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EDITED BY
ALFRED N. GOLDSMITH, Ph.D.

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CORRECTION: On page 159 of the 1918 PROCEEDINGS, 7th line from the bottom of the page, change this to read:
"terminals of a current supply by means of a self-inductance"

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THE DESIGN OF POULSEN ARC CONVERTERS FOR RADIO TELEGRAPHY*

By

Leonard F. Fuller, Ph.D.

(Assistant Manager, Ohio Insulator Company, Barberton, Ohio; Formerly Chief Electrical Engineer, Federal Telegraph Company, San Francisco, California)

PREFACE

Neither time nor space permit a really thoro discussion of the technique of arc design. In this paper, I have endeavored to present those electrical and magnetic features of basic importance and major interest.

Past literature has generally dealt only with the electrical characteristics of the Poulsen arc from the viewpoint of the scientist in the laboratory. I have tried as far as possible to discuss these characteristics from the viewpoint of the designing engineer. This different method of treatment has made it possible to inject new material into the theory of operation.

Those portions of the paper dealing with magnetic matters contain new material also, some of which is of basic importance in the proper and economical proportioning of the bi-polar electro-magnets which have been built in sizes up to 80 tons (72,700 kg.) dead weight.

This paper will be followed by another describing the direct current generating equipment, control apparatus, and other matters of engineering interest connected with high power stations.

At present, a high power station may be defined as one in which the antenna current exceeds 150 amperes under ordinary conditions of ground resistance, and so on. Modern 100 kilowatt converters operate at 150 amperes radiation continuously with a temperature rise not in excess of 40° C. in any part.

HISTORICAL

The negative slope of the volt-ampere characteristic of the direct current electric arc makes it a possible means of obtaining radio frequency currents.

In the early days of radio telegraphy, before the advantages

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* Received by the Editor, February 13, 1919.

of continuous waves were generally realized, several types of arcs were devised for producing continuous oscillations, but due to inherent limitations and the difficulties of development, no marked progress was made in their design until 1913, when tests of the United States Navy Department from the Arlington Station showed that continuous waves should be considered very seriously in the radio telegraphy of the future. This created the demand required to expedite development, and the arc operating upon the basic ideas of Valdemar Poulsen has been rapidly developed since that time. No notable advances have been made with arcs of other types. This is probably due to the fact that the mechanical and electrical problems involved are severe, and further because the Poulsen electrical cycle is admirably suited for converting large amounts of direct current electrical energy into radio frequency energy.

The developments of the last five and a half years have advanced this arc from converters of 30 kw. normal full load rating to 1,000 kw. units with 25 per cent. 2-hour overload capacity. Most of this development has occurred within the last 3 years.

GENERAL

The theory of the operation of the Poulsen cycle has been studied by a large number of investigators. Very complete bibliographies of this literature are given in Zenneck's "Lehrbuch der Drahtlosen Telegraphie" and Pedersen's article "On the Poulsen Arc and Its Theory," PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 5, number 4.

The theory of operation described herein is based upon the theories of many investigators, notably those of Barkhausen and Pedersen, combined with certain conclusions of the writer.

THE POULSEN ARC CONVERTER CYCLE

The arc radio frequency cycle may be divided into two halves. The first is that during which the radio frequency current I_s is circulated by emf. set up by energy stored in the L and C. The second is the energy adding period during which I_s is circulated by emf. set up by energy from the d.c. supply circuit. This may be termed the "charging period."

Referring to Figure 1, the starting of the d.c. generator charges the condenser C_s to the potential E_d. When the arc is struck, direct current I_d flows thru it in the direction of the arrow, forming one component of the arc current I_a. The other component is the discharge current I_s from the condenser C_s, thus:

$$I_d = i_a - i_s \text{ (instantaneous values)} \qquad (1)$$

Due to the fact that arc flame conductivity is dependent upon gas ionization, it is dependent upon gas temperature, and hence I_a, the current thru the arc. Thus as i_s and i_a increase as shown in Figures 2 and 3, the conductivity of the arc flame is raised. This causes a further increase in i_s until finally the peak of the i_s curve is reached at "*b*." At this point the energy which, at the beginning of the cycle was stored in C_s as potential energy, has been completely changed to kinetic energy stored in the magnetic field of the inductor L_s. The condenser charge is therefore zero, and the currents i_s and i_a are a maximum.

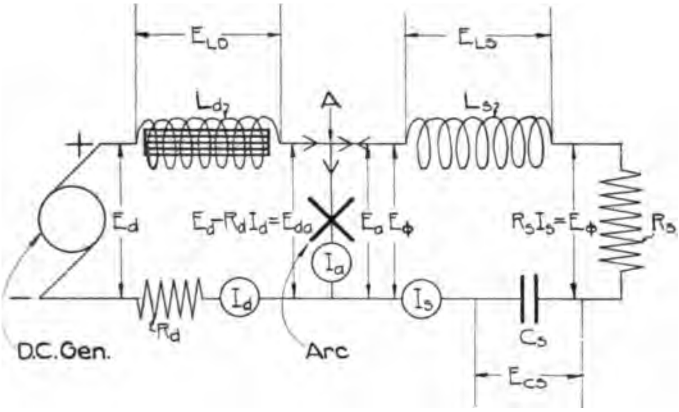
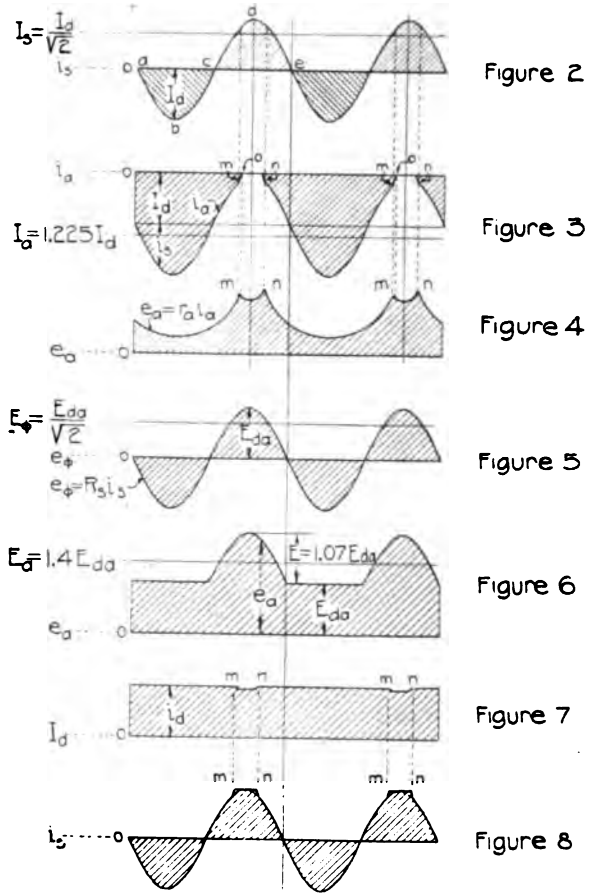


FIGURE 1 —Diagram of Circuits

The magnetic field of L_s now begins to collapse. This continues to make current flow in the same direction. The process continues until the point "*c*," Figure 2, is reached. Condenser C_s is now fully charged in the polarity opposite to its initial charge, and the energy in the oscillatory circuit is once again in the potential form.

The condenser now begins to discharge, and the second half of the radio frequency cycle begins. During this half cycle, energy from the d.c. circuit is supplied to the oscillatory circuit. Current leaving the condenser does not pass up thru the arc, forming a portion of I_a as in the preceding half cycle, but passes thru the d.c. circuit in accordance with the equation:

$$I_d = i_a + i_s \text{ (instantaneous values)} \tag{2}$$



FIGURES 2–8

As i_s increases toward "d," Figure 3 shows that i_a approaches zero, and at "m" it has been reduced to such a low value that the stream of ions forming the arc flame starts to rupture under the influence of the magnetic field. This continues to the point "o," at which the arc is completely extinguished and i_a is zero. Thus:

$$I_d = i_s \text{ (instantaneous values)} \tag{3}$$

The next instant i_s decreases from "c" toward the point "n." Therefore there is a slight reduction in I_d (Figure 7) which induces an emf. E_{Ld} between the terminals of the inductance L_d in the d.c. circuit. This surge has a much steeper wave front than the sinusoidal radio frequency oscillations and is unable to force its way beyond the first few turns of L_s. The resultant increase in voltage across the arc is sufficient to jump the gap between the electrodes and re-establish i_a. This occurs at "n," and more and more I_d is shunted off thru the i_a path as i_s approaches zero at "e."

- The point "e" is at the beginning of a second cycle identical with that just described, with the exception that, whereas at "a," the potential E_c across C_s was only that of E_d, at "e" it has been augmented by the discharge of L_s also. Thus, when the arc is first started, there is a transient period extending over several cycles, during which the peak of E_c for each succeeding cycle is constantly increased until a stable condition is reached, which depends solely upon the resistance of the radio frequency circuit, all other conditions remaining constant. Thereafter the effective value of E_c may be computed by the well known equation:

$$E_c = \frac{I_s}{2\pi f C_s} \qquad (4)$$

THE ARC VOLTAGE E_a

Altho I_s is sinusoidal and I_a is a sinusoidally pulsating unidirectional current, the voltage across the arc, E_a, has a jagged wave form. When i_s is at "a" and the arc is struck by bringing the electrodes together, e_a takes a certain value as shown. Due to the drop in arc flame resistance produced by increasing current and because the flame resistance drops at a rate greater than the first power of the current, e_a, which equals $r_a\, i_a$, decreases with an increase in i_a as previously described. This is the reason for the dip in the e_a curve and illustrates the well known falling characteristic of the arc. As i_a approaches zero, e_a increases up to the extinction point "m." Then comes re-ignition at "n" and e_a drops as gap ionization increases. The cycle then repeats itself.

As Pedersen points out, there is not necessarily much difference in the amplitude of the voltage peaks "m" and "n" because the arc is burning from points back on the electrodes at "m" and is, therefore, long, while at "n" the voltage is only that necessary to jump the gap between the electrodes at their nearest point.

The ignition voltage at "*n*" is of course dependent upon the ionization in the gap at that time. This ionization is controlled by the magnetic field strength, but inasmuch as the field has had the opportunity of scavenging the gap for a time prior to ignition, slight changes in its strength are not likely to make as much difference in the amplitude of the voltage peak at "*n*" as at "*m*," because during the period leading up to the peak "*m*" the gap has been constantly supplied with new ions which were blown out of it by the magnetic field. Hence *slight* changes in field strength probably make a greater difference in the extinction voltage than in that of ignition.

During the period "*a b c*," Figure 2, e_a at any instant equals $r_a\, i_a$ where r_a is the varying resistance of the arc. No simple law is followed from "*c*" to "*e*," because of the points "*m*" and "*n*." During the period "*a b c*," e_a opposes i_s, which is a component of i_a. For maximum I_s it is, therefore, desirable to have E_a a minimum during this period. However, thru "*c d e*" it is desirable to have the effective value of the E_a wave a maximum, provided the "*m*" and "*n*" peaks do not cause too great distortion. Thus for a complete cycle the effective value of the E_a wave useful in circulating I_s is the effective value during the period "*c d e*" minus the effective value during the period "*a b c*."

The equivalent sine wave of in-phase emf., which we may term E_ϕ, is that which has the same effective value as the difference between the effective values of the two halves of the E_a curve above mentioned. This is obviously the voltage drop across R_s, that is $R_s\, I_s$. It is shown in Figure 5.

The peak value of $e_\phi = E_{da}$ ($E_{da} = E_d$ minus the $R\, I$ drop in the d.c. circuit) because experiments show that when the magnetic field strength is of the proper value and the arc is operating under good conditions its effective direct current resistance, $\frac{E_{da}}{I_d}$ equals the resistance R_s of the oscillatory circuit.

Since $\qquad E_\phi = R_s\, I_s,$

substituting $\qquad E_\phi = \frac{E_{da}}{I_d} \cdot \frac{I_d}{\sqrt{2}} = \frac{E_{da}}{\sqrt{2}}$

Hence $\qquad E_{da} = e_\phi$ (peak) $\qquad$ (5)

Figures 9 and 10 give experimental proof of the foregoing. They are plotted from data taken at two high power stations.

Altho the wave form of E_a is not sinusoidal, it is possible to resolve it into components which may be easily treated analytically.

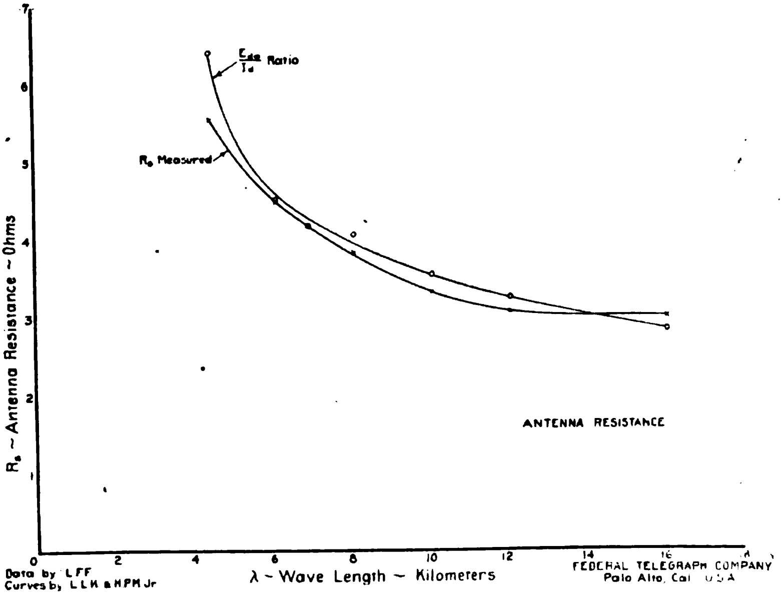


FIGURE 9

These components are:

(1) E_{da} maintained by the d.c. generator.

(2) A sinusoidal uni-directional pulse occurring once per radio frequency cycle.

Figure 6 shows the superposition of these components. As previously stated, the difference between the effective values of the half cycles of this wave must be 0.707 E_{da}. When this is the case the effective value of

$$E_a = 1.4\, E_{da} \tag{6}$$

This is shown in the mathematical analysis which follows and is also proven experimentally.

Referring to Figure 11:

Let e_a = instantaneous voltage across arc.

$$E_a = \text{effective value of } e_a = \left[\frac{1}{2\pi}\int_o^{2\pi} e_a^2\, d\,\theta\right]^{\frac{1}{2}}$$

E = maximum value of uni-directional pulse that occurs once every cycle of the radio frequency current.

e = instantaneous value of pulse $= E \sin \theta$

E_{da} = d.c. component of arc voltage.

$e_a = E_{da} + e = E_{da} + E \sin \theta$

$e_a^2 = E_{da}^2 + E^2 \sin^2 \theta + 2\, E_{da} E \sin \theta$

$$\frac{1}{2\pi}\int_0^{2\pi} e_a^2\, d\theta = \frac{1}{2\pi}\int_0^{2\pi} E_{da}^2\, d\theta + \frac{E^2}{2\pi}\int_0^{\pi} \sin^2\theta\, d\theta + \frac{2 E_{da} E}{2\pi}\int_0^{\pi} \sin\theta\, d\theta$$

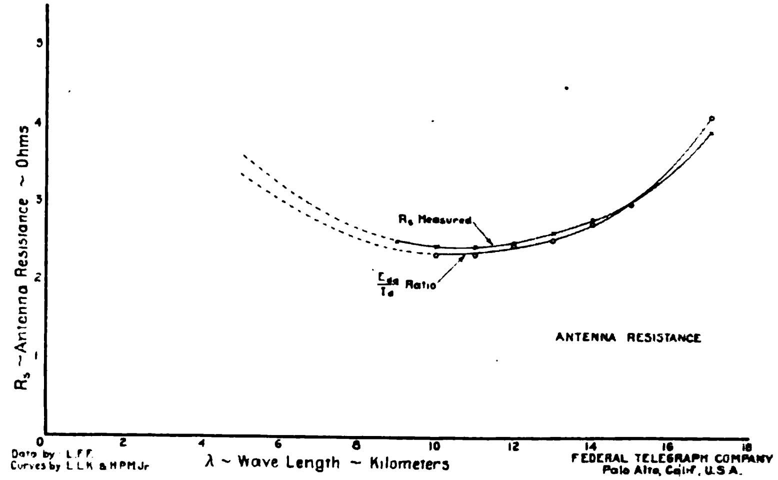


FIGURE 10

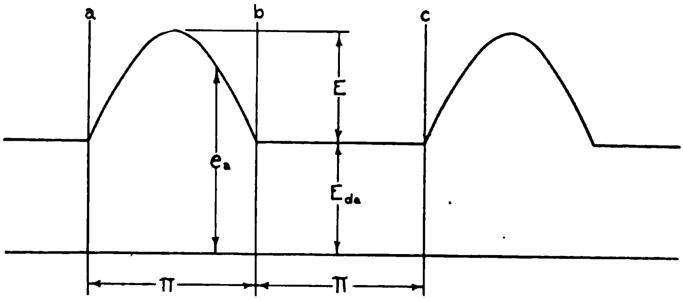


FIGURE 11

Integration of Parts

$$\frac{1}{2\pi}\int_0^{2\pi} E_{da}^2\, d\theta = \frac{E_{da}^2}{2\pi}\int_0^{2\pi} d\theta = E_{da}^2$$

$$\frac{E^2}{2\pi}\int_0^{\pi} \sin^2\theta\, d\theta = \frac{E^2}{4\pi}\int_0^{\pi} (1-\cos 2\theta)\, d\theta = \frac{E^2}{4}$$

$$\frac{E_{da}E}{\pi}\int_0^{\pi} \sin\theta\, d\theta = \frac{2E_{da}E}{\pi}$$

$$\therefore \frac{1}{2\pi}\int_0^{2\pi} e_a^2\, d\theta = E_{da}^2 + \frac{E^2}{4} + \frac{2}{\pi}E_{da}E$$

$$E_a = \sqrt{E_{da}^2 + \frac{E^2}{4} + \frac{2}{\pi}E_{da}E}$$

The value of E_a during the half cycle "*b c*," Figure 11, is E_{da}. During the preceding half cycle "*a b*" the value of E_a may be derived as follows:

$$e_a^2 = E_{da}^2 + E^2\sin^2\theta + 2E_{da}E\sin\theta$$

$$\frac{1}{\pi}\int_0^{\pi} e_a^2\, d\theta = \frac{E_{da}^2}{\pi}\int_0^{\pi} d\theta + \frac{E^2}{\pi}\int_0^{\pi}\sin^2\theta\, d\theta + \frac{2E_{da}E}{\pi}\int_0^{\pi}\sin\theta\, d\theta = E_{da}^2 + \frac{E^2}{2} + \frac{4}{\pi}E_{da}E$$

$$E_a \text{ (half cycle "}a\,b\text{")} = \sqrt{E_{da}^2 + \frac{E^2}{2} + \frac{4}{\pi}E_{da}E}.$$

For the difference between the two half cycles "*a b*" and "*b c*" of e_a to equal $0.707E_{da}$,

$$\sqrt{E_{da}^2 + \frac{E^2}{2} + \frac{4}{\pi}E_{da}E} - E_{da} = 0.707\, E_{da}$$

$$E_{da}^2 + \frac{E^2}{2} + \frac{4}{\pi}E_{da}E = 2.91\, E_{da}^2$$

$$E^2 + \frac{8}{\pi}E_{da}E - 3.83\, E_{da}^2 = 0$$

$$E = \frac{-\frac{8}{\pi}E_{da} \pm \sqrt{\frac{64}{\pi^2}E_{da}^2 + 15.31\, E_{da}^2}}{2}$$

$$E = E_{da} \cdot \frac{-2.54 \pm 4.67}{2} = 1.07\, E_{da}$$

The (−) minus value of 4.67 in the preceding equation is disregarded. It evidently gives the value of $-E$ necessary to satisfy the conditions, but which is of no interest in this analysis.

For the particular case when the difference between successive half cycles of e_a is 0.707 E_{da}, the value of E_a in terms of E_{da} is now obtained by substitution from the two equations.

$$E = 1.07\,E_{da}$$

$$E_a = \sqrt{E_{da}{}^2 + \frac{E^2}{4} + \frac{2}{\pi} E_{da} E}$$

$$E_a = \sqrt{E_{da}{}^2 + \frac{(1.07)^2 E_{da}{}^2}{4} + \frac{2.14\,E_{da}{}^2}{\pi}}$$

$$E_a = E_{da}\sqrt{1 + 0.284 + 0.679} = E_{da}\sqrt{1.963}$$

$$E_a = 1.40\,E_{da}$$

Experimental proof of equation 6 is given by the data taken at Palo Alto plotted on Figure 12.

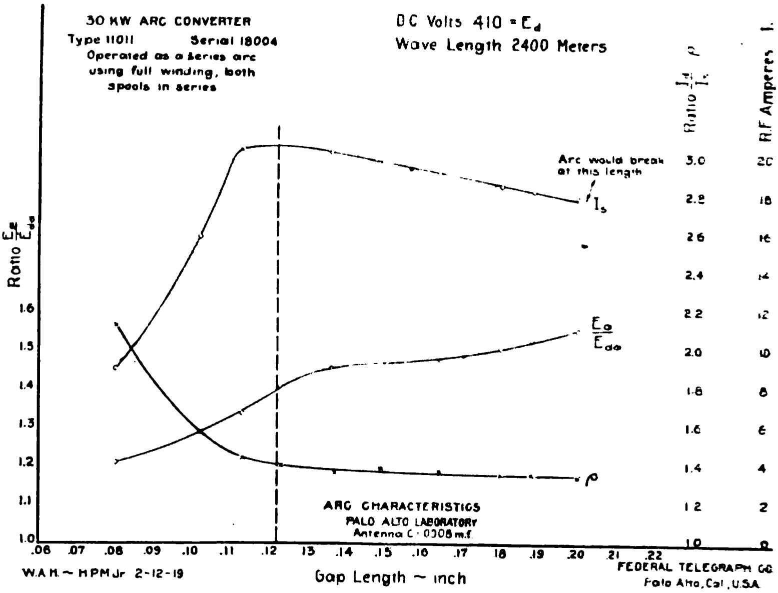


FIGURE 12

It is apparent that when $\rho = \sqrt{2}$, the ratio $\frac{E_a}{E_{da}} = 1.4$.

The values of E_{da}, I_d, and I_s were determined with the usual instruments in the usual manner.

E_a was measured by connecting a radio frequency voltmeter, consisting of a hot wire milliammeter in series with a non-inductive resistance across the radio frequency terminals of the arc. This voltmeter was calibrated on d.c.

The pulsating component of the E_a uni-directional equivalent wave, Figure 6, contains the two peaks "*m*" and "*n*."

It was stated under the heading of "The Poulsen Arc Converter Cycle" that the peak "*n*" was caused by the inductive discharge of L_d and that this pulse of emf. had a steeper wave front than the radio frequency oscillations. These facts have been proven by the following experiments:

Since the voltage E_{L_d} is produced by slight pulsations in I_d in the manner previously described, these cause the collapse of a portion of the air leakage field about L_d. This occurs once every radio frequency cycle, and it is possible to detect the flux changes by placing a wave meter exploring coil in the air in the vicinity of L_d and tuning the wave meter to resonance with the radio frequency. In performing this experiment great care must be taken to make sure that the wave meter ammeter deflection is due solely to the E_{L_d} flux changes and is not due to direct induction from any nearby conductors carrying radio frequency currents or to small radio frequency currents leaking back thru L_d to the d.c. generator.

The extremely steep wave front of E_{L_d} is proven by sphere gap measurements of the voltage between turns of L_s. It is found that the voltage between the end turns next to the arc is higher than between any other turns in the coil. If L_s is not sufficiently large this pulse may carry thru into the condenser C_s. In this case harmonics are set up in the oscillatory circuit.

Figure 8 shows the resultant distortion of the I_s wave. These harmonics will not occur in the antenna current if L_s is sufficiently large. Thus, in practice, a station with a high capacity antenna operating upon short wave lengths is more inclined to have harmonics than would be the case were the L/C ratio higher. As a rule these disturbances are entirely choked back by the end turns of L_s next to the arc.

THE EFFECT OF B_g UPON EXTINCTION AND IGNITION

The theory of the effects of B_g upon extinction and ignition as outlined below is based upon the effect of changes in B_g upon I_s. It is to be understood that no experimental means of localizing and specifically measuring the amplitudes and phase relations of the extinction and ignition voltages has been used.

The magnetic field strength B_g controls both the amplitude and timing of the extinction and ignition voltages.

For any given set of conditions there is a value of B_g which gives optimum I_s. When the arc fields are adjusted to this value, they are said to be "tuned," and the flux density is denoted by β_g.

When B_g is less than β_g, the rate at which ions are removed from the gap is below normal, and hence gap ionization is above normal. This decreases the effective value E_a, which may be proven experimentally by use of the radio frequency voltmeter previously described. Such a condition reduces both the extinction and ignition voltages, and because of the high peak values of these, reduces the effective value of E_a, Figure 4, thruout the "*c d e*" period to a greater extent than thruout the "*a b c*" period. Hence the effective value of the in-phase driving voltage, E_ϕ, Figure 5, is reduced.

The fact that this is the case is easily demonstrated experimentally by lowering the field strength of an arc while it is in operation. The current I_s is immediately lowered.

Conditions with B_g greater than β_g are not altogether the converse of those with B_g less than β_g. This is because, altho the extinction and ignition voltages are abnormally high when B_g is greater than β_g, the time of extinction is advanced and ignition is delayed. This tends to separate the points "*m*" and "*n*" and to foster harmonics. Such improper timing of "*m*" and "*n*" causes a reduction in the amount of energy transferred to the oscillatory circuit and a corresponding reduction in I_s, because the e_a wave form becomes so radically different from the e_ϕ wave of in-phase voltage.

Summing up the foregoing, it is seen that with field strength β_g, the points "*m*" and "*n*," Figure 4, have certain amplitudes and time phase relations with respect to i_s. If B_g is less than β_g, the effective values of both E_a and E_ϕ are reduced and I_s is correspondingly reduced. On the other hand if B_g is greater than β_g, the harmonics in the voltage circulating I_s are augmented and this reduces the energy transferred to the radio frequency oscillations of fundamental frequency. The current I_s is accordingly again reduced.

THE ARC CURRENT I_a

The arc current is made up of the two components I_d and I_s. Figure 13 shows the vector relations of the currents involved. I_s is laid off as a base vector of unit length. I_d is laid off at right angles because it may be considered a sine wave of different frequency, that is, extremely low frequency. Its length is $\sqrt{2}$, since from Figures 2 and 3 it is evident that the crest of the I_s wave equals I_d, and with sinusoidal wave form the ratio of peak to effective values is $\sqrt{2}$.

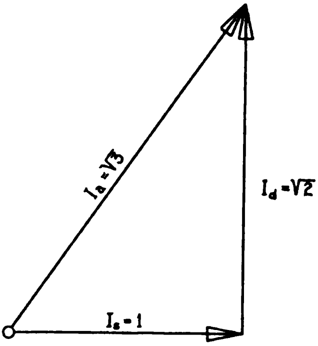


FIGURE 13

The triangle is then closed by $I_a=\sqrt{3}$.

Experimental proof of these current relations is easily obtained by inserting ammeters in an arc circuit to measure I_d, I_a, and I_s (see Figure 1). When the magnetic field strength is of proper value, it is found that

$$I_d=\sqrt{2}\,I_s \tag{7}$$

and

$$I_a=\sqrt{3}\,I_s \tag{8}$$

THE POULSEN CYCLE EFFICIENCY

The efficiency of the Poulsen cycle may be computed from the following:

$$\text{Arc output}=R_s I_s^2=\frac{E_{da}}{I_d}\times\frac{I_d^2}{\rho^2}=\frac{E_{da}I_d}{\rho^2},$$

$$\text{where } \rho=\frac{I_d}{I_s}$$

$$\text{Arc input}=E_{da}I_d$$

$$\therefore \text{ Arc efficiency } \varepsilon=\frac{1}{\rho^2} \tag{9}$$

$$\text{If } \rho=\sqrt{2}, \text{ then } \epsilon=50\%.$$

This is the maximum Poulsen cycle efficiency, and the highest theoretically obtainable. It corresponds to the Carnot cycle in thermodynamics. If the magnetic field strength is too weak, ρ will be greater than $\sqrt{2}$ and $\frac{E_{da}}{I_d}$ may be greater than R_s. Under these conditions true arc efficiency cannot be determined unless R_s is actually known. However, when the arc magnetic field is tuned, $\frac{1}{\rho^2}$ is a very fair approximation to true arc flame ϵ.

This is shown by Figure 14, which is plotted from data taken at the San Diego (California) High Power Naval Radio Station.

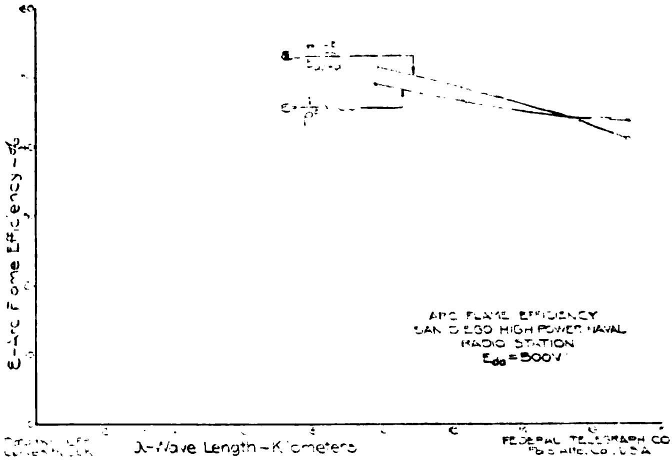


FIGURE 14

THE MAGNETIC FIELD

It is apparent from the theory of the arc that the strength of the magnetic field materially affects its performance. A fraction of each radio frequency cycle is allowed for the extinction of the arc and the scavenging of the gap between the electrodes. The length of this time is inversely proportional to frequency. Therefore, all other factors remaining constant, the strength of the magnetic field required for properly de-ionizing the gap is directly proportional to frequency or inversely proportional to wave length. This is because the rate at which the ions are moved is dependent upon field strength.

Therefore: $$\beta_g \propto \frac{1}{\lambda} \qquad (10)$$

where "λ" is the wave length.

The molecular velocity of the atmosphere in which the arc burns controls the value of β_g. To extinguish the arc properly and de-ionize the gap in the time available, there is no gain in raising the ions above the velocity necessary to break up the ionic stream in the time allowed. Hence, if the molecular velocity of the gaseous medium surrounding the arc is high, it is unnecessary for the magnetic field to increase the velocity of the ions as much as would be the case were their velocity lower. Therefore, the necessary field strength is inversely proportional to the molecular velocity of the gaseous medium surrounding the arc. That is:

$$\beta_g \propto \frac{1}{v} \tag{11}$$

where "v" is the molecular velocity of the gas.

The temperature of the arc flame is so high compared with the temperature of the gases in the chamber when the arc is not in operation that no appreciable error is introduced by the assumption that the absolute temperature of the arc flame is proportional to the power input $E_{da} I_d$. Since the velocity of the molecules of a given gas is proportional to the square root of the absolute temperature of the gas, it follows that

$$v \propto \sqrt{E_{da} I_d} \tag{12}$$

Inasmuch as it is necessary for the magnetic field to extinguish the arc, its best strength, β_g, is directly proportional to the electric field tending to maintain the arc. That is:

$$\beta_g \propto E_{da} \tag{13}$$

The number of ions to be removed from the gap is proportional to the current thru the arc, and hence to I_d. That is:

$$\beta_g \propto I_d \tag{14}$$

From equations 13 and 14:

$$\beta_g \propto E_{da} I_d \tag{15}$$

Hence from equations 10, 11, 12, and 15:

$$\beta_g = \frac{K E_{da} I_d}{\lambda \sqrt{E_{da} I_d}} = K \frac{\sqrt{E_{da} I_d}}{\lambda} \tag{16}$$

where K is a quantity *inversely proportional* to the specific molecular velocity of the gases surrounding the arc. For any particular gas it is a constant, the value of which is determined experimentally from observations involving the other quantities of equation 16. Its numerical value obviously depends upon the units employed.

COMPUTATION OF *K* FROM THE CHEMICAL ANALYSIS OF THE GAS

If kerosene $CH_3(CH_2)_8CH_3$ is used to supply the atmosphere for the arc it dissociates into $10C+11H_2$. The C precipitates and the arc is surrounded by an atmosphere of H_2 only.

If ethyl (grain) alcohol C_2H_5OH is used, it dissociates into CO_2+6H_2+3C. The carbon precipitates and the arc is surrounded by an atmosphere of H_2 diluted by CO_2.

The weights of equal volumes of the chamber gases may be computed from their molecular weights. Thus the

$$\frac{\text{density of chamber gas from kerosene}}{\text{density of chamber gas from ethyl alcohol}}=\frac{14}{56}=\frac{1}{4}$$

The velocities of the molecules of different gases, at the same temperature, are inversely proportional to the square roots of the densities of these gases. Hence the molecular velocity of the chamber gas with kerosene is twice that with ethyl alcohol.

The same method may be used for methyl (wood) alcohol, illuminating gas, and so on.

Thus the value of *K*, equation 16, for ethyl alcohol should be twice that for kerosene. This theory is proven from the following data.

EXPERIMENTAL PROOF OF EQUATION 16

These experimental data were taken at the United States Naval High Power Radio Station, Pearl Harbor, Hawaii, during the months of August and September, 1917. Experimental proof of equation 16 is given for powers up to 500 kilowatts thruout a wave length range of 4.1 to 16.1 kilometers. Values of *K* are derived for kerosene and ethyl alcohol.

In considering experimental data of this sort, it should be realized that there are many factors which render such a station unsuitable for tests requiring those features of unchanging conditions and ample time for observations which can only be obtained in the laboratory.

Antenna resistance R_s changes daily with the weather, for it is affected considerably by the surface condition of the antenna insulation. Furthermore, the field tuning is broad. These facts tend to scatter the observed points.

The lack of opportunity for long runs because of necessary routine work about the plant renders the obtaining of uniform chamber atmospheres on consecutive days practically impossible. This increases the scattering of the *K* determinations.

The reader will realize, therefore, that the data presented in proving equation 16 are essentially those taken in the field and not in the laboratory with its attendant possible niceties of observation.

Figures 15 thru 22 (corresponding to plates 31, 52, 93, 134, 145, 156, 187, and 218) show the effect of variations in B_g and I_d with E_{da} held approximately constant thruout a range of wave lengths of from 4.5 to 16.1 kilometers.

These curves are practically equivalent (except for value of ordinate in amperes) to curves of I_s plotted against B_g, since I_s is proportional to I_d. The proportionality factor, ρ, varies with B_g for a given λ and E_{da}, but this variation is of no interest since we are interested only in the peak values of the curves, and these occur at the same B_g irrespective of which current is used in the scale of ordinates. At the peak of these curves, $\rho = \sqrt{2}$, and on each side of the peak it is greater than $\sqrt{2}$.

It will be noted that the points of maximum current fall approximately on a straight line thru the origin. This is in accordance with the theory used in the derivation of equation 14. Such lines have been drawn on all plates.

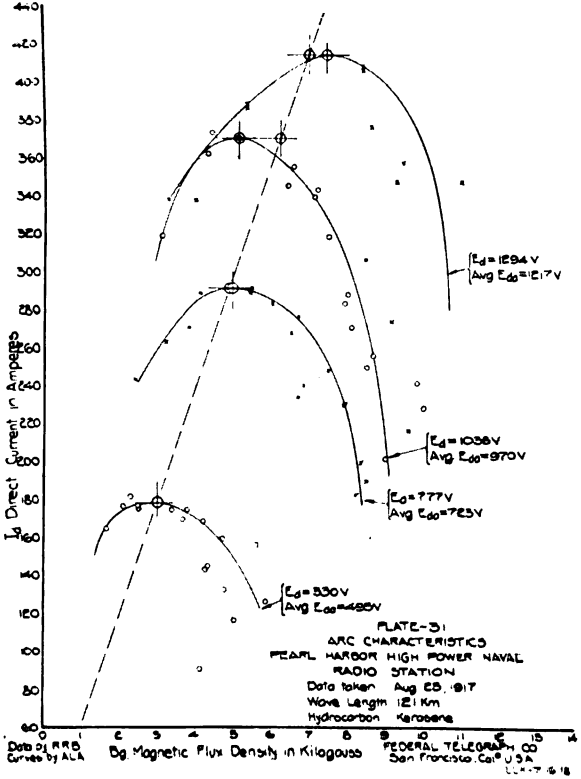


FIGURE 15

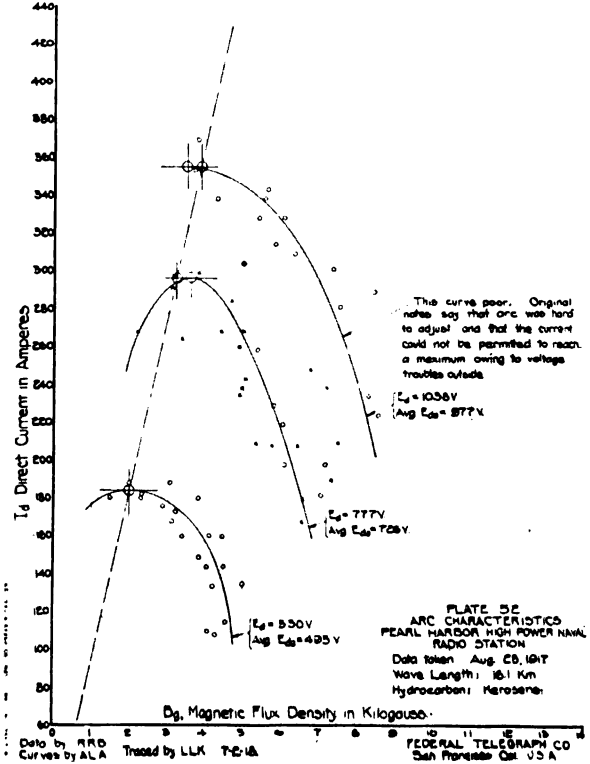


FIGURE 16

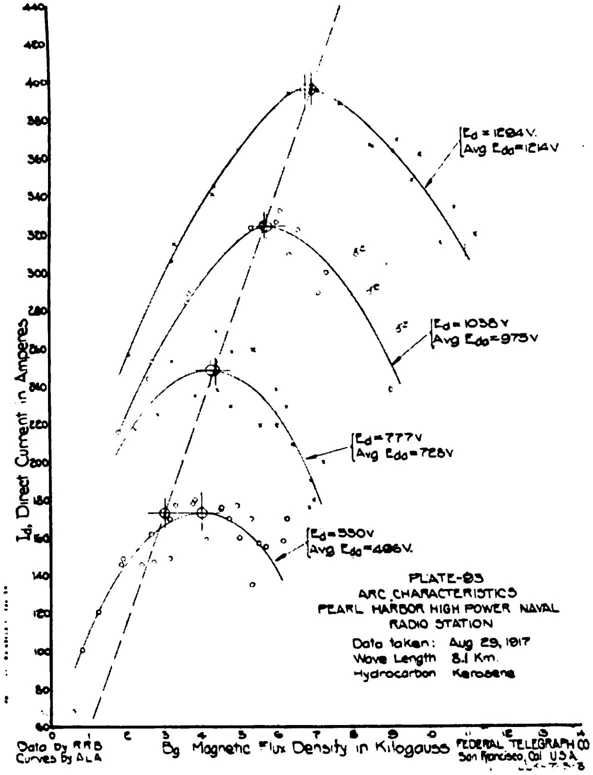


FIGURE 17

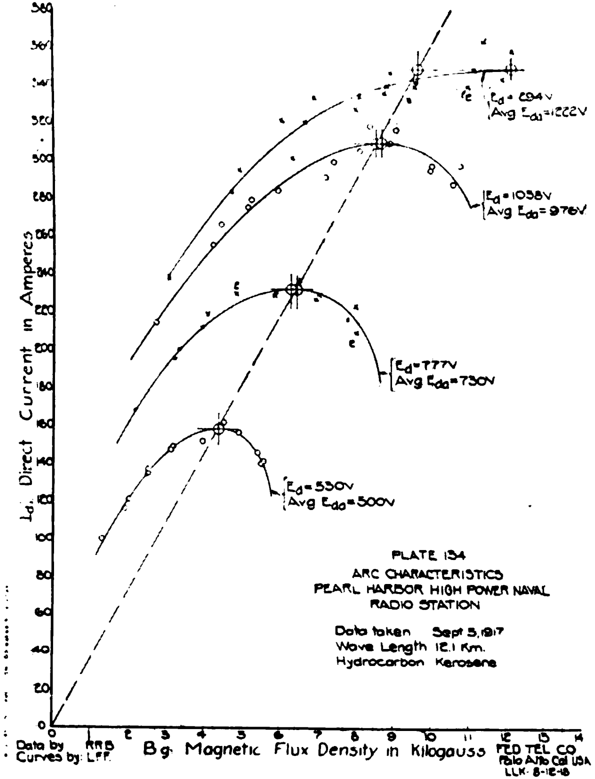


FIGURE 18

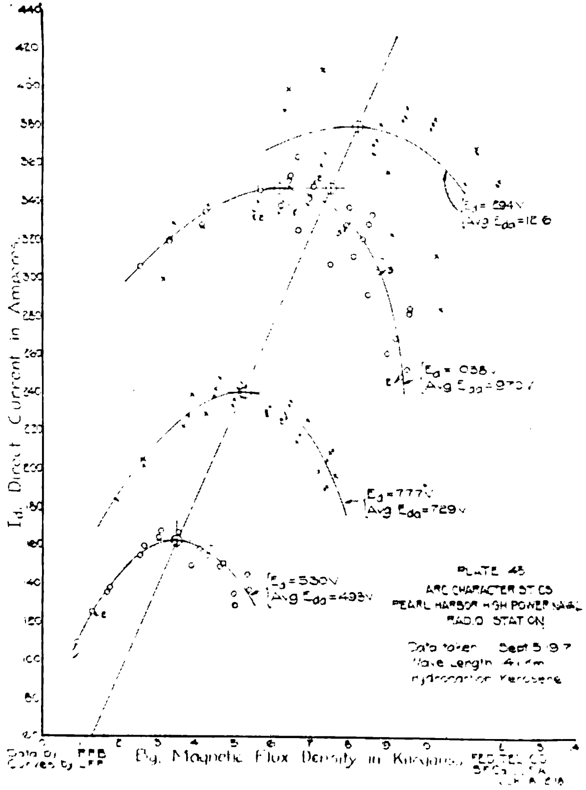


FIGURE 19

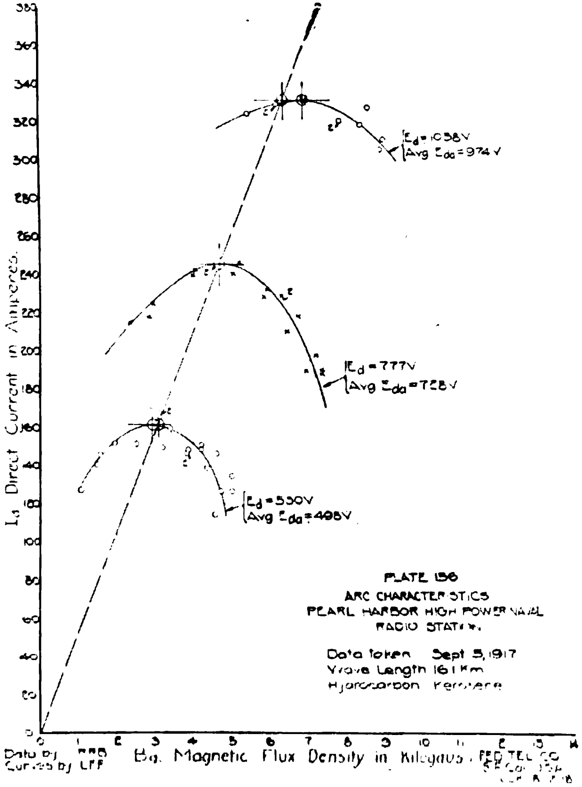


FIGURE 20

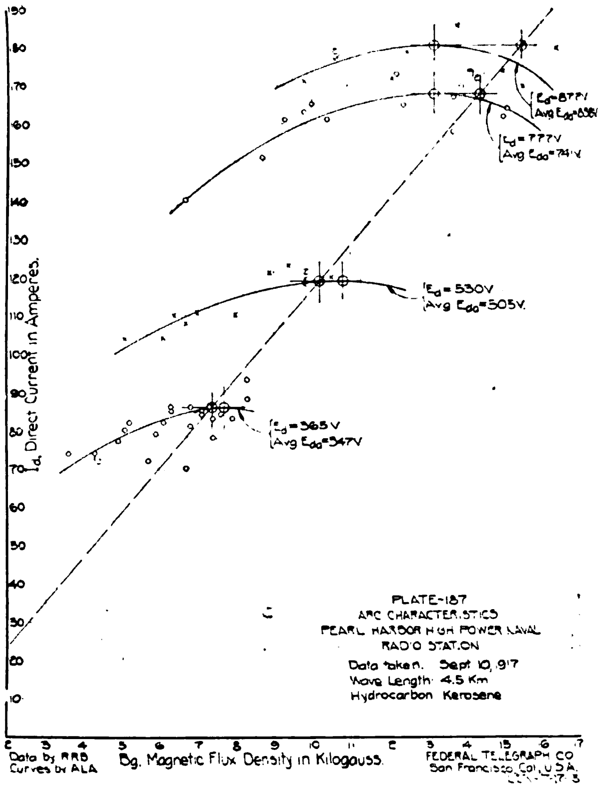


FIGURE 21

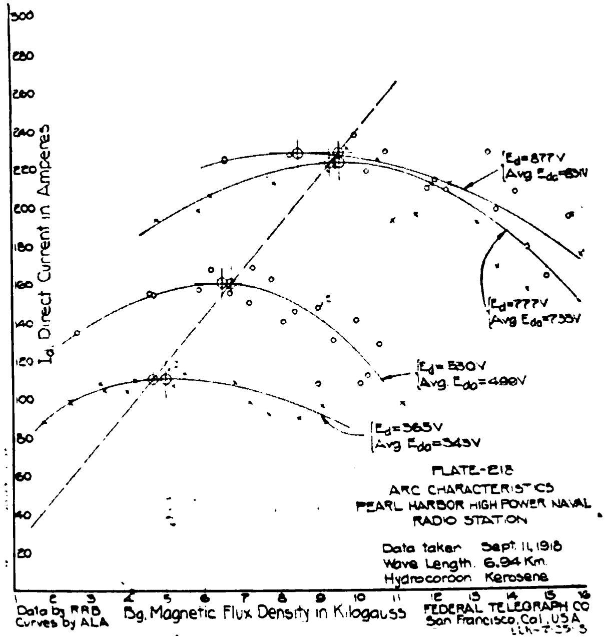


FIGURE 22

The peak values of I_d have been tabulated in Table 1 along with the value of β_g as determined by the intersection of the straight line thru the origin, with the current peak value.

TABLE 1

Figure Number	E_{da} Volts	I_d Amps.	$E_{da} I_d$ Kw. Input	β_g Kilogauss	$Tan\ \alpha$ Slope	c Intercept	λ Wave Length	$c\lambda = K$
15	495	178	88.1	3.0	.532	.275	12.1	3.33
	723	292	211	4.85				
	970	371	360	6.4				
	1,217	415	505	7.4				
16	495	184	91.1	2	.504	.198	16.1	3.19
	726	296	215	3.2				
	977	355	347	3.87				
17	496	173	85.9	3.05	.477	.363	8.1	2.94
	728	248	180.5	4.35				
	975	324	316	5.7				
	1,214	396	481	7.0				
18	500	158	79	4.35	.497	.5	12.1	6.05
	730	232	169.5	6.4				
	976	310	302	8.5				
	1,222	348	425	9.55				
19	498	163	81.3	3.5	.510	.37	14.1	5.22
	729	240	175	5.2				
	970	347	336	7.5				
	1,216	379	461	8.2				
20	498	162	80.8	3.05	.499	.35	16.1	5.64
	728	246	179	4.75				
	974	332	323	6.25				
21	347	86	29.8	7.4	.464	1.55	4.5	6.98
	505	119	60	10.2				
	741	168	124.5	14.4				
	838	180.5	151.2	15.5				
22	343	110	37.7	4.7	.466	.86	6.94	5.97
	499	160	79.9	6.75				
	733	222	163	9.35	Aver. .494		Aver.	4.91
	831	228	189.5	9.6				

The kilowatt input has been computed and tabulated, and on Figure 23 are logarithmic graphs of the relation between $E_{da} I_d$ and β_g. The slope of these lines is tabulated in Table 1, and averages 0.494. The theoretical value is 0.500 as indicated by equation 16.

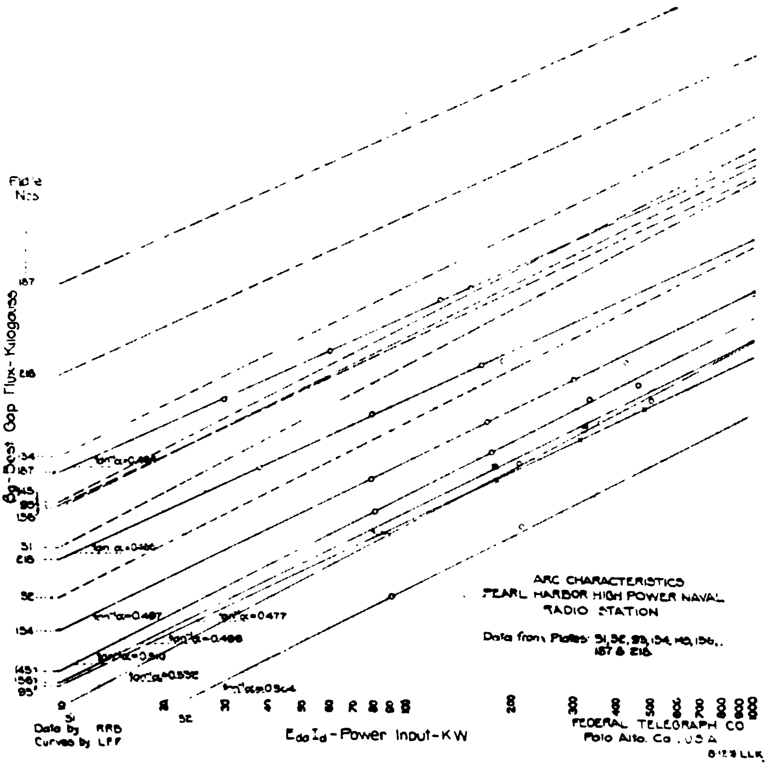


FIGURE 23

Dotted lines show the intercepts on the unit axis. These have been tabulated also. According to equation 10, these intercepts should be inversely proportional to wave length. Therefore the product $c\lambda$ has been tabulated, and the average 4.91 obtained.

We have thus obtained an experimental check upon equation 16, and determined the empirical value of

$$K = 4.91$$

when kerosene is used to supply the arc atmosphere and

E_{da} is expressed in kilovolts
I_d is expressed in amperes
λ is expressed in kilometers
β_g is expressed in kilogauss.

Figures 24 thru 30 (corresponding to plates 231, 242, 253, 264, 285, 296, and 307) repeat the foregoing when ethyl alcohol is used. Figure 31 and Table 2 give the results.

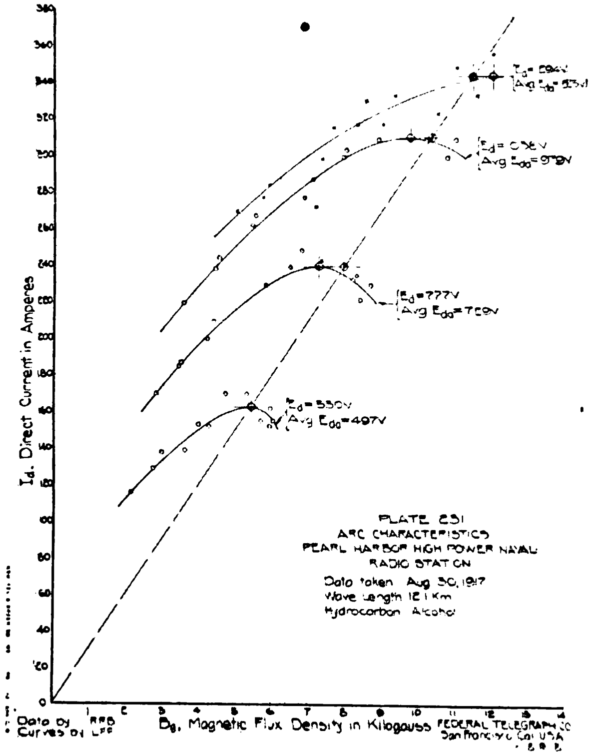


FIGURE 24

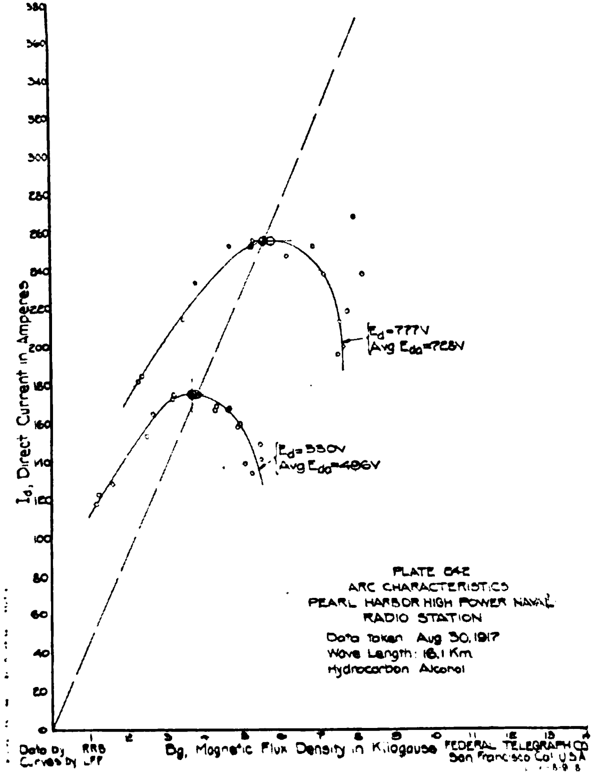


FIGURE 25

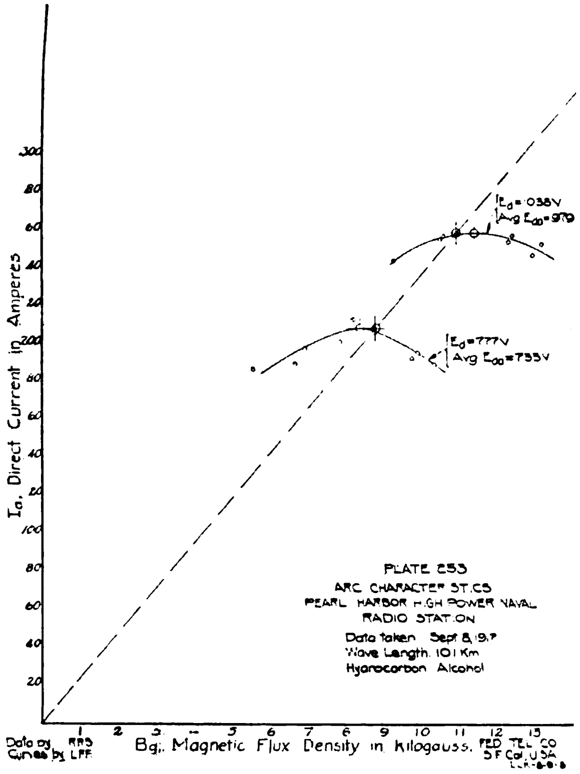


FIGURE 26

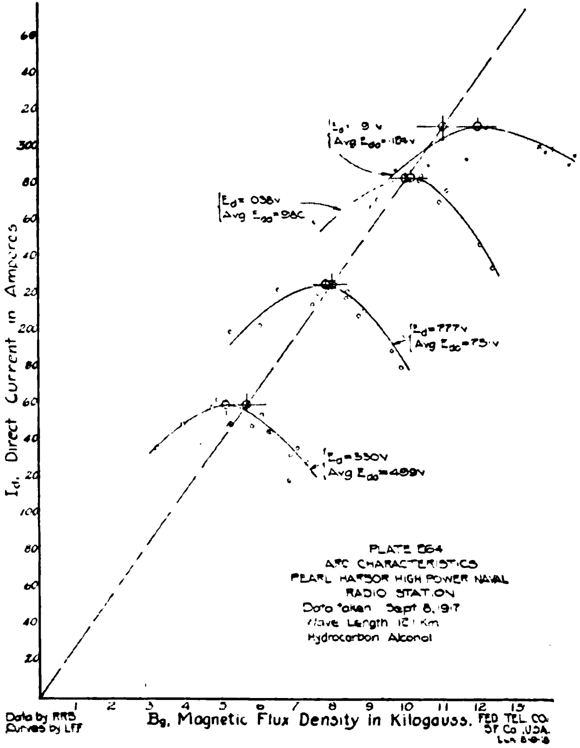


FIGURE 27

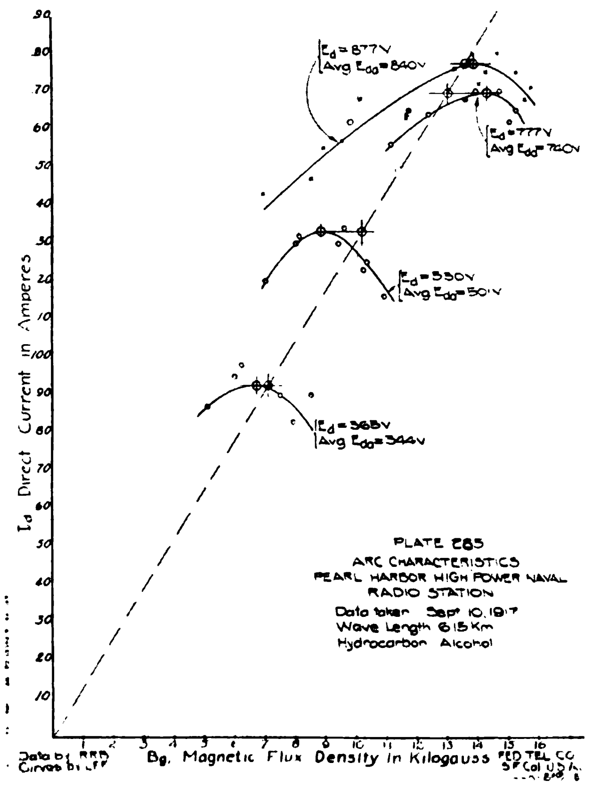


FIGURE 28

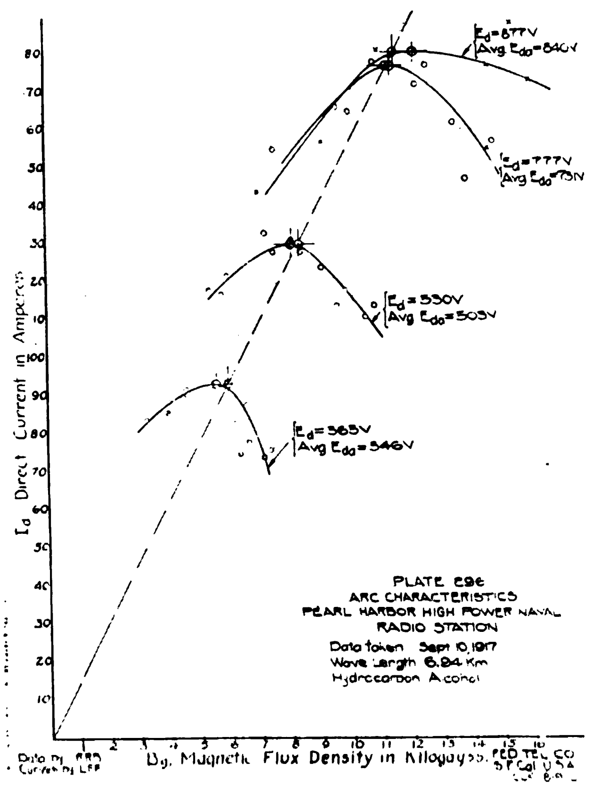


FIGURE 29

The average slope is 0.483, and the value of

$$K=8.32$$

Our theory, given above, showed that the value of K for ethyl alcohol should be twice that for kerosene.

$$2\times 4.91=9.82 \text{ (as against 8.32)}$$

We therefore check our theory within 18 per cent. It is to be remembered that this theory is based upon chemically pure liquid hydrocarbons of the molecular make-up indicated, and that in these tests commercial kerosene and grain alcohol were used. The impurities or variations in the molecular make-up of these would in some degree affect the results.

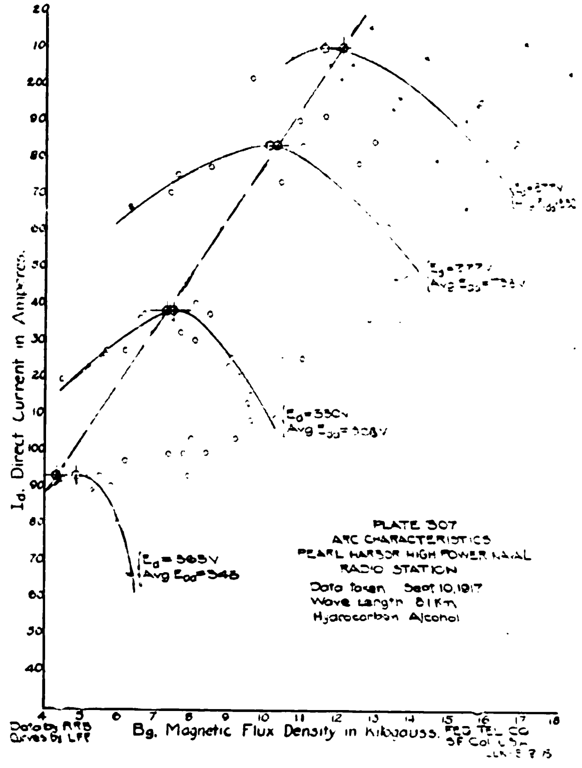


FIGURE 30

Any theory which assumes ideal conditions can only indicate the general trend of the phenomena which will take place under practical conditions.

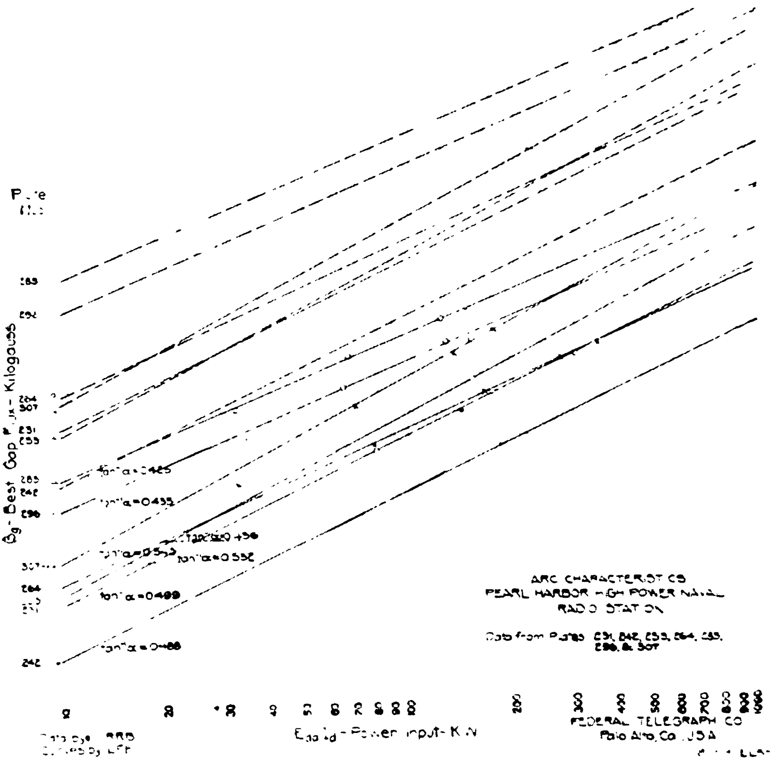


FIGURE 31

In view of the disturbing factors which are known to affect arc performance, such as the impurities in the hydrocarbon above mentioned, and especially those unavoidable variations in the density of the chamber atmosphere previously enumerated, it is felt that an agreement even as close as 18 per cent. establishes the soundness of our fundamental conceptions of arc operation.

While variations in chamber atmospheric density affect the position of the straight lines on the logarithmic sheets and hence the value of *K* so obtained, they do not affect the slope of these lines, provided the rate of hydrocarbon flow is held constant thruout any one run. For this reason the determination of the exponent of the $E_{da} I_d$ product is checked rather closely, that is, within 1.25 per cent. in the case of kerosene and 3.5 per cent. in the case of ethyl alcohol.

TABLE 2

Figure Number	E_{da} Volts	I_d Amps.	$E_{da} I_d$ Kw. Input	B_d Kilogauss	Tan a Slope	c Intercept	λ Wave Length	$c\lambda = K$
24	497	162	80.5	5.4	.499	.62	12.1	7.5
	729	239	174.2	8.0				
	979	310	303.5	10.35				
	1,225	344	420.2	11.45				
25	496	175	86.9	3.85	.488	.46	16.1	7.4
	728	256	186.5	5.6				
26	733	209	153.0	8.7	.532	.60	10.1	6.06
	979	259	253.5	11.3				
27	499	160	79.9	5.6	.456	.78	12.1	9.44
	731	226	165.2	7.95				
	980	284	278.5	10.0				
	1,124	312	351.0	11.0				
28	344	92.5	31.8	7.19	.425	1.68	6.15	10.33
	501	133	66.6	10.13				
	740	169.5	125.5	13.0				
	840	177	148.7	13.5				
29	346	97	33.6	5.88	.435	1.35	6.94	9.37
	503	130	65.5	8.25				
	731	177	129.4	11.13				
	840	180	151.2	11.38				
30	345	94	32.4	4.35	.543	.74	8.1	6.0
	503	139	70.0	7.3				
	738	184	135.8	10.3	Aver. .483		Aver.	8.32
	832	211	175.5	12.05				

In taking these data, it was customary to use alcohol profusely because there was little soot deposited in the chamber, and this practice assured the most uniform results. When kerosene was used, the soot deposit became excessively heavy, and it was therefore customary for convenience in arc operation to throttle down the flow somewhat. This reduced the resultant effective molecular velocity of the chamber gases because they were diluted by O_2 and N_2 from the outside atmosphere which always tends to be drawn thru small leaks into the swirling mass of hot gases within the arc chamber when the liquid hydrocarbon is supplied in insufficient quantity.

It is evident from the foregoing that the value of K determined for kerosene is high (considering the ideal conditions for which equation 16 was derived), and in view of the practical difficulties of taking experimental data of this sort, some of which have already been enumerated, we may generalize somewhat, and are of the opinion that $K = 4.25$ for kerosene and 8.5 for ethyl alcohol are better empirical determinations of this constant. Equation 16 becomes:

$$\beta_g = \frac{4.25\sqrt{E_{da} I_d}}{\lambda} \text{ for kerosene} \qquad (17)$$

and

$$\beta_g = \frac{8.50\sqrt{E_{da} I_d}}{\lambda} \text{ for ethyl alcohol} \qquad (18)$$

General observation and data collected from various sources indicate that, for ordinary Pacific Coast illuminating gas, the value of K lies about midway between that for kerosene and ethyl alcohol.

A consideration of the chemical make-up of methyl alcohol shows that it should require a somewhat higher flux than ethyl alcohol. This is borne out by general experience in arc work.

THE MAGNETIC CIRCUIT

General

In our treatment of the arc design problem thus far, we have covered the theoretical field of arc performance and have shown the relationship between the various voltages and currents involved from theoretical considerations backed by experimental evidence.

We have also derived the so-called "Flux Formula" (Equation 16) from theory, and have proven it experimentally by data taken at the Pearl Harbor High Power Naval Radio Station.

We shall now consider the theories involved in the design of the magnetic circuit and shall follow these by experimental data bearing specifically upon the affect of variations in magnetic circuit design on the gap flux, B_g.

Until the high power arc converter became a necessity in radio telegraphy, this specific problem had not been met in practical design work, except in the case of a few relatively small electro-magnets which had been built for various laboratories thruout the world.

The necessity of building electro-magnets weighing 65 tons (59,100 kg.) in the case of the 500 kw. arc converters and 80 tons (72,700 kg.) in the case of the 1,000 kw. units made it essential that knowledge of these matters be accumulated in a form suitable for design work.

THE IDEAL CIRCUIT

Figure 32 shows two magnet poles "N" and "S" located under ideal conditions as developed in past literature—that is, within a long solenoid, so that at the magnetic air gap the magneto-motive force (abbreviated "mmf.") is uniformly distributed and is parallel to the axis of the poles. If it is desired to obtain a maximum flux density in the air gap for a given applied mmf., it is obvious that this cannot be obtained if the full diameter of the poles is continued up to the air gap, because a certain percentage of the flux will leak around the gap as shown, and the flux density in the main poles will exceed that in the pole tip faces adjacent to the gap. Hence premature saturation will occur back in the body of the main poles.

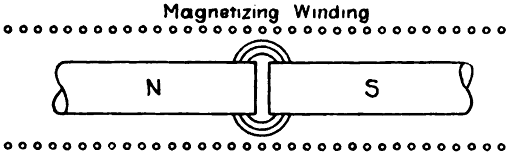


FIGURE 32

If the poles are shaped as in Figure 33, premature saturation of the main pole is eliminated, but an analogous condition exists in the pole tips—that is, premature saturation occurs at some point in the pole tip between its base, where it joins the main pole, and its face, adjacent to the air gap.

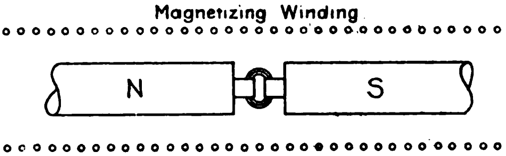


FIGURE 33

It is obvious from the foregoing that if the pole tips are made of a shape somewhat between that of Figures 32 and 33—for example, truncated cones as shown in Figure 34, a maximum flux will be obtained in the air gap for a given applied mmf. *If the poles are made of the best possible shape, equal flux densities* *will exist at all points*, and hence no part will take more than its share of the applied mmf.

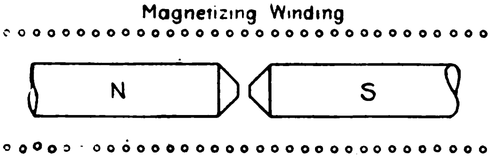


FIGURE 34

In his "Magnetic Induction in Iron and Other Metals," Ewing shows by analytical treatment that the best pole shape is that of a truncated cone having the angle α, Figure 35, 54° 44′. His method of treatment is as follows:

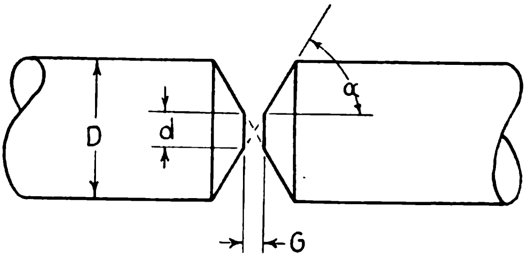


FIGURE 35

The assumption is made that the distribution of magnetization is uniform thruout the cross section of the magnet poles—that is, that the flux lies parallel to the axis of the poles.

The magnetic force in the space between the pole tips is composed of two parts, (1) the magnetic force due directly to the current in the field coils, and (2) that due to the internal or molecular mmfs. induced by the applied mmf. The first of these forms a small part of the whole, and since its distribution is nearly uniform, it becomes a negligible factor.

The pole faces are considered as being made up of a series of coaxial circular rings in planes normal to the axis of the poles. If the induced magnetization of one of these rings is represented by "J" the magnetic force "F"[1], due to it at a point "O" (Figure

---

[1] Using Ewing's terminology.

36) in the axis at a distance "x" from the plane of the ring, is, according to Coulomb's law, given by the equation:

$$F = \frac{J}{l^2} \cdot \cos a, \text{ or by}$$

$$F = \frac{Jx}{l^3} \quad \text{since } \cos a = \frac{x}{l}$$

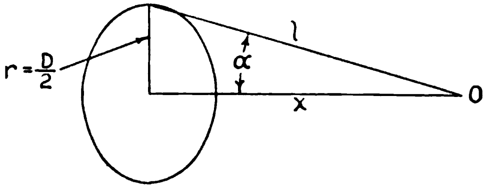


FIGURE 36

Obviously F will be a maximum when $\frac{dF}{dx} = 0$, which occurs when $x = \frac{r}{\sqrt{2}}$; $\tan a = \sqrt{2}$, or $a = 54° 44'$.

Weiss[2] has given experimental data showing that the best pole tip shape is not the uniform cone just considered but one made of a multiple number of angles, which are equivalent to a curved surface. This deviation from the pole tip shape which Ewing's mathematical treatment of the problem indicated as best, is probably due to the following facts:

(1) The fundamental requirement is that premature saturation shall not occur in any part of the magnetic circuit, that is, all parts must reach their limiting value at the same time.

(2) Such a condition was assumed by Ewing in his mathematical analysis, upon the basis of the flux in all parts of the pole tip lying parallel to the axis of the poles.

(3) But experimental data show that the flux does not lie parallel to the polar axis with uniformly conical tips. On the contrary, it concentrates in the portion next to the air gap.

(4) Therefore, in order to fulfil the basic requirement of (1), it is necessary to approach the gap more slowly and thus by

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[2] For various discussions of pole tip angles, see
Weiss, "Journal de Physique," volume 6, page 353, 1907.
DeBois, "Ann. d. Phys.", volume 37, page 1268, 1913.
Ewing, former citation.
Cotton, "Revue Générale des Sciences Pures et Appliquées," volume 25, numbers 13 and 14, 1914.

leakage prevent too high a percentage of the main pole flux from flowing thru the tip faces adjacent to the gap.

Figure 37 shows a pole tip of this shape. It is relatively long as compared with single angle cones of approximately 55° and since, at the flux densities used in arc converters, the percentage of gain in B_g due to its use is small, it is not a desirable shape, because such a long-nosed pole materially increases the height of the magnetic circuit yoke. In arcs of 500 to 1,000 kw. capacity, such an increase adds many tons to the weight of the unit, while the resultant decrease in necessary magnetizing kilowatts is very small. The time and cost of machining this complicated surface is another reason for not considering it in large arcs.

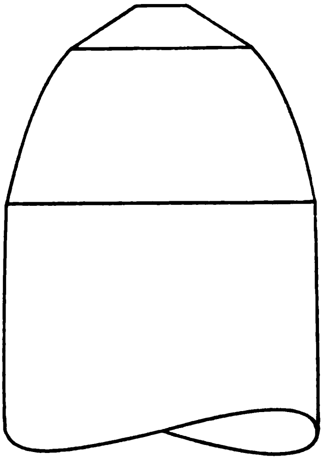

FIGURE 37

Figures 38 and 39 of a 1,000-kw. arc converter show why weight is added rapidly if the height of the yoke is increased.

The greatest flux density will be produced in the air gap when the pole pieces are saturated so that the intensity of induced magnetism J reaches its limiting value in all parts of the metal. Thus, for truncated cones (Figure 35) the surface density is $J \sin a$; and, employing the theory of Ewing previously given, an expression may be obtained for the field intensity in the gap, that is:[3]

$$B_g = 4\pi J\left(1 - \cos a + \sin^2 a \cos a \log_e \frac{D}{d}\right) \qquad (19)$$

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[3] See Weiss, former citation on this matter.

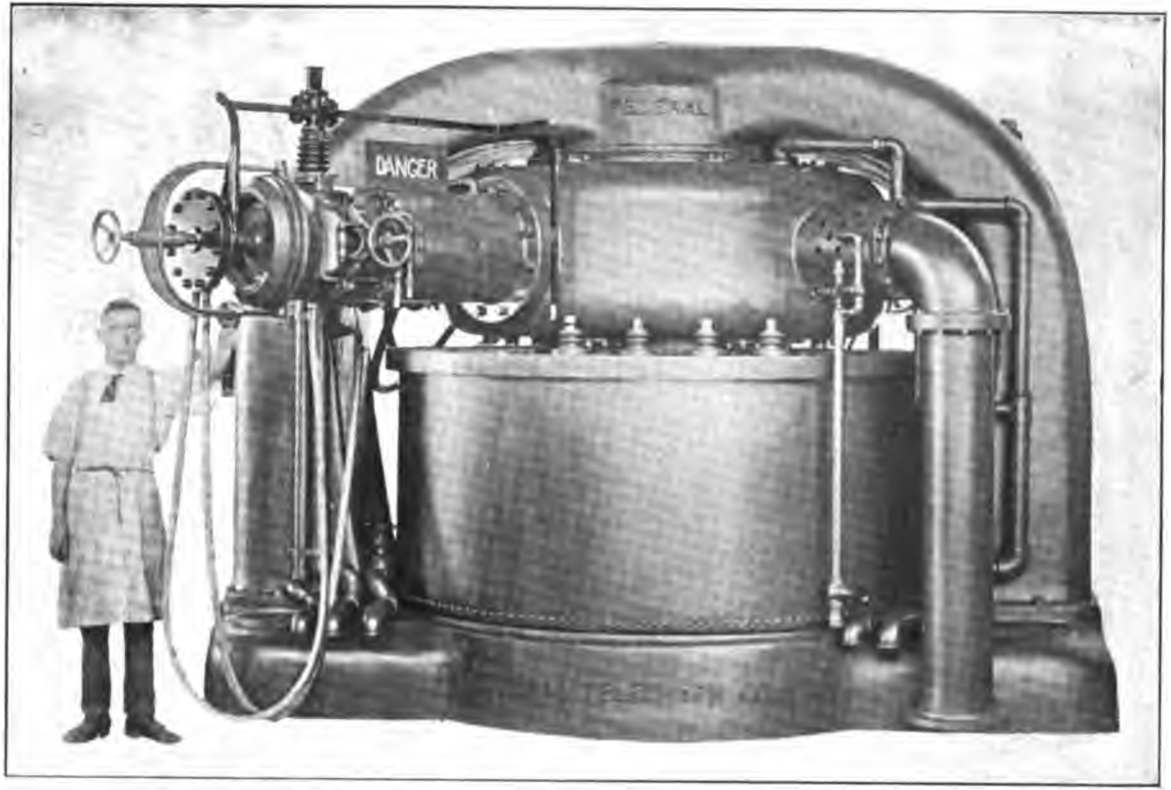

Figure 38—1,000-Kilowatt Arc Converter (Anode Side)

Figure 39—1,000-Kilowatt Arc Converter (Cathode Side)

which of course is a maximum when $a = 54°44'$ for cones the apices of which coincide. In this expression, $1 - \cos a$ represents the flux due to the pole tip face, and the remainder that due to the conical surface.

Since the flux distribution in a pole tip of any shape varies with the flux density and with the permeability of the steel, any mathematical treatment of the problem which seeks to render the computation of B_g possible thruout the broad range of flux densities from 0 to 40 or 50 kilogausses, must be based upon these premises, which are incapable of exact mathematical expression. Therefore a mathematical solution of the problem for this broad range is seemingly impossible.

The range of flux densities used in arc converters is from approximately 2 to 20 kilogausses, and hence we must resort to experimentation upon actual magnetic circuits to obtain arc design data.

BEST PRACTICAL TIP-GAP RATIO $\frac{d}{G}$

The mathematical derivation of the pole tip angle $a = 54° 44'$, Figure 35, makes the ratio of pole tip face diameter "*d*" to gap "*G*" equal to $\sqrt{2}$ for cones with the same apex, since $tan^{-1} a = \sqrt{2}$ and $tan\, a = \frac{d}{G}$.

Since commercial arcs cannot have the mmf. applied ideally, that is, the arc chamber cannot be within the magnet windings, there is more spreading of the flux in the gap than in the ideal case. Hence $\frac{d}{G}$ must be greater than the theoretical value, namely, $\sqrt{2}$. The practical value seems to be very close to $tan\, 60° = \sqrt{3}$. However, the $\frac{d}{G}$ ratio may be varied between 1.6 and 2.0 without seriously reducing the flux density in the gap. Figure 40 gives experimental proof of the foregoing.

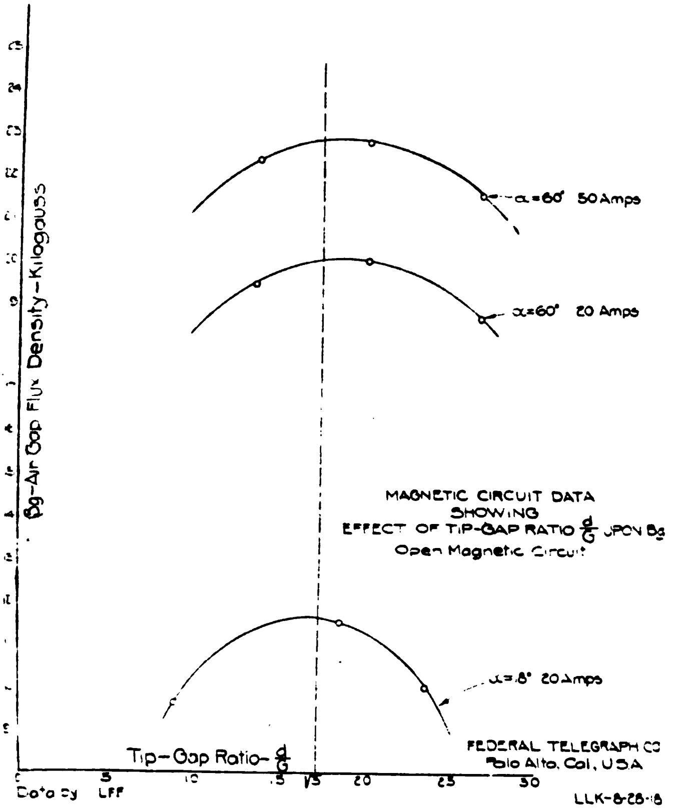

FIGURE 40

In all the work described herein, magnetic flux densities were measured by means of an exploring coil and ballistic galvanometer, in the usual well-known manner.

BEST PRACTICAL POLE TIP SHAPE

The fact that the *best practical* ratio $\frac{d}{G}$ is very close to $\sqrt{3}$ shows that the angle of the two cones, the tips of which touch in the center of the air gap is 60°. However, as shown on Figure 41 and in Table 3, 60° tips are not as good as 55° (keeping $\frac{d}{G} = \sqrt{3}$ in both cases).

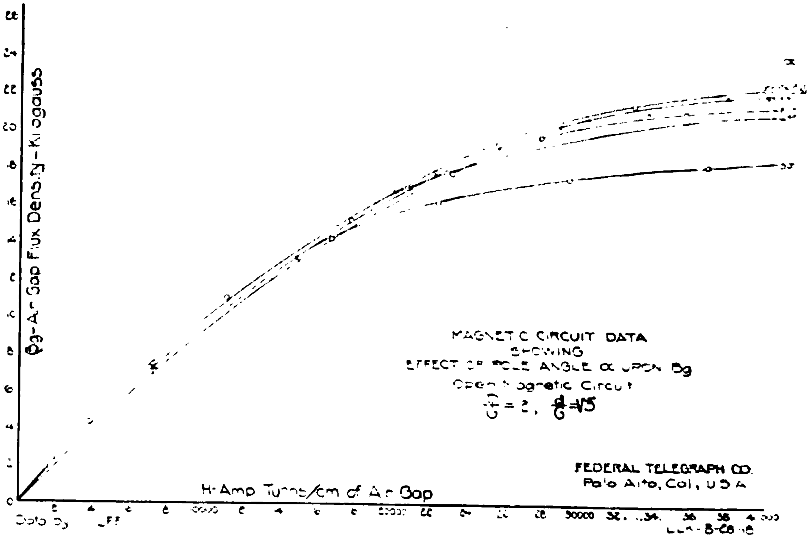

FIGURE 41

TABLE 3

(Figure 41—Pole Tip Shapes)

Open Magnetic Circuits

H	B	
3,850	4,320	$\frac{D}{G}=12$ $\frac{d}{G}=\sqrt{3}$ $a=60^\circ, 55^\circ, 50^\circ$
7,260	7,440	
11,200	11,050	
17,800	15,290	
18,010	15,380	
21,780	17,890	
25,320	19,500	
32,800	21,400	
39,800	22,300	
43,490	22,700	
7,230	7,330	$\frac{D}{G}=12$ $\frac{d}{G}=\sqrt{3}$ $a=55^\circ$
14,840	13,250	
20,000	16,900	
20,900	17,080	
22,250	17,880	
25,600	19,220	
28,900	20,300	
30,300	20,800	
33,500	21,100	
37,800	21,850	
39,500	21,900	
7,350	7,030	$\frac{D}{G}=12$ $\frac{d}{G}=\sqrt{3}$ $a=60^\circ$
16,700	14,280	
23,100	17,850	
27,800	19,800	
35,600	21,000	
7,500	7,620	$\frac{D}{G}=12$ $\frac{d}{G}=\sqrt{3}$ $a=30^\circ$
14,770	13,050	
22,400	16,280	
29,400	17,500	
36,800	18,100	
44,500	18,600	
60,700	19,150	
7,500	7,850	$\frac{D}{G}=12$ $\frac{d}{G}=\sqrt{3}$ $a=45^\circ$
14,700	13,260	
22,300	17,750	
29,580	19,620	
30,850	19,890	
37,450	20,700	
38,050	20,750	

The foregoing indicates that the best *practical* tips should start at 60° near the gap and change to approximately 55° part way back on the cone.

In view of our previous discussion of the Weiss tip of Figure 37, the 55° angle should be reduced near the base of the cone Such a tip is 60°—55°—50° (approximately one-third of the slant height for each angle).

The experimental results of Figure 41 prove the correctness of this reasoning, since the 60°—55°—50° curve lies above all others.

It is probable that some modification of these angles would give a somewhat better tip, but itmust be remembered that it is inadvisable to have a greater portion of the sloping pole surface below 55° than in the tip just considered, because at the rate at which it increases tip height and hence arc weight and dimensions. These reasons practically prohibit the use of any angle less than 50°, and in view of these practical considerations and the ease with which the 60°—55°—50° tip may be machined, it is considered one of the best all-around designs for high power arc work.

BEST PRACTICAL POLE-GAP RATIO $\frac{D}{G}$

According to equation 19, $B_g \propto \log_e \frac{D}{d}$, all other factors remaining constant. Since $d = \sqrt{3}G$ for best results, we would expect $B_g \propto \log_e \frac{D}{G}$. Figure 42 shows a curve plotted to this equation.

Obviously this ratio is most important, for it is the main factor controlling the weight and cost of an arc converter. If it is too low, the magnetizing ampere turns are not working to full advantage; and if it is too high, both steel and copper are wasted because of the excessive mean diameter of the magnet winding.

Of course, the most economical weights of steel and copper are dependent upon the market price of each. In general, however, *the magnetic circuit of an arc converter should be designed so that the knee of the saturation curve is reached at rated full load current.*

In accordance with this principle saturation curves have been taken over a great range of $\frac{D}{G}$ ratios for various pole tip angles.

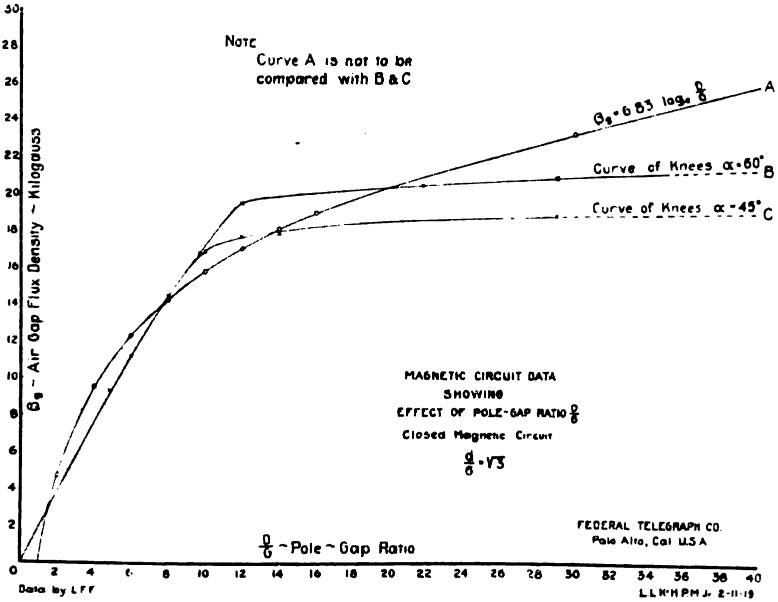

FIGURE 42

The knee of each of these curves has been determined, and B_g at the knee tabulated with $\frac{D}{G}$ and a. In all cases $\frac{d}{G}$ was held constant at its best value $\sqrt{3}$.

Table 4 gives typical data of this sort, which are shown graphically on Figure 42 for $a = 60°$ and 45°. The difference in the shape of these curves and the $log_e \frac{D}{G}$ curve obtained by computation is due to the fact that the ordinates of the experimental curves are B_g *at the knee* which introduces a *variable H* into their past history; whereas the computed curve is for an arbitrarily chosen *fixed value of H*. Since we are interested primarily in the *position of the knee* of the saturation curve, the computed curve is of no particular value in design.

TABLE 4

(FIGURE 42)

$\frac{D}{G}$	B_g (Knee)	
4.83	9,300	$a = 60°$ $\frac{d}{G} = \sqrt{3}$
6.0	11,160	
9.75	16,730	
12.	19,500	
21.8	20,500	
29.	20,900	
35.	21,000	
6.	11,160	$a = 45°$ $\frac{d}{G} = \sqrt{3}$
8.	14,410	
10.	16,820	
12.	17,660	
14.	17,850	
29.	18,850	

Observed Data on Effect of $\frac{D}{G}$ on *Position of Knee* of Saturation Curves with *Variable magnetizing force*

$\frac{D}{G}$	$B_g = 6.83 \log_e \frac{D}{G}$
2	4.74
4	9.50
6	12.22
8	14.2
10	15.75
12	17.0
14	18.05
16	18.95
30	23.25

Computed Data on Effect of $\frac{D}{G}$ on B_g at a *fixed arbitrarily chosen magnetizing force*

$a =$ constant

$\frac{d}{G} =$ constant

Two important conclusions may be drawn from these data.

(1) When $\frac{D}{G}$ is small, the tip angle a is of little importance. Thus in small arcs where weight is often a controlling factor and $\frac{D}{G}$ is therefore made low, any a that works in well with the chamber design may be used.

(2) $\frac{D}{G}$ should not be made greater than 12. As a matter of fact, considerations of cost and weight make it advisable to run

$\frac{D}{G}$ below its best value in high power arcs. For example, the 1,000-kw. arc converter requires 15,000 gauss (under usual specifications) in a seven-inch (17.8 cm.) magnetic air gap. Figure 42 shows $\frac{D}{G}=8.5$ for 15,000 gauss at the knee of the saturation curve. This makes $D=59.5$ inches (151.1 cm.), whereas the arc as designed has $D=$ 45 inches (114.3 cm.), which saves many tons of steel (counting yoke and bedplate), without increasing the amount of copper, because of the reduction in the mean diameter of the winding.

In all the foregoing, $\frac{D}{G}$ has been considered as constant thruout the entire length of the magnetic circuit. Experiments show that it cannot be reduced appreciably in any part of the bedplate or pole pieces, but it may be reduced somewhat in the yoke, because leakage reduces the total flux which must pass thru the yoke. The cross section of the yoke of the 1,000-kw. arc is equivalent to a pole diameter of 40 inches (101.6 cm.), whereas $D=45$ inches (114.3 cm.) in the main pole and bedplate.

In general, B in the lower portion of the pole or bedplate equals B_g approximately, while B in the yoke or at the base of the pole tip equals approximately $\frac{1}{2}$ B_g.

OPEN COMPARED WITH CLOSED MAGNETIC CIRCUITS

It is not customary to have cranes at the point of installation of arcs up to 100 kw., and the weight of the unit is a matter of considerable importance. This is especially true on shipboard.

Unless a closed magnetic circuit has a fairly large $\frac{D}{G}$ ratio, and is therefore heavy, it is of little value. Open magnetic circuits are used exclusively in sizes up to and including 100 kw. because a pound of copper is worth several pounds of steel in producing B_g, and the magnetizing kilowatts are small in any case. Furthermore, in these small sizes it is often found that at the present market prices of steel and copper, a saving in cost is effected by using the open magnetic circuit.

The effect of the arc on a ship's compass is a factor which sometimes makes it desirable to use a thoroly shielded closed circuit design when otherwise the open circuit would be preferable.

MAGNETIC CIRCUIT MODELS

It is not necessary to build a full size magnetic circuit to determine the shape of the saturation curve. The use of models is a·quick and inexpensive means of accomplishing this result.

Figure 43 and Table 5 show how well this can be done. It will be noted that the ratio of the weight of the full-sized magnetic circuit to its model was 650-to-1, and that the measured flux densities of the two lie so close together that it has been possible to draw but one curve thru the two sets of points.

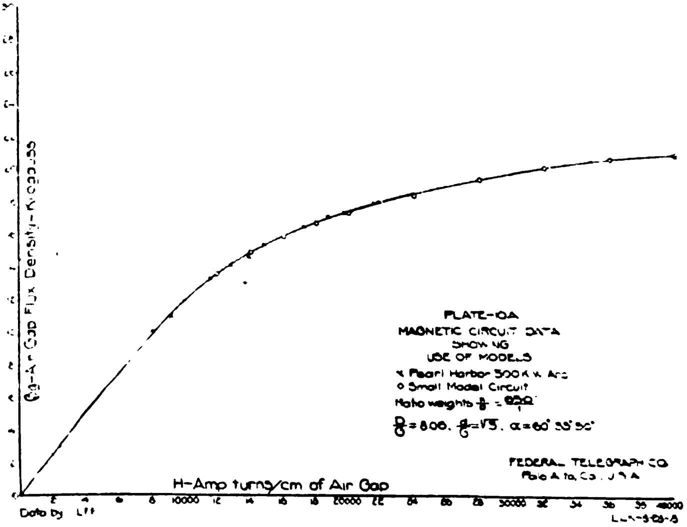

FIGURE 43

TABLE 5

FIGURE 43—MODEL DATA

$\frac{D}{G}=8.06; \quad \frac{d}{G}=\sqrt{3}; \quad \alpha=60°-55°-50°$

PEARL HARBOR 500 kw. Arc.		MAGNETIC MODEL	
H	B_0	H	B_0
2,500	3,100	12,000	13,700
3,800	4,650	14,000	15,700
6,700	8,200	16,000	16,100
8,200	10,100	18,000	16,900
9,300	11,000	20,000	17,500
11,600	13,400	22,000	18,100
12,800	14,300	24,000	18,500
13,900	14,800	28,000	19,500
14,800	15,600	32,000	20,200
16,100	16,100	36,000	20,700
17,200	16,700	40,000	20,900
18,700	17,200		
19,000	17,300		
19,700	17,500		
20,700	17,800		
21,800	18,100		
23,200	18,600		
Ratio of Weights 650:1			

Figures 44, 45, and 46 show these magnetic circuits. It will be noted that the mechanical form of the two circuits is as radically different as their size, and yet they are excellent magnetic equivalents.

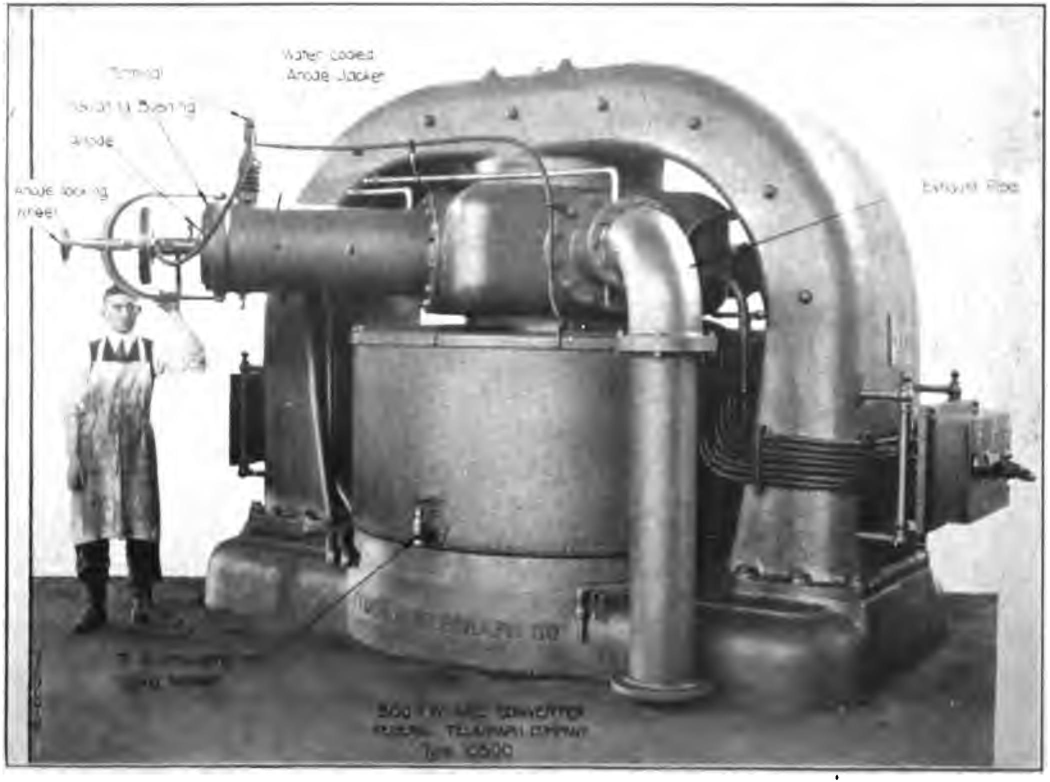

FIGURE 44—500-Kilowatt Arc Converter (Anode Side)

FIGURE 45—500-Kilowatt Magnetic Circuit

FIGURE 46—Model Magnetic Circuit

DETERMINATION OF THE MAGNETIC AIR GAP G

The determination of the magnetic air gap is one of the most important decisions necessary in the design of a large arc converter. It is dependent upon oscillatory circuit resistance, kilowatts input, and, in fact, upon nearly all the specifications which must be given the engineer before design work may be started. The shape of the anode tip is also an important factor.

Analytical attack on this problem has not been possible thus far. All progress has been made by experimentation. It is believed that an analysis of the results would be too cumbersome to include in this paper.

In general it may be stated that the air gaps now in use range from 1 to 7 inches (2.54 to 17.78 cm.).

DETERMINATION OF CHAMBER SIZE

Figure 47 shows the area of chamber cooling surface which is considered good practice at this time. All arcs of modern design are constructed in accordance therewith.

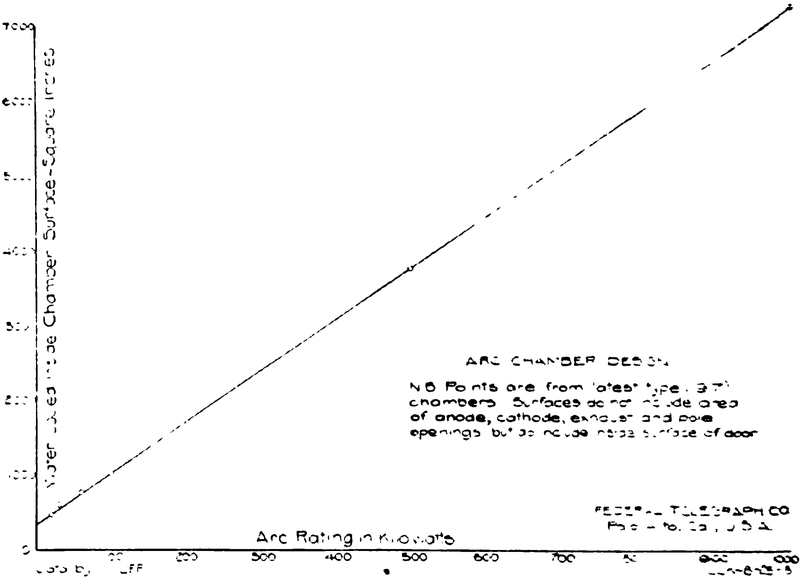

FIGURE 47

Once the necessary area has been determined, the design of the remainder of the chamber is one of purely mechanical problems.

The size of the water jackets is determined by the difficulties of the foundryman to a very considerable extent, as the casting must be watertight.

The thickness of water jacket which is satisfactory to him in his core work is usually of ample cross section to permit the water flow necessary at the usual 15-20 pounds per square inch (1.06 – 1.41 kg. per sq. cm.) pressure available.

CHOICE OF ARC ELECTRODES

In the ordinary carbon arc, particles are carried over from the positive electrode and deposited on the negative. This causes the formation of the well-known positive crater and negative cone.

Some arcs however (such as the magnetite arc used for illumination), use copper anodes, which do not wear away at an appreciable rate. The Poulsen arc is of this type.

Carbon or graphite may be substituted for the copper anode with excellent results, but these materials have never come into regular use because a water-cooled copper electrode is less troublesome.

They are the usual cathode materials, however. Carbon should not be operated above 200 d.c. amperes per square inch (31 amperes per sq. cm.), and graphite twice this density at the usual wave lengths encountered in present day radio telegraphy.

The d.c. amperes may be used as the basis for computing the cathode diameter safely, because the skin effect in materials of high specific resistance is relatively small. For example, at a wave length of 3,000 meters a carbon electrode 1.60 cm. (0.63 inch) in diameter[4] has a radio frequency resistance but 1 per cent. greater than its d.c. resistance. At a wave length of 9,000 meters, this diameter may be increased to 2.77 cm. (1.1 inch). Thus the determination of electrode diameter on the basis of a limiting direct current density does not vary appreciably from the diameter which might be computed with the radio frequency current as a base.

ACKNOWLEDGMENTS

In conclusion, I wish to express my appreciation of the assistance of Mr. R. R. Beal for taking flux data, of Mr. A. [illegible]. Anderson, for tabulating the same, and of Mr. W. A. Hillebrand for many helpful criticisms and suggestions.

SUMMARY: The Poulsen arc converter cycle is studied in detail, and the various relations between direct and alternating arc currents and voltages obtained and discussed. The possible production of harmonics is considered.

The effect of arc field strength on the arc phenomena is then taken up. The efficiency of the Poulsen arc cycle is obtained and checked experimentally.

The theoretical relation between best field strength and wave length, arc current and voltage, and nature of atmosphere surrounding the arc, is deduced, and shown to be correct by elaborate experimental data. In this connection, ethyl alcohol and kerosene atmospheres are compared.

The design of the magnetic circuit is then handled in detail. The most economical pole shape is given, the tip being a triple tapered conical frustrum. The tip-gap ratio and the pole-gap ratio are also experimentally obtained.

Open and closed magnetic circuits are compared. The design of these large electromagnets is facilitated by the use of small models, the results thus obtained being reliable. Data are given for desirable chamber surface for various arc inputs, and for the design of arc electrodes.

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[4] Circular 74, 1918, Bur. Stds., pages 299-310.

THE UNI-CONTROL RECEIVER*

By

Roy E. Thompson

(Chief Engineer and General Manager, Wireless Improvement Company, New York)

The original paper on the "Uni-Control Receiver" was prepared some time ago, and arrangements were made to read it before The Institute of Radio Engineers shortly thereafter. Certain delays interfered until the United States entered the war, so that it was no longer considered proper to read it.

In order to show some of the causes which led up to the design of the receiver originally, I wish to point out that—

The law says in effect to people who instal and operate radio apparatus: "You must provide only apparatus which is capable of selective operation; that is to say, your apparatus must be sharply tuned so that if you are interfering with another station he may tune you out by slightly changing his receiving tune." Then the same law goes on and says in effect: "In view of the fact that all transmitters have now been required by law to be sharply —that is selectively tuned—it is feared that in case of distress a vessel may call for help and not be heard. So, to eliminate this possibility, it is decreed that you must handle your business on one of two wave lengths, namely, 300 or 600 meters. That is, we make you tune sharply so that listeners on slightly different tunes will not hear you; then we say that you shall all send on the same tune so that all listeners *will hear* you."

This provides a situation which in practice is no doubt different from anything the framers of the laws anticipated when they agreed upon the London Convention in 1912.

Now there was a very good and sufficient reason as to why these two major requirements of the law should have been enacted. The flaw in the scheme is that the carrying out of the one negatives the results expected from the other and vice versa.

It was with the above conditions that I and other radio inspectors of the Department of Commerce tried to cope when the

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* Received by the Editor, January 23, 1919. Presented before the Institute, New York, February 5, 1919.

laws became effective on December 13, 1912. It has been said that one never knows the weakness of a law until one tries to enforce it. In this case, we did not fully realize the weakness of the law until after it was fully enforced. We first berated the framers of the law, but upon sober thought we were compelled to acknowledge that it seemed practically impossible to frame a law which would effectively regulate radio communication and secure the desired results, or for any company or government to formulate rules which would properly take care of the conflicting interests represented on one side by the commercial business that must be handled and on the other by the desire and necessity of keeping this commercial business from interfering with possible messages relating to the safety of life at sea.

The thing back of this whole problem—the thing that caused the attempt to solve the problen by regulation and the thing that in turn prevented regulation from being the solution—was plainly the limitation of the radio apparatus itself. The transmitter had to be restricted as to the number of wave lengths it could use so that the receiver might always hear it, and the receiver had its selective ability nullified by being compelled always to keep itself adjusted so that it would hear the transmitter on its restricted wave length.

So far as I know, no laws or regulations have ever been proposed or worked out which would solve the conflicting problems referred to above. In my opinion, neither government nor private monopoly would do it because the only advantage that monopoly has over regulation is the power to regulate arbitrarily instead of equitably.

These and the less important problems relating to the human element or the tendency of operators to neglect fully to carry out regulations, instructions or even arbitrary commands were the causes for the writer's determination to design if possible a receiver which would take care of both the conflicting requirements of the radio laws and permit the emancipation of the transmitter by producing a receiver which would hear everything within a space of a few seconds, or before much harm could come to a distressed vessel and still be able to exclude anything which the present day receivers will exclude.

The first requisite was a receiver that could be caused to "sweep the ether," so to speak, in the same way as a searchlight sweeps the horizon. This means that there must be a gradual and continuous sweep from the shortest to the longest wave length within the range of the instrument. A receiver embodying this faculty in a very simple form is one having only one variable point or element. A fixed inductance and a variable condenser in series with the antenna and ground and with the detector and telephones across the inductance or condenser is a simple illustration. Such a device has not sufficient range to fill the practical requirements however. As a practical matter, it develops that more than one varying or wave changing point must be provided.

The second requisite was that in whatever direction the receiver developed, it must be operated entirely by a single driving force or control. It must further be capable of repeating the wave change cycle over and over again at a speed permitting the operator's attention to be attracted by faint signals whenever the receiver swept by or passed thru the tune corresponding to the wave length of such signals.

Such a device, I believe, is the receiver to be described in this paper.

An elementary diagram illustrating the principle is shown in Figure 1, which shows a unit coil of inductance *U L* and a multiple unit coil of inductance *M L*. A capacity *K* provides for the oscillatory character of the circuit. The unit switch *U S* has attached to its shaft a gear such as the spur or intermittent type, which drives the multiple unit switch *M S* thru a similar gear of slower rotation. As the unit switch brings consecutively into the circuit the inductance represented by taps *a*, *b*, and *c*, respectively, the multiple unit switch moves over to tap 1, 2, or 0 as the case may be. The movement of the multiple unit switch from one tap or segment to another is arranged to take place whenever the unit switch moves from tap *c* to *d*. The unit switch

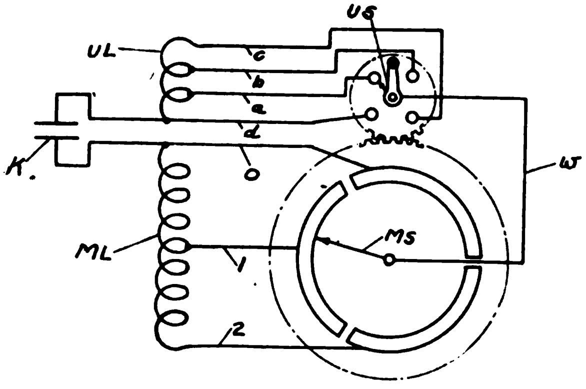

FIGURE 1

moves clockwise and the multiple unit switch counter clockwise.

Figure 2 illustrates the same circuit as Figure 1 with the addition of a variable condenser *V C* which enters the circuit in series with the inductance coils whenever the switch arm *M S* connects the tap or segments 0 and 3.

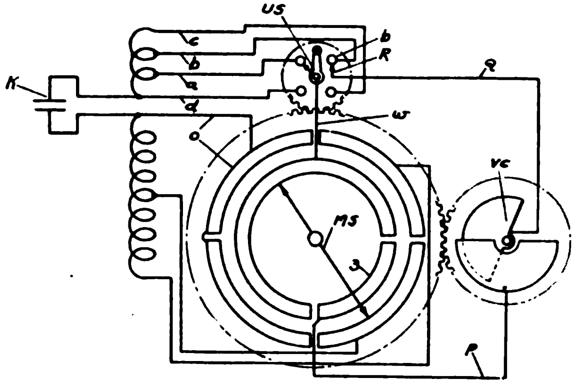

FIGURE 2

It will be noted that whenever condenser *V C* is in circuit, the circuit instead of being thru the return wire *W* and the tap *a*, is thru the wires *P*, *Q*, and the adjustable contact *R*, and the tap *b*. As the contact *R* can be placed on any of the taps *a*, *b*, *c* or *d*, it can be placed so as to compensate for the entrance of the condenser *V C* into the circuit and keep a wave length gap from appearing there. Of course, in practice there are always a few turns of inductance kept in the circuit for coupling to the detector. With the compensating inductance controlled by contact *R* the receiver may be adjusted for use with a condenser *K* having different capacities. As the condenser *K* represents the capacity of an antenna, the set may be adjusted for different antennas so as to have no wave length gap or overlap when the variable condenser *V C* enters the circuit for the purpose of reducing the period of the circuit below its normal or fundamental wave length, such as when it is desired to come down to short wave lengths.

Figure 3[†] is the same as Figure 1, with the condenser of Figure 1 replaced by the antenna *F* and the ground *G*, and there is also

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[†] The method shown in Figures 3 and 4 for securing oscillations of the period of the oscillatory circuit is only one means of securing the desired result. Any other or more preferred method for exciting the antenna or oscillatory circuit at substantially its own period may be used.

connected to the inductance a generator of radio frequency currents in such a manner as to generate waves of substantially the same length as the wave length of the antenna. The signaling device *S* may be a telegraph key or telephone transmitter. This figure illustrates the device as applied to a transmitter.

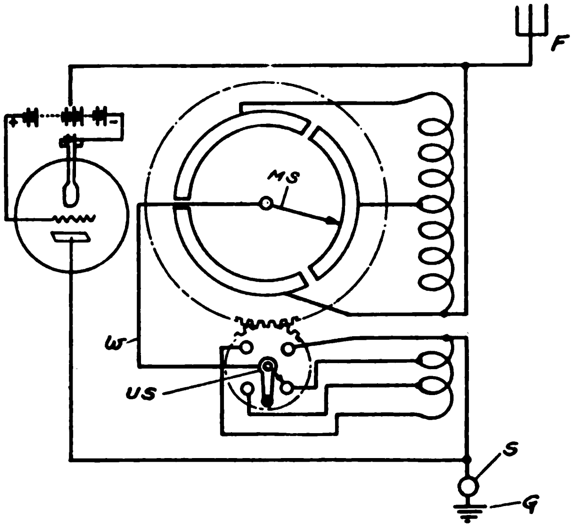

FIGURE 3

Figure 4† illustrates the same circuit as Figure 3, with the addition of a detector circuit for indicating such damped wave trains as may be produced in the antenna *F-G* by the arrival of damped wave trains or continuous wave signals, either or both, from a distant station.

Figure 5 represents a wiring diagram of a receiver having a range from 150 up to about 3,500 meters on the ordinary ship's antenna.

The fixed or minimum number of turns in the antenna coil is 10 turns. The total turns controlled by the unit switch is 25 turns and therefore each section of the multiple unit coil has 26 turns. Every other section is cut off from the rest by a dead-end cut-off switch.

The ratio of the gears of the unit switch to the multiple unit switch is 1-to-12, and between the multiple unit switch and the

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† The method shown in Figures 3 and 4 for securing oscillations of the period of the oscillatory circuit is only one means of securing the desired result. Any other or more preferred method for exciting the antenna or oscillatory circuit at substantially its own period may be used.

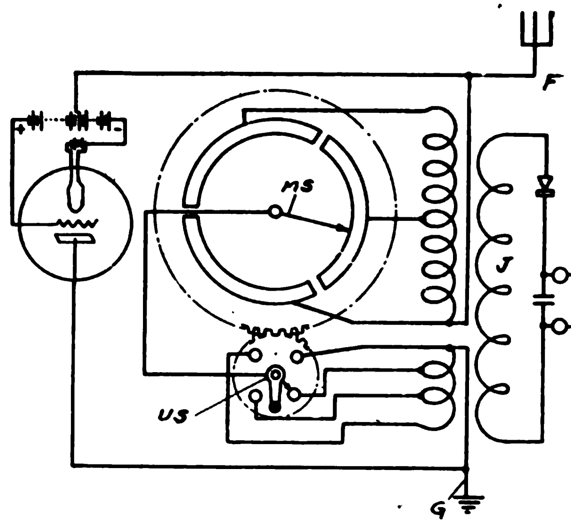

FIGURE 4

variable condenser is 3-to-1. That is, the multiple unit switch travels one-sixth of its circumference on the segments 3 and 0 while the variable condenser is going from 0 to 180 degrees.

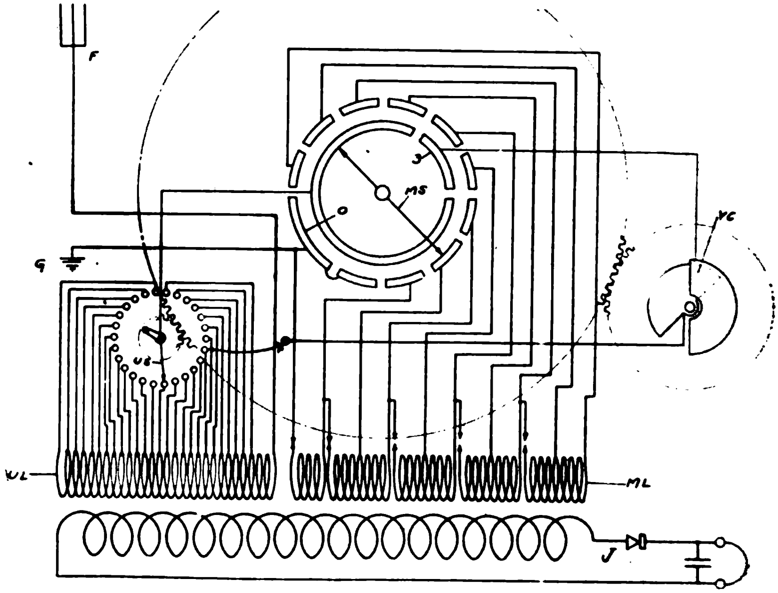

FIGURE 5

Tho the condenser keeps revolving while the unit switch is varying the wave length, it is not in circuit except during the above described period. Also, tho the unit switch keeps revolving while the variable condenser is in circuit, the circuit is then no longer thru the unit switch so that the inductance is not varied.

If the detector circuit *J* is properly constructed and associated with the antenna inductance coils, the antenna is left free to oscillate without interference or reaction by associated circuits and the full advantage may be taken of antenna resonance. The detector coil and circuit as a whole must be substantially non-accumulative. That is to say, the capacity which gives the ordinary coil and associated elements the power to accumulate energy in substantial quantities to react against the antenna or exciting frequency must be eliminated to a point where its effects are no longer felt and then if this coil and the antenna coils are associated with the proper degree of intimacy, the antenna and detector coil act entirely as one at all frequencies and the maximum combined efficiency and selectivity are obtained without the many objectionable features of attaching the detector physically to any part of the antenna circuit or attaching it to an associated tuned circuit.

I have made the essential requirements for the construction and association of such coils and circuits so as to obtain the maximum efficiency and selectivity the subject of separate patent applications, and will be glad at some future date to read a paper and describe in detail the principle and construction involved whereby I am able to secure for any wave length range equal or greater selectivity and efficiency than is secured by the most modern two-circuit receivers.

Figure 6 is a photograph of a type of receiver furnished to the Signal Corps and is intended as the ordinary commercial or ship type. It is to be noted that the detector coil is movable with respect to the antenna coil. This, however, merely has the effect of decreasing or strengthening the signals, useful in congested areas where one does not always want the fullest strength of signals obtainable. A hand crank only was provided with these particular receivers.

Figure 7 was taken with the front panel of the receiver off and shows the dial calibration card with the wave length space blank. When the receiver is attached to a particular antenna this calibration card is taken off and the wave lengths corresponding to the divisional lines are marked in the space provided. This card is then properly adjusted on the receiver with respect

Figure 6

to the positions of the switches and incoming wave lengths are then read directly.

Figure 8 shows the calibration card removed, exposing the gear drive which is self-contained in an aluminum casting frame. The large gear is of bakelite.

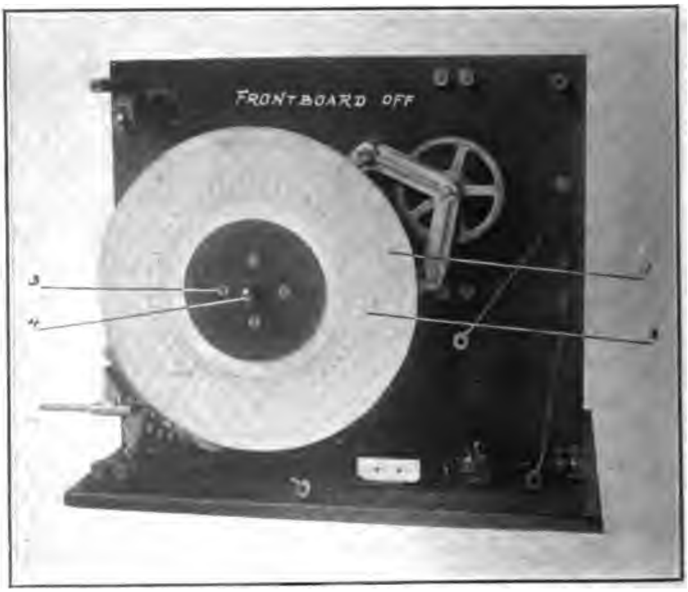

Figure 7

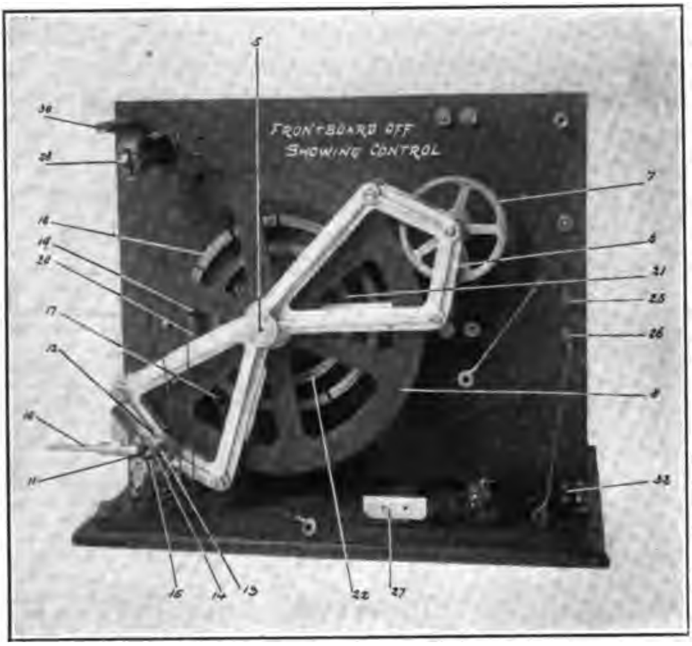

FIGURE 8

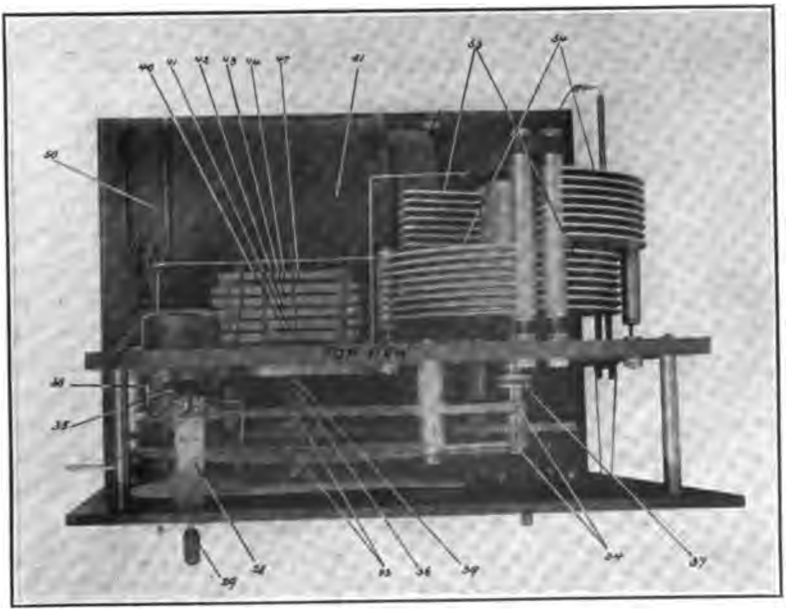

FIGURE 9

Figure 9 is a top view showing antenna coils, variable condenser, dead-end cut-off switches, and so on. All apparatus is mounted on the middle or bottom panels.

Figure 10 shows the motor drive and worm gear box for driving the receiver thru an especially designed flexible speedometer drive. A speed control rheostat and start and stop push button is also shown on the table.

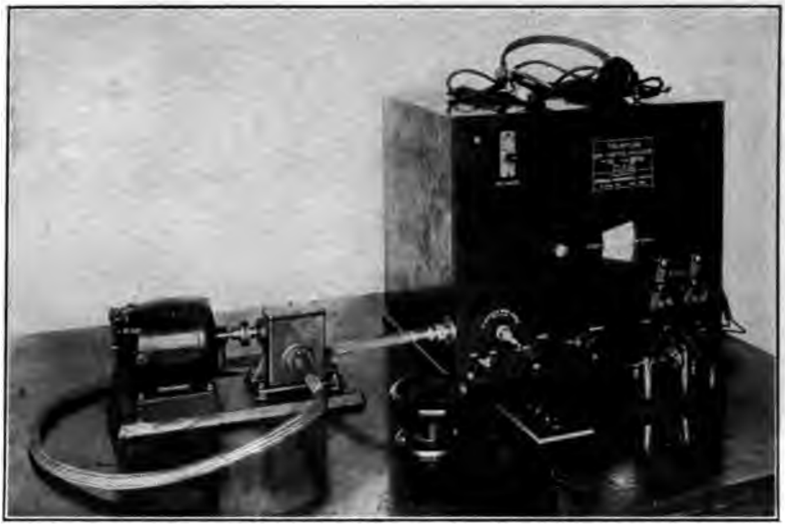

FIGURE 10

The schematic arrangement is shown in Figure 11. The apparatus to the left of the thin dotted line may be under the table or some place out of the way of the operator. The apparatus to the right of the dotted line should be in easy reach of the operator. The clutch mechanism whereby the operator engages or disengages the power drive is best shown in this figure. The flexible power drive shaft is connected to the shaft 10 which thru the bevel gear 11 drives the bevel gear 12. This gear 12 rides free on the main or hand driving shaft 15 except when the teeth 13 are engaged with similar teeth 13A on the collar 15A which turns with the shaft 15 but which can be moved in or out by the operator to engage or disengage the power drive as desired.

In December, 1918, Commander Hooper, while testifying before the Congressional Committee on Merchant Marine and Fisheries which was hearing the Navy's evidence as to why it thought that it should have a monopoly of all radio stations with reference to ship to shore business said:

> "It was found, after the stations became sufficiently numerous, that when one station was working another station would be interfered with, not because there were not a large number of wave lengths in this area of wave lengths, but in order to guarantee that all ships can intercommunicate and communicate with any shore stations they happen to pass in any part of the globe, they must all communicate on one wave length, which happens to be designated as 600 meters. That wave length is agreed to internationally and is in common use thruout the world. If that had not been agreed upon, it is obvious that ships choosing any wave length they wished to call the shore station, and the shore station listening on all wave lengths at the same time, they would not hear the calls. A ship in distress might require hours before she could reach anybody, and it would be a very serious situation. In fact, it is absolutely necessary that all ships and all coastal stations which are able to work with the ships should call and answer each other on 600 meters. Now, since that is necessary, it must be a matter of very careful regulation to see that they do not interfere with one another. For example, a ship on the high seas, 300 or 400 miles (500 to 700 km.) off the coast, wishes to send a message to Norfolk at the same time that Norfolk wishes to send a message to the ship. He calls Norfolk, and Norfolk tries to send a message to him on 600 meters, and Charleston begins to send a message to some other ship on 600 meters, and this poor fellow is out there where the signals come in equally strong from both stations, and he cannot read either. With hundreds or thousands of ships along the coast and many coastal stations all trying to work on the same wave length, it can readily be seen that there is endless confusion unless the most careful regulation is exercised."

Mr. Bankhead: "What sort of regulation do you suggest, in that connection?"

Unfortunately Commander Hooper apparently did not understand the question and his answer therefore did not give us the solution. The laws of selectivity as at present understood do not permit a multiplicity of stations to transmit on the same wave length without interference regardless of how sharp the transmitted wave or how selective the receiver.

Commander Hooper, still speaking of this phase, said:

> "If it were not for the fact that all the ships have to listen for calls on the same wave lengths and that the apparatus should not be tuned too sharply—otherwise the man listening will not hear the ship call, even if he has nearly the same wave length—then there would be no question in it as to this second phase. But the ships must listen on this 600 meters, and the shore station must listen on that, otherwise their calls will be unheeded. I think it is obvious that to get the best service we must have it under the most highly organized control. I do not think there will be any objection to this on the part of the commercial companies. Their objection is going to be on the third phase."

It is plain from Commander Hooper's statements that the most convincing argument for Government ownership is this impossible situation of all ship-to-shore or ship-to-ship business having to be carried on and all listening and all calling being done on 600 meters. This is true even tho the proponents of Government ownership do not clearly explain, in the light of the international treaties and regulations and the fact that a great part of the ships causing interference fly foreign flags, just how Government monopoly is going to overcome the difficulty.

It may now sound like a rather far-fetched prediction but I truly believe that if all ships at present had permission to transmit on any and all wave lengths and were in turn all equipped with some such device as the uni-control receiver, if then they all operated in accordance with well conceived international regulations, interference would be reduced far below anything which may possibly be brought about thru government or private monopoly. Not only do I believe this would be true but I further believe that the chances for distress messages going unheard would be likewise reduced, regardless of what wave length the ship in distress chose to send its distress call upon.

Furthermore, it would no longer be necessary for all ships to quit work within the radius of the distressed vessel, except those engaged in helping the distressed vessel. International regulation could simply reserve a certain wave length range for distress business and all other stations not concerned could shift to other ranges and go about their normal business.

Let us see how this might possibly be done.

First, let us assume that the present receiver will do everything claimed for it as regards selectivity and efficiency, or that it can in the hands of proper radio engineers be made to do so. I believe that it is said that with undamped single wave transmission, stations the wave lengths of which do not differ less than 5 per cent. will not interfere. Now if the transmitters only have a range from 300 to 3,000 meters there are still 48 wave lengths within this range, all of which differ at least 5 per cent. from each other. As I see it, there is no reason then why at least 48 ships or land stations might not send and 48 land or ship stations all receive, or a total of 96 stations work, all within the same radius without using up any more of the total practical wave length range available than from 300 to 3,000 meters. As ships may easily go up to 5,000 or 6,000 meters without getting into the high power station range, it is seen that the theoretical limit has by no means been reached.

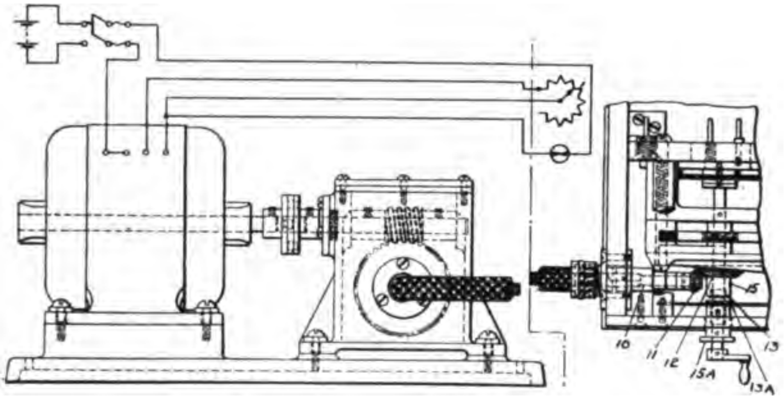

FIGURE 11

The reason why this cannot be done with present apparatus is that unless a station could know on just which one of these 48 wave lengths it was going to be called, it might never hear the station doing the calling. And then if a ship should open up with a distress call it would probably be found that the stations within hearing distance would be listening on almost any and every wave length except the one used by the vessel in distress. If, however, these 48 wave lengths were consecutively and continuously being passed by the ear of listening operators by means of the motor driven uni-control receiver, no one could possibly call without being heard within a few seconds at the latest and once the call was heard and the receiver stopped at that particular wave length none of the other 47 transmitters need interfere.

Further to illustrate the possibilities of eliminating interference thru the use of the uni-control receiver and still permit a large number of stations to work without fear of not being heard in case of distress calls, let us assume that there are within a radius of 500 miles of New York a total of 96 ship and shore stations, all of whom desire to pair off and work at the same time. This means that 48 stations would be sending and 48 receiving after they all got into communication.

Let us take the dial calibration card that goes with each receiver and divide it up into 48 sectors, each sector to correspond to one of the 48 wave lengths with which each transmitting station would be provided. Let us then number these sectors from 1 to 48 consecutively—Sector 1 to correspond to 300 meters and Sector 48 to correspond to 3,000 meters, and the intermediate sectors to correspond to intermediate wave lengths, no two of which would be closer than 5 per cent. from each other. In addition to these sectors, there would still be the division lines on the card and the actual wave lengths in units of 10 or 25 meters would be marked directly on the card.

A ship 300 miles from New York wishes to get into touch with a station on Long Island. He simply listens while his receiver makes a few complete cycles during which he will hear all of the stations sending between 300 and 3,000 meters. He notes the numbers of the sectors in which there are stations working, and he notes the numbers of the sectors in which he hears no signals. For instance, he finds that stations are working on a number of wave lengths, but he notes that when his receiver is passing thru sectors from 16 to 20, inclusive, he hears no sound. He is, therefore, fairly safe in assuming that the wave lengths corresponding to these sectors are not being used within his receiving radius, and he therefore chooses sector number 18 upon which to transmit his call to the Long Island station. When the receiver of the Long Island station passes thru sector number 18 he will hear his call and will hear no other signals provided there are no other stations using this same wave length closer than the ship which is calling him. He would then choose this same wave length corresponding to sector number 18 upon which to answer, or he can choose a sector corresponding to any other wave length which from his observation will cause the least interference in his neighborhood. In any event, a ship station will hear him about as quickly if he choose sector number 44 as if he had chosen number 18 or number 1. The point is that each one chooses a wave length or sector upon which to call the other which is not being used by anyone within hearing distance. If upon establishing communication, the stations find that they are actually interfering with some other station the choice of one or two unoccupied sectors upon which to try communication again would undoubtedly result in the establishment of communication without any further interference.

All this time, if any station should open up with a distress call, using any wave length of the 48 between 300 and 3,000 meters, any of the receiving stations the receivers of which were still revolving (indicating that they were not working) would hear them by the time their receiver made one complete cycle, and if by chance the transmitters were equipped with uni-control devices as well as the receivers, the distress call could be sent out on all 48 of the transmitting wave lengths within a few seconds to attract the attention not only of those stations which were not working but also those stations which were.

To accomplish these results neither Government nor private monopoly is necessary, but only such international regulations as would compel all ship and general public service shore stations to be provided with the same 48 wave lengths upon which to transmit, and also to be provided with uni-control receivers with dial cards divided into 48 sectors corresponding to the wave lengths of the transmitters.

The main purpose of this paper is to point out some of the results which might become possible thru the introduction of such a receiver as the uni-control into general use.

In order to encourage radio engineers and operating companies to give the matter due thought and at least attempt in some measure to realize some of the results pointed out as possibilities, the Government and such reputable radio concerns as may wish it, will, for a nominal royalty, be given a license under such patents as may issue.

No attempt was made by me to get any department of the Government to purchase or use the receiver. It was spoken of to representatives of the Bureau of Steam Engineering some time ago, but they said they would not be interested in new devices during the war.

The original sample was given to Dr. Austin in order to secure a comparison of this receiver when tested with other receivers available in the Navy Department. His report was that the receiver compared quite favorably with other well constructed receivers as regards selectivity and efficiency but that he could see no particular advantage in the uni-control feature. This is the first attempt I have made to argue its possible advantages. The only ones sold have been some which were sent to Colonel Krumm in France, who happened to know of my efforts while he was Chief Radio Inspector in the Department of Commerce, and who cabled for them thru General Pershing.

The wave length ranges and the number of wave lengths which might be used without interference, as mentioned herein, are for illustrative purposes only, and are given simply to illustrate the idea and possibilities of this type of receiver in connection therewith.

I have not attempted to go into the advantages of this type of receiver where inexperienced operators only are available, and neither have I attempted to point out the many valuable uses to which a uni-control receiver could be put in simplifying the work of the average ship operator, whether or not it was desirable to use the motor drive feature and take advantage of the possibilities opened up thru its use.

Undoubtedly the mechanical construction of the receiver can and, in the ordinary course of events, would be designed to meet the requirements to which the receiver would be put. I have simply shown circuits and mechanism which will serve all the requirements of a ship or general public service land station set, utilizing the range of wave lengths now generally employed in such receivers.

I have not attempted to describe a receiver which will cure all of the troubles inherent to radio communication, but have simply described one which I believe will certainly add nothing to the complications already existing and which may, and in fact should, without doubt, make it much easier for the operator to secure such results as he secures at the present time with the additional possibilities outlined herein and others which will undoubtedly suggest themselves to other workers.

If thru this paper other companies may take up the subject and determine the full possibilities thru practical application, I shall consider that my work has not been entirely in vain.

SUMMARY: The design and construction of a receiver, operating efficiently and selectively over a long range of wave lengths on any antenna of ordinary dimensions, and controlled by a single handle, are described in detail. The addition of a motor for driving the wave-changing adjustment continuously is shown.

The possibilities of such a receiver for the solution of the interference *problem* are discussed.

DISCUSSION

John V. L. Hogan: Mr. Thompson's admirable paper has brought out clearly the fallacy which underlies our present law on radio signaling. The combination of first requiring a certain definiteness of tuning to minimize interference, and thereafter forcing all public service communication to proceed upon a single wave length is, from the commercial viewpoint, worthy of Alice in Wonderland. From the opposite side, however, it should be noted that by confining the business of radio to a narrow zone of wave lengths and restricting the breadth of tuning so that little interference can be produced outside of that zone, the activities of the commercial companies are effectively limited while the governmental stations are virtually unhampered.

The limitation of radio apparatus, to which Mr. Thompson refers as a basis for the present law, surely need not exist. He proposes that all stations be permitted a substantially free choice of transmitted wave lengths, and that each be equipped with a receiver which will "sweep the ether" with sufficient rapidity to intercept any and all calls, upon whatever wave they may be uttered. This resolves itself into two main elements: (1) a receiver which will respond to successively different wave lengths and which is controlled by a single motion, and (2) a mechanism to adjust the receiver continuously and repeatedly thru its wave-frequency range at a definite rate.

I cannot endorse too heartily the value of the uni-control feature in either a receiver or a transmitter. In my experience with the conditions of commercial and military radio operations I have found a well-tuned receiver to be the exception, whenever primary and secondary circuits were separately adjustable. Frequently the difficulty of establishing or maintaining communication has been traced to nothing more than a failure to tune in a proper manner both circuits of the receiving apparatus. As the International Radio Telegraph Company and its predecessor, the National Electric Signaling Company, have long realized the use of a single variable element for adjusting, the entire receiver will eliminate much of this trouble. I may say, without going into further detail, that we have built simple apparatus embodying this single-variable or uni-control feature, and that our demonstrations have convinced us of its great utility. With it we have invariably been able to pick up signals of unknown wave length in a time much shorter than was possible with the separately adjustable circuits, and frequently we have discovered and copied messages arriving thru interference which obliterated them when broadly tuned or closely coupled secondary circuits were used. I feel that the single variable tuner should come into extensive use, and that thru it we will be able to solve many of our traffic problems.

As to the second factor, I do not feel so sanguine. It requires a definite time, of say five seconds or more, to recognize a station call in Morse, and at least this interval should be spent in listening on each wave length within the range of the receiver. If we should use the 48 wave lengths proposed by Mr. Thompson, it would require four minutes to complete the cycle and to begin again; manifestly we should be likely to miss many important signals on the momentarily silent or detuned wave lengths. By reducing the number of waves used this difficulty would be correspondingly diminished in importance, but at the same time the possibilities of sinultaneous signaling would be cut down in proportion. I still incline toward the plan of using a specified wave length for all calls and distress signals*, and, by the utilization of single-control senders and receivers, passing to other free but officially determined wave lengths for the transmission of messages immediately after communication has been established. Since all receivers and transmitters remain normally at the "calling" frequency, and since traffic is entirely on other frequencies, this plan should give the maximum protection to life and property at sea as well as the maximum freedom for simultaneous transmission of messages by radio.

Mr. Thompson's receiver appears to vary the tuning of only the antenna circuit. It seems that this process will not give the greatest signal intensity combined with the greatest selectivity. I am sure that all of use will await with interest Mr. Thompson's future paper, which he hints will reconcile the conflicts that, in our present views, limit selectivity of spark signals by the rate at which energy is drawn from the tuned receiver circuits. On the whole, however, we should be gratified by the progress which is indicated in the design of the apparatus described in the paper, and we should join in congratulating Mr. Thompson upon his work.

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*Compare "International Radio-Telegraph Congress," Hogan, "Electrical World," New York, June 22, 1912.

ON THE THEORY OF RADIOTELEGRAPHIC AND RADIOTELEPHONIC RECEIVER CIRCUITS*

BY

J. F. J. BETHENOD

(PARIS, FRANCE)

In two previous papers (see: "Jahrbuch der drahtlosen Telegraphie und Telephonie," 1909, volume 2, number 6, page 603 and volume 3, number 3, page 302) I have already published the general conditions which will give the greatest efficiency for a receiving set, when the detector (a bolometer, for instance) is inserted in the secondary oscillating circuit. The first object of the present publication is to extend these conditions to receiving sets in which, as is more usually the case, the detector D (a valve of any kind) is (Figure 1) connected across the terminals of the secondary tuning condenser C_2, and a condenser K of relatively high capacity is shunted across the telephone T. A further object is to present some formulas concerning the best adjustment of capacity K and of the constants of the telephone T, especially in case of a beat reception. In this connection, the theory of the "approximate rectifier" (see B. Liebowitz, "Quantitative Relations in Detector Circuits," PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 5, number 1, page 33, 1917) is

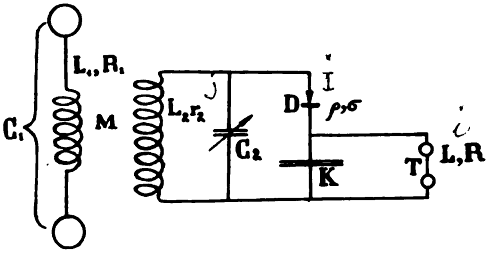

FIGURE 1

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* Received by the Editor, December 3, 1918.

established in a novel manner. For greater clearness, the latter subject will be treated partially in the first portion of this paper, this serving as an introduction to the remaining portions.

I. THE APPROXIMATE RECTIFIER

Instead of presenting the characteristic of an approximate rectifier by:

$$I = a_1 V + a_2 V^2 + a_3 V^3 + \cdot \cdot \cdot,$$

as proposed by H. Brandes ("Elektrotech. Zeitschr.," 1906, page 1,015), Tissot, and Liebowitz (former citation), we prefer to employ the power series:

$$V = \rho I + \sigma I^2 + \tau I^3 + \cdot \cdot \cdot, \tag{1}$$

where the current and the voltage are denoted by I and V; and the magnitude and the sign of the coefficients ρ, σ, τ are determined by the shape of the characteristic.

As a rough approximation, we limit the power series (1) to the term of second degree:

$$V = \rho I - \sigma I^2, \tag{1'}$$

and this term will be taken as negative, as shown by a comparison with the first method of expansion, in which the coefficient a_2 is positive (Liebowitz, former citation).

1—Suppose now that at time t, the current thru the condenser C_2 is J, and the current thru the telephone T is i.

Keeping in mind equation (1′), the Ohm and Kirchhoff laws give the following equation:

$$0 = r_2 \int (I + J)\, dt + \rho \int I\, dt - \sigma \int I^2\, dt + R \int i\, dt,$$

since the average value of the emf. induced by the primary winding is zero, if this emf. is periodic (sustained or weakly damped waves) and if the limits of integration are sufficiently separated. But, under the same conditions, we may write:

$$\int J\, dt = 0,$$

and (2)

$$\int i\, dt = \int I\, dt$$

which means that the average currents thru the condensers are both zero.

It follows that:

$$\int i\,dt = \int I\,dt = \frac{\sigma}{r_2+\rho+R}\int I^2\,dt; \qquad (3)$$

consequently, the *average current* thru the detector D (or the telephone) is always different from zero, as well as the square of the effective current.

This result illustrates clearly the rectifying property of the detector. Further, if we employ an electromagnetic (polarised) ammeter and a hot wire apparatus, the sensibility of which is sufficiently high, formula (3) will easily permit the experimental determination of the coefficients ρ and σ. Denote by y the ratio $\frac{\int I^2\,dt}{\int I\,dt}$. The variation of the sum $R+r$, being obtained by means of additional resistance, plot a curve (Figure 2) with different values of y as ordinates and the correspondent values of this sum as abscissas. The curve thus determined from (3) is a straight line, and it cuts the horizontal axis at the point S, the distance of which from the origin O is just equal to ρ; the coefficient σ is given then by

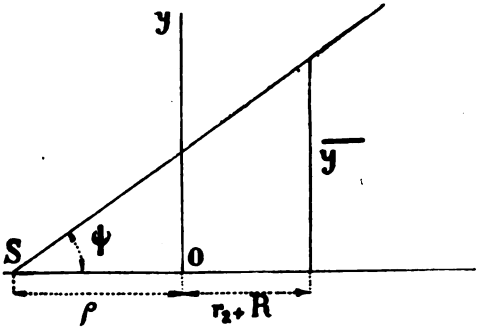

FIGURE 2

$$\sigma = \frac{1}{\tan\psi}$$

Since the relation (1′) is only approximate, the experimentally-determined curve may differ from a straight line, and it is thus possible to obtain in each case the degree of approximation.

2—Put

$$I = I_2 \sin \Omega t + I_2' \sin \Omega' t + i';$$

the equation $(1')$ then becomes:

$$\begin{aligned} V=\rho I_2 \sin\Omega t+\rho I_2' \sin\Omega' t+\rho i' \\ -\sigma i' \left[2 I_2 \sin\Omega t+2 I_2' \sin\Omega' t+i'\right] \\ -\sigma \left(I_2 \sin\Omega t+I_2' \sin\Omega' t\right)^2. \end{aligned} \tag{4}$$

In this expression, we may neglect the term which contains $\sigma i'$ as a factor, if both these quantities are sufficiently small.[1] The application of Ohm and Kirchhoff laws to the secondary circuits of Figure 1 thus proves easily that the current

$$I_2 \sin\Omega t+I_2' \sin\Omega' t$$

may be considered as produced by an emf.

$$E_2 \sin(\Omega t+\chi)+E_2' \sin(\Omega' t+\chi'),$$

induced in the secondary winding, and that the current i' flows simultaneously as the result of an emf.[2]

$$e=\sigma\left(I_2 \sin\Omega t+I_2' \sin\Omega' t\right)^2, \tag{5}$$

which originates in the detector D, regarded as a generator of internal ohmic resistance ρ. Of course, according to relation (4), this detector acts as an ohmic resistance of this same value ρ so far as the flow of the current $I_2 \sin\Omega t+I_2' \sin\Omega' t$ is concerned. Finally, the emf. $E_2 \sin(\Omega t+\chi)$ will be taken as the emf. of radio frequency $\frac{\Omega}{2\pi}$ induced from the primary winding, while the emf. $E_2' \sin(\Omega' t+\chi')$ is furnished by a local generator (not indicated in Figure 1), the frequency of which $\frac{\Omega'}{2\pi}$ is given by

$$\Omega'=(1+\varepsilon)\,\Omega,$$

where ε is a small fraction.

This local generator is the "heterodyne" oscillator of the receiving set, and when $I_2'=0$, we obtain the case of the radio-telephone receiver. We can now determine the best conditions for the use of a given detector.

II. The Radio Frequency Circuits

According to the above mentioned results, we may write, using the customary complex method and taking $j=\sqrt{-1}$:

$$\begin{aligned} E\,l=R_1 I_1+\left(L_1\Omega-\frac{1}{C_1\Omega}\right)I_1 j+M\Omega\,(I_2+J)j, \\ 0=r_2\,(I_2+J)+L_2\Omega\,(I_2+J)\,j+M\Omega\,I_1 j+\rho I_2, \\ -\frac{J}{C_2\Omega}j=\rho I_2. \end{aligned} \tag{6}$$

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[1] This assumption will be further justified.

[2] See M. Latour, "Electrical World," April 24, 1915.

In these equations we denote by:

E, the emf. induced by the waves, per centimeter of length of the antenna;

l, the effective length of the antenna;

R_1, L_1, and C_1, the resistance, inductance, and capacity of the primary circuit (including the constants of the antenna);

I_1, the primary current;

M, the coefficient of mutual induction between the two circuits; the other symbols having the same significance as above.

The capacity K is supposed sufficiently large to prevent the flow of any radio frequency current thru the telephone T. It follows that:

$$\begin{aligned} E\,l &= R_1 I_1 + \left(L_1 \Omega - \frac{1}{C_1\Omega}\right) I_1 j + M\,\Omega\, I_2 j - M C_2 \Omega^2 \rho\, I_2, \\ 0 &= M\,\Omega\, I_1 j + [r_2 + \rho\,(1 - L_2 C_2 \Omega^2)]\, I_2 + \Omega\,(L_2 + r_2 C_2 \rho)\, I_2 j. \end{aligned} \tag{7}$$

In order to find the conditions for which the maximum current I_2 is obtained, it is possible to employ the method published in the "Jahrbuch." But we prefer to utilize a general theorem which is a very useful one for solving such a problem. Let ϕ_1 be the phase displacement between E and I_1; from the principle of conservation of energy, and taking account of the third of the equations (6), we have:

$$E\,l\,I_1 \cos\phi_1 = R_1 I_1^2 + r_2\,(I_2^2 + J^2) + \rho\, I_2^2 \text{ (effective values),}$$

or

$$E\,l\,I_1 \cos\phi_1 = R_1 I_1^2 + [r_2\,(1 + C_2^2\,\Omega^2 \rho^2) + \rho]\, I_2^2.$$

But we may always write:

$$I_2 = X\, I_1,$$

where the coefficient X is a function of the constants C_1, L_1, M, L_2 · · ·, and so on. We obtain finally

$$I_2 = \frac{X\,E\,l\cos\phi_1}{R_1 + [r_2\,(1 + C_2^2\,\Omega^2 \rho^2) + \rho]\, X^2}. \tag{8}$$

The angle ϕ_1 is a function of the various constants C_1, L_1, M, L_2 . . . , and as the number of these constants is sufficient, we can choose ϕ_1 and X as independent variables, for a given value of C_2. The maximum of I_2 occurs then when:

$$\cos\phi_1 = 1 \tag{9}$$

and

$$X^2 = \frac{R_1}{r_2\,(1 + C_2^2\,\Omega^2 \rho^2) + \rho}. \tag{10}$$

As r_2 is generally very small, we may write approximately:

$$X^2 \doteq \frac{R_1}{\rho}. \tag{10'}$$

From (8) and (9) we get

$$I_1 = \frac{E\,l}{2\,R_1}\cdot \quad \text{(effective values)} \tag{11}$$

Hence, when the current I_2 is a maximum, the primary current is in phase with the impressed emf. and the primary losses are equal to the power delivered to the secondary circuits. When applied to the first of the equations (7), this gives immediately:

$$R_1\,I_1 = \left(L_1\,\Omega - \frac{1}{C_1\Omega}\right)I_1 j + M\,\Omega\,I_2 j - M\,C_2\,\Omega^2\,\rho\,I_2, \tag{7'}$$

and therefore, eliminating the ratio $\frac{I_1}{I_2}$, we obtain the two following conditions:

$$R_1\left[r_2 + \rho\left(1 - L_2 C_2\,\Omega^2\right)\right] + \Omega\left(L_2 + r_2 C_2\,\rho\right)\left(L_1\,\Omega - \frac{1}{C_1\Omega}\right) = M^2\,\Omega^2,$$

$$R_1\,\Omega\left(L_2 + r_2 C_2\,\rho\right) - \left(L_1\Omega - \frac{1}{C_1\Omega}\right)\left[r_2 + \rho\left(1 - L_2 C_2\,\Omega^2\right)\right] = M^2\,\Omega^3 C_2\,\rho. \tag{12}$$

Discussion: We shall now briefly discuss these conditions:

(a)—From (8), (9), (10), and (11) the maximum secondary current is:

$$I_{2\,max} = \frac{E\,l}{2\sqrt{R_1}\cdot\sqrt{r_2\left(1 + C_2^2\,\Omega^2\,\rho^2\right) + \rho}} \tag{8'}$$

and the radio power supplied to the detector

$$W_{2\,max} = \frac{E^2\,l^2\,\rho}{4\,R_1\left[r_2\left(1 + C_2^2\,\Omega^2\,\rho^2\right) + \rho\right]}.$$

This also increases when C_2 decreases, and the limit is

$$\frac{E^2\,l^2\,\rho}{4\,R_1\left(r_2 + \rho\right)}.$$

(b)—When $C_2 = 0$ (aperiodic receiver) the formulas (12) are reduced to:

$$\begin{gathered} R_1\left(r_2 + \rho\right) + \Omega L_2\left(L_1\,\Omega - \frac{1}{C_1\Omega}\right) = M^2\,\Omega^2, \\ \frac{L_1\,\Omega - \frac{1}{C_1\Omega}}{R_1} = \frac{L_2\,\Omega}{r_2 + C}, \end{gathered} \tag{13}$$

a result which agrees completely with the formulas of my precious papers, derived by quite a different method.

(c)—It is impossible to assume simultaneously:

$$\Omega^2 L_2 C_2 = \Omega^2 L_1 C_1 = 1,$$

because of conditions (12).

(d)—Eliminating M between these conditions, we obtain a relation which will be fulfilled by the constants L_1, C_1, L_2, C_2, before coupling.

III. The Audio Frequency Circuits

The formula (5) can be written

$$e = \frac{\sigma}{2}(I_2^2 + I_2'^2) - \frac{\sigma}{2} I_2^2 \cos 2\Omega t - \frac{\sigma}{2} I_2'^2 \cos 2(1+\varepsilon)\Omega t \\ -\sigma I_2 I_2' \cos(2+\varepsilon)\Omega t + \sigma I_2' I_2 \cos \varepsilon \Omega t. \tag{5'}$$

We retain only the first and the last terms, because the others cannot produce any sensible current thru the telephone T, as the correspondent frequency is too high.

Thus, the emf. e may be considered as the sum of a direct emf.

$$e_d = \frac{\sigma}{2}(I_2^2 + I_2'^2),$$

and furthermore of a sinusoidal emf. equal to:[3]

$$e_a = \sigma I_2' I_2 \cos \omega t;$$

where the frequency $\frac{\omega}{2\pi} = \frac{\varepsilon \Omega}{2\pi}$ will be chosen sufficiently low to give a musical tone in the telephone (beat detector).

We will consider now two cases:

(a)—$I_2' = 0$. In this case, the direct current which flows thru the telephone (or polarised galvanometer of any kind), according to the preceding considerations, is:

$$i_d = \frac{\sigma I_2^2}{2(r_2 + \rho + R)}, \tag{14}$$

and as the ampere-turns are proportional to product $i_d\sqrt{R}$, the effect is a maximum when

$$R = r_2 + \rho; \tag{15}$$

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[3] This expression, of course, is valuable as long as the approximation (1') is admissible; if this is not the case, the computations are very complex. Further, when the coefficient σ is sufficiently small, the products by this factor of the currents corresponding to the emf. e_d and e_a will be negligible, and the approximation which leads to the relation (5) is then justified.

This condition determines the number of turns of the winding, when its volume is given.

(b)—$I_2'>0$. This is the case of the best reception. We will suppose that the reactance ωL_2 and the susceptance ωC_2 are negligible, and write (where $j=\sqrt{-1}$):

$$e_a=(r_2+\rho)i_a'+L\,\omega\,i_a j+R\,i_a,$$
$$-\frac{i_a'-i_a}{K\,\omega}j=L\,\omega\,i_a j+R\,i_a.$$

Eliminating i_a', we get:

$$\frac{e_a}{i_a}=R+(r_2+\rho)\,(1-\omega^2 L\,K)+[L\,\omega+(r_2+\rho)\,K\,R\,\omega]\,j, \qquad (16)$$

a relation which can easily be discussed by means of the diagram of the Figure 3, in which:

$$\overline{OP}=r_2+\rho+R,$$
$$\overline{PQ}=L\,\omega,$$
$$\overline{HO}=(r_2+\rho)L\,K\,\omega^2,$$
$$\overline{HA}=(r_2+\rho)\,K\,R\,\omega,$$
$$\tan\delta=\frac{L\,\omega}{R},$$

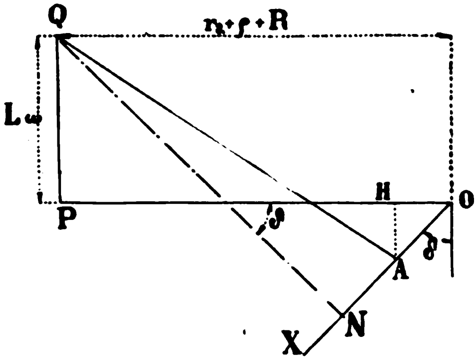

FIGURE 3

and, therefore,

$$\overline{QA}=\frac{e_a}{i_a}.$$

From (16) we see that the audio frequency current i_a is proportional to the product of the secondary current I_2 by the current I_2' induced by the local generator (heterodyne), as has been shown for the first time by Mr. Marius Latour (former citation).

If we then change the value of the capacity K, the locus of the point A is the straight line OX, and the maximum of i_a for a given value of e_a, occurs when the point A reaches the point N, QN being perpendicular to OX. It follows from an inspection of Figure 3:

$$\overline{OP} = \frac{\overline{QP}}{\tan\delta} + \frac{\overline{ON}}{\sin\delta},$$

or

$$K = \frac{L}{R^2 + L^2\omega^2} = \frac{\sin\delta\cos\delta}{\omega R} = \frac{\sin^2\delta}{\omega^2 L}. \tag{17}$$

Consequently, the best capacity is independent of the constants of the detector.

The current i_a is then:

$$i_a = \frac{e_a}{\sqrt{[R + (r_2+\rho)\cos^2\delta]^2 + [R\tan\delta + (r_2+\rho)\sin\delta\cos\delta]^2}}. \tag{18}$$

The effective ampere-turns are proportional to the product $i_a\sqrt{R}$, and the ratio $\frac{L\omega}{R} = \tan\delta$ may be supposed to be constant.

The above product is therefore a maximum when:

$$R = (r_2+\rho)\cos^2\delta. \tag{19}$$

It is interesting to compare conditions (15) and (19) which may differ considerably from each other in practice.

It may be further mentioned that the adjustment of the number of turns of the winding can be avoided by means of an audio frequency transformer, inserted between the condenser K and the telephone T, as proposed originally by the late Mr. Jégou.[4] The transformation ratio a of this transformer will be easily adjusted to the best value

$$a \doteq \sqrt{\frac{R}{r_2+\rho}} \times \frac{1}{\cos\delta},$$

according to the previous formula.

The use of this transformer also avoids the flow of the direct current i_d thru the telephones.

SUMMARY: Proceeding from a theory of the approximate rectifying detector, the most advantageous proportioning of the constants of the secondary circuit of a receiver is obtained. The constants of the most desirable telephone winding and the value of the most suitable telephone shunting condenser are then derived.

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[4] Mr. Jégou was a radiotelegraphic expert with the Army of the Orient. He died at Florina Hospital in 1917.

DETERMINATION OF RATE OF DE-IONISATION OF ELECTRIC ARC VAPOR*

BY

HENRY G. CORDES

(RADIO RESEARCH ENGINEER, BREMERTON, WASHINGTON)

A direct current arc in a vacuum is maintained by the ionising effect of the current. When the current is stopped for an instant the gas between the arc electrodes becomes de-ionised. The rate of this de-ionisation can be determined by the method here outlined provided certain quantities can be measured with sufficient accuracy.

At the instant the current thru the arc reaches zero the cathode is incandescent and the gas between the electrodes is ionised. The rate at which the gas becomes de-ionised depends upon the ionising effect of the incandescent cathode and upon the rate that the ions disappear from the gas.

When the arc has been extinguished the potential required to re-ignite the arc depends upon the time that the arc has been extinguished. The re-ignition potential also depends upon the kind and pressure of the gas surrounding the electrodes. The kind of gas is largely determined by the material of the electrodes, especially the cathode. According to Dr. Steinmetz the mercury arc in a good vacuum may not restart when extinguished for a few micro-seconds.

Figure 1 shows an arrangement for determining the rate of de-ionisation.

A current I flows thru the circuit $B_1-L_g-r_o-V_1$ where B_1 is a source of direct current, L_g is the inductance of the circuit, r_o the resistance of the circuit and V_1 is the valve to be tested. The battery B_3 and switch SW are used to prime the valve V_1, and SW is then opened.

Close the switch S-1. This closes the circuit $B_2-L-R-V_1-C$ where B_2 is a source of direct current, L is an inductance which is small compared to L_g, R is a resistance, and C is a condenser of capacitance C. Current will flow from B_2 to C until the latter

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is charged to a potential $E_i - E_v$, where E_i is the potential of B_2 and E_v is the drop thru V_1.

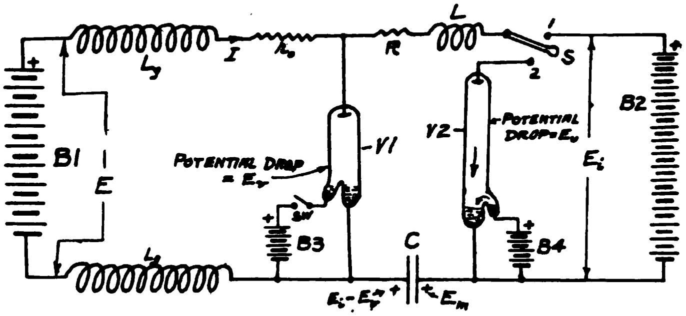

Figure 1

Transfer S-1 to S-2 quickly. If the value of $E_i - E_v$ is less than 350 volts, then no spark will pass until S is less than 5×10^{-4} cm. from 2 (See J. J. Thomson's "Conduction of Electricity thru Gases," 1st. edition, page 361). Let S move toward 2 at the rate of 10^3 cm. per second; then the time required to pass from the sparking potential to actual metallic contact between S and 2 will be less than 5×10^{-7} second.

The valve V_2 is a constantly primed mercury vapor valve the sparking potential of which to inverse current is greater than the sparking potential of valve V_1 which is to be tested.

Assuming E_i sufficiently large, the effective discharge of C_1 thru V_1, R, L, and V_2 will momentarily extinguish the arc of valve V_1 and charge C in the opposite sense to a potential E_a, at which the arc is re-ignited. The potential of C increases to E_m, at which instant all the current passes thru the arc again.

Figure 2 shows graphically the potential and current relation of C. The condenser C is part of two circuits; the discharge circuit, $C - V_1 - L - V_2$, and the charging circuit $B_1 - L_g - r_o - L - V_2 - C$.

The extinction and re-ignition of the arc as described above consists of three partial oscillations. The first partial oscillation takes place in the discharge circuit during the interval from the instant of initial discharge of C to extinction of the arc. The second partial oscillation takes place in the charging circuit during the interval of extinction and re-ignition of the arc. The third partial oscillation takes place in the discharge circuit during

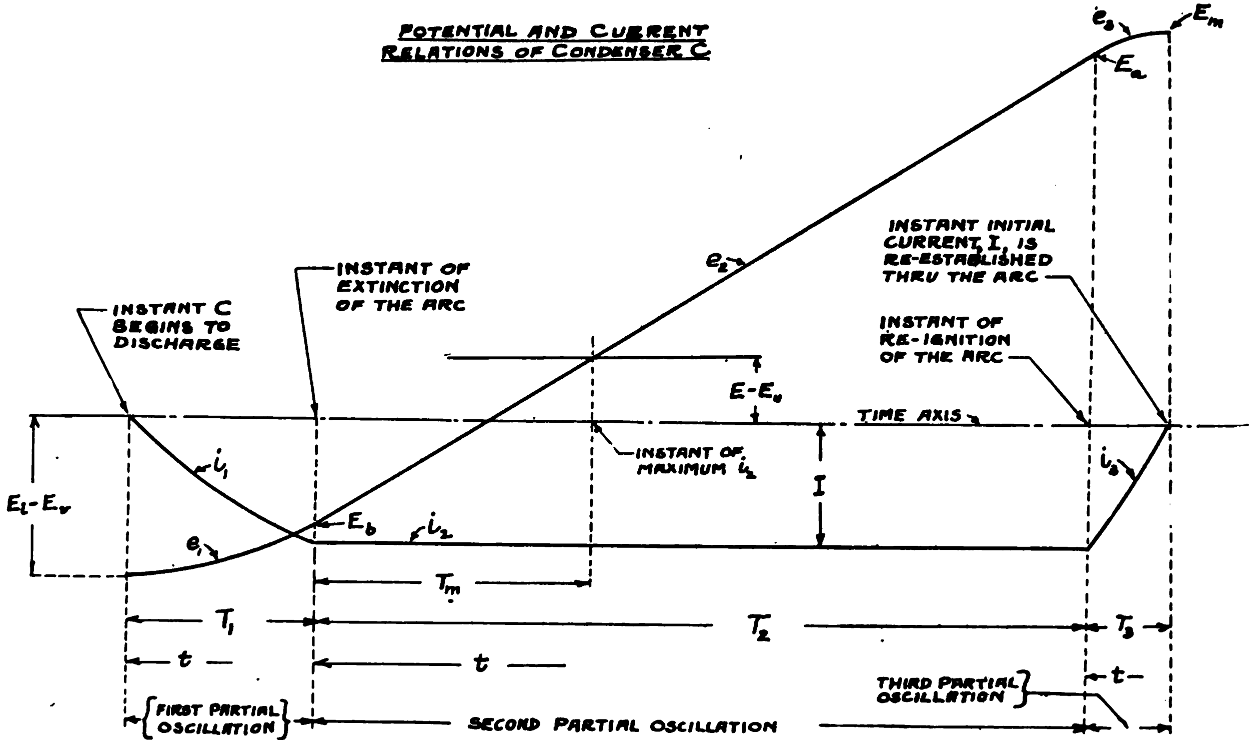
POTENTIAL AND CURRENT RELATIONS OF CONDENSER C
e_3
E_m
E_a
INSTANT INITIAL CURRENT, I, IS RE-ESTABLISHED THRU THE ARC
INSTANT OF RE-IGNITION OF THE ARC
e_2
INSTANT OF EXTINCTION OF THE ARC
INSTANT C BEGINS TO DISCHARGE
$E-E_v$
TIME AXIS
INSTANT OF MAXIMUM i_2
i_1
i_3
I
E_l-E_v
E_b
i_2
e_1
T_m
T_1
T_2
T_3
t
t
t
FIRST PARTIAL OSCILLATION
SECOND PARTIAL OSCILLATION
THIRD PARTIAL OSCILLATION

FIGURE 2

the interval from re-ignition of the arc until the current thru V_2 reaches zero.

The ratio between the re-ignition potential E_1 and the duration of the second partial oscillation is a measure of the rate of de-ionisation of the arc vapor. Other quantities remaining constant, a decrease in the capacitance C will increase the slope of e_2; T_2 will decrease; and E_a, the potential of C at re-ignition, will decrease due to less time for de-ionisation of the arc vapor.

The potential drop thru V_1 and V_2 is nearly constant for different values of current thru the vacuum tubes.

FIRST PARTIAL OSCILLATION

Let i_1 be the instantaneous current in the discharge circuit during the first partial oscillation.

Let L be the inductance, C be the capacitance, and R be the resistance of the discharge circuit. Equating potentials in the discharge circuit.

$$L\frac{di_1}{dt}-E_u+R\,i_1+E_r+\int\frac{i_1\,dt}{C}=0 \qquad (1)$$

The solution of (1) is

$$i_1=I_1\,\varepsilon^{-at}\,sin\,(\omega t+\theta) \qquad (2)$$

where $a=\frac{R}{2L}$, $\omega=\sqrt{\frac{1}{LC}-\frac{R^2}{4L^2}}$ and I_1 and θ are constants to be evaluated.

When $t=0$, then $i_1=0$, therefore $\theta=0$ or π. From Figure 2, $\frac{d\,i_1}{d\,t}$ is negative when $t=0$, therefore $\theta=\pi$.

When $t=0$ the potential of C is E_i-E_r. Substitute these initial values in (1) and the equation of initial potentials in the discharge circuit is

$$\left[L\frac{d\,i_1}{d\,t}\right]^{t=0}-E_u+[R\,i_1]^{t=0}+E_r+E_i-E_r=0 \qquad (3)$$

or,

$$I_1=\frac{E_i-E_u}{\omega L} \qquad (4)$$

When $t=T_1$, then $i_1=-I$. Substitute these terminal values and (4) in (2)

$$-I=\frac{E_i-E_u}{\omega L}\varepsilon^{-aT_1}\,sin(\omega T_1+\pi) \qquad (5)$$

From (5)

$$T_1=\frac{1}{\omega}\,sin^{-1}\,\frac{\omega L I}{(E_i-E_u)\,\varepsilon^{-aT_1}} \tag{6}$$

from which T_1 can be evaluated by one or two trials.

When $t=I_1$, let the potential of C be E_b. Substitute these terminal values in (1),

$$\left[L\frac{d\,i_1}{d\,t}\right]^{t=T_1}-E_u+[R\,i_1]^{t=T_1}+E_v+E_b=0 \tag{7}$$

From (4), (5) and (7)

$$E_b=(E_i-E_u)\varepsilon^{-aT_1}\,cos\,\omega\,T_1+aL\,I-E_v+E_u \tag{8}$$

From (6) and (8)

$$E_b=\sqrt{(E_i-E_u)^2\,\varepsilon^{-2at_1}-(\omega L\,I)^2}+aL\,I-E_v+E_u \tag{9}$$

The value of a may be determined by discharging condenser C. Let I_1 be less than I. Then the arc will not be extinguished by the discharge of C. Let the initial potential of C be E_i' and let E_r be the potential of C at the end of a half cycle when i_1 becomes zero. Then $\omega\,t=\pi$, which substituted in (1) gives

$$\left[L\frac{d\,i_1}{d\,t}\right]^{t=\frac{\pi}{\omega}}-E_u+E_v-E_T=0 \tag{10}$$

Equation (10) reduces to

$$(E_i'-E_u)\varepsilon^{-\frac{\delta}{2}}-E_u+E_v-E_T=0 \tag{11}$$

where $\delta=\dfrac{2\pi a}{\omega}$.

From (11)

$$\delta=\frac{2}{log\,\varepsilon}\cdot\,log\,\frac{E_i'-E_u}{E_T+E_u-E_v} \tag{12}$$

SECOND PARTIAL OSCILLATION

At the instant when the arc is extinguished the direct current circuit becomes the charging circuit which is an oscillating current circuit. The condenser C is charged initially to a negative potential E_b, which is the first partial oscillation terminal potential of C, and its value is expressed by equation (9). Another initial condition of the second partial oscillation is a negative current I flowing in the circuit. Let E_a be the potential of C when V_1 is re-ignited. If the line inductance L_0 is large compared to L then the re-ignition potential of V_1 will be practically E_a+E_u+IR. The capacitance C must be small enough to make the rise of potential of C rapid and approach a linear function of the time as shown in Figure 2. The current is theoretically a maximum when $t=T_m$.

In the charging circuit let r_2 = resistance, L_2 = inductance, and C = capacitance.

Let $a_2=\frac{r_2}{2L_2}$ and $\omega_2=\sqrt{\frac{1}{L_2C}-\frac{r_2^2}{4L_2^2}}$. The inductance $L_2=L_0+L$ and resistance $r_2=r_o+R$.

The equation of potentials in the discharge circuit is

$$E+L_2\frac{d\,i_2}{d\,t}+r_2\,i_2-E_u+\int\frac{i_2\,d\,t}{C}=0 \tag{13}$$

The solution of (13) is

$$i_2=I_2\,\varepsilon^{-a_2t}\sin\left(\omega_2t-\beta\right) \tag{14}$$

where I_2 and β are constants to be evaluated.

Referring to T_m of Figure 2, $\beta=\omega T_m+\frac{\pi}{2}$.

When $t=0$ then $i_2=-I$. Substitute these initial values in (14).

$$I=I_2\sin\beta \tag{15}$$

When $t=0$, the potential of C is E_b. Substitute these values in (13) to get the equation of initial potentials which is

$$E+\left[L_2\frac{d\,i_2}{d\,t}\right]^{t=0}+[r_2\,i_2]^{t=0}-E_u+E_b=0 \tag{16}$$

From (15) and (16)

$$E-\omega_2L_2\sqrt{I_2^2-I^2}+a_2L_2\,I-r_2\,I-E_u+E_b=0 \tag{17}$$

From (17)

$$I_2=\frac{1}{\omega_2L_2}\sqrt{(E_b+E-E_u-a_2L_2\,I)^2+(\omega_2L_2\,I)^2} \tag{18}$$

From (15) and (18)

$$\beta=\tan^{-1}\frac{\omega_2L_2\,I}{E_b+E-E_u-a_2L_2\,I} \tag{19}$$

When the current i_2 charges C to a potential E_a, the arc V_1 is re-ignited. The value of E_a depends upon the time T_2 between extinction and re-ignition of V_1 and upon C, I_R and E_b. At re-ignition the following terminal potential relations exist in the charging circuit.

$$E+\left[L_2\frac{d\,i_2}{d\,t}\right]^{t=T_2}+[r_2\,i_2]^{t=T_2}-E_u-E_a=0 \tag{20}$$

which reduces to

$$E+\varepsilon^{-a_2T_2}\left\{\left[\frac{I}{C}-a_2\left(E_b+E-E_u\right)\right]\frac{\sin\omega_2T_2}{\omega_2}-\left(E_b+E-E_u\right)\cos\omega_2T_2\right\}-E_a-E_u=0 \qquad (21)$$

Equation (21) expresses a relation between T_2 and E_a.

The value of E_a will be obtained from E_m in the third partial oscillation.

Solving (21) for T_2

$$T_2=\frac{1}{\omega_2}\left[\sin^{-1}\frac{\left(E_a+E_u-E\right)\varepsilon^{a_2T_2}}{\sqrt{\left[\frac{I}{\omega_2C}-\frac{a_2}{\omega_2}\left(E_b+E-E_u\right)\right]^2+\left(E_b+E-E_u\right)^2}}+\tan^{-1}\frac{E_b+E-E_u}{\frac{I}{\omega_2C}-\frac{a_2}{\omega_2}\left(E_b+E-E_u\right)}\right] \qquad (22)$$

When a is negligible, (22) reduces to

$$T_2=\frac{1}{\omega_2}\left[\sin^{-1}\frac{\omega_2C\left(E_a+E_u-E\right)}{\sqrt{I^2+\omega_2^2C^2\left(E_b+E-E_u\right)^2}}+\tan^{-1}\frac{\omega_2C\left(E_b+E-E_u\right)}{I}\right] \qquad (23)$$

In (21) let $a=0$, let $\sin\omega_2T_2=\omega_2T_2$ and let $\cos\omega_2T_2=1$, then

$$T_2=\frac{C}{I}\left(E_a+E_b\right) \qquad (24)$$

Equation (24) is based upon the assumption that L_g is infinitely large and that I is constant during the interval T_2.

Let the charging current at the instant of re-ignition be $-I'$; then from (14) and (15)

$$-I'=\frac{I\,\varepsilon^{-a_2T_2}}{\sin\beta}\sin(\omega_2T_2-\beta) \qquad (25)$$

THIRD PARTIAL OSCILLATION

The third partial oscillation is similar to the first except that the initial potential and current in the circuit is different.

Equations (1) and (2) apply except I_1, and θ will have different values. Call these values I_3 and ϕ then (2) becomes

$$i_3=I_3\,\varepsilon^{-at}\sin\left(\omega t-\phi\right) \qquad (26)$$

When $t=0$ then $i_3=-I'$. Substitute these initial values in (26)

$$I'=I_3\sin\phi \qquad (27)$$

Let E_m be the potential of C when $I_3=0$ and $t=\frac{\phi}{\omega}=T_3$.

Then from (1) the equation of terminal potentials is,

$$\left[L\frac{d\,i_3}{d\,t}\right]^{t=T_3} -E_u+[r\,i_3]^{t=T_3}+E_v-E_m=0 \tag{28}$$

from which

$$\omega L\,I_3\,\varepsilon^{-aT_3}-E_u+E_v-E_m=0 \tag{29}$$

From (27) and (29)

$$\phi=\omega\,T_3=sin^{-1}\frac{\omega L\,I'\,\varepsilon^{-aT_3}}{E_m+E_u-E_v} \tag{30}$$

from which ϕ or T_3 may be evaluated by one or two trials when $a\,T_3$ is not negligible.

Since E_a is the potential of C at re-ignition equation (1) becomes

$$\left[L\frac{d\,i_3}{d\,t}\right]^{t=0} -E_u+[R\,i_3]^{t=0}+E_v-E_a=0 \tag{31}$$

from which

$$E_a=\omega L\,I_3\cos\phi-aL\,I'-E_u+E_v. \tag{32}$$

From (30) and (32)

$$E_a=\sqrt{(E_m+E_u-E_v)^2\,\varepsilon^{2aT_3}-(\omega L\,I')^2}+E_v-E_u-aL\,I' \tag{33}$$

To evaluate E_a from (33) assume $I'=I$ and solve for E_a. Use this first trial value of E_a in (24) and solve for T_2. Use this first trial value of T_2 in (25) and solve for I'. Use this value of I' in (33) and (30) for a final value of E_a. A practically exact value of T_2 may be obtained by using these values of T_2 and E_a in (22) or (23).

DE-IONISATION CURVE

To show the rate of de-ionisation graphically a curve can be plotted for different values of E_1 and T_2. In order that the conditions for de-ionisation remain constant it is necessary to maintain I, E_u, R, and E_b constant. From (24) is seen that T_2 must be changed by varying C. To keep E_b constant, (9) shows that E_i, ωL, and I must remain constant.

This curve will show the de-ionisation characteristics of an arc under given conditions. To compare an arc under different conditions of electrode material, temperature and pressure the ratio $\frac{E_1}{T_2}$ will indicate the relative rates of de-ionisation when either E_1 or T_2 is assigned a definite value.

Figure 3 shows the general form of a T_2–E_1 curve. As the capacitance C is increased the potential of C rises more slowly while the re-ignition potential E_1 rises. By keeping $E_b-E_u-I\,R$ constant, the inverse potential impressed upon the valve will not affect the value of E_1.

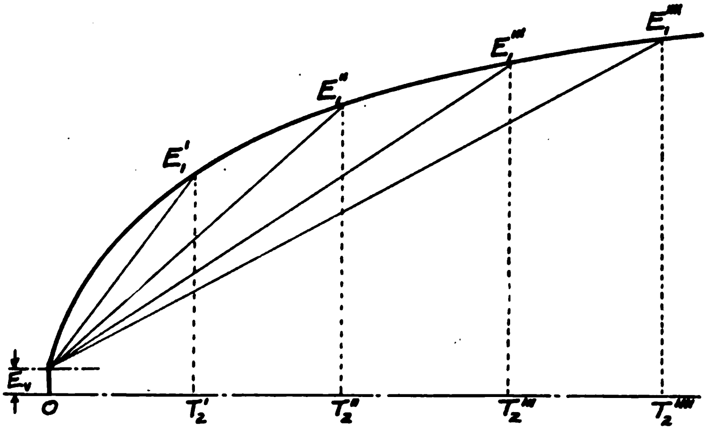

FIGURE 3

Another important curve will be obtained by plotting E_a and E_b in (24) while T_2, I and C remain constant. E_b can be varied by changing the initial potential E_i. The effect upon E_a of changing the inverse potential upon the valve can thus be ascertained.

NUMERICAL EXAMPLE

The application of the preceding equations can be illustrated by assuming values for the quantities which can be measured.

Assume $E_i'=90$ volts, $E_u=E_v=20$ volts, and $E_T=63.4$ volts. From (12), $\delta=0.2$.

Let $T_n=\frac{1}{f}=$ the natural period of the discharge circuit. Assume $f=10^5$ and $C=0.2\ \mu$f.

Then $L=\frac{10^6}{8\pi^2}$, $\omega=2\pi\,.\,10^5$, $\omega L=\frac{10^{11}}{4\pi}$, $\alpha=0.2\,.\,10^5$, $\alpha L=\frac{10^{10}}{4\pi^2}$ and $T_n=10$ micro-sec. Assume $E_i=110$ volts and $I=10$ amperes.

From (6), $T_1=0.663$ micro-seconds, and from (9) $E_b=24$ volts. In (30) and (33) assume $I'=I$ and $E_m=500$ volts. Then

$T_3=0.25$ micro-sec., and $E_a=491.5$ volts. Substituting in (24), $T_2=10.3$ micro-seconds. Since $R=2fL\grave{o}$, $R=0.5$ ohm and $R=516.5$ volts.

These values of E_1 and T_2 are based upon the assumption that L_g is infinitely large.

Assume $L_2=100L$ and $E=110$ volts.

From $r_o=\frac{E-E_r}{I}$, $r_o=9$ ohms. Since $r_2=r_o+R$, $r_2=9.5$ ohms.

The natural period of the charging circuit is then $T_c=100$ micro-seconds and $\omega_2=2\pi \cdot 10^4$.

Substitute this value of ω_2 in (25), then $I'=7$ amperes. From (30) and (33) $E_a=495.2$ volts, and $E_1=520.2$ volts.

Solving (22) completely, $\omega_2 T_2=38.6°$ and $T_2=10.7$ micro-seconds. An error of only 4 per cent. was made by assuming L_g to be infinitely large.

The value of L_g must be determined for a natural period of 100 micro-seconds. An iron magnetic circuit will increase the inductance and energy stored in a given coil. During the time T_2, part of this energy is transferred to condenser C and part is dissipated by eddy currents in the iron. Other conditions remaining the same, the ratio of energy transferred to C to energy dissipated by eddy currents in L_g decreases with a decrease in capacitance C. In other words, L_g is variable when its value depends upon the presence of iron. Iron should therefore be used only when L_g is to be considered infinitely large. When no iron is used, the source of the direct current should be a generator shunted with a large condenser or a battery.

The charging current circuit resistance r_o must be so constructed that its value will be the same for a current of period of 100 micro-seconds as for a continuous current.

STARTING TERMINAL

The effect of a starting terminal on an electric arc valve will reduce the re-ignition potential.

Figure 4 is similar to Figure 1 except that V_1 is provided with a starting terminal T the presence of which will reduce the re-ignition potential E_1. The effect of a starting terminal is illustrated by the starting band of a mercury vapor lamp. The potential between T and K is the same as the potential of C. It may be made less by dividing C into a number of condensers in series and connecting T to a point between the condensers.

In Figure 4, the valve V_2 is not a constantly primed valve.

The switch S may be moved slowly from 1 to 2 and a sufficient potential impressed upon C_u for a spark to pass from F to K_2 which will prime V_2 and allow C to discharge. When this method of discharging C is used the potential E_i may be made as high as desired.

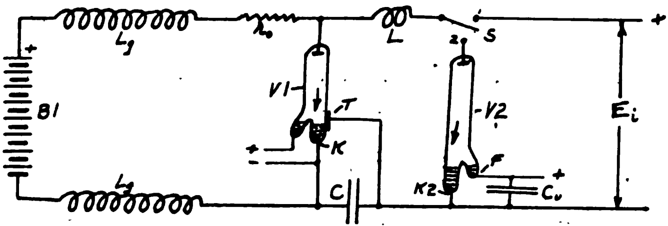

FIGURE 4

The re-ignition potential E_1 may be increased by placing the arc in a magnetic field.. This is illustrated by the Poulsen arc.

INVERSE CURRENT

The maximum inverse potential impressed upon V_1 is $E_b - E_u - I\,R$. This potential will produce inverse current which is difficult to measure at high frequencies. The following arrangement is suggested.

Figure 5 is similar to Figure 4 except the additional valves V_3 and V_4 have been introduced and T omitted. All current passing from anode to cathode in V_1 passes thru V_4, but all inverse current thru V_1 passes thru V_3. Place a transient-current-indicating device D in series with V_3. Then D will indicate the inverse current thru V_1. The value of E_v in the equations will be the potential drop thru V_1 and V_4 in series.

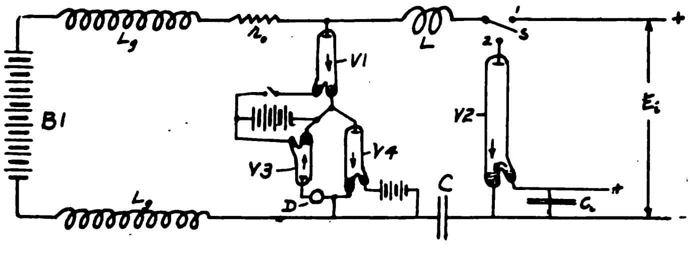

FIGURE 5

It may be possible, with this arrangement to ascertain the cause for the inverse discharge at the beginning of each half cycle in a mercury vapor rectifier. (See "General Electric Review," October, 1913, page 701.)

REMARKS

There is a minimum current which will sustain a given arc. The maximum amplitude of i_1 may be less than I and still the arc will be extinguished. If the arc is not extinguished, the final potential of C will be E_T, which is less than E_i, but when extinction takes place the final potential of C will be E_m, which is greater than E_i. To extinguish the arc the ratio $\sqrt{\frac{L}{C}}$ must be less than the ratio $\frac{E_i - E_u}{I}$, so that the term under the radical in (9) is positive. In order to use a low potential for E_i it is necessary to make L very small when the natural period of the discharge circuit is a micro-second or less. If V_2 in Figure 1 is omitted, V_1 will probably be permanently extinguished.

The relation between E_1 and T_2 for an arc in mercury vapor at low pressure will probably be expressed in hundreds of volts and a fraction of a micro-second because of the known quenching action of mercury vapor.

The equations of the first and second partial oscillations are applicable to the Poulsen arc but in the third partial oscillation the value of E_v varies. Its average value is much higher than in the first partial oscillation. This has been shown with a Braun tube. If E_m is not much greater than E_a, then valuable information may be gained by the method here described.

The accuracy of the results in the numerical example would have been increased if E had been reduced from 110 volts to 30 volts. The effect of r_0 would then have been still more negligible.

If $E_i - E_u$ is measured with a ballistic galvanometer, then C may be charged to a potential E_i and then discharged thru the galvanometer and V_2 in series which will give the potential difference directly.

The method here developed is based only upon theoretical deductions. Experimental research is required to determine the rate of de-ionisation of arc vapor under different conditions. The results of such research will be of great value.

SUMMARY: After discussing the de-ionisation and consequent loss of conductivity of mercury vapor carrying a momentary arc, the author considers an arrangement of circuits for determining the rate of de-ionisation, and the effect of this rate on the voltage required for a subsequent re-ignition.

The theory of the circuits shown is given, and illustrated by numerical examples. It is suggested that the arrangements shown be experimentally carried out because of possibly important practical applications.

THIRD DISCUSSION ON

"THE ELECTRICAL OPERATION AND MECHANICAL DESIGN OF AN IMPULSE EXCITATION MULTI-SPARK GROUP RADIO TRANSMITTER

(A Paper by Ensign Bowden Washington, U.S.N.R.F)

By

Lieutenant Ellery W. Stone, U. S. N. R. F.

(Officer in Charge, U.S. Naval Radio Station, San Diego, California)

In reply to Mr. Washington's discussion, which reached me this date, I should like to state that I am quite in accord with his definition of impact excitation, as is evidenced by definitions of the term given in my previous articles on the subject. If, however, thru accident or design, the gap circuit of an impulse transmitter delivers a little more than the single half cycle which characterizes its normal operation, it can hardly be placed in the ordinary quenched gap type of transmitter, inasmuch as the excitation of the antenna is still of the shock type. The major portion of the energy is unquestionably resident in the first half cycle.

In connection with the tests of the Kilbourne and Clark transmitter conducted by Mr. Washington at Harvard University in which he obtained two and one half oscillations, it is presumed that these tests were those conducted for the Marconi Company in 1916 during its suit against the Kilbourne and Clark Company. It may be stated that the defendant (Kilbourne and Clark) proved to the satisfaction of the Court that these tests were conducted under abnormal conditions,to-wit; abnormal gap length, and improper adjustment of the circuits, and that attempt was made to produce oscillations in the gap circuit rather than to demonstrate normal operation.

If the photographs showing a single impulse in the gap circuit were not indicative of impact excitation, they were not so considered by the Court. These were taken at the University of Washington by Lieutenant Greaves, who had considerable experience in this work at Harvard University, in the presence of Mr. F. A. Kolster, Mr. Frederick Simpson, myself and several others.

In the decision of the Court, in which the impulse nature of this transmitter was upheld, Judge Netterer rules as follows:

"The defendant, to demonstrate the fact of the 'single chunk' (impact, E. W. S.) "conversion of antenna energy, introduced the result of experimentation conducted at the University of Washington with the Braun tube on the behavior of the Simpson Mercury Valve Transmitter. . . The deflection of the spot of light across the screen corresponds with the motions of the current, first in one direction and then in the other, and if the disturbing" (gap, E.W.S.) "circuit is not characteristically an oscillating circuit . . . the spot of light would appear as in the photograph. . . The contention of the plaintiff" (Marconi Company) "with relation to the Massachusetts" (Harvard University) "test, in which it was shown that there were two and one half oscillations in the circuit, and that this must refute the contention of the defendants with relation to the Washington University photographic test, may be answered by the suggestion that the Washington University result was obtained,—the photograph speaks for itself—and defendant's witnesses to that extent are corroborated. The Massachusetts experiments show that there were many elements that entered into the experiments with relation to the appliances and the adjustment of the apparatus. Dr. Zenneck's testimony, which does not seem to be denied, shows that photographs were only taken when the adjustments were such as to produce the desired result, and that the effort was for the purpose of obtaining evidence of oscillations in the trigger" (gap, E.W.S.) "circuit, rather than to present to the Court the result of all the experiments that were made, together with the adjustments for each result. . . No facts shown indicate that the oscillations" (antenna) "were the result of resonant transfer of energy."

I do not feel required to defend the term "partial discharge," the expression being taken from Zenneck's writings. I should say that the definition of "full charge" which Mr. Washington seeks, is that charge given the condenser by the time the peak of the transformer secondary wave has been reached, the separation of the gap permitting, or the maximum charge which the condenser can receive with a given secondary potential. This "full charge" will be recognized as distinct from the partial charge which the condenser ordinarily receives as a result of the minute separation of the impulse gaps, thus giving rise to several discharges of the condenser per alternation.

February, 17 1919.

FURTHER DISCUSSION ON "RECEPTION THRU STATIC AND INTERFERENCE"

BY

ROY A. WEAGANT

Lee De Forest (by letter): I regret that I was out of the city when Mr. Weagant's paper on static elimination was presented, and particularly that copy of his paper was not received until the PROCEEDINGS were ready to issue.

I have read with intense interest the paper and such discussion as appeared with it. Such abundance of well merited praise has therewith appeared that I feel justified in limiting my present remarks chiefly to helpful criticism. I too, perhaps earlier than most of our readers, have fought with static, and been burned by it. I can honestly state that I know from long and intimate acquaintance what genuine, sub-tropical, summer static is—perhaps far better than some others who from cool northern laboratories have casually announced its final "elimination."

My experience has indeed been such that even now, as during the earlier years, I doubt that the "99 per cent, reliable, guaranteed, copper-riveted static eliminator" has been discovered. And certain recent careful inquiries among some very capable radio observers and experts (some in the Government service) have elicited statements, the accuracy and fairness of which I am bound to accept, to the effect that the Weagant eliminator, like a legion of others, falls down at times. It is, in short, by no means all that its enthusiastic proponents claim.

If such be the fact, I regret it as much as anyone. Having spent all my working years in the development of the radio art, I rejoice at each actual step in advance, by whomsoever wrought. Static has been our *bête-noir* from "Genesis"; and I too await for "Revelation"—I hope to see it. But let us not throw our hats skyward over the assassination of "Satan Static," until further evidence than that of the inventor of an eliminator, and other interested observers, comes forward after long summer months of trial, to lay its wreath of unbiased testimony upon the "Tomb of Trouble."

Possibly I have been misinformed. Let other users of the Weagant system, not employees or associates, who have successfully used the system thru say six summer months of European radio reception in the South, come forward. In THE INSTITUTE OF RADIO ENGINEERS we simply want facts, not flattery.

Mr. Weagant's paper can be divided into two parts—The first and by far the largest and most exhaustive, outlines in great detail the amazing lengths and profligate expense to which the Marconi Company has gone to accomplish what Mr. Weagant himself admits in the brief, *second* part of his paper, can be achieved by far simpler and more rational methods. Therefore we may dismiss with sincere praise for the inventor's courage and persistence the consideration of vertical loops 400 by 1,000 feet (120 by 300 m.) in dimensions and located miles apart, or of horizontal antennae 6 miles (9.6 km.) long, of miles of pasteboard tubes covered with tinfoil "gleaming in the Florida moonlight." Sad indeed would appear the future of radio communication if we believed that static elimination depended in the slightest degree on the utilization of devices of such Brobdingnagian dimensions. I do not believe that it is essential to separate the "static tank" loops as one does water tanks along a railroad.

But while describing these experiments Mr. Weagant is sadly misleading in his historical omissions. To those not well versed in early radio history it would have been only instructive and fair had he pointed out that Mr. John Stone Stone first conceived and described the two vertical receiving antennas, separated by a half-wave length, or portion thereof, arranged in the plane of propagation—differentially connected, thru long horizontal leads, to a common receiving system, to balance out interfering disturbances. In Stone's U. S. patent 767,970, filed June, 1901, this system is carefully outlined and analyzed, together with the third vertical antenna located directly at the receiver. . (This latter is for use as a transmitter, the arrangement b ing such that the powerful impulses from this transmitter shall be completely neutralized upon the two receiving systems.)

Mr. Weagant mentions "among the early workers with the loop, Bellini—Tosi, and Braun"; but completely ignores the fact, of which we Americans should be proud, that the first disclosure of the loop receiver and direction finder was in Stone's U. S. patent, filed January 23, 1901; and that he laid down at this remote date the basic principles on which the entire art of direction finding (and incidentally of Mr. Weagant's eliminator) are founded. Mr. Weagant further erroneously ascribes the first use of the horizontal linear aerial to Mr. Marconi. As a matter of fact this was, I believe, also an American discovery—at Block Island in 1903.

It seems to be equally unknown that the first patent on the horizontal receiving loop or horizontal conductor, with length independent of the wave length and rotating around a vertical axle, for localizing the direction of incoming signals, was issued to the writer, in 1904.

Mr. Weagant describes the differentially combined "interference-prevention" circuits of Fessenden as "fundamentally incorrect" because "the detuning of one branch circuit affects the intensity of both the signal and static currents in the secondary circuit in the same ratio." As a matter of fact, where enlightened methods of this sort are employed in receiving undamped waves, a very great improvement in the signal-static ratio may be noted.

Moreover, after styling the Fessenden differential principle as "fundamentally incorrect," Mr. Weagant actually relies on exactly that principle to achieve the final elimination of static impulses between his "static tank" circuit and his third static-signal circuit. Note his arrangements in Figures 7, 11, 13, 18, 30, and so on.

The theory Mr. Weagant advances of the vertical origin of the "grinders" is novel, if we consider that he means that all such disturbances come from directly above the receiving station. But the long established fact that the same violent static impulse is frequently noted simultaneously at stations separated by hundreds of miles precludes the acceptance of this view. Then, moreover, would it be possible to eliminate such disturbances by rotating a small loop-receiving antenna about a horizontal axis.

Both audio and radio balancing between two helices at right angles have been tried by Major Charles A. Culver in recent tests for the Signal Corps in an effort to neutralize static effects, but without success. Simultaneous photographic records of "X" impulses received on two helices placed at right angles to one another and in a vertical plane appear to show that the extraneous disturbances do not occur simultaneously at two mutually perpendicular planes.

It has long been accepted generally that static impulses originating in the tropics are reflected by the Heaviside layer, or by upper banks of ionized air, and consequently reach northern and southern latitudes with a downward vertical component. This explanation was cited by Professor Pupin in his discussion of the Weagant paper. Moreover if the startling theory of vertical origin were correct it would obviously become a very simple matter to neutralize the static impulses on two small vertical loops, placed at right angles, while receiving the desired signals on that loop which lay in the plane of their propagation. Such, of course, is by no means the case. The germ of genuine merit in Mr. Weagant's voluminous paper resides, it seems to me, in the idea of the so-called "static-tank," balancing out the signal in two receiving systems, leaving only static, and then balancing that against the static in a third system, obtaining finally only a residuum of signal, and then amplifying this remnant. But what justifiable considerations lead him to accomplish these effects by use of antenna systems which require an entire township for their exploitation, "across a canal, thru cow pastures and frequently broken?" Certainly it was *not* to avoid the use of the audion amplifier! No such reluctance in employment of another's device to accomplish so useful an end, characteristic tho it be with certain investigators, would be justifiable.

To illustrate how simple it would be to accomplish by sensibly small loop antennas what Mr. Weagant does with his gigantic "loops" connected to his receiver by miles of horizontal conductors (systems which possibly operated not as *true loop* antenna at all) let me cite the results obtained by Latour at Lyons. Using three radio frequency audion amplifiers, in cascade, an audion detector, and then several audio frequency amplifiers, in cascade, the French military administration has been receiving from Annapolis at a point only one mile from the Lyons arc transmitter station—without any interference therefrom whatever,—while Lyons was transmitting at full power (150 kilowatts) with a wave-length only 2.5 per cent different from that of Annapolis. And Latour does this using as a receiving antenna *a coil only 60 cm. (24 inches) in diameter!* Contrast this with one 400 by 1,000 ft. (120 by 300 m.) Of course, French static is not to be compared with our summer variety; but every advantageous result which Mr. Weagant describes can, I believe, be accomplished (as Prof. Pupin urges) with receiving circuits of very ordinary dimensions, perhaps "such as can be used on board ship." For compare these results at Lyons with what the huge Weagant arrangement accomplishes; "The reception of Carnarvon's signal, 14,200 meters, thru the powerful interference of the 200 kilowatt Alexanderson alternator (supposedly perfect sine-wave emission) at New Brunswick, *only* 25 *miles* (40 *km.*) away, working at 13,600 meters (a 4.4 per cent difference), has been an every day performance of the system."

As further bearing out this statement, and Latour's results, consider the results described by Lieut.-Commander A. H. Taylor in the June number of the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS—obtained with loops only 3 meters (9 feet) square. If one uses such loops it will not be "found necessary to have an operator located at the remote loop to make adjustments in accordance with instructions telephoned to him by the observer in the receiving station, using the cable wire for this purpose." I must disagree with Mr. Weagant's statement that "very satisfactory practical working was secured," since, to quote further, "with both these arrangements local tuning of the loops was necessary, and this always involved a tedious adjustment until the correct setting for a given wave length was obtained, and even when this setting was known, it was necessary for some one to go to each of the loops—not a convenient procedure with antennas three miles (4.8 km.) apart."

A stiff course in practical "statics" has heretofore been recommended as an effective cure for any tendency to pedantic and dogmatic theorization on their behavior. Hence, after studying Mr. Weagant's Figures 9, 10 and 17, one can but wonder that any person who has struggled with the irrational idiosyncrasies of subtropical static as Mr. Weagant has, can still retain sufficient patience, or religious faith, to attempt to describe their operation in terms of cosine curves, and "azimuthal angles!" In others, therefore, who have likewise gone thru the static mill a moderate amount of more or less profane skepticism as to the pertinence of these figures must be tolerated.

A common oversight on the part of inventors of most so-called "static eliminators" has been the fact that powerful static disturbances may reach the highly sensitive detector-amplifier directly thru the low-frequency conductors attached thereto, that is, the battery leads, the telephone cord, the body of the operator himself, or act directly upon the sedondary coil, or, if unshielded, the metallic plates of the condensers attached to the receiver. Thus no matter how perfect and intricate a "filtering" system may have been installed between the antenna and the detector, the disturbances which have been successfully barred from entrance by the fortified front of the house steal in thru the back, where they find the entire roof and walls missing. To expect then to exclude effectively static disturbances from a receiving and detector system, the various elements of which are not effectively and in succession screened electrically from the other links in the filtering system, is as futile as to hope to per-form delicate photometric work in a room elaborately equipped with the proper apparatus, but the walls of which are white or silvered, and where on all sides are unmasked arc lights, dazzling sparks, magnesium flares, and windows open to the sunlight. Especially does the above analogy hold good when violent electrical storms are in the neighborhood of a long distance radio receiving station.

From the foregoing, it should be apparent that it is practically futile to conduct radio signaling which shall be at all times immune to static disturbances and interruption so long as it is possible for violent disturbances to produce in the receiving system effects which simulate those produced by the waves emitted from the transmitting station. Yet this situation is inevitable so long as attempts to solve the problem are limited exclusively to the receiving apparatus.

Unquestionably, Mr. Weagant has made a contribution of genuine value towards the long-desired goal. But until efficient shielding methods are adopted there are still certain to occur intervals when the only satisfactory means for cutting out unwelcome disturbances is that which was so effectively adopted during the public discussion of Mr. Weagant's paper—lay the "phones on the table, and refuse to listen."

Roy A. Weagant (by letter): The tone of Dr. de Forest's comment is such as to tempt one to ignore it. Also, to one familiar with the paper, his failure to read it carefully is so evident that a reply seems unnecessary. However, lest silence should seem to give assent to some of his misinterpretations, the following reply is submitted.

Dr. de Forest has expressed doubt that the "99 per cent reliable, guaranteed, copper-riveted, static eliminator" has been discovered. Reference to the text of the paper fails to disclose any statements in this language, or which convey any such inference, but on the contrary the capabilities of the apparatus and its limitations have been expressed in a perfectly definite way and should be easily understood by any experienced radio man. These may be summarized by stating that with this apparatus practically continuous reception from such stations as Carnarvon, Nauen, or Lyons is possible save only when there is local lightning present, while with any other known receiving method reception from these stations in the afternoon and evening during the summer is nearly always entirely impossible, and is also impossible to a considerable extent, at other seasons of the year. In this statement it is assumed that the receiving station is within 100 miles (160 km.) of New York City.

Since the time of delivery of the paper the greater part of another summer season has passed, during which various forms of the static arrangement have been in continuous service. Furthermore, the static conditions experienced this year have been much more severe than those encountered last year, yet the continuity of reception from the stations mentioned has been greater than that of last summer and we have been able to receive continuously even thru the worst fading periods, which occur in the afternoon between four and seven o'clock, without interruption by anything except local lightning. With regard to this latter cause of interruption, to date there have been only two days on which lightning has rendered reception impossible; in one case for a period of approximately three hours, and in the second case for approximately two hours. There have also been several days—perhaps four in all—when lightning has caused appreciable trouble but not complete interruption; that is to say, thru these periods messages in plain language, sent twice, could have been received completely, but code, sent words once, could not have been completely copied.

Dr. de Forest's suggestion that the opinion of unbiased and qualified experts on the working of this system is desirable before its efficacy can be completely accepted, is entirely reasonable, and it was for this reason that the offer to conduct tests for the benefit of a committee to be appointed by the Institute was made. The response to this offer indicated that this was perhaps a rather difficult thing to carry out since a considerable period of observation would be necessary in order to arrive at a correct conclusion. With this point of view the writer is unable to differ since he was unwilling to accept the results himself until the system had been tested thru an entire summer, twenty-four hours a day, with an operator constantly on watch.

The most conclusive proof of the correctness or otherwise of the claims on the working of this system will be had when the Marconi Company resumes commercial working with Europe, after its stations are returned by the United States Government.

In reply to Dr. de Forest's statement that certain individuals in the Government service have informed him that the apparatus does not work as claimed, it is enough to state that only one man in the Government service has had any experience or familiarity with the system, and that this gentleman, Mr. George H. Clark, has already set forth the result of his observations, in his discussion of my paper.

With regard to the criticism that the arrangements used are of "brobdignagian" dimensions, it would seem pertinent to inquire how long it has been such a colossal task to construct six miles (10 km.) or so of ordinary telephone line, which, from the constructional point of view, is all the largest arrangement requires. Dr. de Forest has often boasted of the part his audion has played in transcontinental telephony, which involves some 3,000 miles (4,800 km.) of this same sort of construction. The cost is certainly not prohibitive, for the total expense of the Lakewood installation was less than one-half of that of a single tower of the type which the Marconi Company had at its Belmar receiving station, six of which were considered necessary for reception a few years ago.

Dr. de Forest has referred to some of the later arrangements as being far simpler and more rational because of their smaller size, but while this is true the fact is that none of them has yet been developed to the point where it is equal to the Lakewood arrangement in the range of conditions it is able to cope with.

With reference to this historical references of the paper, it is sufficient to say that, as specifically stated, no attempt was made to present a complete historical outline. There can be no ground for charging unfairness, therefore, and it is not necessary here to either accept, deny, or qualify Dr. de Forest's statements.

The writer takes issue squarely with Dr. de Forest in his statement that the Fessenden interference preventer circuit "where enlightened methods are employed" causes a great improvement in signal-static ratio, or that it is possible to secure with this arrangement any signal-static ratio which cannot be duplicated with other well-known receiving methods used with equal enlightenment.

He is also entirely incorrect when he states that that principle is relied upon to achieve the final elimination of static impulses between the static tank and the static signal circuits, for the reason that in this latter, one circuit has both signal and static currents, while the other has only static currents; consequently when the two are connected together in opposition, signal current only is left. If both circuits had both signal and static currents, then his statement would be correct.

Dr. de Forest is quite right when he states that if the hypothesis of overhead origin and vertical propagation were correct it should be possible to eliminate static by rotating a small loop-receiving antenna about a horizontal axis. In fact this does accomplish the elimination of static, but unfortunately it also accomplishes the elimination of signal. If it were possible to transmit waves which were horizontally polarized instead of vertically, as at present, and if they would remain so at great distances, then a loop with its plane horizontal would furnish an ideal means of working thru static of the grinders type.

Dr. de Forest also refers to certain tests recently made by Major Charles A. Culver, in which he shows that static currents produced by two loops at right angles will not balance. If he had read the paper more closely he would have found this identical fact stated (at bottom of page 216 and top of page 217 of the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, June, 1919). It was discovered by the writer more than three years before the work which Major Culver reports was undertaken. His further statement that if the hypothesis of vertical propagation were correct, loops at right angles should balance, is also entirely incorrect, as will appear from a less superficial analysis of the proposition. If it be assumed that these electromagnetic waves are generated by linear oscillators, then, in order that two loops at right angles to each other shall be affected by the wave originating at each oscillator simultaneously and with the same relative intensity, which is the prerequisite to balancing, the horizontal projection of each of these oscillators must make the same angle with the two loops, since if different impulses were due to oscillators, the horizontal projection of whose axes may be at different angles with the two loops, there would be no possibility of securing adjustment, which would annul any appreciable percentage of them. The conception that these oscillators are so arranged seems to me utterly impossible, and in order that the hypothesis of overhead origin and vertical propagation may be rational it is necessary to assume that the axes of the oscillators producing static waves shall assume all possible angles in space; that is, they shall be heterogeneous in their disposition. Under this assumption it becomes impossible for loops in different planes to balance. At this point it should be emphasized, as it was in the paper, that this hypothesis is set up merely as a convenient working base, and that it cannot be regarded as proven. On the other hand, however, the fact that antennas situated considerable distances apart are simultaneously affected by the type of static known as grinders, is proven beyond question.

Dr. de Forest's reference to the work of Latour in receiving with a small closed loop, and his comparison with the reception of Carnarvon's signal thru the interference of New Brunswick, is quite beside the point for the simple reason that the arrangement of Latour is in no sense a static eliminator, but is merely a small loop-receiving arrangement, whereas it was definitely stated in the paper that the result mentioned was accomplished *while maintaining a good static balance*, which is quite a different proposition.

His reference to Commander Taylor's results obtained with loops only three meters (9 feet) square also has no bearing since the arrangement described by Lieutenant-Commander Taylor is not a static preventer but a simple loop-receiving arrangement.

With regard to the cosine and other curves which Dr. de Forest scoffs at, it is suggested that he study them a little more closely until he discovers their significance, as his comment thereon indicates so complete a lack of understanding that reply is useless. If he so entirely fails to understand the paper he would equally fail to comprehend the reply.

His lengthy statements relative to the necessity for shielding the receiving apparatus itself from the direct effect of static are plausible but unsound. While it is a very common observation to note that considerable static and even signal is heard at a receiving station when the antenna switches are open, most of this is due to the electro-static coupling which exists between the aerial and the receiving instruments, and that part of it which is due to direct action on the receiving coils themselves proves to be so small as to be entirely negligible, provided an aerial of relatively large dimensions is used. If the dimensions of the aerial are reduced to the extreme limit, then of course the capabilities of the receiving coils become comparable to the capabilities of the antenna for picking up both signal and static, but extensive experience with this has shown that even with a loop aerial only four feet square the order of this effect is not sufficient to be serious, whereas with large aerials such as the Lakewood installation it is totally negligible. In the working of this latter system it is at times an interesting observation to note that the amount of static disturbances which is heard after a proper balance is obtained, is less than that which is heard when all three aerials are disconnected from the receiving set.

In conclusion, Dr. de Forest again intimates that there are still certain to occur periods when the only way in which we can get rid of static is to lay the telephones on the table. No such periods, with the exception of those caused by local lightning, have occurred during the prolonged use to which this apparatus has been subjected, and it therefore does not yet appear that Dr. de Forest is correct. The offer to demonstrate made in the paper still stands, and Dr. de Forest himself is not excluded.