equation, which must be considered in most meridian operations, is removed.

As a matter of fact, the practical realization of this new process presents very great difficulties which for the most part are not yet overcome. Nevertheless, we must mention certain previous rather encouraging experiments carried on at the observatory in Paris.

In order to get the desired results, it is necessary to measure the amplified photo-electric current with rapidly responsive indicating apparatus. Now such apparatus in general is only slightly sensitive. Therefore, the arrangement used for stellar photometry has been somewhat modified. As mentioned above, the current was amplified by means of a two-grid tube. A resistance of 50,000 ohms was inserted into the plate circuit of this tube, and the variations of voltage at the terminals of this resistance amplified by means of a new amplifying tube using direct current.

A Dufour galvanometer with photographic recording equipment was placed in the plate circuit of this new tube, the apparatus being such as is used by the geographic service of the army for range-finding by means of sound.

A plate having an aperture of one millimeter was placed in front of the cell in the photographic equatorial telescope previously mentioned. When the equatorial is held stationary, no photo-electric current is produced until the star, as a result of its apparent movement, passes in front of the aperture. In observing the star Vega, a deviation of a centimeter was revealed on the film of the photographic recorder, corresponding to the production of a photo-electric current having a certain duration of time, and the beginning and end of which seem to be shown accurately by observing a few precautions.

Altho only preliminary research has been conducted thus far, it seems possible that a new field has been found for photo-electric cells in astronomy.

Another application of the amplification of very weak currents has been studied by Lejay, who has employed it for measuring the potential gradient of the atmosphere by connecting the control grid to a potential terminal or test point. He has proven by comparison with a Mascart electrometer having photographic recording equipment that the errors amounted at most to two hundredths of the total deflections. He employed the ballastic method involving the changing of an auxiliary condenser.[6]

[6] P. Lejay: "An Electrometer Using Triode Tubes and Its Use for Measuring the Electric Gradient of the Atmosphere," "Comptes rendus de l'Ac. des Sc.," volume 178, pages 1480-1482, April 28, 1924. "The Use of Tubes with Several Electrodes in Photometry," "C. R.," volume 178, pages 2171-2173, June 23, 1924.

GENERATION OF POLYPHASE OSCILLATIONS BY MEANS OF ELECTRON TUBES*

By
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(Professor of Hydrography at the Laboratory for the Military Radio Telegraphy)

General Principle

If a connection having a geometrical and electrical symmetry of the order n is obtained by n identical triodes, the system constituted in this way should form under favorable conditions a unit of polyphase oscillations of the order n. This proposition is obvious; but it remains to be established *a priori*, whether the operation of such a system is stable. The slightest difference between two homologous elements, for instance, might interrupt the polyphase operation, thus producing several oscillations of different frequencies in the circuits. It seems to be impossible to verify the stability by means of calculation. Without considering the difficulties arising from the large number of elements in operation, too little is known of the phenomena taking place in the triodes. In contrast to this, a quick and safe method has been obtained experimentally.

The connection illustrated in Figure 1 was devised for three tubes, and the three-phase operation easily secured. The three filaments are in parallel from the same source; the three plates are connected at a common point P by means of three inductances, the same is the case with the three grids, the coils of which have a common point C; the coils of the plate and of the grid of the same triode are coupled magnetically. An electromotive force of some hundred volts is inserted between the point P and one of the terminals of the filaments, as for a single tube connection; the point C is connected to one of the filament terminals either directly or thru a resistance of approximately 10,000 ohms. The purpose of this resistance is to avoid overload of the grids by reducing very considerably the electron current which flows thru them; it is unnecessary to shunt it by a capacity as in the single triode connections because it does not transmit alternating current.

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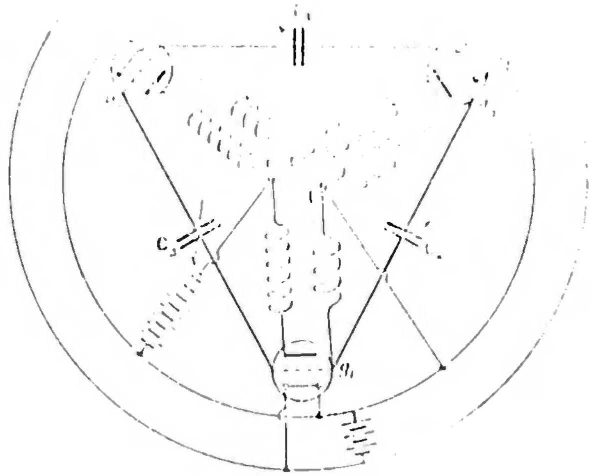


Figure 1

A variable condenser which produces an oscillatory circuit in conjunction with the corresponding inductances is placed between the grids (or the plates) of two adjacent tubes.

This system oscillates spontaneously in three phases, when the three oscillatory circuits, connected in this way have the same frequency, and the mutual inductances are suitably chosen.

The oscillations thus obtained are very stable and persist even with differences between the homologous elements amounting to 4 or 5 percent, a fact which makes it possible to carry different loads in the different circuits. When the differences between these elements are too large, the system develops oscillations at two or three principal frequencies, but the three-phase oscillations of a single frequency occur abruptly as soon as the limits indicated above are reached, as the capacities or the inductances are varied.

The unit can be considered to be the summation of three oscillatory circuits $g_1\,C'\,g_2\,C_3$; $g_2\,C'\,g_3\,C_1$, and $g_3\,C'\,g_1\,C_2$, in part superimposed on each other, and each of them giving rise to an oscillation 120° behind its predecessor and 120° in advance of its successor or *vice versa*. The frequency is determined by the common values of the inductances and the capacity of each of these circuits to the same degree of approximation as for the single tube connections. Frequencies of the order of 10^6 cycles per second have been obtained without difficulty.

The existence of three-phase oscillations can be demonstrated by developing a rotary field by means of the same processes as those used for industrial frequencies, for instance, by sending the three currents 120° out of phase into three coils which are themselves placed at an angle of 120°; these coils are inserted between the point C on the one hand and the three inductances connected to the three grids.

A squirrel cage motor, consisting of closed windings of fine wire and placed inside the coils mentioned above, begins to rotate rapidly as soon as the three-phase oscillations are generated. The rotation may be in either of the possible directions.

The power of the motor constructed in this way with frequencies of 5×10^5 cycles was of the order of 10^{-3} watts; however, by using a set oscillating on frequencies of 500 to 1,000 cycles per second, powers of a few watts could be obtained with a current of 1 ampere in the oscillatory circuits. It is probable that the speed of rotation in a vacuum would be very nearly constant. It depends only on the frequency of the oscillations, which can be kept almost constant, and on the mechanical resistances: if the motor rotates in a vacuum, the latter will be almost uniform, and the apparatus can be used for spinning mirrors at great speed and very regularly.

Measurement on the Separate Phases

The measurement which seems to be of greatest interest at high frequency, is that of the separate phases. In Figure 2, F_1 F_2 F_3 designate the three coils at 120° mentioned above. These coils have the axis O perpendicular to the plane of the figure and as a common axis of symmetry. The squirrel cage is replaced by a coil M, rotateable around the axis O, the turns of this coil being parallel to the axis of rotation. This coil will be the seat of an electromotive force of the same frequency as the oscillations and of a phase depending on the orientation of the movable coil. When properly constructed, the latter makes possible definite variations of the phase equal to the angle to which it is turned. We will assume that this condition, which will be considered later, is realized.

When the coil M is introduced in a circuit E C including a condenser C and another coil E, the entire circuit can be turned to the frequency in question. A receiver system, connected to the terminals of the condenser, picks up the oscillations induced in the circuit. If the orientation of the coil M is changed, the sound remains the same since the rotating field is circular. But, if the coil E is coupled to a third coil B, thru which flows a current of the same frequency, a coupling value and an orientation of M will exist for which no audible sound is produced; at this instant the electromotive forces induced in M by the rotating

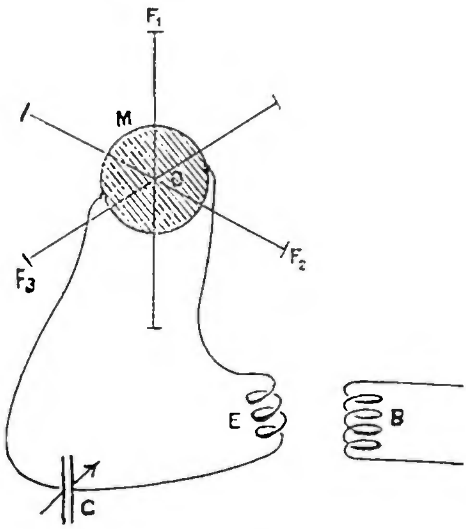


FIGURE 2

field and in E and B will be exactly opposite. A graduated circular scale is mounted on the axis O, its displacement in front of an index indicates the orientation of M and consequently the phase of the resulting current with respect to a phase used as an origin. In order to determine this origin, the point of extinction obtained by connecting E with a few turns in series with the circuit of one of the stationary coils, F_1, for instance, should be found. Zero is marked on the graduated circle at this point, and the figures read on the scale during the following measurements will constitute the differences in phase between the observed currents and the current in F_1.

The resulting points of extinction are very sharply defined and permit readings within a fraction of a degree.

The magnetic coupling between B and E can be replaced by a resistance and capacity coupling.

Naturally the frequency in the coil B should be equal to that of the generator of polyphase oscillations. This condition is easily obtained by producing the oscillations of the system which contains B by the generator itself. If, for instance, it is desirable to study the variations of the phase which occurs at the different stages of an amplifier using triodes, this amplifier is supplied by a potential difference in a section of the circuit F_1 which determines the reference phase.

In case the related phases in the different circuits of a generator are to be investigated, the three-phase system can be synchronized with the generator by establishing a suitable coupling between the latter and one of the three phases. When the frequencies are adjusted to be sufficiently nearly alike, they drive one another and oscillate synchronously.

ACCURACY OF THE MEASUREMENTS

The first condition for obtaining the results below is the uniform proportional variation of the phase of the electromotive force induced in the coil M as a function of the angle thru which it is rotated. For this purpose it is sufficient to construct the coils F and M in such a way that the coefficient of mutual induction between M and the coil F_1 varies as the cosine of the angle between the planes of their windings. Let us call Φ, the flux produced in M by one of the coils F when their windings are parallel, and α the angle between the windings of F_1 and those of M for any position of the latter; then the entire flux which flows thru M in this position will be:

$$\Phi\left[\cos\omega t\cos\alpha+\cos(\omega t+120)\cos(\alpha+120)\right.$$
$$\left.+\cos(\omega t-120)\cos(\alpha-120)\right]$$

the angle α being reckoned in the reverse direction to that of the variations of the phase between the coils F_1, F_2, F_3. This expression is reduced to

$$\frac{3}{2}\Phi\cos(\omega t-\alpha)$$

which establishes the proposition.

On the other hand we have determined very general conditions for a mutual induction proportional to $\cos\alpha$; they are as follows:

(a) The coil F should have a symmetrical plane passing thru the axis of rotation of M.

(b) The coil M should be wound on a core having the shape of a solid of revolution around its axis of rotation.

(c) The planes of the windings of M should be equally spaced.[1]

So far we have assumed that the currents circulating in F_1, F_2, F_3, have exactly the same intensity. Experience shows that polyphase oscillations can take place also when this condition is not fulfilled, if the threefold symmetry is imperfect, which always seems to be the case. Then the rotating field is elliptical, and variations in the sound heard are perceived accompanying a rotation thru 360° of the coil M. This defect can be corrected by adjusting the different elements of the circuits: couplings, capacities, resistances. If the two axis of the ellipse

[1] R. Mesny, "Radiation Measurements," "Onde Electrique," volume 1 (1922), pages 54-62.

of the rotating field are called a and b, the ear can easily perceive such deviation as

$$\frac{a-b}{a}$$

amounting to 1/10. Consequently, the flattening of the ellipse can be corrected without difficulty within the above limits. If more accuracy is desired, a voltmeter amplifier can be used instead of the ear.

On the other hand, when the field is elliptical it is easy to prove that the angle α, read on the scale, or the phase of the electromotive force induced in M for an orientation α of this coil, causes an error, at most equal to the angle ε given by the formula

$$\sin \varepsilon = 2\frac{a-b}{a+b}.$$

It should be added that the system of coils F and M of the generator should be spaced carefully in order to avoid parasitic inductions; a distance of 1.50 to 2 meters is suitable. It is also advantageous to inclose this system (F, M) in a cage of wire gauze.

Radiation of a Rotary Field

A rotary field can easily be radiated with this connection. It is sufficient to substitute for the coils vertical loops placed at 120° to one another.

Under these conditions, the radiated field[2] is symmetrical about the vertical axis passing thru the central point of the transmitter. The vector field describes an ellipse, the plane of which is perpendicular to the direction of the transmitter.

The small axis of this ellipse intersects the vertical axis of the field, its longer axis being horizontal: the ratio of the two is equal to $\cos \theta$, where θ designates the angle from the zenith of the point in question, as seen from the transmitter.

As one special case, the vector field describes a circle around the vertical axis of the system, and is polarized horizontally near the ground.

Such a transmission might serve an airplane for determining the direction in space of the transmitter and, consequently, for assisting in landing at a given point.

[2] The word "field" is here conceived in the sense of the space where the radiation takes place.

THE SHIELDING OF ELECTRIC AND MAGNETIC FIELDS*

By

John H. Morecroft and Alva Turner

(Columbia University, New York)

An examination of the past Proceedings of this Institute shows no papers on the question of shielding; as the subject is becoming of increasing importance in radio apparatus it seems worth while to bring up a discussion of the matter at this time. The theory and experiments reported in this paper make no pretense at completeness, but they do serve, however, to point out some of the essential principles and to give data which apparently is not available elsewhere.

The general question of shielding naturally falls into two general classes: shielding against steady or constant fields and shielding against changing fields. The former is comparatively simple, from both theoretical and experimental viewpoints, whereas the latter can in general not be handled from the theoretical viewpoint except in an approximate manner. It is here, therefore, that experimental evidence is most needed and most of the experimental work following falls into this class.

Constant Magnetic Fields

Shielding against constant magnetic fields falls into two classes according to the way in which the field is set up; if by a permanent magnet one treatment is possible, whereas an electromagnetic field may demand entirely different treatment.

The flux from a permanent magnet is fixed in quantity; it can be neither increased nor decreased by changes in the surrounding conditions. Advantage is taken of this fact in the general scheme of shielding; the space to be shielded may be surrounded by a shield of highly permeable material (iron) and most of the flux will be diverted from the space to be shielded. Figure 1 shows the flux distribution after introducing an iron shell into the field of a permanent magnet. The shielding is not perfect

* Received by the Editor, December 16, 1924. Presented before The Institute of Radio Engineers, New York, December 17, 1924.

because any two points in the iron shell (*A* and *B*) must be at a difference of magnetic potential equal to the product of the flux and the reluctance of the intervening magnetic path. Because of this difference of potential there will be some flux from *A* to *B*. The amount of this flux can be kept low by reducing the magnetic potential between *A* and *B*, and this in turn is kept low by using a thick iron shield, or still better, a series of shields are inside the other.[1]

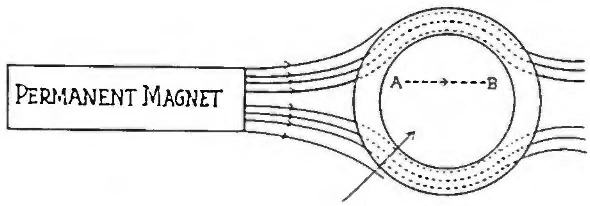


FIGURE 1

Where a comparatively large space is to be shielded from a uniform magnetic field such as that of the earth, Helmholtz's coils accomplish the purpose very well. The space to be shielded from the parallel field is indicated in Figure 2. Two large circular coils, *A* and *B* are placed co-axially, and their axis coincides with the direction of the earth's field; by sending a sufficient current, in the right direction, thru these coils the desired shielding effect is obtained. It is comparatively easy to reduce the earth's field by this method to less than 1 percent of its normal value.

If a conductor is carrying current a flux will be set up around the conductor. The amount of this flux is not fixed (for a given current), as was the case for the permanent magnet, but is determined by the reluctance of the magnetic circuit surrounding the conductor. If the space to be shielded is at *A* (Figure 3), a surrounding iron shell will accomplish the purpose; by making the shell sufficiently thick, any desired degree of shielding may be obtained. It might seem that the space *A* could be shielded by putting a heavy iron pipe around the conductor as indicated in Figure 4; one might think that all the flux which the conductor generates would go thru the low reluctance pipe leaving no flux to reach out in the space *A*. Unfortunately, such a method of shielding fails completely; there is just as much flux density at *A* with the iron pipe around the wire as when it is not there.

If the conductor is located centrally in the iron pipe, the flux

[1] "Phys. Rev.," volume IX, number 4, Wills, "On the Magnetic Shielding Effect of Tri-lammelar Spherical and Cylindrical Shells."

density in the air (both inside and outside the pipe) is exactly as it was without the pipe. The total flux surrounding the wire is increased because of the high permeability of the iron pipe, but the density of flux in the air remains unchanged.

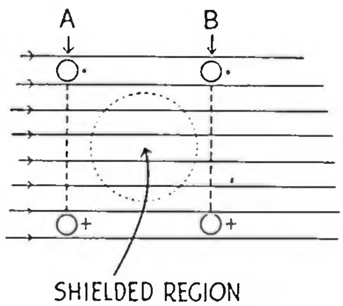


FIGURE 2

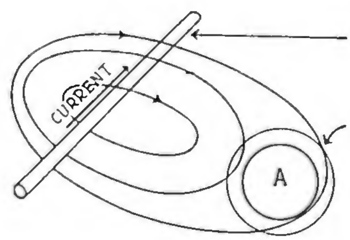


FIGURE 3

A general idea of the shielding accomplished by iron sheets in the form of pipe or otherwise may be gained from Figure 5. At any place +, close to the iron sheet, the flux density may be estimated by figuring the magnetic potential difference between two neighboring points on the shield, *A* and *B*. By supposing a Faraday tube to originate at *A*, go thru x, and end on *B*, the reluctance can be figured and the density at x then calculated. To shield the point x thoroly the two points *A* and *B* must be brought to a small potential difference, by some means or other. When an iron pipe completely surrounds the wire, the potential difference between points *A* and *B* is the same as if the pipe were not present. By shaping the iron in such a way that most of the magnetomotive force, due to the current, is used at the left side of the wire (Figure 5), shielding to some extent on the right side is made feasible.

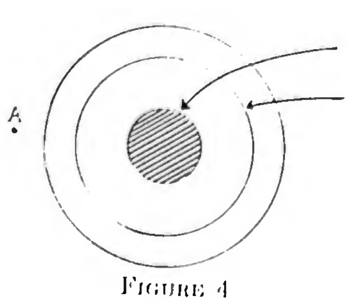
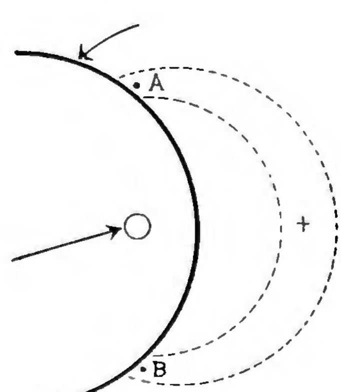


FIGURE 4



FIGURE

This effect is shown in Figure 6; a rectangular piece of sheet iron 0.11 centimeters thick was bent around the wire carrying the current, as shown in the lower part of the diagram. The flux at the point where shielding was desired was measured by a small search coil (2 centimeters in diameter), connected to a ballistic galvanometer. Twenty wires each carrying the same current were used to set up the magnetic field, the number of ampere conductors used being as high as 220. After the sheet of iron had been demagnetized the current in the wires was increased in steps, the field density was measured for each current value, and then the current was decreased in corresponding steps and the flux density again measured. This process was carried out both with the iron present and without it. The shielding is here defined as the ratio of the change in field strength, due to the presence of the iron, to the field strength with no iron present. If the iron so acts as to give no field at all at the point investigated, the shielding is perfect, or 100 percent.

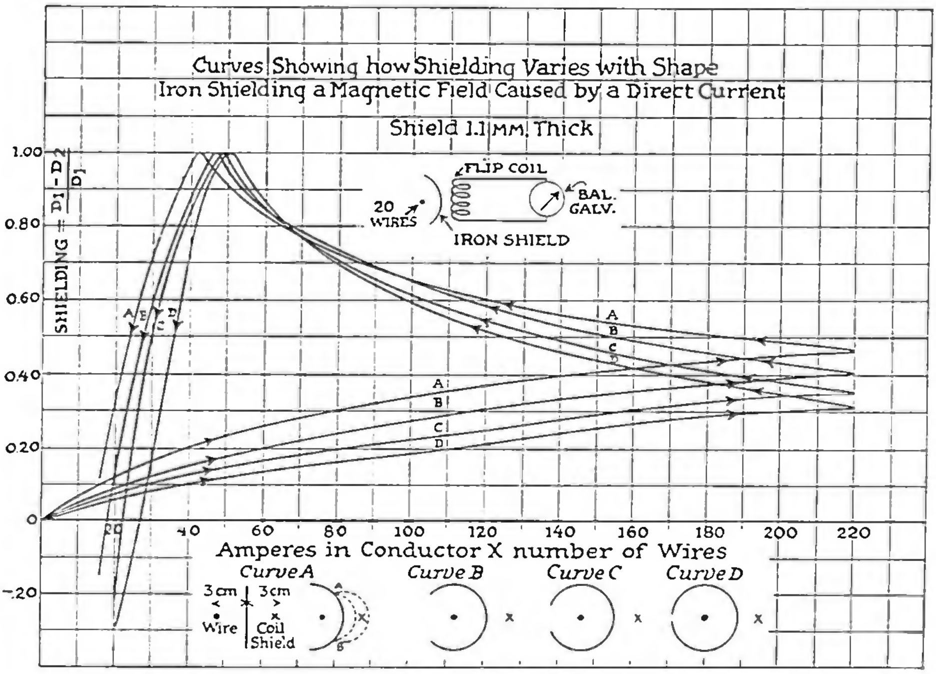


FIGURE 6

The shape of these curves (Figure 6) with increasing current indicates that the iron shield should be flat; a given length of iron shields better when plane than when partially surrounding a conductor. With decreasing current, the shielding increases because of the retentivity of the iron; for small values of current (decreasing) the residual magnetism in the iron is sufficient completely to neutralize the field of the currents and perfect shielding results. For currents smaller than these, the ballistic galvanometer indicates that the flux present at the flip coil was in the opposite direction to that set up by the current, and for very weak currents the shielding becomes negative. There is actually more flux present with the iron shield than would be there if the iron were not present. The amount of this effect would quite evidently depend upon the magnetic properties (principally retentivity) of the iron used for shielding.

We would naturally expect that the shielding obtained in Figure 6 would be increased if the shield were made thicker; such is shown to be the fact in Figure 7, where three thicknesses of iron were used, the shield being in the form of a flat plate. Examination of the "decreasing current" part of these curves shows that the density of flux set up in the shield is greater for the thin shield than for the thick; the total flux thru the thick shield is greater but the density of flux is less.

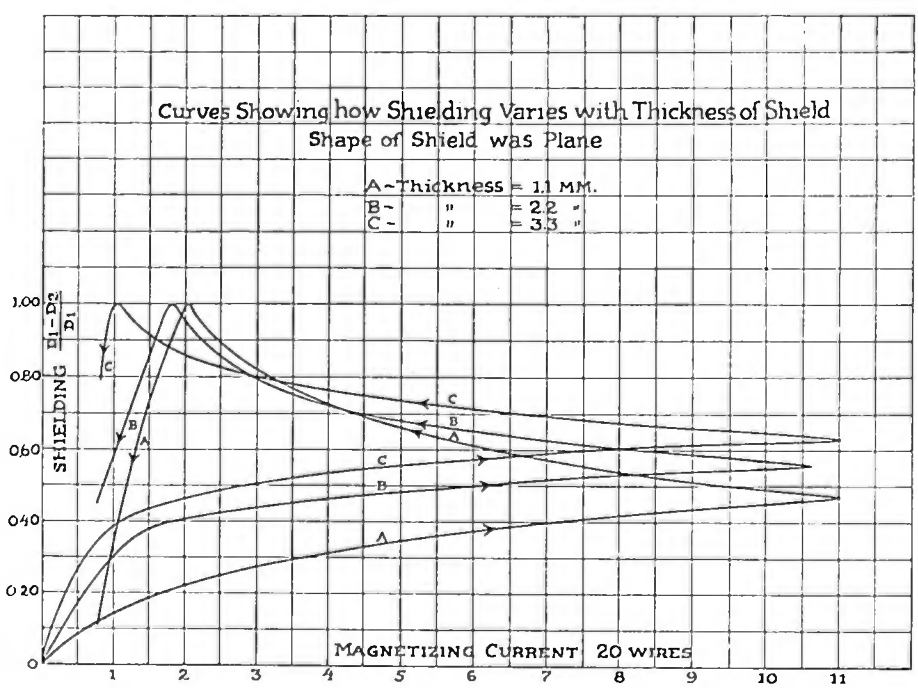


FIGURE 7

CONSTANT ELECTRIC FIELDS

The space surrounding an electric charge exhibits a radial field distribution, if the charge is isolated from other bodies; with increasing distance from the charge, the electric potential due to the charge in question continually diminishes. Any other electric charge brought into the electric field will be urged to move towards or away from the first charge, according to its polarity.

Space in the proximity of an electric charge can be completely shielded from its field by surrounding the space in question with a completely closed metal cage, as suggested in Figure 8. Induced charges will be set up on the outer surface of the metal cage with such density and distribution that the net electric field inside the cage is zero. Actually the space inside must be considered as influenced by both the original charge and the induced charges; the induced charges will always so arrange themselves that there is no electric field at all inside the cage. It is to be noted that whereas the shielding is perfect after the induced charges have taken up their final disposition, the enclosed space is not shielded while this rearrangement of charges is taking place.

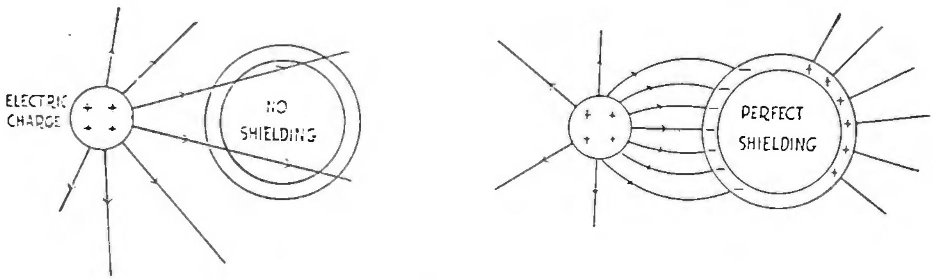


FIGURE 8

CHANGING MAGNETIC FIELDS

Consider a solenoid (Figure 9a) carrying a changing or alternating current. At any point A in the vicinity of the solenoid there is a magnetic field and, due to the rate of change of this magnetic field, an electric field. By interposing a sheet of metal between the solenoid and the point A (Figure 9b), the magnetic field is so redistributed that practically none penetrates to A. In case the metal shield is of iron, the shielding action previously referred to (Figure 5) will occur and in addition there occurs another action tending to shield point A. In the metal sheet, whether ferromagnetic or not, there will be set up eddy currents due to the alternating magnetic field, and the magnetomotive force at point A will be the resultant due to the solenoid and that due to the eddy currents. With a reasonably thick metal sheet of sufficiently low resistivity, the magnetomotive force of the eddy currents will practically neutralize that of the solenoid, so that

A is practically free of magnetic field. Being free of magnetic field we may say in general that it is also free of the electric field, due to the rate of change of this magnetic field.

The degree of shielding affected by eddy currents will be examined more in detail later in the paper, and experimental proof of the theory given.

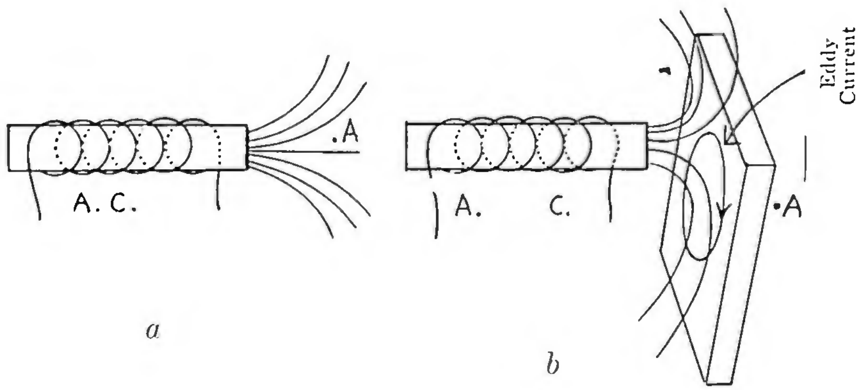


FIGURE 9

A very interesting illustration of apparent shielding is indicated in Figure 10; it represents a piece of sheath-covered wire, such as a submarine cable. If alternating current flows in the wire, voltages will be induced in the sheath and current will flow longitudinally, if possible. The formula for the mutual induction from wire to sheath is given in any handbook. The question may be asked—if alternating current flows in the sheath, will voltages be induced in the wire, these induced voltages, of course, being due to a changing magnetic field set up by the current in the sheath?

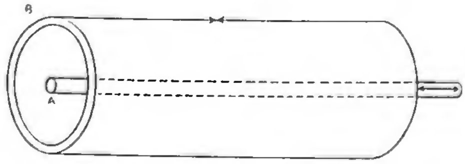


FIGURE 10

Now current flowing down a tubular conductor produces no magnetic field inside the tube, so that the apparently anomalous condition arises in which (if a voltage is induced in the wire) a voltage is induced by a changing magnetic field inside the tube when there is actually no magnetic field there. We must grant that voltage *will* be induced in the wire, because if there is mutual induction between the wire and sheath, there must be a reciprocal action between the sheath and wire; mutual induction is not a one-way action.

A reasonably clear idea of the induction of voltage in the wire by alternating current in the sheath is obtained when we conceive of the electric current as the flow of electrons, which we now know it to be. It bothers the student very frequently in the study of induced voltages to get a concept of a changing magnetic field bringing about a motion of electrons (electric charges) when he has in mind the fundamental postulate that a magnetic field can exert no force whatsoever on an electric charge.

If we conceive of a magnetic field as nothing but an electric field in motion, the picture becomes much clearer; an electric field in motion *is* a magnetic field, the direction of which depends upon the direction of the electric field and the direction of its motion. With this picture in mind we can analyze the action which induces voltages in the wire of Figure 10.

Consider two oppositely placed filament elements of the tubular sheath, as indicated in Figure 11. Consider that the electron motion in the sheath is from left to right and that the electrons are accelerated in this direction. The fields of the electrons considered (*A* and *B* of Figure 11) are radial when they are stationary, or moving with constant velocity, but have backward "kinks" produced in them when the acceleration of the electrons takes place. These two kinks are shown in Figure 11 and it will be at once perceived that when such a kink traveling out from the electron with the velocity of light reaches the central wire, electron *C* in the wire will be urged from right to left because of the component of electric field in this direction.

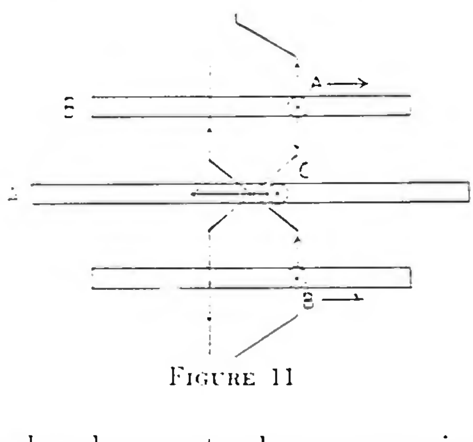


FIGURE 11

We know that induced currents always occur in opposite phase to that of the inducing current, and this picture at once gives us the reason therefor.

This same picture shows why there is no magnetic field inside a tubular conductor carrying current. All the elements of the tube may be considered in pairs, so that whatever action the pair of elements in Figure 11 brings about will be duplicated by all other pairs. The electric field from electron A, considered inside the tube, is down and moving to the right; it will produce a certain magnetic field. The electric field from B is upward and moving to the right; it will produce a magnetic field exactly equal to that produced by electron A, but in the opposite direction. The actual net magnetic field is, therefore, zero. Yet in ordinary nomenclature it is the rate of change of this field (of value constantly equal to zero) that induces the electromotive force in the wire of the cable.

Changing Electric Fields

In discussing the shielding of electric fields we said that any space completely surrounded by conducting material is completely shielded,—that the induced charges on the enclosing conductive cage completely neutralize the field which would exist without the cage. If, however, the electric charge, to which the field is due, is moving, the space inside the cage is not completely shielded. Thus in Figure 12 a charge is shown moving toward the shielding cage; insofar as the induced charges are not in their steady state (for the instantaneous position of the inducing charge under consideration), the space inside the cage is not shielded. The poorer the conductivity of the cage material, the poorer would be the shielding, because the induced charges would be so much the farther from their steady state disposition.

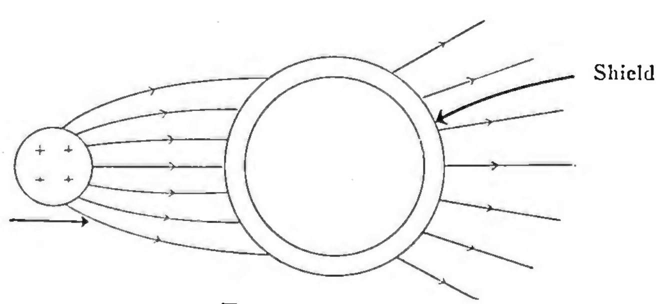


Figure 12

Leakage of Magnetic and Electric Fields

In general, a magnetic or electric field is desired in a certain part of space only; thus in a transformer it is desired that all the magnetic field be set up in the iron core where it is intended to go, and in a condenser all the electric field is supposed to be directly between the two sets of plates. That these conditions are not so is shown by the induced voltage set up in a search coil in the vicinity of a transformer and by the change of note in an oscillating radio receiving set, for example, when the hand is brought into the vicinity of the tuning condenser.

An idea of the reason for these leakage fields may be obtained from the simple diagram shown in Figure 13; the coil sets up a magnetic field in the iron core and the magnetomotive force of the coil is used up thruout the different parts of the core (not only in that part of the core inside the coil). Knowing approximately the flux thru the core and the reluctance of the core, the difference in magnetic potential between two points *A* and *B* can be calculated. By imagining a Faraday tube between these two points, the flux in the tube can be calculated from the reluctance and the difference in magnetic potential between points *A* and *B*. This external or leakage flux will evidently increase with any factor which raises the difference in magnetic potential between *A* and *B*, such as increasing flux density or the presence of a secondary coil on the right leg of the core, this coil carrying a current opposite in phase to that of the current in the magnetizing coil. Such is the case of secondary and primary windings of an ordinary transformer.

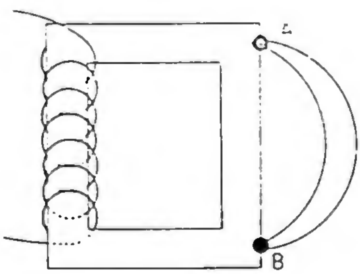


FIGURE 13

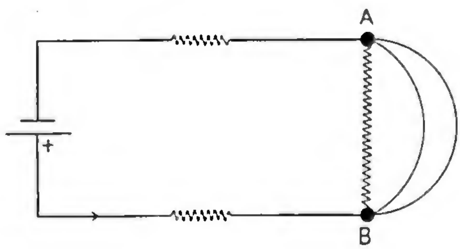


FIGURE 14

Electric leakage exists around an electric circuit for the same reason that magnetic leakage exists around a magnetic circuit, namely, a difference in electric potential between two points of the circuit. Thus in Figure 14 a current is made to flow around the circuit by the electromotive force of the battery; this emf. is used up all around the circuit, part of it in overcoming the resistance reaction between *A* and *B*. A hypothetical electric field circuit (a Faraday tube) joining *A* and *B* will have a field density proportional to the difference in electric potential of points *A* and *B*.

CIRCUITS WITH NO LEAKAGE

It is frequently said that the toroidal form of coil has no magnetic leakage, that is, no external magnetic field; such a form of coil is shown in Figure 15, and we may readily see that there is no difference in magnetic potential between two points *A* and *B* picked at random on the periphery of the toroid. For if there is a difference in potential this difference must increase as we increase the distance between them, and by imagining the two points to separate farther and farther they will soon meet on the other side of the toroid. But when they meet there is evidently no difference in potential between them so we must conclude that that is never any difference in potential between them. If there is no difference in magnetic potential, however, between any two points *A* and *B*, there can be no magnetic field between them, and hence it is said that a toroid is a perfectly shielded magnetic circuit, having no external field.

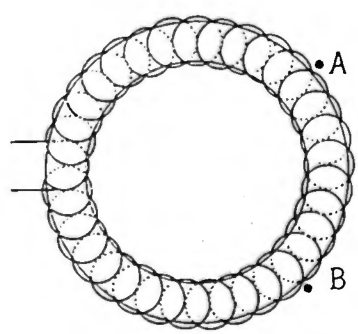


FIGURE 15

As a matter of fact this is not quite true; the toroid does have an external field and this is perpendicular to the plane of the toroid, that is, perpendicular to the paper in Figure 15. The amount of this magnetic fields is exactly the same as tho the toroid were a single turn of wire of the same diameter as the average diameter of the actual toroidal coil. This fact, while almost self-evident, was verified experimentally in our tests, by measuring the voltage induced in a search coil, first from a toroid and than from a single turn of the same diameter. The voltage induced in the search coil was the same for the two cases within experimental error.

An electric circuit around which there is no electric field (no electric leakage) is indicated in Figure 16a; a great number of cells are connected in series with an equal number of resistances to form a closed circuit. In such a circuit there is no difference in electric potential between A and B and there will be no electric field between these points. Another circuit in which large currents may be flowing and yet have no measureable difference of potential between any two points is shown in Figure 16b.[2] An alternating magnetic field set up by a solenoid is supposed to thread a copper ring, the axis of the field being perpendicular to the paper (in Figure 16b) and thru the centre of the ring. Such an alternating field will set up large currents in the ring, yet any two points, such as A and B, have no difference of potential whatsoever between them.

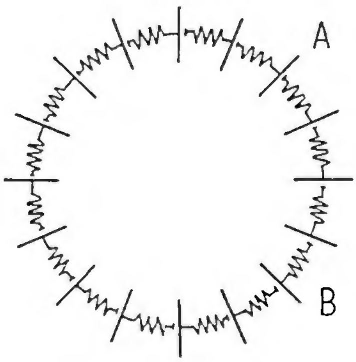


FIGURE 16a

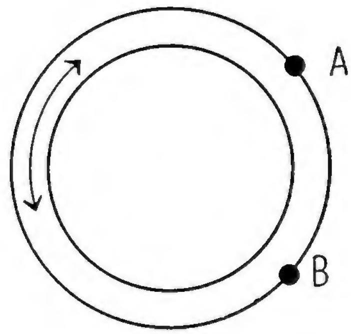


FIGURE 16b

The foregoing ideas regarding leakage fields may be summarized as follows—*any circuit in which the emf. (or mmf.) generated per differential length is the same as that used up in the same length, in overcoming the resulting reactions in this part of the circuit, will have no external field, as no point in the circuit will be at a potential different from that of any other.*

A THEORY OF SHIELDING

Leaving out of the question for the moment shields made of ferromagnetic materials, we may say that shielding is due to the eddy currents set up in the shielding material. In the general case, the paths of the eddy currents are not readily determined, so we will consider the easiest case, where the amount and position of the eddy current can be exactly determined. In Figure 17 is shown a short solenoidal coil A, another coil B, and between them a third coil C. If the current is set up in A, the magnetic field from this coil will naturally reach into B and induce voltages therein. This inducing field now has to link with coil C,

[2] In such circuits the potential is said to be a multiple valued function, having varying values as the circuit is traversed one or more times in the same direction.

however, and will set up currents therein which will tend to prevent the flux from A reaching into B. Coil C is said to be shielding coil B. The greater the eddy currents in C (up to a certain limit) and the more nearly they lag 180 degrees behind the current in A, the more perfectly is B shielded from A.

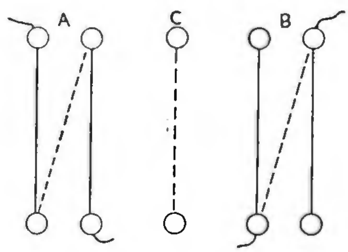


FIGURE 17

The extent of the shielding action can be derived as follows:

Let M = coefficient of mutual induction between A and B when C is absent (that is, without C). Then the voltage induced in B by a current i in A is given by $e = M\frac{di}{dt}$. Let M' = the correspondingly defined value of M when coil C is present. Then we shall define the shielding as equal to $\frac{M-M'}{M} \times 100$ percent. Evidently if the shielding is perfect M' = zero and the above formula yields a value of 100 percent.

To determine the shielding due to a certain arrangement, therefore, it is only necessary to measure the mutual induction with and without the shielding circuit present and to use the above formula.

The best method for measuring M will depend somewhat on the constants of the coils A and B and of the frequency to be used. At audible frequencies the best method is to measure the effective self-induction of the two coils A and B connected in series, once with the mmfs. in the same direction and again with the mmfs. in opposition. One-quarter of the difference of the two values for L so found is the mutual induction of the two coils, as can readily be seen by writing the equation of reactions of the circuit for the two cases.

Above audible frequency the bridge method may still be used employing the heterodyne method of determining when the bridge is balanced. At frequencies so high that unknown errors creep into the bridge determination, the resonance method may best be used for determining the self-induction required.

In case the shielding circuit involves iron, the bridge scheme is not applicable, as will be pointed out later.

A Short-Circuited Coil Used as Shield

Let two coils of inductances L_1 and L_2 be connected in series across a voltage $E_m \sin \omega t$, so that the field of L_2 can be reversed with respect to that of L_1 as shown in the diagram of Figure 18. Let a third coil L_3 be inserted between coils 1 and 2

The calculation of the change in mutual induction M_{1-2} can be most easily carried out by considering the induced voltage in the circuits. If it is supposed that one ampere (effective) of current is flowing in coils 1 and 2, then the induced voltage in this circuit, 90 degrees behind the current, is at once a measure of the reactance of the circuit. In part, this induced voltage is due to the self-induction of coils 1 and 2, and their mutual induction, while the rest of the induced voltage must be due to current set up in coil 3 reacting back on the original circuit.

If we consider two coils only, the second one being short-circuited, with a current of one ampere in coil 1, the induced voltage, E_2, in coil 2 will be ωM, and the current will be $\frac{\omega M}{Z_2}$ The component of this current 90° behind the voltage E_2 will be $\frac{\omega M}{Z_2^2}\omega L_2$. This current will induce in circuit 1 a voltage 90° behind itself in phase and in magnitude equal to $\frac{(\omega M)^2}{Z_2^2}\omega L_2$, and this voltage in circuit 1 will be in phase opposition to the inductance reaction in this circuit.

The total induced voltage in circuit 1, 90° behind the current in this circuit is $\omega L_1 - \frac{(\omega M)^2}{Z_2^2}\omega L_2$, and this is the effective reactance of circuit 1. The effective self-induction can be obtained by dividing thru this expression by ω. It will be seen that the presence of circuit 2 diminishes the self-induction of circuit 1 by an amount $\left(\frac{\omega M}{Z_2}\right)^2 L_2$.

The coils of Figure 18 can be treated in the same manner, remembering that the current in coil 3 is due to emfs. induced from both coils 1 and 2.

Let R_1, R_2, and R_3 be the resistances of the three coils and M_{1-2}, M_{1-2}', M_{2-3} and M_{1-3} the mutual inductances between coils 1 and 2, 2 and 3, and 1 and 3, M_{1-2} representing the case in which coil 3 is open-circuited and M_{1-2}' the case in which the circuit of the coil is closed. Assume the reversing switch to be thrown so that the fields of coil 1 and 2 are in the same direction and the effective voltage E to be such that the effective current in coils 1 and 2 is one ampere when coil 3 is short-circuited. The effective induced voltage in coil 3 due to the changing current in coils 1 and 2, and 90 degrees behind the current will be

$$\omega\,(M_{1-3}+M_{2-3})$$

The component of the current in coil 3 due to this voltage and 90° behind it will be

$$\frac{\omega^2(M_{1-3}+M_{2-3})L_3}{Z_3^2}$$

The voltage in the circuit made up of coils 1 and 2, due to this component of current and 90° behind it, will be

$$\frac{\omega[\omega^2(M_{1-3}+M_{2-3})^2\,L_3]}{Z_3^2}$$

This voltage will be 270° behind the one ampere current supposed in the circuit of coils 1 and 2, and therefore 180° behind the inductive reaction $\omega(L_1+L_2+2\,M_{1-2})$. It can, therefore, be considered as an inductive reaction, and the effective inductive reaction in the circuit containing coils 1 and 2 is decreased by it to the value given by

$$\omega(L_1+L_2+2\,M_{1-2})-\frac{\omega[\omega^2(M_{1-3}+M_{2-3})^2L_3]}{Z_3^2}$$

The effective inductance in this circuit when coil 3 is short circuited is therefore

$$L'''=L_1+L_2+2M_{1-2}-\frac{\omega^2(M_{1-3}+M_{2-3})^2\,L_3}{Z_3^2} \qquad (1)$$

When the reversing switch is thrown so that the electromagnetic lines of force linking coil 2 are in the opposite direction to those linking coil 1, and coil 3 is short circuited, the voltage in coil 3 due to the one ampere current in coil 2 is opposite in phase to that due to this current in coil 1. The effective voltage in coil 3 due to one ampere in coil 1 and 2, and 90° behind it will be $\omega\,(M_{1-3}-M_{2-3})$. The component of the current in coil 3, 90 behind this voltage, will be

$$\frac{\omega^2(M_{1-3}-M_{2-3})L_3}{Z_3^2}$$

The voltage induced in coils 1 and 2 due to this component of current and 90° behind it will be

$$\frac{\omega[\omega^2(M_{1-3}-M_{2-3})^2\,L_3]}{Z_4^2}$$

As in the preceding case, this voltage will be 180° behind the inductive reaction and the effective inductance in this circuit when coil 3 is short-circuited is therefore

$$L^{IV}=L_1+L_2-2\,M_{1-2}-\frac{\omega^2(M_{1-3}-M_{2-3})^2\,L_3}{Z_3^2} \qquad (2)$$

The effective mutual inductance between coils 1 and 2, M_{1-2}', is $\frac{L'''-L^{IV}}{4}$ and from equations (1) and (2)

$$M_{1-2}'=M_{1-2}-\frac{\omega\,L_3}{Z_3^2}\,M_{1-3}\,M_{2-3}$$

The change in the mutual inductance between coils 1 and 2, due to coil 3, which is short-circuited, is therefore

$$\Delta\,M_{1-2}=M_{1-2}-M_{1-2}'=\frac{\omega^2\,L_3}{Z_3^2}\,M_{1-3}\,M_{2-3} \qquad (3)$$

Expressing the mutual inductances in terms of the coefficients of coupling of their respective coils, we have

$M_{1-2}=k_{1-2}\sqrt{L_1\,L_2}$, $M_{1-3}=k_{1-3}\sqrt{L_1\,L_3}$, and $M_{2-3}=k_{2-3}\sqrt{L_2\,L_3}$.

The expression we shall use as a measure of shielding is $\frac{\Delta\,M_{1-2}}{M_{1-2}}$ and from equation (3) and the preceding relations we have

$$\frac{\Delta\,M_{1-2}}{M_{1-2}}=K\frac{\omega^2\,L_3^2}{Z_3^2} \qquad (4)$$

where $K=\frac{k_{1-3}\times k_{2-3}}{k_{1-2}}$ which is constant for a given arrangement of coils. Also we have $Z_3^2=R_3^2+(\omega\,L_3)^2$, and $\omega=2\,\pi f$.

The shielding depends on the frequency of the alternating electromagnetic field and on the inductance and resistance of the shielding coil according to the expression of equation (4). The effect of the frequency and resistance only were examined experimentally, as it is not feasible to vary the inductance, keeping the resistance constant. Theoretical values of $\frac{\Delta\,M_{1-2}}{M_{1-2}}$ were calculated from equation (4) using the same values of K, L_3, R_3, and f as were used to obtain the experimental results.

The coils used for the experimental results were wound with Number 24 insulated copper wire on hard rubber forms 1.3 cm. wide and 12 cm. in diameter. The coils used for frequencies up to 50,000 cycles were bank wound with 4 layers of wire having the respective inductances $L_1=0.777$ mh., $L_2=0.732$ mh., and $L_3=0.760$ mh. The shielding coil L_3 was used for all frequencies.

The two coils used with L_3 for frequencies between 50,000 and 100,000 cycles were bank wound with two layers of wire having the inductances $L_1 = 0.2160$ mh. and $L_2 = 0.2413$ mh. and the two used with L_3 for the high frequencies were single layer coils of inductances $L_1 = 0.075$ mh. and $L_2 = 0.077$ mh.

The three coils were arranged with the shielding coil, L_3, between the other two coils so that the coefficient of coupling between each pair was a maximum. One of the two outside coils was connected in series with the other by means of a reversing switch as shown in Figure 18. The shielding coil was connected in series with a variable resistance to determine the effect of resistance of the shielding circuit on the amount of shielding obtained. The curves of Figures 19 and 20 show the theoretical and the experimentally determined results; they differ by amounts within the experimental error.

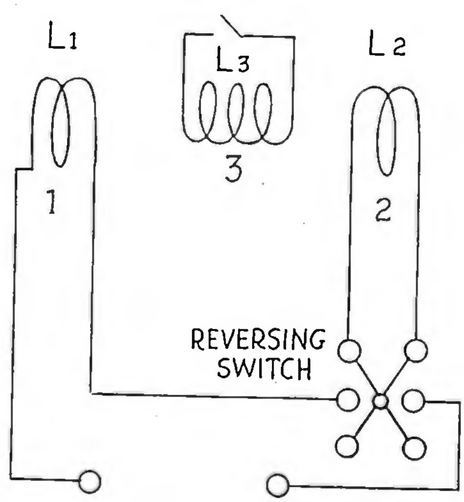


FIGURE 18

USE OF SHEETS OF NON-PERMEABLE METALS AS SHIELDS

The shielding coil, L_3, was replaced by square sheets of different thicknesses of copper, brass, and tin foil in this case.

In general, shielding is accomplished about as indicated in Figure 21; a sheet of conductor is interposed between the coil carrying current, A, and the coil B to be shielded from the current. The current in the shield in the case is in the form of a circular band having different densities in different parts of the shield about as indicated in Figure 21. The density will be greatest at the surface of the metal sheet next to coil A, and in this surface it will be greatest where it is closest to the conductors of coil *A*. In Figure 21 an attempt to show this is made by the proximity of the + and − signs.

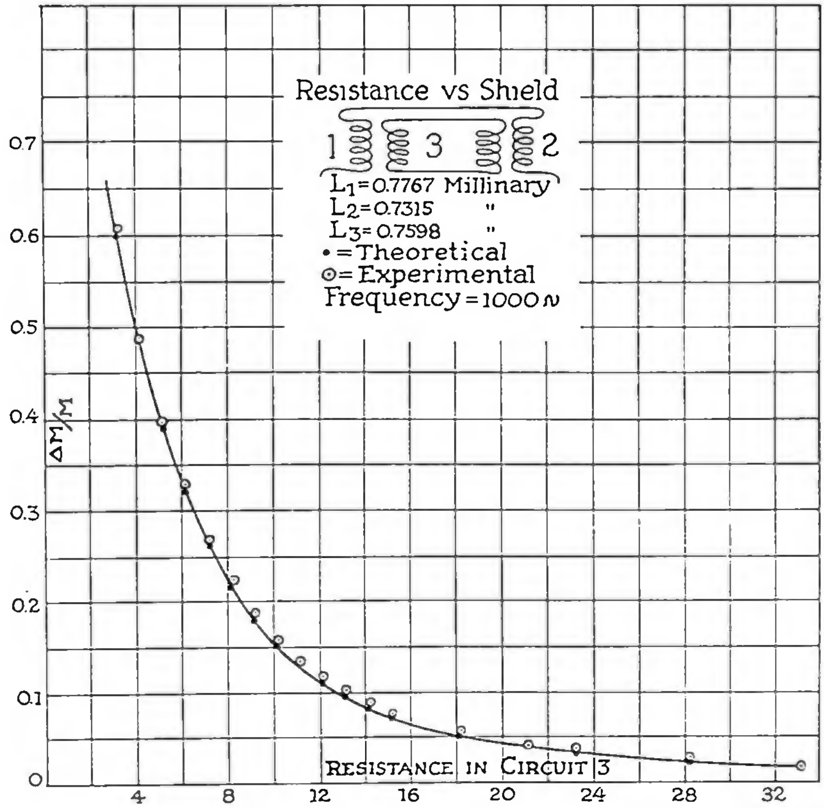


FIGURE 19

The curves of Figures 22, 23, and 24 give the relation between shielding and frequency for different thicknesses of the different metals between 0 and 18,000 cycles. The curves of Figures 25 and 26 show this relation for frequencies between 1,000 and 1,000,000 cycles. Logarithmic paper was used for these two sets of curves due to the large range of frequencies.

The shielding depends on the thickness of a particular kind of shield for a constant frequency as shown by the curves of Figures 27, 28, and 29.

The effective resistance of coils 1 and 2 depends somewhat on the frequency of the alternating electromagnetic field when the shield is between the coils and the fields of the coils are in the same direction. The curves of Figures 30, 31, and 32 show this relation for copper, brass, and tin foil as shields.

It is to be noticed that for a given frequency a definite thickness of shield introduced a maximum resistance into the shielded circuit.

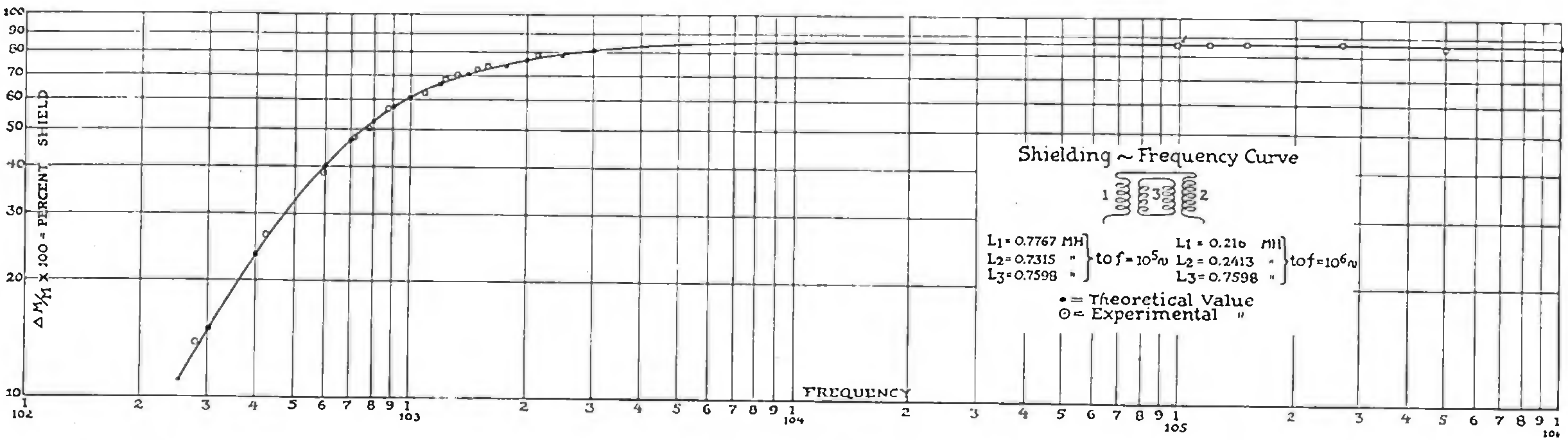

Shielding ~ Frequency Curve
1
3
2
L1 = 0.7767 MH
L2 = 0.7315 "
L3 = 0.7598 "
to f = 10^5 ~
L1 = 0.216 MH
L2 = 0.2413 "
L3 = 0.7598 "
to f = 10^6 ~
• = Theoretical Value
⊙ = Experimental "
ΔM/M x 100 = PERCENT SHIELD
FREQUENCY

Figure 20

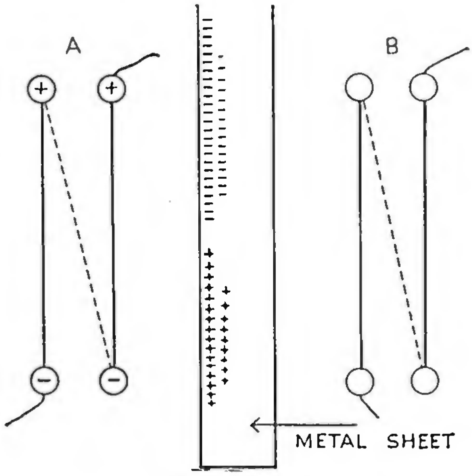


FIGURE 21

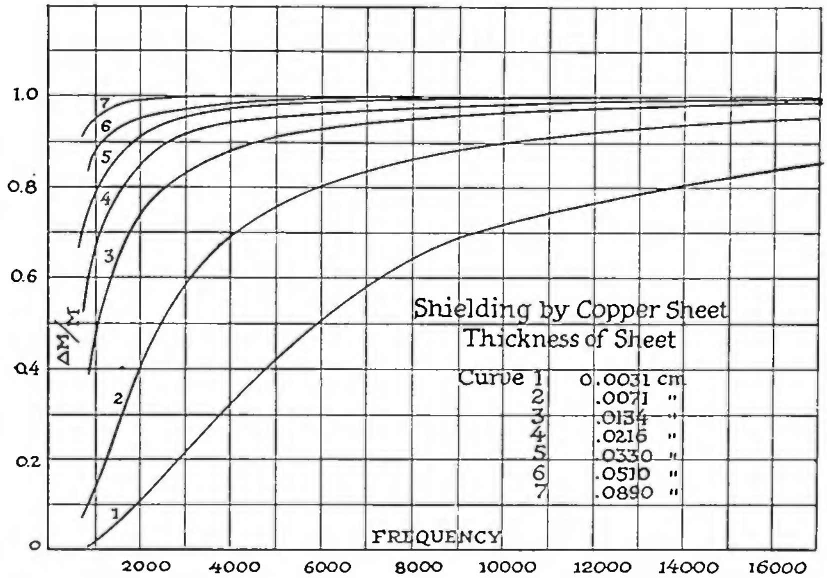


FIGURE 22

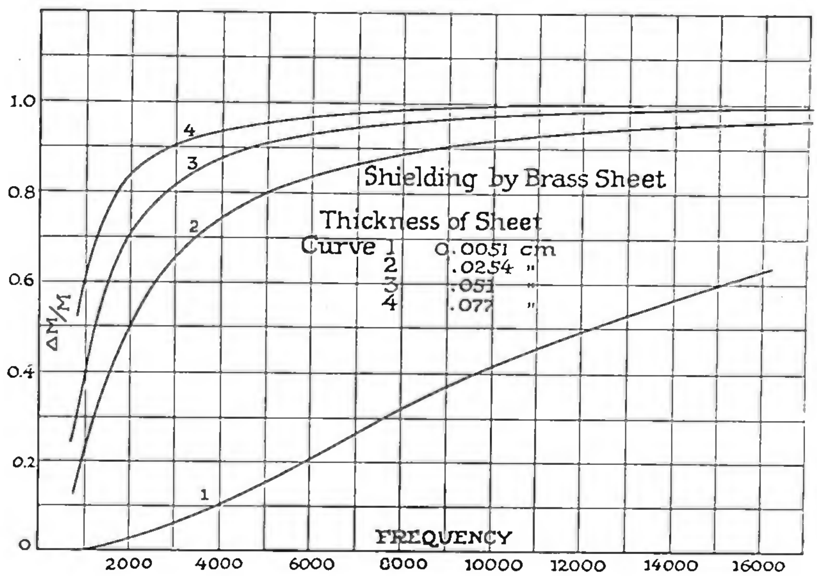


FIGURE 23

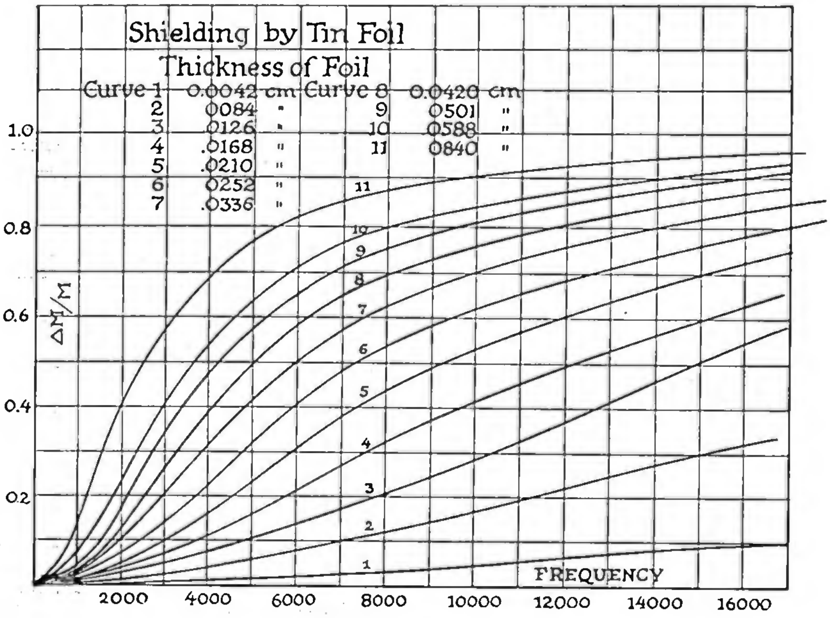


FIGURE 24

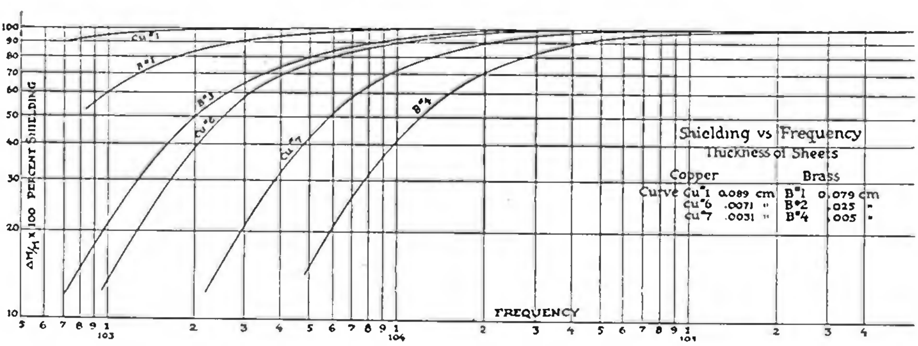


FIGURE 25

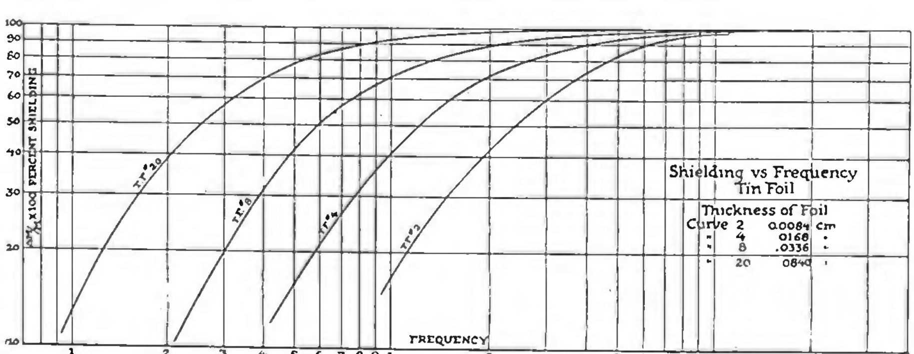


FIGURE 26

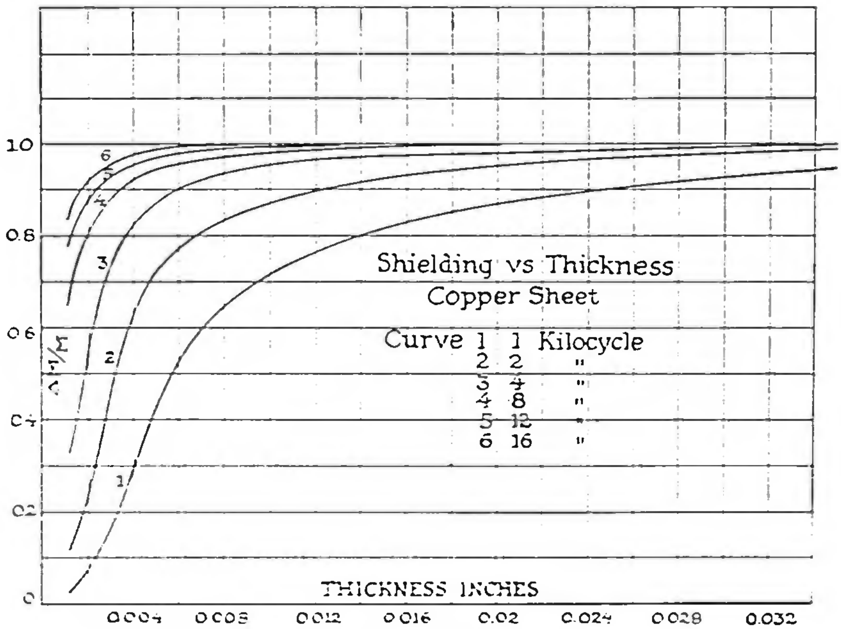


Figure 27

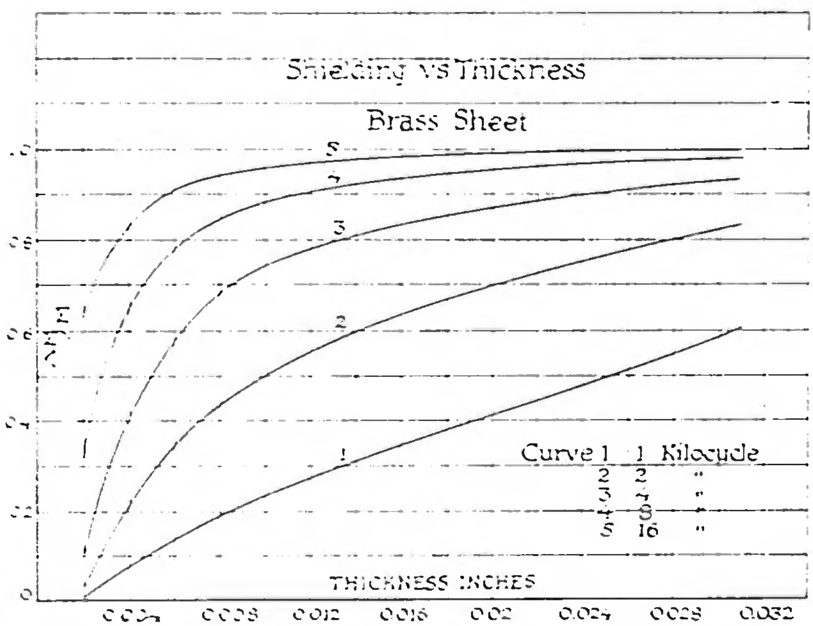


Figure 28

The shielding depends on the resistivity of the shielding metal for a definite frequency and thickness as shown by the curves of Figure 33.

The conclusion to be drawn from these results is that maximum shielding with minimum increased resistance is obtained by using a thick sheet of material of high conductivity.

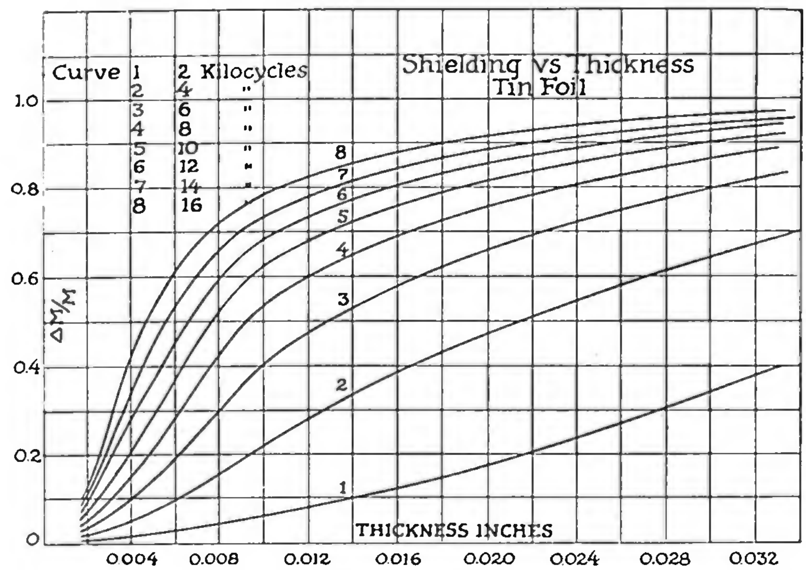


FIGURE 29

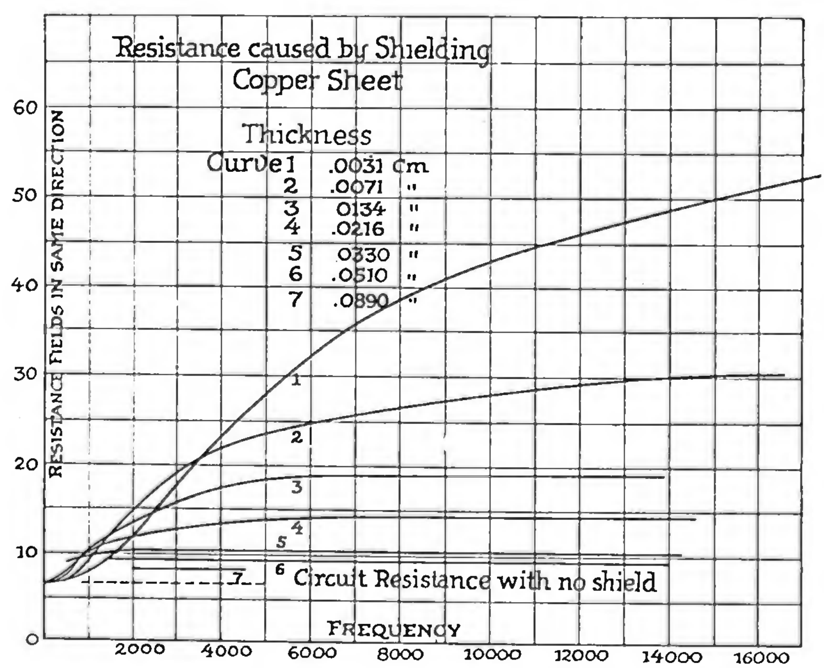


FIGURE 30

Position of Shielding Plate

The square sheet of metal used for a shield was arranged in each case so that its center coincided approximately with the intersection of the line joining the centers of the two coils and the plane of the shield. The shield was moved about, keeping the coils in the same position with respect to each other and no

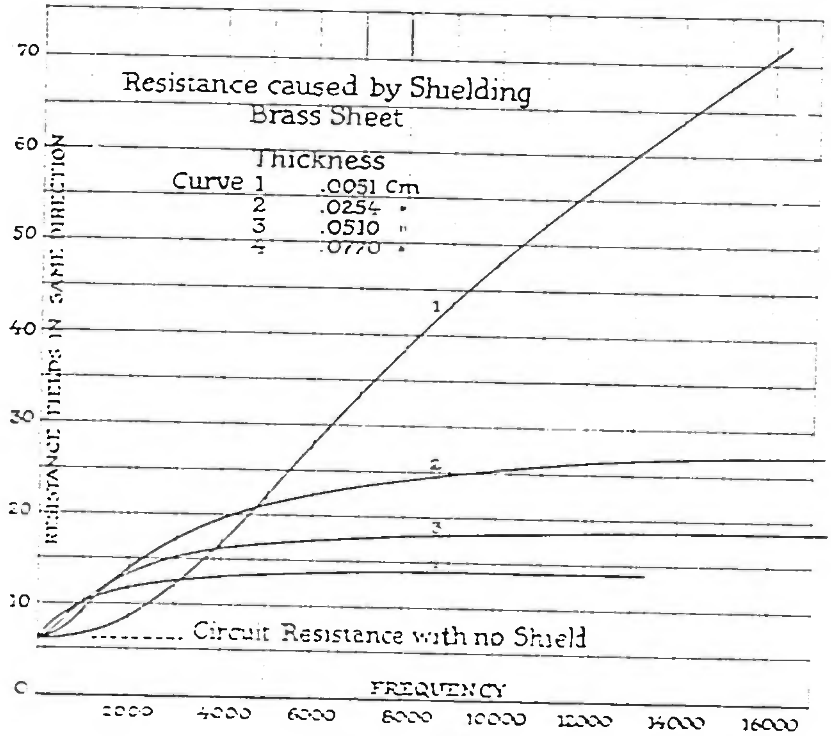


FIGURE 31

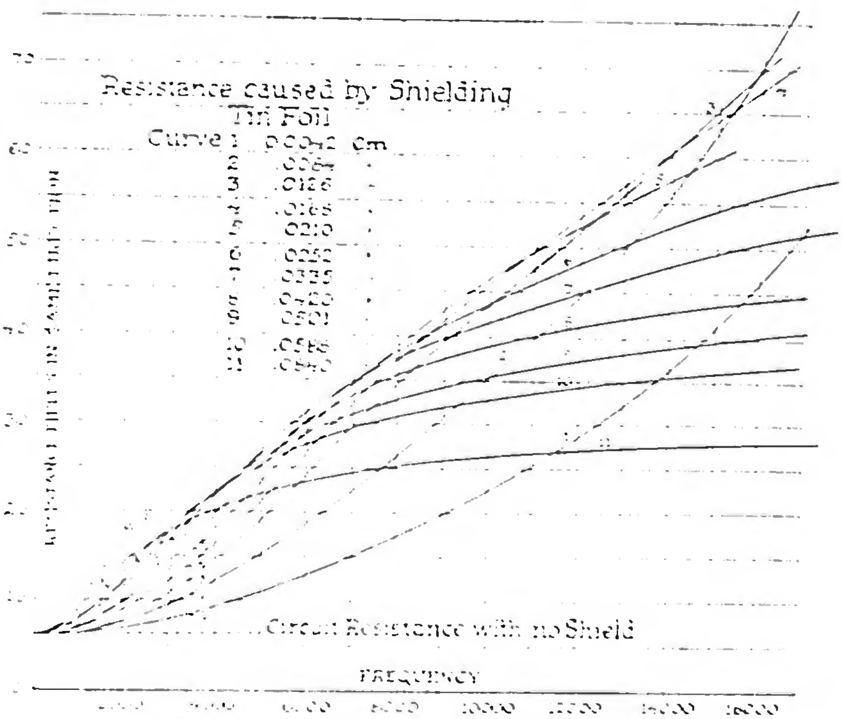


FIGURE 32

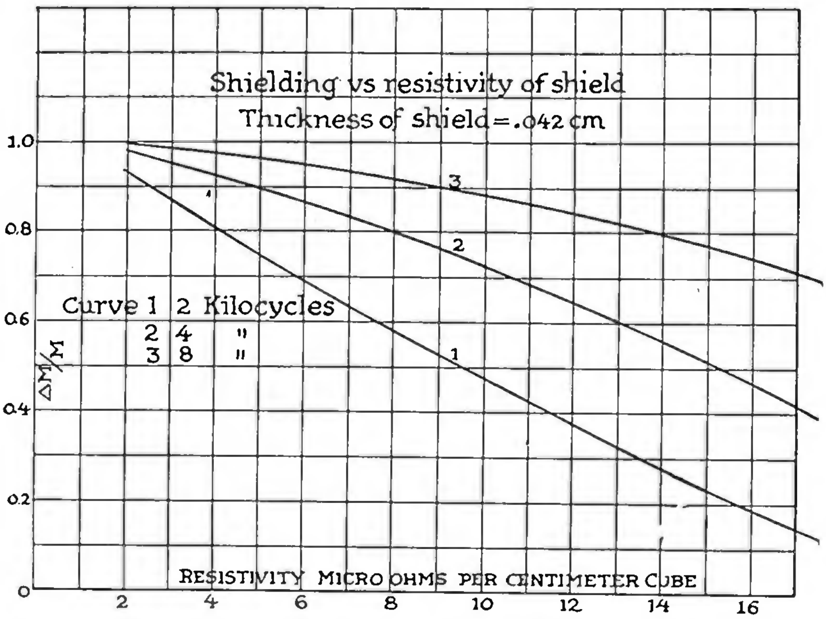


FIGURE 33

difference in the shielding effect was noticed until less than a half an inch of the shield was extending outside of the coils on one side. This was tried with copper and zinc and the results were the same.

Effect of Shape of Shielding Plate

A sheet of copper 0.021 cm. thick was slit diametrically across the effective shielding area and $\frac{\Delta M_{1-2}}{M_{1-2}}$ was obtained for 1,000 cycles. The result was 4 percent less than that for the same sheet without the slit. A second diametrical slit was made in this sheet of copper at right angles to the first slit and $\frac{\Delta M_{1-2}}{\Delta M_{1-2}}$ was obtained for the same frequency, giving a result 4 percent less than that for one slit.

An ordinary piece of copper mesh was used as a shield for different frequencies, and the results showed very little shielding effect. A border of solder 0.5 cm. wide was put around the edge of this shield so as to make good contact between the ends of the wires, and the shielding was increased approximately 75 percent.

In one case where a high degree of shielding was necessary, all the apparatus was mounted on a heavy copper plate, and a heavy copper box arranged to lower over the apparatus, to rest on the copper plate. Altho the fit was reasonably good, the shielding was comparatively poor. Some copper strips were soldered on the base plate of copper to make a ditch into which mercury could be poured; the ditch of mercury was so placed that the lower edge of the copper cover rested in the mercury. The shielding was now nearly perfect and the idea to be derived from this experience may be stated as follows: *if shielding is to be obtained by eddy currents, they must be free to flow as they will.* Any imperfect joint in the shield, which tends to constrain the eddy currents to restricted paths, will seriously interfere with the shielding obtainable.

The Case which Makes Use of Sheets of Iron as a Shield

When iron is used as the shield, the previously-described method of measuring the shielding leads to anomalous results; thus the two coils, connected in series, having an iron plate between them for shield may have an effective self-induction greater when their mmfs. are in opposition than when they are in conjunction.

To measure the shielding in such a case, the apparatus was arranged as in Figure 21; coil *A* is connected to a source of variable frequency thru an ammeter and coil *B* is connected to a vacuum tube voltmeter. The mutual induction between the two is proportional to the voltage induced in coil *B*, the current and frequency used in coil *A*. Now the current and frequency of coil *A* being maintained constant, the iron shield was slipped between the two coils and the voltage induced in coil *B* was again measured. If the shielding were perfect, no voltage would be induced in *B*; the shielding is given by the ratio of the difference of the two voltages to the original voltage.

As was the case for other shielding metals, it would be expected that the shielding would increase in amount as the iron was increased in thickness; such is shown to be the case in Figure 34. At the lower frequencies the degree of shielding will depend upon the permeability of the iron, and, as this varies greatly with different kinds of iron and the amount of magnetomotive force used, the results of Figure 34 can be used in a qualitative way only.

At low frequencies where the eddy currents do not assure very effective shielding, the iron may be expected to show up as the superior shield because of the effect referred to in connection with Figure 5. At high frequencies the copper, allowing larger eddy currents to flow, might be expected to show up as the better shield, and such is shown to be the case in Figure 35, which figure shows how iron and copper compare thruout the range of audible frequencies.

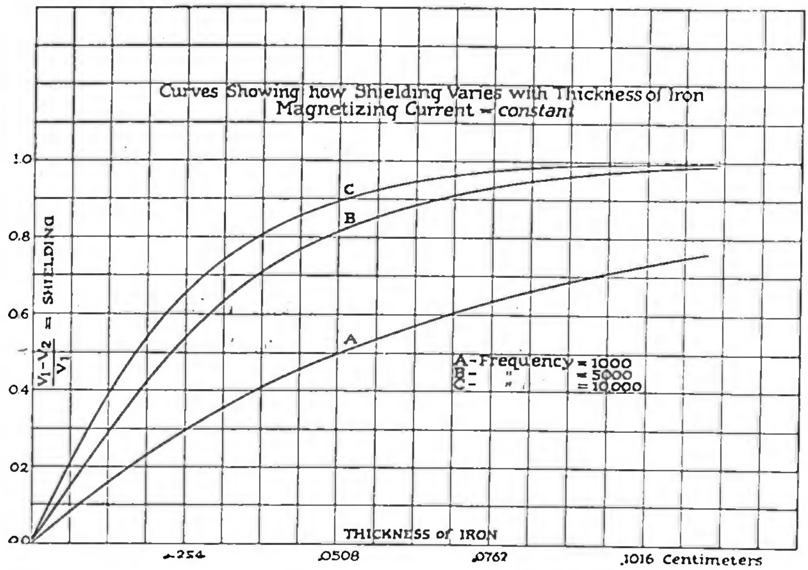


FIGURE 34

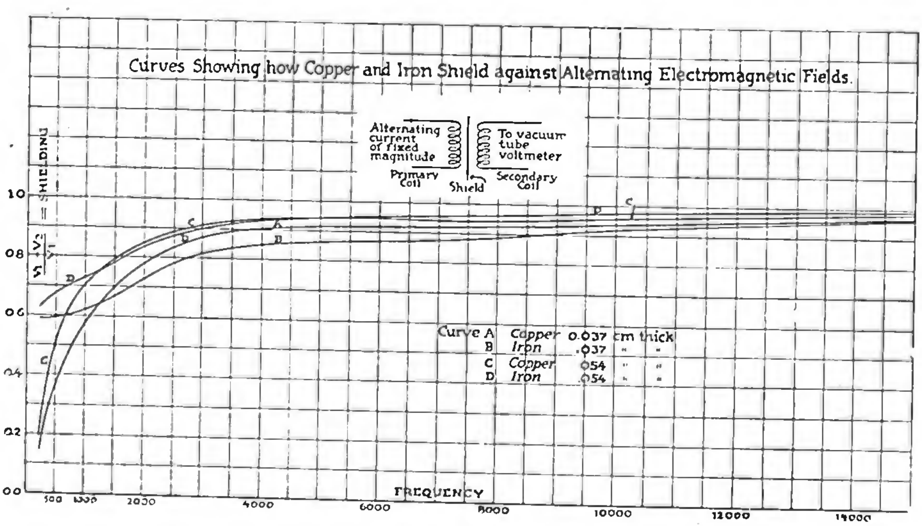


FIGURE 35

CONCLUSIONS

The theoretical and experimental results, when a short-circuited coil was used for a shield, show that:

1. The shielding is zero when either the inductance of the shielding coil or the frequency of the alternating electromagnetic field is zero, and is perfect when the resistance of the shielding coil is zero.

2. When the frequency of the alternating electromagnetic

field and the inductance of the shielding coil remain constant and the resistance in the circuit with this coil is varied, the shielding decreases, approaching zero as the resistance becomes larger.

3. When the resistance and inductance of the shielding coil remain constant and the frequency of the electromagnetic field is varied, the shielding increases, approaching a limit as the frequency becomes very large. This limit is small for large values of the shielding coil resistance and approaches perfect shielding for small values of this resistance.

4. When the frequency of the alternating electromagnetic field and the resistance of the shielding coil remain constant and the inductance of this coil is varied, the shielding increases approaching a limit as the inductance becomes large. This limit is small for large values of the shielding coil resistance and approaches perfect shielding when this resistance is small.

The results, when sheets of non-permeable metals were used as shields, show that:

1. When the resistivity and thickness of the metal remain constant and the frequency of the alternating electromagnetic field varies, the shielding increases approaching values close to unity as the frequency becomes infinitely large.

2. When the frequency of the alternating electromagnetic field and the resistivity of the metal remain constant and the thickness of the shield is varied, the shielding increases and approaches perfect shielding as the thickness increases.

3. When the frequency of the alternating electromagnetic field and the thickness of the metal remain constant and the resistivity is varied, the shielding decreases with an increase in resistivity.

4. Shielding is always accompanied by an increase in the resistance of the shielded circuit; for a given kind of metal at any specified frequency a certain thickness of shield introduces a maximum resistance into the shielded circuit. The thickness of shield which gives maximum added resistance to the shielded circuit decreases as the frequency increases.

5. The effective shielding area of the sheet of metal is that which cuts the electromagnetic lines of force within the coil.

6. The shielding qualities of a sheet of metal are decreased by slits across the effective shielding area of the metal, which constrain the eddy currents to flow in other than the natural paths.

7. The shielding of copper mesh against electromagnetic induction depends on the connections between the wires of the

mesh so that good connections cause good shielding and poor connections cause poor shielding.

8. The results for a permeable metal show that the shielding may be better or poorer than that afforded by copper, depending upon the frequency of the alternating electromagnetic field, the thickness, and resistivity of the metal of the shield.

SUMMARY: An experimental investigation of the shielding of electric and magnetic fields is reported, for both constant and changing fields.

The effect of using iron shells, or sheets, for shielding against the fields of permanent magnets, as well as those set up by electric currents, is considered; the best form for the iron sheets is deduced and an expression for a measure of the shielding action is suggested.

The reason for the leakage of magnetic and electric fields is shown to be due to differences of magnetic or electric potentials in the circuit in which the fluxes are being set up; several cases are cited in which no external fields are set up, as the circuits exhibit no differences in potential.

An expression for the shielding effect of a short-circuited coil is deduced and experimental verification is offered for frequencies between 10^2 and 10^6 cycles per second.

Finally the shielding effect of metal sheets against changing magnetic fields is analyzed and experimental results are given to show how the action depends upon the characteristics of the material of which the shielding plate is made, its thickness, and upon the frequency being used. The effect of slits in the metal sheet, and the value of wire mesh, is indicated.

"THE STRAIGHT-LINE FREQUENCY" VARIABLE CONDENSER*

By

Henry C. Forbes

(Colonial Radio Corporation, New York)

The type of rotary variable condenser having its plates so shaped that the graph of the relation between the frequency of the current in the circuit in which it is connected, and the angle of rotation of the condenser, is a straight line, possesses several advantages. Perhaps the first of these is that a direct scale calibration of the condenser in terms of frequency will be of uniform spacing; that is, each division of the scale will represent a certain number of cycles, this number being constant over the range of the condenser.

Under the system used at the present time in this country, there are assigned approximately one hundred communication channels to the broadcast service, extending from a frequency of 550 kc. to 1,500 kc. (546 to 200 meters, respectively), each with a frequency difference of approximately 10 kc. It is then quite convenient so to construct a variable condenser for use as a tuning element in a transmitting or receiving circuit that each division on the scale shall represent ten kilocycles. Since it is customary to use scales with one hundred divisions to a 180° angle of rotation, this arrangement will permit the frequency range of the broadcast service to be included within the one hundred divisions on the scale and allow a slight over-lap at either end.

The shape of plate for a condenser which will tune a circuit in this manner is dependent upon the constants of the particular circuit in which it is to be used. This will be shown in the development which follows:

The fundamental condition for a straight-line frequency condenser is that:

$$\frac{\Delta f}{\Delta \theta} = -K \qquad (1)$$

* Received by the Editor, January 21, 1925.

where Δf = cycles per division
$\Delta \theta$ = angular measure of one division
K = a constant

Expressed as differentials, we have:

$$df = -K\,d\theta \tag{2}$$

In a tuned circuit,

$$f = \frac{1}{2\pi\sqrt{LC}} = \frac{D}{\sqrt{C}}$$

where f = frequency
C = capacity of tuned circuit
L = inductance of tuned circuit
$D = \frac{1}{2\pi\sqrt{L}}$, a constant of the circuit for variable C.

Integrating $$\frac{D}{\sqrt{C}} = -K\theta + B$$

Determining the value of B:

when $\theta = 0$, $C = C_o$

Hence $$B = \frac{D}{\sqrt{C_o}}$$

and $$C = \left[\frac{D}{\frac{D}{\sqrt{C_o}} - K\theta}\right]^2 \tag{3}$$

where C_o = capacity in tuned circuit at zero setting of condenser.

The capacity of a multi-plate air condenser neglecting the edge effects is:

$$C = nkA$$

where n = number of dielectric spaces
$k = \frac{10^{-11}}{36\pi d}$, a constant
d = gap between plates
A = active area of each plate.

In the rotary plate condenser this becomes:

$$C = \frac{nk}{2}\int r^2\,d\theta \tag{4}$$

where r = radius vector to edge of rotary plate at the angular setting θ.

Equating (3) and (4), and differentiating:

$$\frac{dC}{d\theta} = \frac{nk}{2} r^2\,d\theta = 2\left[\frac{D}{\frac{D}{\sqrt{C_o}} - K\theta}\right]\left[\frac{DK}{\left(\frac{D}{\sqrt{C_o}} - K\theta\right)^2}\right]d\theta$$

or

$$r = \sqrt{\frac{4\,D^2}{n\,k\,K^2\left[\frac{D}{K\sqrt{C_o}} - \theta\right]^3}}$$

To take account of the customary cut-out of the stationary plates, we have:

$$r = \sqrt{\frac{4\,D^2}{n\,k\,K^2\left[\frac{D}{K\sqrt{C_o}} - \theta\right]^3} + r_1^2} \qquad (5)$$

which is the equation of the desired rotary plate when

$D = \frac{1}{2\,\pi\sqrt{L}}$, a circuit constant for variable C.

$K = -\frac{d\,f}{d\,\theta} = \frac{f_o - f_{100}}{\pi}$, cycles per radian on condenser scale.

n = number of dielectric spaces in condenser.

$k = \frac{10^{-11}}{36\,\pi\,d}$, a constant for the capacity of the condenser.

C_o = total capacity in circuit when $\theta = 0$.

θ = angle of rotation of rotor plates.

r_1 = radius of cut-out on stationary plates.

d = air-gap between plates.

All dimensions are in centimeters, the inductance is in henrys, the capacity in farads, and the angles are expressed in radians.

The capacity of the condenser alone, at any angular position of the rotor, θ', is:

$$C_\theta = \frac{D^2}{\left[\frac{D}{\sqrt{C_o}} - K\,\theta'\right]^2} + \frac{n\,k}{2} r_1^2\,\theta' - C_o \qquad (6)$$

SUMMARY: The equation for the shape of the rotary plates in a rotary variable condenser is developed so that the frequency—angular setting characteristic is a straight line. The equation for the capacity of this condenser at any angular setting is also given.

CALCULATION OF THE MUTUAL INDUCTANCE OF CO-AXIAL CYLINDRICAL COILS OF SMALL RADIAL DEPTH*

By

F. B. Vogdes

(Research Laboratory, General Electric Company, Schenectady, New York)

Many radio circuits utilize the mutual inductance between co-axial cylindrical coils of small radial depth.

If a set of curves, similar to Figure 1a, showing the mutual inductance between co-axial circles is available, the mutual inductance of such coils may be estimated quite rapidly by a simple process of summation. The method of constructing such curves is described in a recent publication of the Bureau of Standards[1] and several examples are given.

Figure 1a differs from these curves only in that it is made slightly more convenient for the purpose at hand, by adding intermediate curves. The process of summation referred to is accomplished by dividing the coils into a number of parts, determining the mutual inductance between the parts separately, and then adding the values so obtained to get the total. This is very rapidly accomplished if a templet representing the coils drawn to scale is constructed. Cutting out this templet and sliding it over the curves gives the mutual inductances of the parts and all that remains to be done is to sum them up and make allowance for the scale and numbers of turns in the coils.

Figure 1b illustrates such a templet representing two coils "A" and "B." Coil "A" has a radius of 10 cm. (3.94 in.) and length of 8 cm. (3.15 in.) and contains 85 turns. Coil "B" has a radius of 13 cm. (5.12 in.) and length of 5 cm. (1.97 in.) and contains 62 turns. Coil "A" is drawn to such a scale that its radius corresponds to 1 cm. in Figure 1a. The coil "A" has been divided into four sections, designated a_1, a_2, a_3, etc., and coil "B" has been divided into three sections designated b_1, b_2, etc.

*Received by the Editor, December 24, 1924.

[1] "Formulas, Tables and Curves for Computing the Mutual Inductance of Two Co-axial Circles," by Harvey L. Curtis and C. Matilda Sparks, "Scientific Paper 492, Bureau of Standards."

Let N_A = number of turns in "A"
N_B = number of turns in "B"
n_A = number of arbitrary sections in "A"
n_B = number of arbitrary sections in "B"
r_A = radius of coil "A"

Then the number of turns per section is $\frac{N_A}{n_A}$ for "A" and $\frac{N_B}{n_B}$ for "B" and the mutual inductance between any two sections is given by

$$M_{ab} = r_A \frac{N_A N_B}{n_A n_B} M'_{ab}$$

where M'_{ab} is the mutual inductance of two co-axial circles obtained by application of the templet to Figure 1a. The mutual inductance of the two coils is therefore

$$M = r_A \frac{N_A N_B}{n_A n_B} \Sigma M'_{ab}$$

For the case under consideration

$r_A = 10$	$N_B = 62$	$n_B = 3$
$N_A = 85$	$n_A = 4$	

Finding the values of $M'ab$ for the different sections gives—

$M'a_1b_1 = 5.25$	$M'a_3b_1 = 8.80$
$M'a_1b_2 = 4.25$	$M'a_3b_2 = 6.85$
$M'a_1b_3 = 3.45$	$M'a_3b_3 = 5.50$
$M'a_2b_1 = 6.70$	$M'a_4b_1 = 11.40$
$M'a_2b_2 = 5.40$	$M'a_4b_2 = 8.90$
$M'a_2b_3 = 4.33$	$M'a_4b_3 = 7.00$

and the sum of these is 77.83. Hence the mutual inductance is given by

$$M = 10 \times \frac{85 \times 62}{4 \times 3} \times 77.83 = 341{,}500 \text{ milli-microhenrys.}$$

The accuracy of the results obtained is dependent on the number of sections into which the coils are divided. In general the sections should be taken small enough so that the value of M'_{ab} for the midpoints of the sections will be a good average for that function over the whole of both sections involved.

SUMMARY: This note shows how the mutual inductance of coaxial cylindrical coils of small radial depth may readily be obtained by the use of curves of a type recently described by the United States Bureau of Standards. These curves cover the mutual inductance between coaxial circles, and by a very simple process of summation their usefulness can be extended to coils of small radial depth.

Let N_A = number of turns in "A"
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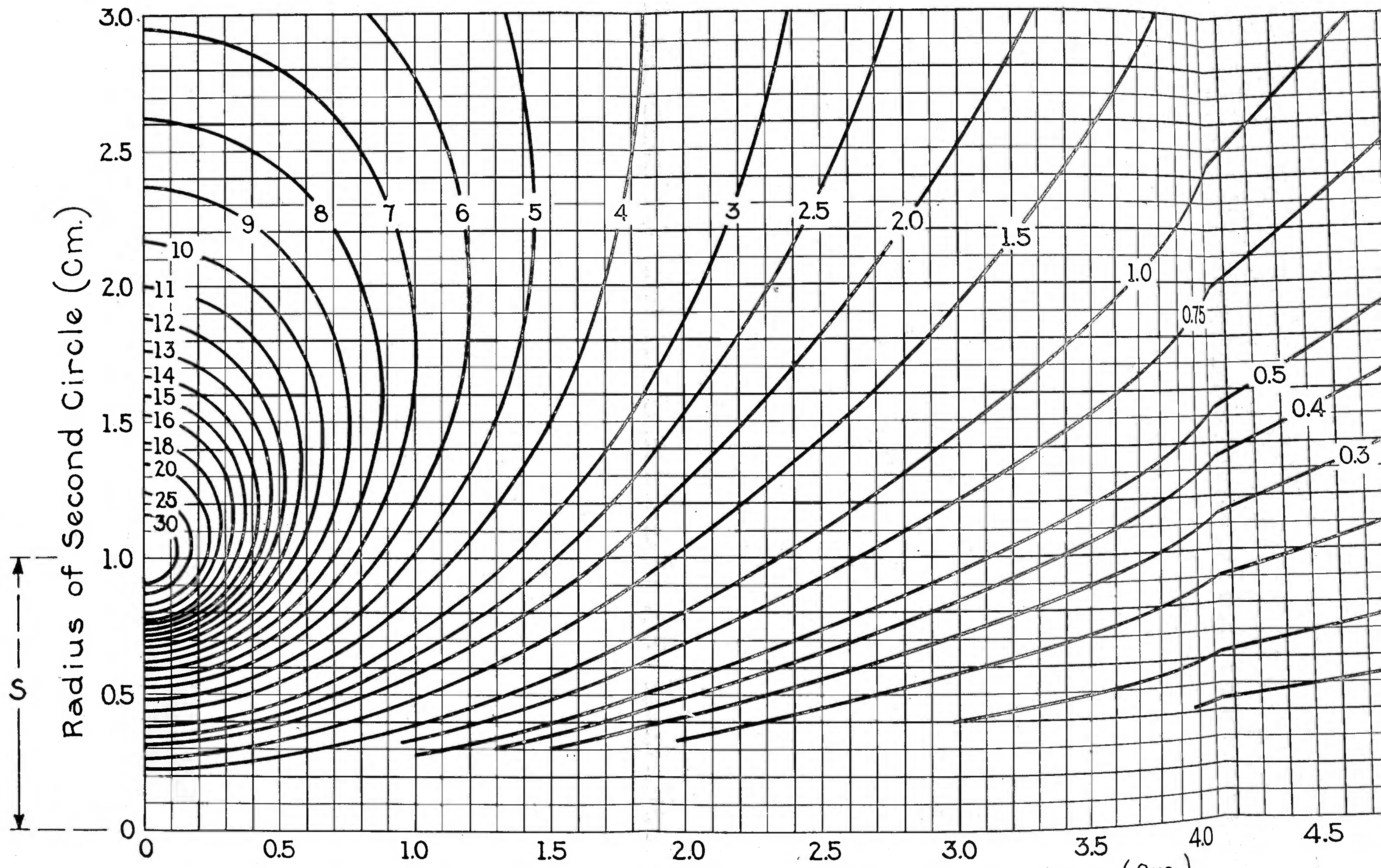

Fig.1a. Mutual Inductance of Two Coaxial Circles. The Radius of
Circle is Taken as 1Cm. The Answer is in Cm. (Milli-microhenr

Note:- Always Construct Templet to Such a
is Equal to S of Fig. 1a

Let N_A = number of turns in "A"
N_B = number of turns in "B"
n_A = number of arbitrary sections in "A"
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r_A = radius of coil "A"

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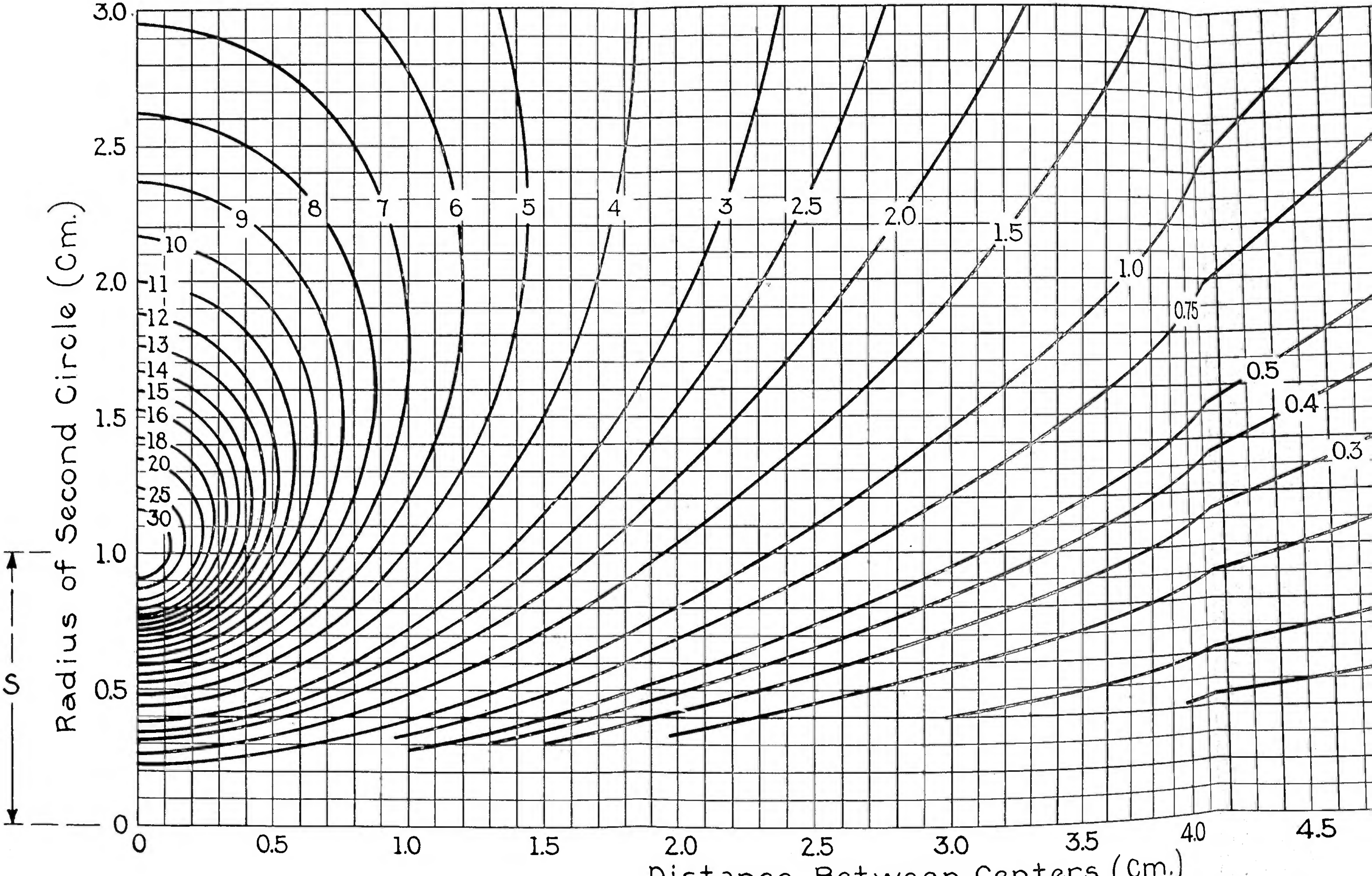
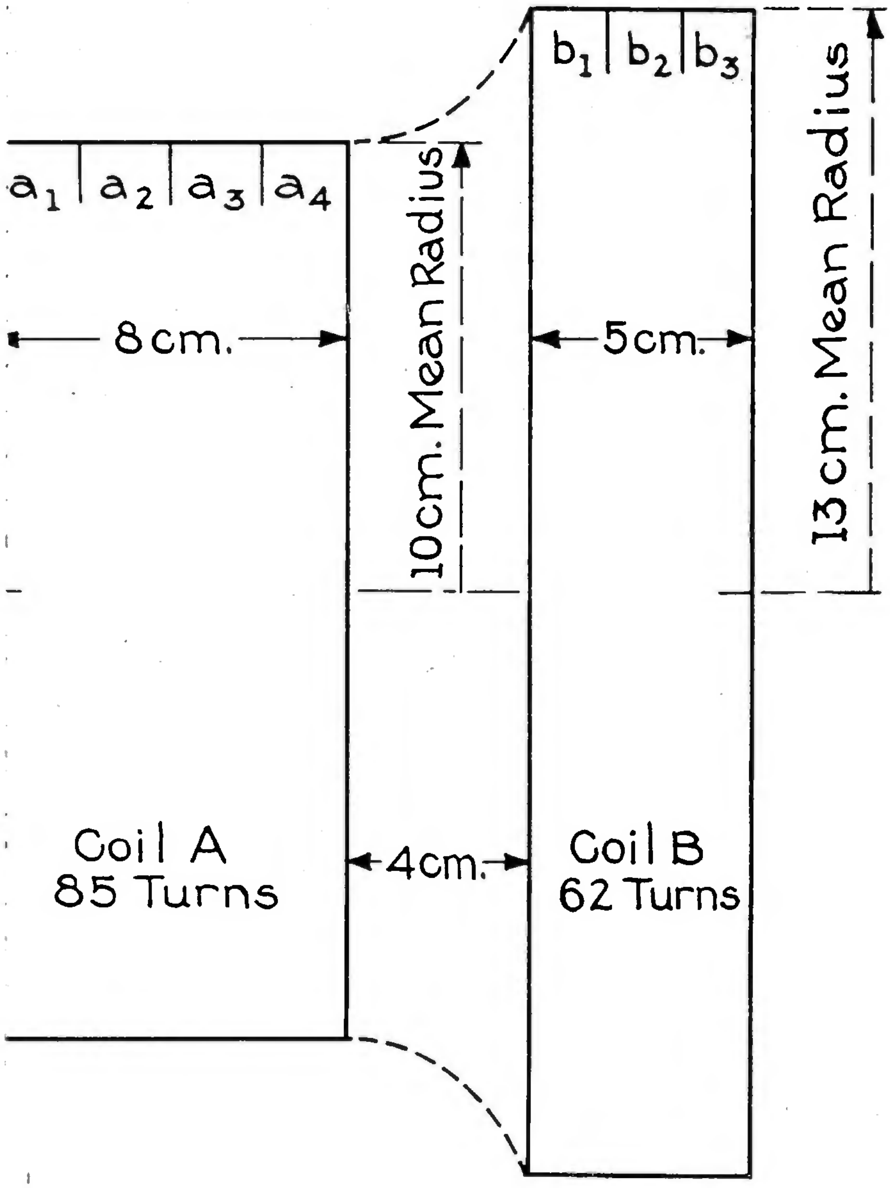


Fig.1a. Mutual Inductance of Two Coaxial Circles. The Radius of
Circle is Taken as 1Cm. The Answer is in Cm. (Milli-microhenr

Note:- Always Construct Templet to Such a
is Equal to S of Fig.1a



g.1b Example of Templet for
se in Finding Mutual Induct-
ance of Coaxial Coils

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

Issued May 5, 1925–June 30, 1925

By

John B. Brady

(Patent Lawyer, Ouray Building, Washington, District of Columbia)

1,529,416—F. H. Hendey and R. B. Everson, filed August 3, 1922, issued May 26, 1925.

Radio Detector and Process for Making the Same, wherein a detector element of a content of lead sulphide over 90 percent by weight and a content of free lead of over 5 percent by weight is provided.

1,536,453—G. W. Pickard and J. A. Proctor, filed November 8, 1924, issued May 5, 1925. Assigned to Wireless Specialty Apparatus Company, Boston.

Vernier for Tuning Reactances more particularly for variable condenser in which an auxiliary condenser plate is rotatably mounted on the shaft which carries the main condenser plates. the auxiliary condenser plate being arranged to co-operate with an independent plate which may be varied in its angular position with respect to the auxiliary plate.

1,536,855—W. G. Houskeeper, filed July 20, 1920, issued May 5, 1925. Assigned to Western Electric Company, Incorporated.

Electron Discharge Device of high power construction, in which the tube electrodes are supported intermediate of the tube by means of a crimped metallic collar surrounding the neck of the glass plant within the tube. The crimped collar forms a substantial mounting for the electrodes within the tube.

1,536,860—P. G. Jacobson, filed July 5, 1922, issued May 5, 1925.

Condenser of variable capacity in which the plates are

*Received by the Editor, July 11, 1925.

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

ISSUED MAY 5, 1925–JUNE 30, 1925

BY

JOHN B. BRADY

(PATENT LAWYER, OURAY BUILDING, WASHINGTON, DISTRICT OF COLUMBIA)

1,529,416—F. H. Hendey and R. B. Everson, filed August 3, 1922, issued May 26, 1925.

RADIO DETECTOR AND PROCESS FOR MAKING THE SAME, wherein a detector element of a content of lead sulphide over 90 percent by weight and a content of free lead of over 5 percent by weight is provided.

1,536,453—G. W. Pickard and J. A. Proctor, filed November 8, 1924, issued May 5, 1925. Assigned to Wireless Specialty Apparatus Company, Boston.

VERNIER FOR TUNING REACTANCES more particularly for variable condenser in which an auxiliary condenser plate is rotatably mounted on the shaft which carries the main condenser plates. the auxiliary condenser plate being arranged to co-operate with an independent plate which may be varied in its angular position with respect to the auxiliary plate.

1,536,855—W. G. Houskeeper, filed July 20, 1920, issued May 5, 1925. Assigned to Western Electric Company, Incorporated.

ELECTRON DISCHARGE DEVICE of high power construction, in which the tube electrodes are supported intermediate of the tube by means of a crimped metallic collar surrounding the neck of the glass plant within the tube. The crimped collar forms a substantial mounting for the electrodes within the tube.

1,536,860—P. G. Jacobson, filed July 5, 1922, issued May 5, 1925.

CONDENSER of variable capacity in which the plates are

*Received by the Editor, July 11, 1925.

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

Issued May 5, 1925–June 30, 1925

By

John B. Brady

(Patent Lawyer, Ouray Building, Washington, District of Columbia)

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mounted in arcuate slots distributed along supporting sleeves. The plates enter the slots and are secured therein in spaced relationship.

1,536,954—B. R. Webster, filed April 28, 1924, issued May 5, 1925. Assigned to Reliance Die & Stamping Company, Chicago.

ELECTRIC CONDENSER of variable capacity in which the stationary plates and movable plates are supported by means of rods which extend between the end frame plates forming the condenser. The plates are grooved to fit around the rods for supporting the plates in spaced relationship.

1,536,974—G. A. Rosenfelder, filed March 3, 1924, issued May 5, 1925.

CRYSTAL DETECTOR of cartridge construction in which an insulated barrel is provided with a crystal holder at one end and a resilient mounting for a cat whisker at the other end.

1,536,997—A. E. Wyatt, filed March 13, 1924, issued May 5, 1925.

LOOP ANTENNA FRAME CONSTRUCTION which may be folded into a small space and the supporting arms unfolded and automatically locked in outstanding position for supporting the loop antenna.

1,537,021—H. C. Rentschler, filed November 9, 1918, issued May 5, 1925. Assigned to Westinghouse Lamp Company.

OSCILLATION GENERATOR OF THE ARC TYPE, where the arc takes place between electrodes disposed in an atmosphere of a mixture of hydrogen and mercury vapor at a relatively high pressure for the securing of a fine stream discharge.

1,537,124—W. Lytton, filed February 13, 1923, issued May 12, 1925. Assigned to Lytton, Incorporated, Chicago.

RADIO RECEIVING DEVICE comprising a socket which is arranged to receive either the usual vacuum tube or a base supporting a crystal detector. The connections within the socket are arranged so that a crystal detector carried by the usual electron tube base may be inserted within the socket to make connections with the radio receiving circuits.

1,537,228—J. O. Gargan, filed June 3, 1922, issued May 12, 1925. Assigned to Western Electric Company, Incorporated.

Means for Cooling Carrier Wave Apparatus, in which the apparatus is mounted in a supporting frame in such manner that air currents may readily move upwardly thru the parts of the set for cooling the apparatus under conditions of operation.

1,537,386—E. M. Tingley, filed November 24, 1920, issued May 12, 1925. Assigned to General Electric Company, Schenectady, New York.

Electrostatic Condenser in which the condenser stack is secured under pressure by clamping members which are directed at right angles to each other and which are secured across opposite sides of the stack. The clamps for the stack also serve as terminals for the condenser.

1,537,660—W. Dubilier, filed January 31, 1924, issued May 12, 1925. Assigned to Dubilier Condenser and Radio Corporation.

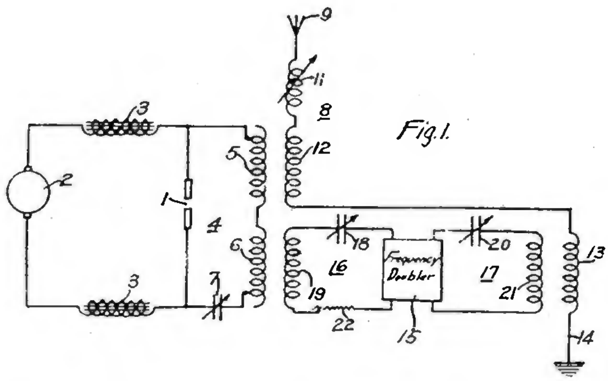
Electrical Condenser in which the stack is secured under pressure by the conjoint action of a flattened tubular casing and tubular rivets which extend thru the stack. The capacity of the condenser may be fixed to a substantially permanent value by reason of the pressure under which the stack is placed.

1,537,561—F. E. Stern and J. C. Randall, filed August 16, 1922, issued May 12, 1925. Assigned to Stern & Company, Hartford.

Variable Condenser in which the semi-circular stator plates are supported in rail members positioned between the condenser plates and then the end of the rotatable spindle secured in position with a flat spring member which bears directly against the end thereof.

1,537,609—J. V. L. Hogan, filed May 19, 1922, issued May 12, 1925. Assigned to Westinghouse Electric and Manufacturing Company.

Arc Transmission System, wherein the purpose is to increase the radiation of the system. A non-sinusoidal generator is employed and the frequency of the main wave multiplied and the multiplied frequency fed in phase with a harmonic of the output of the generator to the antenna circuit. In this way the full power of the several frequencies is radiated.



NUMBER 1,537,609—Arc Transmission System

1,537,708—W. Schottky, filed August 27, 1919, issued May 12, 1925. Assigned to Siemens & Halske, Siemenstadt, Berlin.

THERMIONIC VACUUM TUBE in which the reaction between the electron discharge and external magnetic fields surrounding the tube in an amplifier circuit is diminished by arranging in front of the anode an open work or grid shaped conductor insulated from the anode as well as from the controlling grid electrode, and possessing a constant voltage relatively to the cathode. The peculiar action of this protective net is explained by the fact that it protects electrostatically the field in the vicinity of the auxiliary or grid electrode against the field of the anode, while at the same time the field directed from the grid towards the protective net and partly penetrating into the space between cathode and grid causes a considerable part of the electrons to pass thru the grid even in the case where the grid is given a potential lower than that of the cathode.

1,537,856—F. Michels and A. Erisman, filed September 16, 1922, issued May 12, 1925.

CRYSTAL DETECTOR having a tubular container enclosing a crystal holder and a crystal detecting element which is secured in fixed position with respect to the crystal for maintaining the adjustment of the detector under conditions of vibration.

1,537,990—L. Espenschied, filed April 11, 1924, issued May 19, 1925. Assigned to American Telephone and Telegraph Company.

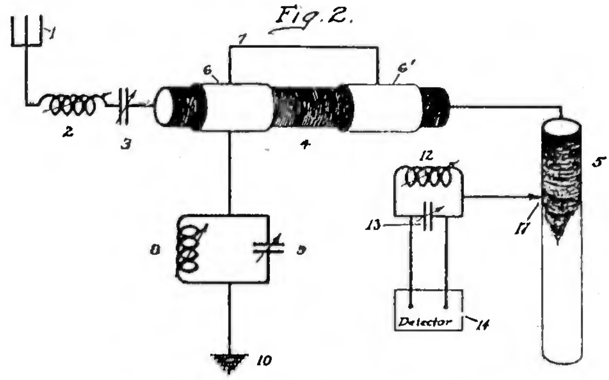
METHOD OF IMPROVING BROADCAST RECEPTION by reducing "fading" effects. It is proposed to reduce the effects of attenuation due to the distance of the point from which the signal is broadcast and also to reduce the fading effect, by producing at a local station in the area in which is included a large number of receiving points, a carrier wave of exactly the same frequency as that employed by a distant broadcasting station, and then broadcasting the wave to the various receiving sets in the local area. The amplitude of this wave may be made so great that the locally produced carrier will be quite large at each receiving point as compared with the amplitude of the carrier actually received from the broadcasting station. The received signal will then be proportional to the product of the received side band and the carrier transmitted from a point in the neighborhood of the receiving station. This will result in receiving a signal of greater strength than would be possible where the signal depended upon the transmission of both carrier and side band from the distant transmitting station.

1,538,344—E. S. Miller, filed February 1, 1923, issued May 19, 1925.

VARIABLE CONDENSER having fixed and movable plates where the movable plates are supported on a shaft which is carried in a single bearing, the bearing consisting of a pair of opposed frustro-conical portions in which the rotatable shaft may be journaled and adjusted to bring the removable plates intermediate the stator plates.

1,538,466—Louis Cohen and J. O. Mauborgne, filed October 25, 1920, issued May 19, 1925.

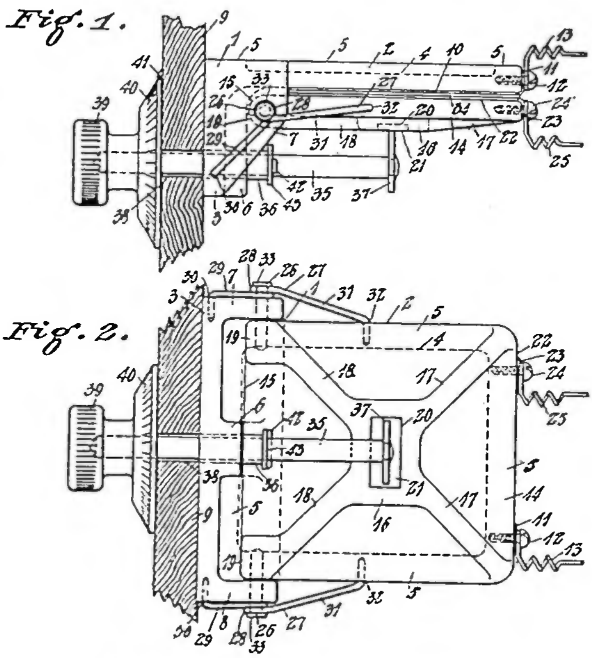
Fig. 2.



NUMBER 1,538,466—Electrical Signaling

ELECTRICAL SIGNALING for the reception of signals without interference arising from static. The received energy is caused to act upon an ungrounded antenna system and pass thru a wave coil for producing a wave development on the wave coil. The wave coil is operatively associated with adjustable metal tubes which are changed in position along the wave coil for the best signal reception.

1,538,472—P. Crosley, Jr., filed May 23, 1921, issued May 19, 1925.



NUMBER 1,538,472—Condenser

CONDENSER of the book type in which one plate is hingedly mounted with respect to another plate and moved about a pivot with respect to said plate by means of a cam actuated by a shaft member extending thru an instrument panel.

1,538,487—O. Meirowsky, filed April 29, 1922, issued May 19, 1925.

ELECTRICAL CONDENSER of variable capacity in which the rotatable plate is formed by a helical member which may be screwed axially between a fixed plate also formed of a helical member for adjusting the capacity of the condenser.

1,538,523—Le Roy W. Staunton, filed June 9, 1924, issued May 19, 1925. Assigned to C. Brandes, Incorporated.

GEARING FOR INSTRUMENT DIALS, in which a small attachable supporting member may be placed upon an instrument panel carrying a resilient member thereon with a rotatable friction wheel at the end thereof arranged to engage the instrument dial for rotating the instrument dial thru small angular distances.

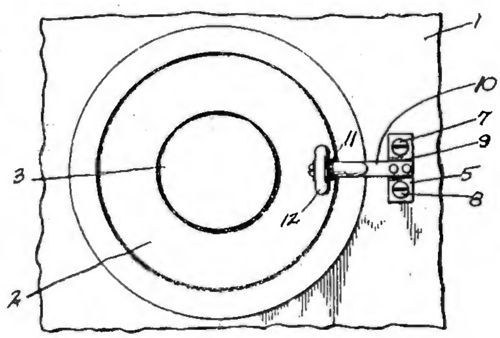


FIG 1

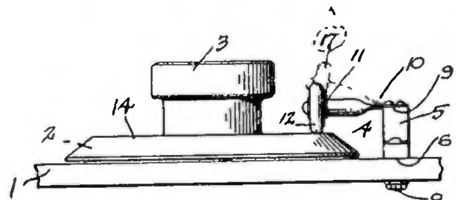
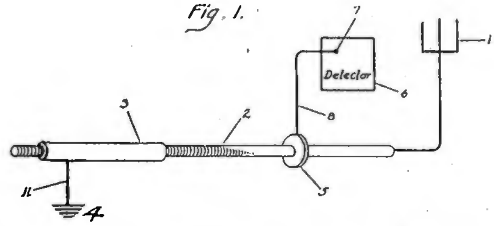


FIG 3

NUMBER 1,538,523—Gearing for Instrument Dials

1538,570—L. Cohen and J. O. Mauborgne, filed June 16, 1920, issued May 19, 1925.

Fig. 1.



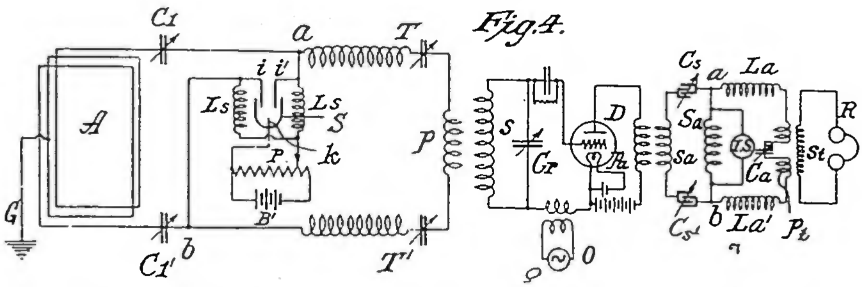
NUMBER 1,538,570—Electrical Signaling

ELECTRICAL SIGNALING system for receiving radio signals, where an antenna is connected to one end of a resonance wave coil with an adjustable grounded metal tube operatively associated with the wave coil. A secondary take-off circuit is coupled with the wave coil for operation of receiving apparatus.

1,538,666—C. M. Small, filed July 8, 1924, issued May 19, 1925.

ELECTRIC SWITCH, which includes a lightning arrestor for the connection of radio apparatus with an antenna system. The lightning arrestor and switch are mounted together and serve to protect the apparatus from excessive currents arising from atmospheric disturbances.

1,538,975—F. K. Vreeland, filed August 6, 1919, issued May 19, 1925.



NUMBER 1,538,975—Stray Elimination in Radio Receivers

STRAY ELIMINATION IN RADIO RECEIVERS, in which a baffle circuit tuned to the signal frequency is provided with a by-pass circuit including a reactance and an intensity selector co-operating to divert preferentially stray energy from the receiving system. The receiving apparatus is connected with the baffle circuit.

1,539,150—O. Von Bronk, filed September 3, 1921, issued May 26, 1925. Assigned to Gesellschaft für drahtlose Telegraphie m. b. H., Hallesches, Berlin.

RECEIVING DETECTOR FOR RADIO TELEGRAPHY, where a generator is provided at the receiving station with the receiving circuit connected to the field of the generator. A circuit is provided connected to the armature of the generator and arranged to resonate simultaneously the frequencies equal to the sum and difference of the signal frequency and natural generator frequency. An audible frequency is thus produced of desired tone quality for observing the transmitted signals.

1,539,402—H. W. Nichols, filed February 24, 1919, issued May 26, 1925. Assigned to Western Electric Company, Incorporated.

MEANS FOR PRODUCING ELECTRICAL OSCILLATIONS, comprising an amplifier having input and output circuits, the circuits of which combined with the amplifier constitute a network for determining the frequency of the generated oscillations independent of any electrical capacity.

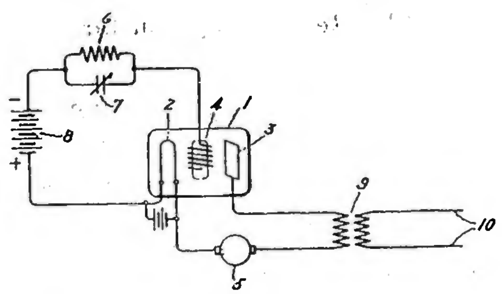
1,540,176—F. P. March, filed June 23, 1922, issued June 2, 1925.

CONDENSER of the variable capacity in which movable plates are mounted upon a sleeve member which is journaled to rotate in end plates which form the condenser frame. The sleeve member extends thru the end plates and the rotatable control knob is secured upon the sleeve member.

1,540,355—R. C. Mathes, filed October 20, 1919, issued June 2, 1925. Assigned to Western Electric Company, Incorporated.

Vacuum Tube Testing Device, in which a vacuum tube is mounted upon a vibrating table and subjected to vibratory tests to determine the mechanical rigidity of the mounting of the electrodes with the tube. Circuits are provided for testing the tubes after periods of vibrations to determine the effects of the vibratory tests thereon.

1,540,578—H. C. Thompson, filed July 1, 1921, issued June 2, 1925. Assigned to General Electric Company, Schenectady.



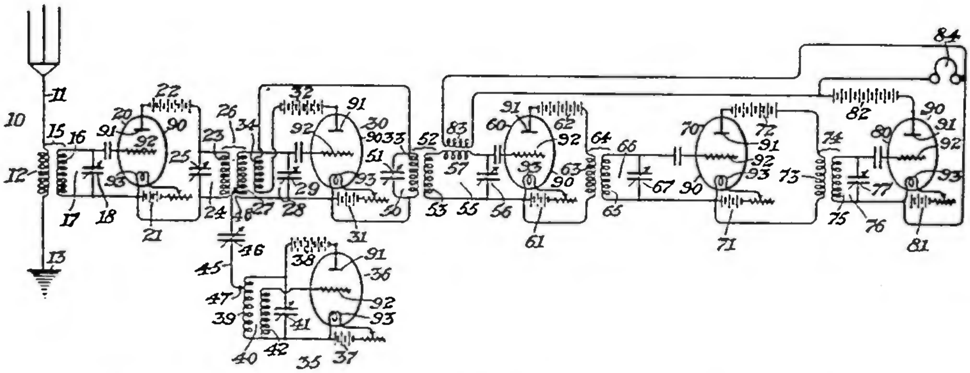
Number 1,540,578—Means for Producing Oscillations

Means for Producing Oscillations, wherein a three-electrode electron tube device has an oscillatory circuit connected between the cathode and the grid with a source of potential in the output plate circuit of such value as to permit of the effective emission of impact electrons from the grid in sufficient amount to produce a negative resistance characteristic in the circuit connected thereto over a range of positive potential of the grid. The patent covers the particular values of grid and plate potentials which are desirable for the production of oscillations.

1,540,712—L. Pungs, filed August 23, 1921, issued June 2, 1925. Assigned to C. Lorenz Aktiengesellschaft, Berlin-Tempelhof, Germany.

Signal Sending Apparatus in Wave Telegraphy, wherein a radio frequency machine is employed having a plurality of syntonizing circuits of different frequency with a coil having an iron core electrically connected with said circuits whereby the coil may be subjected to superposed magnetic continuous current induction, thereby varying the inductivity of the coil and changing the conditions of resonance of the syntonizing circuits.

1,540,881—J. H. Hammond, Jr., filed July 9, 1918, issued June 9, 1925.



NUMBER 1,540,881—Receiving System for Radiant Energy

RECEIVING SYSTEM FOR RADIANT ENERGY, in which a circuit is provided for producing beats for actuating a detector. A circuit is arranged to be controlled by a detector which circuit reacts upon the first circuit for accentuating the beats in the receiving circuit.

1,540,998—H. Plauson, filed January 13, 1921, issued June 9, 1925.

CONVERSION OF ATMOSPHERIC ELECTRIC ENERGY by the use of collecting aerial networks which are elevated in the air and interconnected with a circuit by which static electricity is conveyed to earth in the form of direct current of high voltage and low current strength and converted into electrodynamic energy in the form of high frequency vibrations. The energy derived from atmospheric discharge is intended to be usefully employed for lighting, production of heat, and for use in electro-chemistry.

1,541,566—A. W. Hull, filed May 18, 1921, issued June 9, 1925. Assigned to General Electric Company, Schenectady, New York.

SYSTEM FOR PRODUCING OSCILLATIONS by selecting the potential of the grid and plate electrodes of an electron tube. An emission of secondary electrons from the grid is produced sufficient to cause a negative resistance characteristic in the grid circuit over a range of positive grid potential and thereby causing the generation of oscillations in the grid circuit independently of any coupling between the circuits and a work circuit associated with said plate circuit.

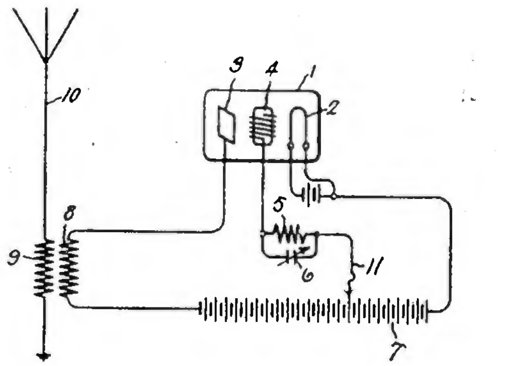
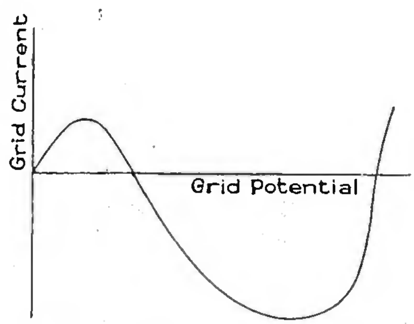
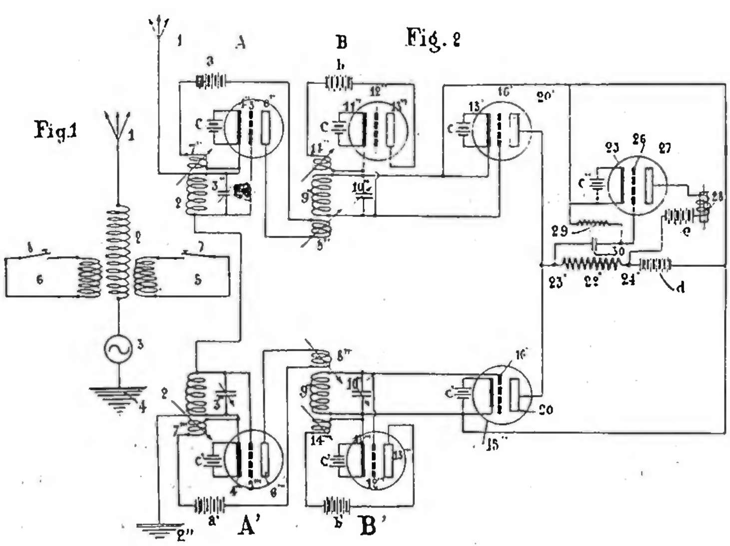


Fig. 2.



NUMBER 1,541,566—System for Producing Oscillations

1,541,608—H. Abraham, filed September 3, 1921, issued June 9, 1925.



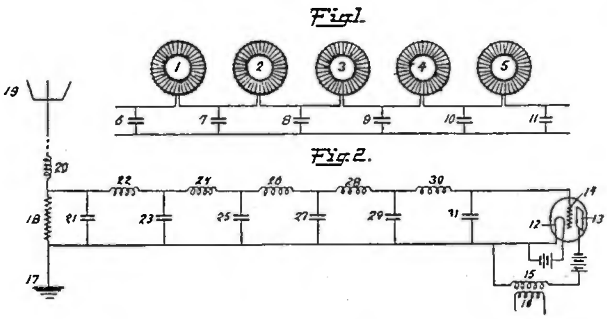
NUMBER 1,541,608—Radio Telegraphy

RADIO TELEGRAPHY system, by which several messages can be radiated simultaneously from the same antenna system. The several transmitters are each connected with the antenna system in such manner that signals are transmitted at separated frequencies without reaction of one frequency upon the others.

1,541,630—W. Dubilier, filed April 22, 1924, issued June 9, 1925. Assigned to Dubilier Condenser and Radio Corporation.

Electrical Condenser for Ignition Circuits, having top and bottom plates of insulation material and separated side plates joining the top and bottom plates and providing terminals. The stack is capable of insertion as a unit between the side plates for properly securing the stack in position.

1,541,845—M. I. Pupin, filed December 11, 1915, issued June 16, 1925. Assigned to Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pennsylvania.



Number 1,541,845—Electrical Wave Receiving System

Electrical Wave Receiving System, in which the antenna circuit is connected with the receiving circuit thru a recurrent network of similar sections. The network contains damping resistances in each section. The object of the invention is to exclude from the receiving circuit all waves which are not intended to be received.

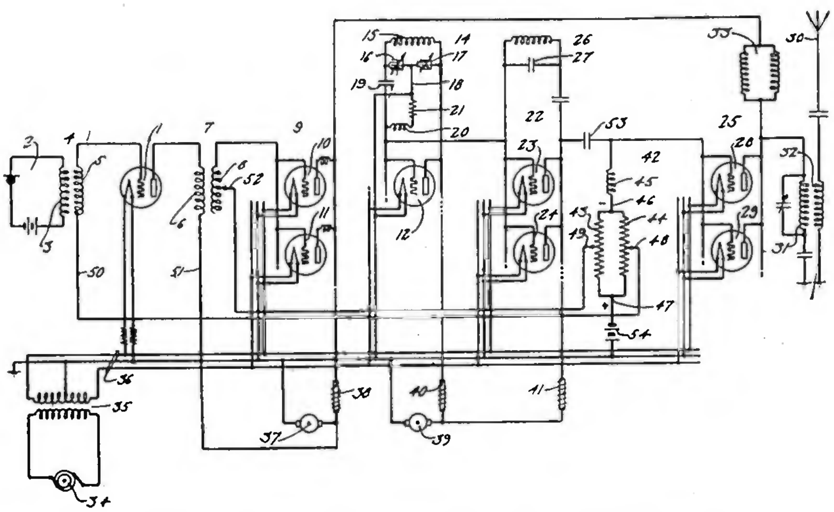
1,542,258—J. McMenamin, filed October 17, 1922, issued June 16, 1925.

Mineral Detector and Rectifier for Radio Reception, which includes a mass of rectifying material and a plurality of insulated wires grouped at one end to form a compact mass with a flush face and presenting a plurality of fixed contacts opposite to the mineral. The wires are independently brought out for connection in the receiving circuit whereby the most sensitive junction may be utilized in the receiving circuit.

1,542,366—W. R. Brough, filed December 2, 1920, issued June 16, 1925. Assigned to Western Electric Company.

Vacuum Tube Base, which consists of a sheet metal shell which supports a thin disc of insulating material in one end thereof the disc carrying terminal pins for the electron tube electrodes which terminal pins are arranged in the corners of a quadrilateral, with two of said terminal pins at different distances from the shell.

1,542,381—J. C. Gabriel and Arvid G. Landeen, filed June 13, 1924, issued June 16, 1925. Assigned to Western Electric Company.



Number 1,542,381—Discharge Device System

Discharge Device System for radio transmission, wherein the power amplifier tubes of the system are provided with a potentiometer circuit in shunt with the input circuit of the power amplifier, insuring a relatively large continuous flow of current therethru, with taps taken from a plurality of points on the potentiometer to connections with the grid circuits of a plurality of tubes in the transmitting system for controlling the negative grid potentials of said tubes from a single location in the system.

1,542,385—J. E. Harris, filed October 17, 1920, issued June 16, 1925. Assigned to Western Electric Company.

Thermionic Cathode and Method of Making the Same, where the cathode is formed by an alloy containing approximately 95 percent platinum and 5 percent nickel.

1,542,386—R. V. L. Hartley, filed December 14, 1920, issued June 16, 1925. Assigned to Western Electric Company.

VACUUM TUBE DESIGN, in which the characteristic of the vacuum tube is modified so that the space current, when the grid potential is given increasing negative values, approaches a zero value more rapidly than heretofore, thereby giving a more accurate determination of the values of the negative grid potential required to produce zero space current. The arrangement of the tube circuit permits the device to be used in the measurement of alternating current potentials by means of a meter disposed in the output circuit.

1,542,389—W. G. Houskeeper and Wm. R. Brough, filed November 19, 1920, issued June 16, 1925. Assigned to Western Electric Company.

VACUUM INSULATED TERMINAL for an electron tube discharge device where a tubular member is disposed within the vacuum tube and provides a passageway thru which a lead wire extends from the outside of the tube to one of the interior electrodes of the tube.

1,542,724—O. I. Price, filed May 31, 1922, issued June 16, 1925.

RADIO APPARATUS, in which apparatus is mounted upon an instrument panel by means of screw members which pass thru the panel and are embedded directly in the material which supports the instruments. A variable condenser construction is represented in the patent as supported on the rear of the receiving set panel.

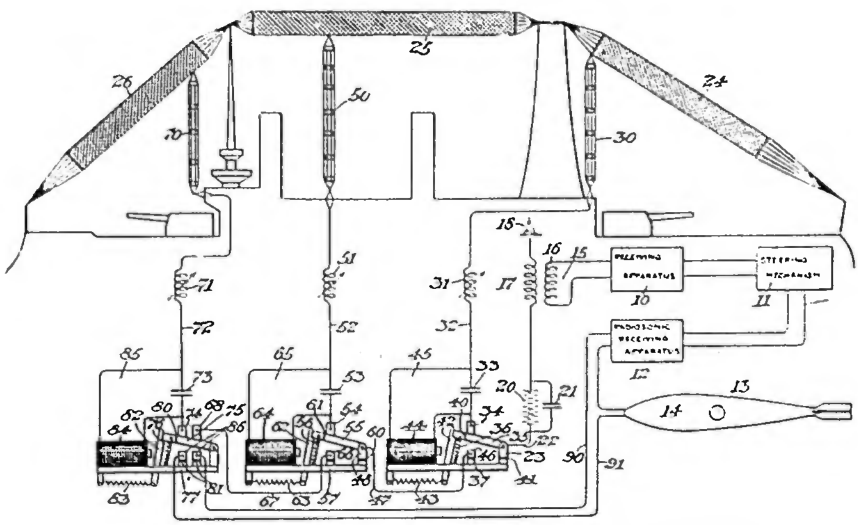
1,542,937—J. H. Hammond, Jr., filed May 8, 1920, issued June 23, 1925.

OPTICAL INSTRUMENT for detecting objects in the dark which are invisible to the human eye. A receiver consisting of a thallium oxi-sulphide cell sensitive to light waves is provided and the effect of such light waves upon the object to be detected measured by means of a receiving circuit which discloses the presence of such object.

1,542,938—J. H. Hammond, Jr., filed July 9, 1920, issued June 23, 1925.

AUTOMATIC ANTENNA SYSTEM, particularly adapted for warship use where a plurality of antennas are provided for connection with a receiving apparatus with an automatic switching system for connecting one antenna with the receiving apparatus in place of an antenna which may be shot away or otherwise destroyed.

Fig. 1



NUMBER 1,542,938—Automatic Antenna System

1,542,995—M. Eastham, filed October 11, 1923, issued June 23, 1925. Assigned to General Radio Company.

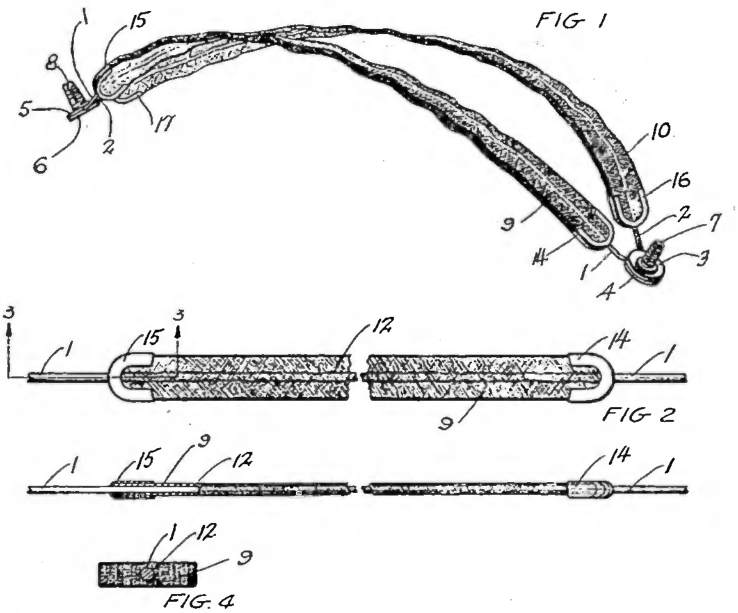
CONDENSER of the variable type in which the stator plates are provided with peripheral lugs angularly related to the plane of the plates and arranged to overlap partially correspondingly positioned lugs on one of the stator plates next adjacent thereto. The assembly of the condenser plate spaced by means of the peripheral lugs is intended to reduce manufacturing costs in condenser construction.

1,543,033—W. O. Snelling, filed May 20, 1922, issued June 23, 1925.

AN ELECTRODE for use in electron tubes in which a grid of electrically conducting material is provided with a light transparent metallic film connecting the individual members of the grid.

1,543,325—F. Dietrich, filed December 8, 1923, issued June 23, 1925. Assigned to C. Brandes, Incorporated.

HEADBAND FOR TELEPHONE HEADSETS, wherein seamless fabric webbing is provided over the wire members which form the headband. The seamless fabric webbing is readily manufactured and serves as a comfortable construction of headband at the same time that manufacturing costs are considerably reduced.



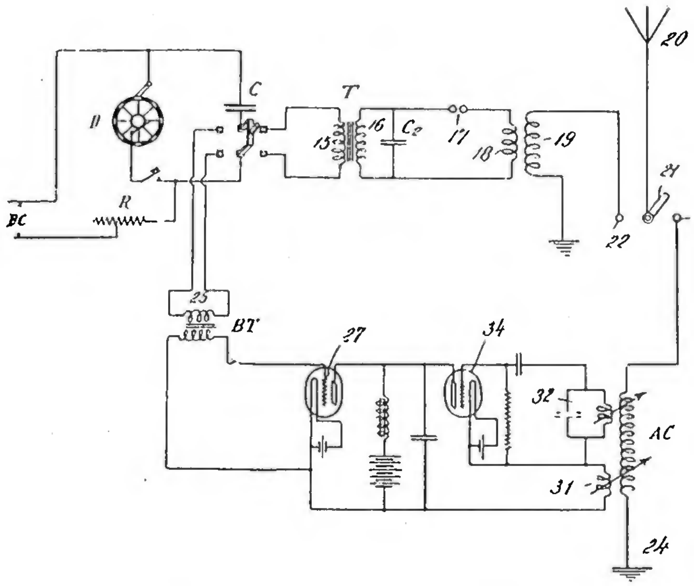
NUMBER 1,543,325—Headband for Telephone Headsets

1,543,326—W. Dubilier, filed February 7, 1921, issued June 23, 1925. Assigned to Dubilier Condenser and Radio Corporation.

CONDENSER AND CLAMP THEREFOR. The condenser comprises a stack of conducting and dielectric sheets with bearing members engaging the opposite faces of the stack. The bearing members are clipped together by substantially circular clamps which fit into grooves in the bearing members.

1,543,475—W. S. Lemmon, filed January 14, 1920, issued June 23, 1925.

RESONANT CONVERTER for producing oscillations for use in radio signaling systems where a direct current source is provided and inductance and capacity elements connected across the terminals of said source with an interrupter in parallel therewith. An oscillatory circuit tuned to the frequency of the alternating current to be produced is connected in series between the source and the inductance and capacity elements and arranged to cooperate with the interrupter for producing oscillations which may be impressed upon the signaling circuit.



NUMBER 1,543,475—Resonant Converter

1,543,726—K. Rottgardt, filed August 26, 1921, issued June 30, 1925. Assigned to Westinghouse Electric and Manufacturing Company.

RADIO TRANSMISSION RECORDING SYSTEM, in which the signals which are transmitted by means of a hand key at the transmitting station are simultaneously recorded by a Morse writer. The Morse writer is controlled by the operation of the hand key to make a record of the signals being transmitted.

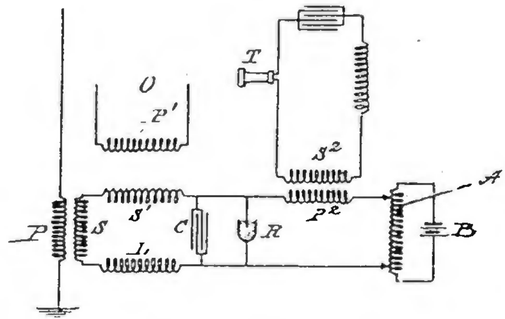
1,543,872—S. Ruben, filed April 13, 1923, issued June 30, 1925.

VACUUM TUBE APPARATUS for making and breaking a circuit by relay operation. The discharge device contains a cathode and a plurality of anodes located in the vacous space with a separate external circuit connecting the cathode with either of the anodes. Another circuit is provided within the tube which includes a gap located in said vacuous space and arranged to be closed and opened by the expansion and contraction respectively, of one of said anode elements. The device is used for controlling any desired electrical circuit.

1,544,081—F. K. Vreeland, filed (original) January 2, 1907. This application filed October 27, 1915, issued June 30, 1925. Assigned to Vreeland Apparatus Company.

TRANSMITTING INTELLIGENCE BY RADIANT ENERGY and receiving such signals by exciting a receiving circuit by the received wave energy and also by an auxiliary current of a frequency related to the frequency of the received energy as to produce beats therewith, and then rectifying and using this composite current to operate a receiving instrument, whereby to amplify the effect of the received signal. This patent contains broad claims on heterodyne reception.

Fig. 2



NUMBER 1,544,081—Transmitting Intelligence by Radiant Energy

1,544,102—P. O. Pedersen, filed June 21, 1919, issued June 30, 1925. Assigned to Poulsen Wireless Corporation.

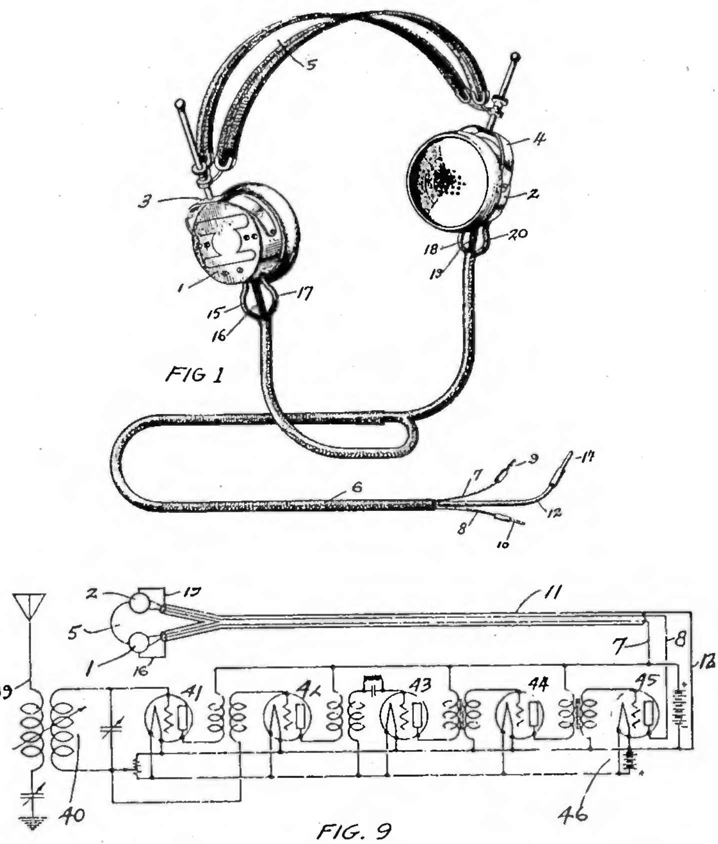
AN ARC GENERATOR, including a pair of electrodes between which the arc is formed with a magnetic blow-out for extinguishing the arc. The shape of the electrodes is such that the arc is caused to increase in length periodically between the electrodes before it is blown out.

1,544,133—C. C. Culver, filed June 29, 1921, issued June 30, 1926.

A TRIDIMENSIONAL RADIOCOMPASS for use in aircraft where a plurality of coils are provided forming a plurality of dihedral angles, the axes of said dihedral angles being angularly disposed with respect to each other and to the longitudinal axis of said aircraft. By use of a multiple number of coils an exact direction may be determined independent of the loading or angular position of the aircraft during flight.

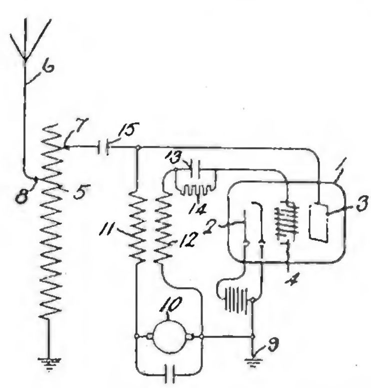
1,544,136—F. Dietrich, filed November 5, 1923, issued June 30, 1925. Assigned to C. Brandes, Incorporated.

ELECTRICAL CONNECTION FOR TELEPHONE HEADSETS, where a flexible metallic shield surrounds the telephone conductors with connections between telephone conductors and the magnet bobbins within the receiver. The flexible shield terminates in a stay cord which is utilized to remove the strain from the telephone conductors which lead into the telephone receiver casing.



NUMBER 1,544,136—Electrical Connection for Telephone Headsets

1,544,202—W. C. White, filed January 20, 1921, issued June 30, 1925. Assigned to General Electric Company.


NUMBER 1,544,202—System for Producing Oscillations

SYSTEM FOR PRODUCING OSCILLATIONS by use of an electron tube which has an oscillating circuit coupled to a shunt circuit between its cathode and anode. The input and output circuits of the tube are coupled, but the frequency of the oscillations is determined principally by the constants of the oscillating circuit.

1,544,486—J. Sedlak, filed May 31, 1924, issued June 30, 1925.

A Switching Device for Radio Sets, in which connections are made to a panel board on the rear of a radio receiving set by means of a multiple blade switch co-operating with contacting clips which connect with the internal circuits of the radio receiver.