VOLUME 6 DECEMBER, 1918 NUMBER 6

PROCEEDINGS
of
The Institute of Radio Engineers
(INCORPORATED)

TABLE OF CONTENTS

COMMITTEES AND OFFICERS OF THE INSTITUTE

INSTITUTE NOTICE

TECHNICAL PAPERS AND DISCUSSIONS

INDEX FOR VOLUME 6, 1918

EDITED BY
ALFRED N. GOLDSMITH, Ph.D.

PUBLISHED EVERY TWO MONTHS BY
THE INSTITUTE OF RADIO ENGINEERS, INC.
THE COLLEGE OF THE CITY OF NEW YORK

THE TABLE OF CONTENTS FOLLOWS ON PAGE 289

GENERAL INFORMATION

The right to reprint limited portions or abstracts of the articles, discussions, or editorial notes in the PROCEEDINGS is granted on the express condition that specific reference shall be made to the source of such material. Diagrams and photographs in the PROCEEDINGS may not be reproduced without securing permission to do so from the Institute thru the Editor.

Those desiring to present original papers before The Institute of Radio Engineers are invited to submit their manuscript to the Editor.

Manuscripts and letters bearing on the PROCEEDINGS should be sent to Alfred N. Goldsmith, Editor of Publications, The College of The City of New York, New York.

Requests for additional copies of the PROCEEDINGS and communications dealing with Institute matters in general should be addressed to the Secretary, The Institute of Radio Engineers, The College of the City of New York, New York.

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

Payment of the annual dues by a member entitles him to one copy of each number of the PROCEEDINGS issued during the period of his membership. Members may purchase, when available, copies of the PROCEEDINGS issued prior to their election at 75 cents each.

Subscriptions to the PROCEEDINGS are received from non-members at the rate of $1.00 per copy or $6.00 per year. To foreign countries the rates are $1.10 per copy or $6.60 per year. A discount of 25 per cent is allowed to libraries and booksellers. The English distributing agency is "The Electrician Printing and Publishing Company," Fleet Street, London, E. C.

Members presenting papers before the Institute are entitled to ten copies of the paper and of the discussion. Arrangements for the purchase of reprints of separate papers can be made thru the Editor.

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

THE COLLEGE OF THE CITY OF NEW YORK
NEW YORK, N. Y.

CONTENTS

Following the Index at the end of this number are the title page, page of general information, and table of contents page for the entire Volume 6 (1918) of the PROCEEDINGS. These last may be suitably placed at the beginning of the volume for binding.

OFFICERS AND BOARD OF DIRECTION, 1918

(Terms expire January 1, 1919; except as otherwise noted.)

PRESIDENT

GEORGE W. PIERCE

VICE-PRESIDENT

JOHN V. L. HOGAN

TREASURER	SECRETARY
WARREN F. HUBLEY	ALFRED N. GOLDSMITH

EDITOR OF PUBLICATIONS

ALFRED N. GOLDSMITH

MANAGERS

(Serving until January 5, 1921)

GUY HILL	MAJOR-GENERAL GEORGE O. SQUIER

(Serving until January 7, 1920)

ERNST F. W. ALEXANDERSON	JOHN STONE STONE

(Serving until January 1, 1919)

CAPTAIN EDWIN H. ARMSTRONG	GEORGE S. DAVIS
LLOYD ESPENSCHIED	LIEUT. GEORGE H. LEWIS
MICHAEL I. PUPIN	DAVID SARNOFF

WASHINGTON SECTION

EXECUTIVE COMMITTEE

CHAIRMAN	SECRETARY-TREASURER
MAJOR-GENERAL GEORGE O. SQUIER War Department, Washington, D. C.	GEORGE H. CLARK, Navy Department, Washington, D. C.

CHARLES J. PANNILL
Radio, Va.

BOSTON SECTION

CHAIRMAN	SECRETARY-TREASURER
A. E. KENNELLY, Harvard University, Cambridge, Mass.	MELVILLE EASTHAM, 11 Windsor Street, Cambridge, Mass.

SEATTLE SECTION

CHAIRMAN	SECRETARY-TREASURER
ROBERT H. MARRIOTT, 715 Fourth Street, Bremerton, Wash	PHILIP D. NAUGLE, 71 Columbia Street, Seattle, Wash.

SAN FRANCISCO SECTION

CHAIRMAN	SECRETARY-TREASURER
W. W. HANSCOM, 848 Clayton Street, San Francisco, Cal.	V. FORD GREAVES, 526 Custom House, San Francisco, Cal.

H. G. AYLSWORTH
145 New Montgomery Street
San Francisco, Cal.

PAST-PRESIDENTS

SOCIETY OF WIRELESS TELEGRAPH ENGINEERS

JOHN STONE STONE, 1907-8
LEE DE FOREST, 1909-10
FRITZ LOWENSTEIN, 1911-12

THE WIRELESS INSTITUTE

ROBERT H. MARRIOTT, 1909-10-11-12

THE INSTITUTE OF RADIO ENGINEERS

ROBERT H. MARRIOTT, 1912
GREENLEAF W. PICKARD, 1913
LOUIS W. AUSTIN, 1914
JOHN STONE STONE, 1915
ARTHUR E. KENNELLY, 1916
MICHAEL I. PUPIN, 1917

STANDING COMMITTEES

1917

COMMITTEE ON STANDARDIZATION

JOHN V. L. HOGAN, *Chairman*	Brooklyn, N. Y.
E. F. W. ALEXANDERSON	Schenectady, N. Y.
CAPTAIN EDWIN H. ARMSTRONG	New York, N. Y.
LOUIS W. AUSTIN	Washington, D. C.
A. A. CAMPBELL SWINTON	London, England
GEORGE H. CLARK	Washington, D. C.
WILLIAM DUDDELL	London, England
LEONARD FULLER	San Francisco, Cal.
ALFRED N. GOLDSMITH	New York, N. Y.
GUY HILL	Washington, D. C.
LESTER ISRAEL	Washington, D. C.
FREDERICK A. KOLSTER	Washington, D. C.
LIEUTENANT GEORGE H. LEWIS	Brooklyn, N. Y.
VALDEMAR POULSEN	Copenhagen, Denmark
GEORGE W. PIERCE	Cambridge, Mass.
JOHN STONE STONE	New York, N. Y.

Charles H. Taylor	New York, N. Y.
Roy A. Weagant	Roselle, N. J.

COMMITTEE ON PUBLICITY

David Sarnoff, *Chairman*	New York, N. Y
John V. L. Hogan	Brooklyn, N. Y.
Robert H. Marriott	Seattle, Wash.
Louis G. Pacent	New York, N. Y.
Charles J. Pannill	Radio, Va.
Robert B. Woolverton	San Francisco, Cal.

COMMITTEE ON PAPERS

Alfred N. Goldsmith, *Chairman*	New York, N. Y.
E. Leon Chaffee	Cambridge, Mass.
George H. Clark	Washington, D. C.
Melville Eastham	Cambridge, Mass.
John V. L. Hogan	Brooklyn, N. Y.
Sir Henry Norman	London, England
Wichi Torikata	Tokyo, Japan

SPECIAL COMMITTEES

COMMITTEE ON INCREASE OF MEMBERSHIP

Warren F. Hubley, *Chairman*	Newark, N. J.
J. W. B. Foley	Port Arthur, Texas
Lloyd Espenschied	New York, N. Y.
John V. L. Hogan	Brooklyn, N. Y.
David Sarnoff	New York, N. Y.

THE INSTITUTE OF RADIO ENGINEERS
announces with regret the deaths of

Walter Everett Chadbourne
and
Thomas Leo Murphy

Mr. Chadbourne was born in Waterboro, Maine, in 1882 and spent most of his early years in Dorchester, Massachusetts. He attended the Mechanic Arts High School, and later Massachusetts Institute of Technology, from which he received the degree of Bachelor of Science in Naval Architecture. Thereafter he studied electrical engineering at the Lowell Institute.

After working for a short time with the Edison Company, he entered the radio field. He worked with Mr. Fessenden of the National Electrical Signaling Company for some years at Brant Rock, and then with the Marconi Wireless Telegraph Company in New York. While with the latter company, he went to Europe to study radio stations.

In September, 1914, Mr. Chadbourne was assigned as Expert Radio Aide of the United States Navy to Charlestown Navy Yard. Apparatus of his design was used in the Naval stations. While still engaged in this work in May, 1918, Mr. Chadbourne fell ill and died. He was well known to radio workers in the United States, and was an Associate Member of The Institute of Radio Engineers.

Mr. Murphy was one of the early workers in radio in the United States Navy, and did much to further the development of radio for naval uses. He was affiliated with The Institute of Radio Engineers as an Associate Member.

While serving as a Radio Gunner in the Navy, he was seriously injured in a seaplane accident at Ravenna, Italy, on September 15, 1918. From the effects of these injuries he later died.

ON THE

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

By

Bowden Washington

(Radio Engineer, Cutting and Washington, Cambridge, Massachusetts)

Electrical Operation of Apparatus

There are two phenomena that are characteristic of the type of radio transmitter here described which, tho not essentially new, have not, to the best of my knowledge, been put into thoroly practical operation before. These two phenomena are impact excitation and the multi-spark system of procuring a tonal group.

To obtain impact excitation, two requirements must be fulfilled: a suitable gap must be found, and the radio frequency circuits designed to have appropriate constants for this form of energy transfer. We have at present three forms of gap which are practically interchangeable. The first is the aluminum-copper gap in an air-tight chamber to which alcohol is fed thru a wick and is converted into vapor by the heat of the gap. The second is a copper-copper or silver-silver gap of similar construction. In the third gap, both electrodes are of thin tungsten thoroly welded to copper backs and operating in air. These gaps all have practically identical electrical properties. There are some small differences, however, which may be noted.

The copper-aluminum gap seems to have remarkable inherent quenching properties, and will operate successfully with a primary circuit of far less desirable constants (i. e., a "stiffer" circuit), than is usually possible with impact excitation. It shows a really beautiful regularity of operation. It is, however, somewhat less efficient than the other two. The copper and tungsten gaps are practically identical in operation—the copper requires a somewhat higher voltage. The copper-

---

* Received by the Editor, February 28, 1918.

aluminum gap is generally run with an opening of 0.006 to 0.014 inches (0.15 to 0.36 mm.), while the two latter gaps operate between 0.001 and 0.003 inches (0.02 to 0.06 mm.). The operation of these gaps has been taken up before. (See "PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS," August, 1916, page 34, Volume 4, Number 4, and December, 1916, Volume 4, Number 6.)

The operation of these gaps is as follows:

The gap is connected in the usual way with a primary condenser, and the primary inductance of the coupling coil. This circuit, however, is designed to have a very low persistence. In our type 4A 0.5 kilowatt set the condenser has the value of 0.16 μf. The inductance—a single turn of heavy copper tubing—is approximately 1.2 microhenries. For maximum energy transfer, this primary circuit should have a free period of from 1.2 to 1.7 that of the secondary. The primary condenser is connected to a source of potential, either direct or alternating, having a value of from two to four hundred volts. If direct current is used, a fairly large iron core inductance should be inserted in this line. If an inductor alternator is used, the inductance of a machine is found sufficient. The condenser charges up until it has reached a potential sufficient to break down the gap; it then discharges thru the gap in a single loop or half cycle which sets the antenna in oscillation. The condenser immediately begins to charge again, and when it has reached a potential almost sufficient to break down the gap, the slight counter e.m.f. induced in the primary by the still oscillating secondary adds just sufficient increment to "trigger" the gap off in the proper phase relation to maintain smoothly the antenna oscillations. If direct current is employed, this process continues at regular intervals and as the value of the feed current is increased the gap discharges more and more frequently. The number of antenna oscillations which occur between the discharges of the gap is called by us the "inverse charge frequency."

The following oscillograms may be helpful to a clearer understanding of these phenomena. The pictures were taken with the Braun tube at an antenna frequency of 500,000 cycles per second.

Figure 1 shows the *E-I* characteristic of the gap—the current vertical, voltage horizontal. A large residual charge is shown in the primary condenser.

FIGURE 1

Figure 2 shows the gap current. In this photograph, the beam was deflected vertically by the current thru the gap and the horizontal time axis was obtained from the antenna potential.

FIGURE 2

Figure 3 shows a highly damped train of oscillations in the antenna (the antenna resistance in this case was about 40 ohms) with an inverse charge frequency of 9.

FIGURE 3

Figures 4, 5, 6, and 7 show the antenna oscillation train with an antenna resistance of 5 ohms and an inverse charge frequency of six, four, three, and two, respectively. These wave-train pictures were taken by deflecting the beam vertically with the antenna current, and horizontally with the potential of the primary condenser. The gap discharges and the wave-train starts in the antenna. The gradual rise of potential in the primary condenser gives us our time axis until the gap discharges again when the spot returns to zero and traces the pattern over again. In Figures 5, 6, and 7 the return of the spot, which takes a time interval equal to nearly a whole antenna cycle, may be seen. It should be noted that these pictures were taken with exposures of from 0.1 to 0.4 seconds, so that the pattern was repeated several thousand times, showing a remarkable regularity of functioning of the gap.

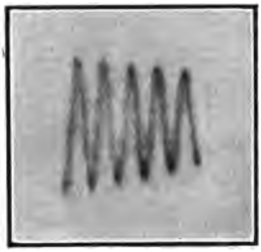


FIGURE 4

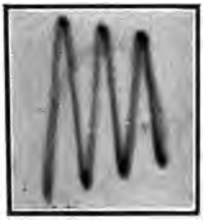


FIGURE 5

FIGURE 6

FIGURE 7

Figures 8 and 9 are of interest principally as showing what can be done with the Braun tube. Figure 8 shows the damped train of Figure 3 in polar co-ordinates. Figure 9 shows two antennas of slightly different period coupled to the same primary showing the re-transfer of energy between the two, and the production of beats.

FIGURE 8

FIGURE 9

The remaining oscillographs were taken with a special high speed Duddell oscillograph—some with direct current feed and others with a 60-cycle alternating current feed. The antenna in this case had a natural frequency of three or four thousand cycles per second.

In Figure 10, the upper curve shows the primary current and the lower curve the secondary. The inverse charge frequency is 3. The small loop on the lower side of the zero line is due to insufficient damping of the oscillograph vibrator and not to any reversal of current thru the gap. It will be easily seen that the envelope of these primary pulses in no sense approaches a logarithmic envelope, so that even without the Braun-tube oscillograms one would be reasonably sure of the uni-directional current pulse of this gap. (All the oscillograms have been retouched by tracing them carefully with white ink to enable them to be properly reproduced.)

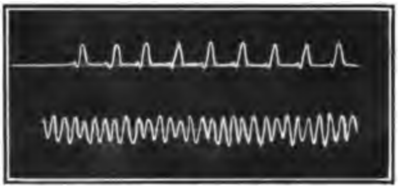


FIGURE 10

Figure 11 shows the antenna current in the upper curve and the primary current in the lower. The inverse charge frequency is one, and a practically undamped wave is emitted. This can be done quite successfully at even the shorter wave lengths. We have gotten fair "beat receiving" at a wave length of 450 meters, tho, of course, the adjustment of the receiving apparatus at this high period is extremely critical.

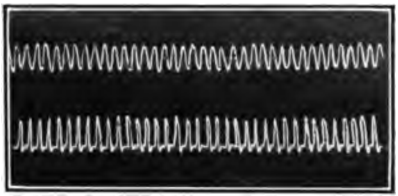


FIGURE 11

Figure 12 is taken with a 60-cycle feed current—the top curve being the primary curve, the bottom the secondary. It will be seen that the functioning of the gap is similar but the radiated energy is divided into tonal groups.

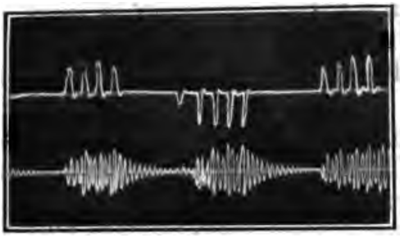


FIGURE 12

In Figure 13, the upper curve shows the primary or condenser voltage, the lower the primary current. A 60-cycle feed was employed.

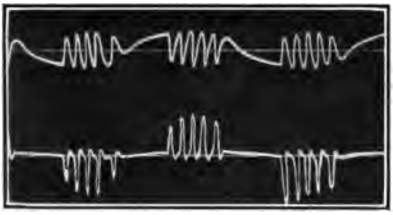


FIGURE 13

Figure 14 is a set of curves obtained partly from oscillograms and partly by calculation, and portrays, with I think fair accuracy, the operation of a 0.5 kilowatt set at a wave length of a thousand meters. The first curve shows the feed current, the peculiar shape of which will be explained later. The second curve shows the condenser voltage and will be seen to be similar to the top curve of Figure 13. The third curve shows the primary or gap current, the fourth the antenna current. It is obvious that the gap discharges at a rapidly increasing rate as the alternating feed current approaches its maximum and at a decreasing rate from maximum to zero, only to repeat this process, but with opposite polarity, during the next half cycle.

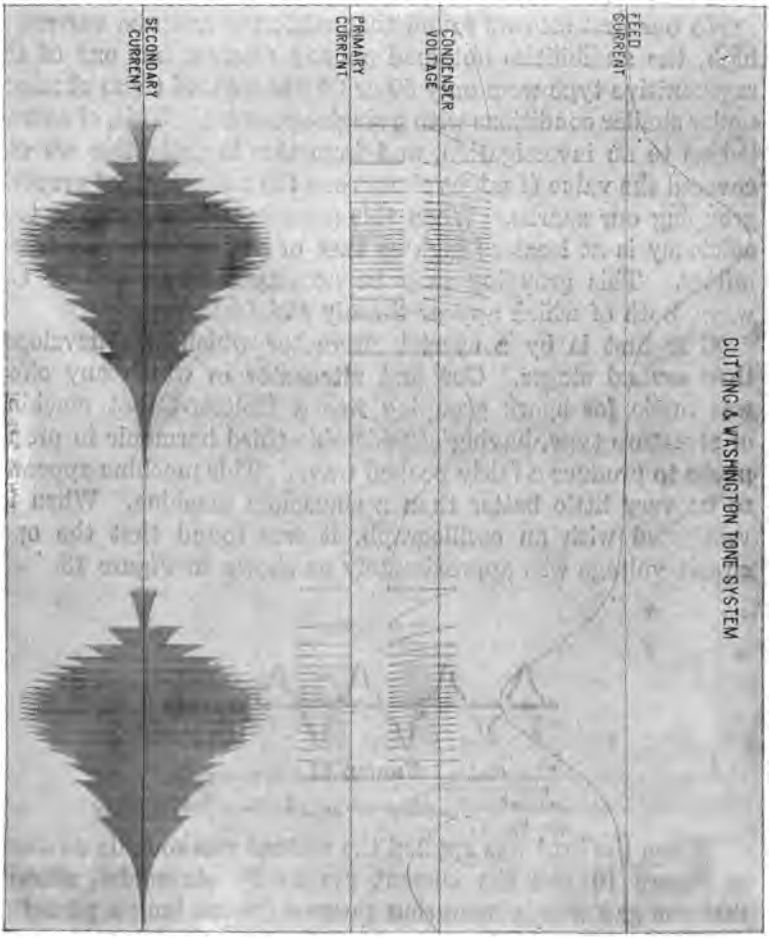


FIGURE 14

The envelope of the antenna current is a curve of substantially the same shape as the feed current.

This leads us to a consideration of the effect of this envelope, when rectified, upon the receiving telephones. It will be seen that if a sinusoidal e.m.f. is applied to the gap the results in the receiving telephones will be a wave which is approximately a rectified sine similar to that obtained by beat reception. This is a far from efficient way of exciting a telephone diafram, as there is thruout almost every moment a force applied to the diafram and it is not allowed to swing naturally thru the zero point and return; in other words, it might be said there is a large direct current component which is of no value as a sound producer.

In our first sets we found that while the antenna current is high, the audibilities obtained on any receiver but one of the regenerative type were only 50 or 60 per cent. of those obtained under similar conditions with a single-spark set. This, of course, led us to an investigation, and from this investigation we discovered the value (I might almost say the necessity), of properly grouping our sparks. When this grouping is correct, the tone efficiency is at least as high as that of any other group transmitter. This grouping may be accomplished in one or two ways, both of which appear thoroly satisfactory.

The first is by a special alternator which was developed thru several stages. Our first alternator in which any effort was made for spark grouping was a Holtzer-Cabot machine, of armature type, having considerable third harmonic in proper phase to produce a fairly peaked wave. This machine appeared to be very little better than a sinusoidal machine. When investigated with an oscillograph, it was found that the open circuit voltage was approximately as shown in Figure 15.

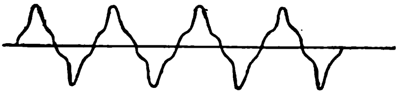


FIGURE 15

When the load was applied the voltage was roughly as shown in Figure 16 and the current practically sinusoidal, showing that the gap was in operation thruout far too long a period for good tone efficiency. Our next step was to build an inductor

FIGURE 16

alternator of the Alexanderson type, having a single concentric field coil between two stators, and an unwound rotor. The pole spacing of this machine is shown roughly in the straight line sketch of Figure 17.

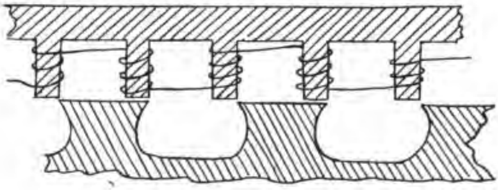


FIGURE 17

This gives a tremendously peaked no-load voltage, and both load voltage and audibility appeared to be somewhat better. A sketch of the load voltage is shown in Figure 18.

FIGURE 18

There was, however, a change of flux density thruout the whole machine due to the varying air gap, which caused exceedingly high losses in the cast iron frame-ring and in the center of the rotor. It occurred to us, as we had plenty of winding room, to intersperse poles between the wound poles purely to cut down this loss due to varying flux. It was then decided to wind these poles with a few turns (in practice about twenty-five per cent. of the turns on the main alternator poles), these turns to be in the opposite direction from those on the preceding pole, as shown in Figure 19.

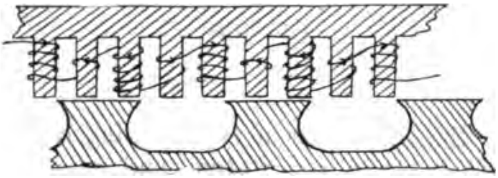


FIGURE 19

This gave a wave shape on open circuit approximately as shown in Figure 20 and a load voltage like Figure 21.

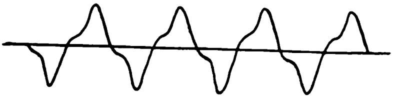


FIGURE 20

FIGURE 21

The portion of these load voltage curves shown by a ragged line occurs when the gap is in operation, as the discharges of the gap occur too rapidly, when using 500 cycles and 20 or 30 discharges per alternation, for the oscillograph vibrator to follow. This alternator is very satisfactory, for the purity of tone is absolutely independent of generator speed.

Our second method consists of placing an inductance and capacity in series across the primary condenser, the two having a period of approximately 1,500 cycles (called by us a "concentration circuit"). The operation of this circuit may be explained as follows. During the first sixty degrees of the alternating current pulse, this circuit acts almost as a short circuit on the machine and its condenser charges up. From sixty to one hundred twenty degrees, this circuit discharges into the primary condenser in conjunction with the machine. From one hundred twenty to one hundred eighty degrees, it is again a partial short circuit on the line. This circuit gives a remarkably desirable tone; and if of the right constants, it is much less critical than would be supposed. In fact, with a standard Crocker-Wheeler, 500 cycle, 0.5-kilowatt, motor-generator set containing a shunt wound motor and a properly designed concentration circuit, the direct current voltage may be varied from 85 to 135 without a "break" in the note.

Figure 22 shows a curve of secondary current of one of these sets plotted against secondary wave length. The primary wave length remained fixed and had a value of about 850 meters. It should be noted that a good value of antenna current is obtained from 490 to 675 meters without change of primary. The advantages of a transmitter of this type seem to the writer quite numerous.

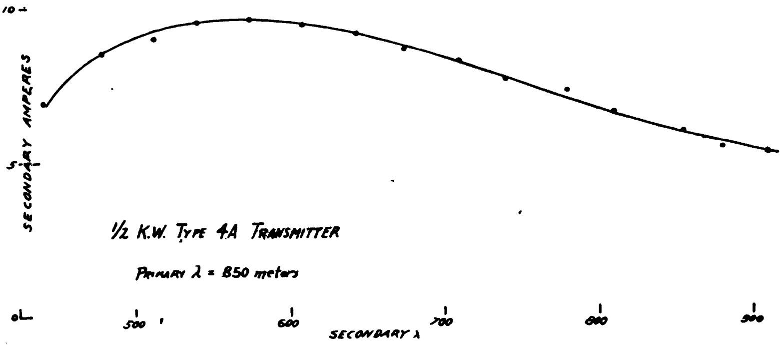


FIGURE 22

The main advantage perhaps is the almost entire lack of critical adjustment of both the audio and radio frequency circuits. Owing to the multi-spark system, a comparatively large change in the 500-cycle voltage will not affect the note with only 4 or 5 sparks more or less out of 20 or 30, and will not appreciably affect the shape of the tone envelope. With the interpole generator, there is no audio frequency resonance, and with the concentration circuit it is very broad. The note is stable thruout a large range of generator speeds. To be more specific, a properly designed cencentration circuit will give a good note anywhere between 400 and 600 cycles. If the interpole generator is used, the note will remain good thruout any range of frequency in which the generator is likely to be operated. In fact, the one limiting factor of this case is that the speed must not be lowered to such an extent that the input is of such small value as to give an insufficient number of sparks to produce a smooth tone envelope. Even in this case the note can be returned to its original purity by short-circuiting one of the two gaps usually supplied. A change of 4:1 in primary condenser and 2:1 in number of gaps does not ordinarily effect the note. As for the radio frequency adjustments, they are few. The gaps are screwed in until the electrodes are touching, and then opened about 0.002 inch (0.051 mm.). The primary inductance is fixed and the coupling is fixed. A 4:1 change is made in the primary condenser between 300 and 600 meters by the wave-shifting switch. The periods of the primary for these two wave lengths are approximately 425 and 850 meters respectively. If a third wave length is desired, such as 476 or 756, the 600 meter condenser can be so proportioned that 600 and one of these two wave lengths can be used with good efficiency in conjunction with the same primary. The only adjustment, therefore, in the radio-frequency circuit, apart from the length of gap, is the amount of inductance in the secondary or antenna circuit. As the apparatus emits one wave and that at the natural frequency of this secondary circuit, it is only necessary to tune this circuit for the desired wave lengths. With the exceedingly low voltages used—the total gap voltage on a 0.5-kilowatt set being about 900 maximum and 200 root-mean-square—the insulation can be of considerably less bulk than is usual in sets of the same power and yet the factor of safety may be much greater. The low voltage and the lack of adjustment make for a set that is compact, light, inexpensive to build, and very easy to operate.

It is the writer's opinion that the less radio apparatus is dependent upon the intelligence of the operator, the more satisfactory service it will give. Both the transmitter, and receiver, which will be described later, are designed with this point in view.

Another point of some importance is that the high rate of charging the primary condenser, which may be considered approximately 15 or 20 thousand cycles per second, reduces the losses of this piece of apparatus to a very great extent. This fact, in common with the low voltages, enables a remarkably small condenser to be used with a large factor of safety.

The space taken up by the 0.5-kilowatt set, type 4A, as shown by the detailed description which follows, is very limited, but the output appears to be about the same as that of the best quenched sets—five to nine antenna amperes being obtained, and the tone efficiency or audibility per ampere, as shown by recent exceedingly careful tests conducted by ourselves and in a preliminary test by the Marconi Company, seems to be equal to that of the quenched spark set.

MECHANICAL DESIGN OF TYPE 4A RADIO TRANSMITTER AND TYPE 8A RADIO RECEIVER

Figures 23 and 24 show the front and rear views respectively of the complete transmitter, excepting, of course, the motor-generator set, which is a standard 0.5-kilowatt Crocker-Wheeler type. The dimensions of this transmitter are 14 inches (35.6 cm.) wide, 28 inches (71.1 cm.) high and 18 inches (45.7 cm.) deep over all, including gaps. The panel is divided into two parts, which may be roughly termed audio and radio frequency panels. These panels are of one-half inch "bakelite dilecto." It may be noted in passing that all insulation, with the exception of the field rheostat, transformer paper, and condenser dielectric, is bakelite, either moulded or sheet. On the lower part of the audio frequency panel will be seen the D. C. line switch, used for starting and stopping the motor generator, the motor field rheostat, and an automatic starter of the two step current

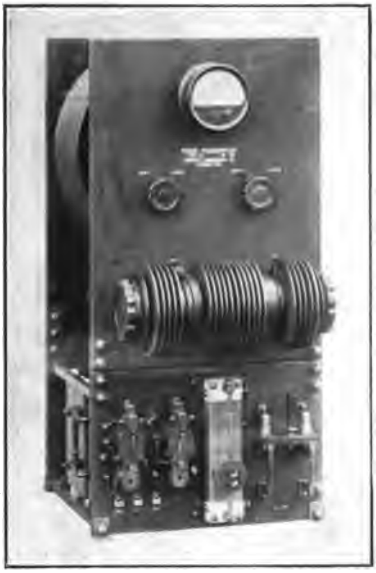


FIGURE 23

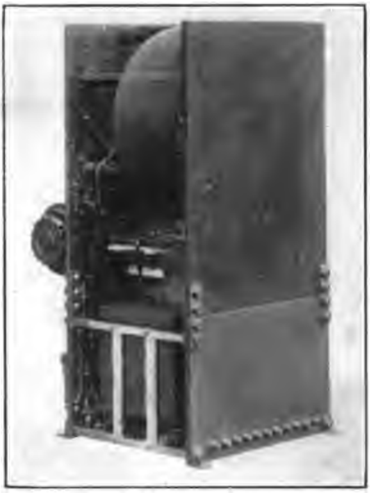


FIGURE 24

limit type. These two panels are complete mechanical units in themselves. The lower unit also contains a concentration circuit, the condenser of which is seen at the left (Figure 23), and the inductance at the left (Figure 24). A fixed resistance for the generator field, and another for the concentration circuit, is contained in this unit. At the rear of the lower unit is a terminal board.

On the upper or radio frequency unit are mounted the gaps. Suitable cooling fins are provided, and the current is led to the two movable sections by heavy multi-leaf brushes, which bear on the inside fin of this section. Locking screws are supplied in order to lock the two units in correct adjustment. On the right hand gap (Figure 23) a scale will be seen, which reads gap lengths directly in thousandths of an inch. Above the gaps are the antenna transfer switch and wave changer. The antenna transfer switch shifts the antenna from transmitter to receiver, and in the receiving position opens the generator field. The wave shifter picks off desired numbers of turns from the secondary of the coupling coil by means of flexible leads, and clips suitable inductance values for the 300 and 600 meter waves; and in the 600 meter position cuts in some additional primary condenser. These switches are mechanically identical. The radiation meter is of the hot band type, and 10 amperes are required for full scale deflection. The primary of the coupling coil is a single turn of 0.375 inch (0.95 cm.) copper tubing. The secondary consists of 30 turns of edgewise strip, 0.1875 inch (0.48 cm.) by 0.0625 inch (0.16 cm.), having a diameter of thirteen inches (33 cm.) and a total inductance of 320 microhenries, which is sufficient for antennas down to the value of 0.0003 microfarad. A good deal of work was entailed in the design of this coupling coil; the diameter and inductance were fixed upon, and strips of various cross-sections were wound with different spacing and the resistance determined with an oscillating, 3-element vacuum tube with a view to obtaining a coil of the lowest radio frequency resistance commensurate with this diameter and type.

The primary condenser is seen mounted on skids directly back of the gaps, and on the same skids is the transformer, mounted in a copper box as a shield from the high frequency field of the coupling coil. This transformer is of the closed core type with very low magnetic leakage. It has a short magnetic path and the primary and secondary are divided equally between the two legs. It is insulated to stand the full antenna voltage between primary and secondary. The weight is in the neighborhood of five pounds (2.3 kg.). Its efficiency is 92 per cent., the losses being distributed equally between the iron and copper (about 20 watts each).

The complete connections of this transmitter, with the exception that but one unit of the starter is shown, are given in Figure 25.

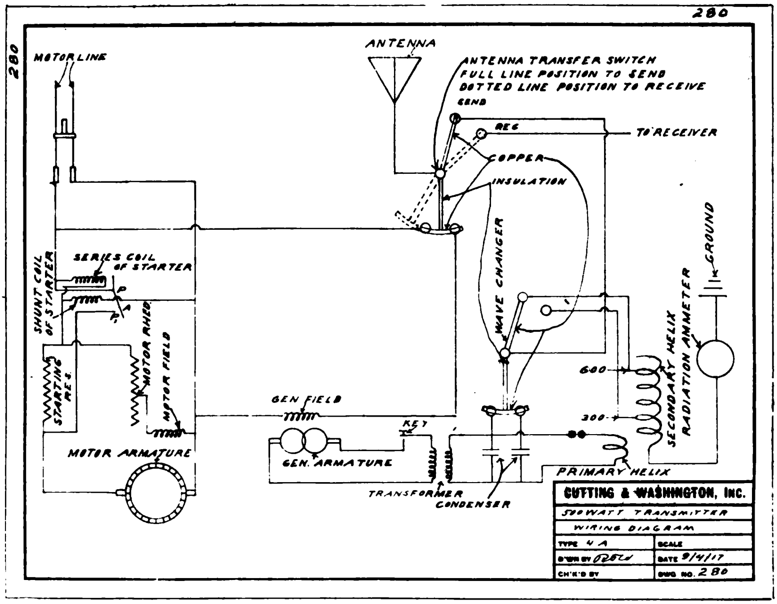


FIGURE 25

The gap handles, handle guards, gap supports, wave changer, antenna transfer switch handles, switch insulators and transformer supports are moulded. The radio frequency panel is an even one-quarter of a sheet of bakelite. The helix posts, skids and audio frequency panel are made of one-eighth of a sheet. The pointers, switch blades and connecting bars are punched. The angles supporting the helix posts and skids are identical, and these ~~bakelite~~ parts are identical, except that the helix posts have slots milled in them to take edgewise strip with a "gang miller." The gaps are made with cast aluminum flanges forced on a copper core. The thread on the movable sections is cut on a section of Shelby steel tubing, shrunk on the inside fin, and working in a cast bronze ring. The transformer supports form the bottom half of the insulated bushing thru which the transformer terminals are brought, and the supporting rods form the terminals themselves. We have confined ourselves as much as possible to similar sizes of holes in these panels, so that a panel may be drilled with the aid of a jig in a multi-spindle press with great rapidity.

The insulation factor of safety has been kept very high thruout. The primary condenser, for instance, is subjected to a maximum working voltage of 1,000 volts, is provided with a safety gap of 0.016 inch (0.4 mm.) and tested at 6,000 volts with a spark gap of 0.032 inch (0.8 mm.). On an antenna of average size, the potential from the rat-tail to the ground is sufficient to break down a 0.25 inch (0.64 cm.) needle gap, and yet the insulation is comparable with that in some of the more compact types of quenched transmitter.

One of these transmitters, of the 2-kilowatt size, has been subjected in the laboratory to forty-eight hours of continuous operation, in eight-hour shifts, and to sixteen hours in two eight hour shifts of five minutes on and five minutes off, without showing signs of deterioration. The electrodes were cleaned off once with emery paper by hand during the two tests, and the radiation was maintained practically constant thruout the entire period. The set was, of course, operated at full power. Out of some ninety sets of this type, which have been given a one-hour key-locked run, but two have shown electrical or mechanical breakdown in any part, and this was in both cases due to defects of material rather than to faulty design or construction.

Figure 26 shows a 0.5 kilowatt set of the same type, mounted in a fiber chest.

TYPE 8A RECEIVER

The type 8A commercial receiver is shown in Figure 27, and its wiring in Figure 28.

All adjustments are made with the one handle. The receiver is of the untuned secondary type and is equal in efficiency and sharpness to those commercial receivers the writer has had opportunity to test. It has the one disadvantage that no "stand-by" is provided, but the simplicity of operation is such that we feel this to be not a great disadvantage. The multipoint switch shown in the lower portion of the panel operates on the first section of the primary coil, and cuts in inductance at a gradually increasing rate. When this switch is rotated

Figure 26

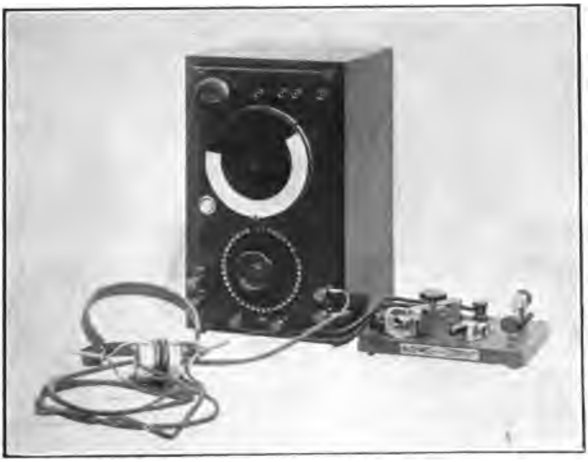


Figure 27

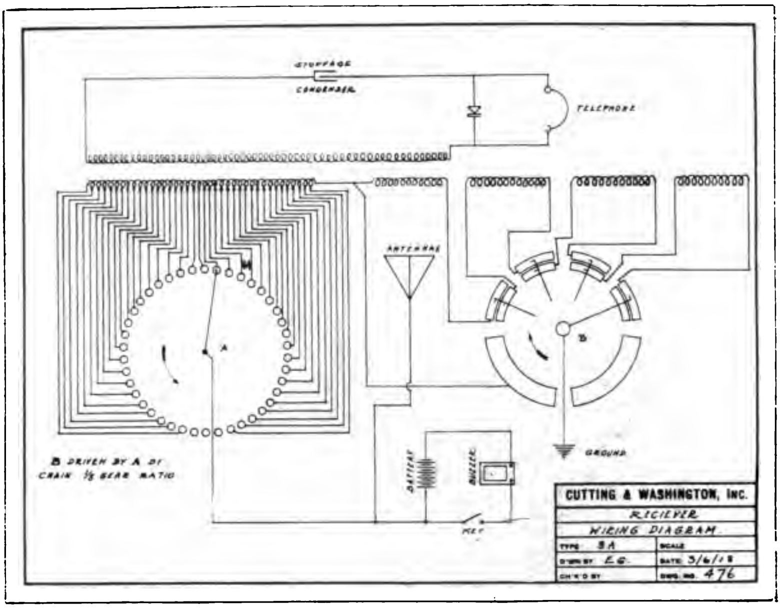


Figure 28

thru one complete revolution, the disc shown above the switch, which is connected to the switch-shaft by a light sprocket and chain and is geared down at a ratio of 8:1, cuts in the second section of the primary coil, which is equal in inductance to the whole of the first section. This process is repeated with the third section of the primary coil at the end of the third revolution of the switch handle and so on. This disc is also a dead-end switch. On the dull-silver plated scale the operator can mark in pencil the adjustment for certain wave lengths which are used frequently. The relative positions of the primary and secondary coils are fixed. The secondary coil consists of 25 turns of Number 30 B. and S. wire,* spaced 16 to the inch (6.3 to the cm.), and is a true untuned secondary, as its period is well below 100 meters which is the shortest wave length which we are equipped to measure easily. A test buzzer and silver chloride dry cells are provided in the cabinet. The detector is a combination of silicon, antimony, and galena, made by the Wireless Specialty Apparatus Company. The wave length range of the tuner on an antenna having a capacity of 0.0005 microfarad is fairly wide. On very large antennas, a small fixed series condenser is inserted in the primary circuit

---

* Diameter of number 30 wire = 0.010 inch = 0.25 mm.

The completely assembled set on shipboard is shown in Figure 29. In Figure 30, a larger set of the same type is illustrated. In this 2-kilowatt set, the panel design is again used. The increased number of gap sections is indicated.

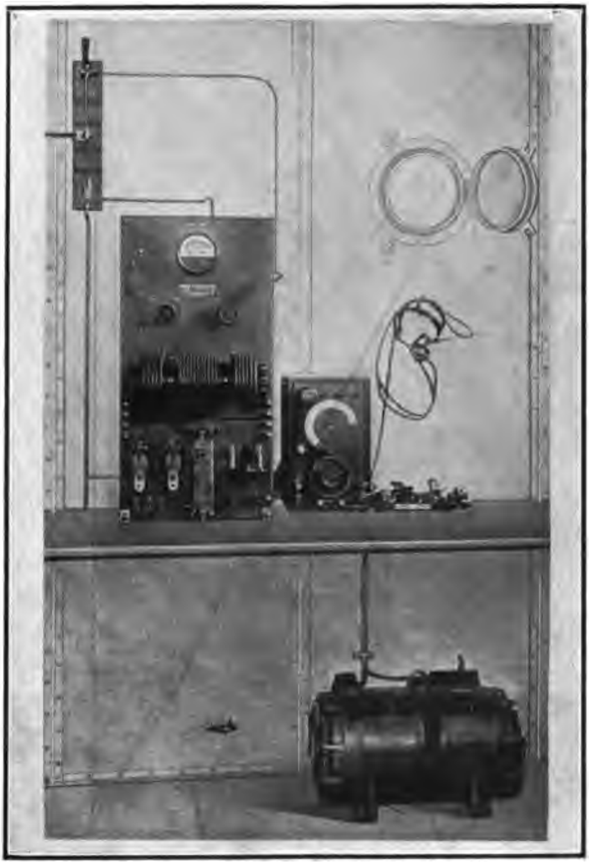


FIGURE 29

ANTENNA

As shown in erecting sketch, Figure 31, we have made an effort to standardize our antenna construction. The main insulators used are the Ohio Brass Company's compression strain type, about six inches (15.2 cm.) in diameter, one at each bridle being found sufficient. The spreaders are one and one-half inch (3.8 cm.) galvanized Shelby steel tubing, twelve feet

(3.66 m.) long, and are provided with clamps, as shown in the sketch at the lower left-hand corner of this figure. The screws which tighten these clamps on the spreader are provided with

FIGURE 30

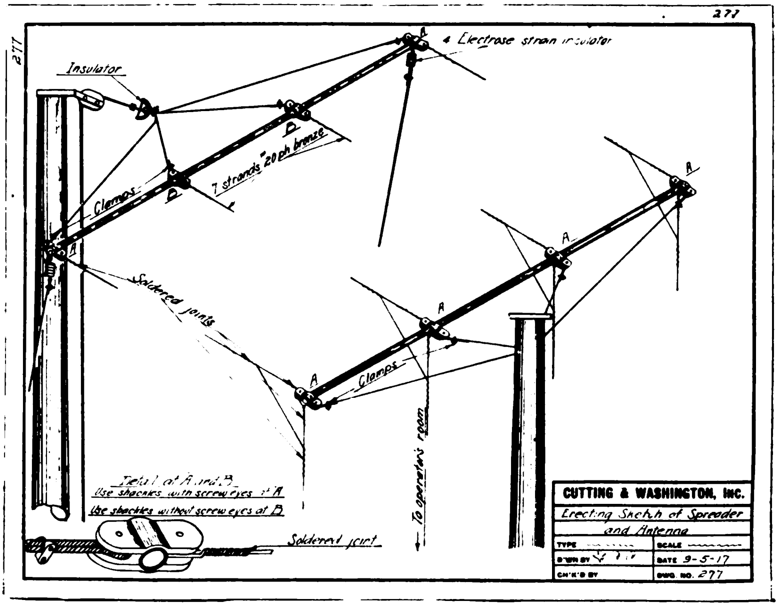


FIGURE 31

two small sheaves which give both the antenna wire, and the stranded ploughshare steel rope used for the bridle, a sufficient bending radius to reduce the chances of breakage at this point to a minimum.

SUMMARY: After a discussion of impulse excitation, three forms of gaps suitable for such extreme quenching are described. Braun tube oscillograms showing the operation of such gaps for various values of "inverse charge frequency" (number of secondary oscillations per primary discharge) are given. They show a remarkably regular gap-functioning over hundreds of thousands of cycles.

The problems of commercial construction of such sets are then considered. The necessity for using an alternator giving a special (highly non-sinusoidal) wave for feeding the gap transformer is demonstrated. The use of a modified tone or "concentration circuit" across the gap is justified on the basis of the increased receiving station audibility per ampere in the transmitting antenna.

The actual 0.5- and 2-kilowatt sets are then fully described, and the simple mode of wave changing explained. The receiver is also considered. A standardized antenna for these sets is shown.

THE VERTICAL GROUNDED ANTENNA AS A GENERALIZED BESSEL'S ANTENNA*

By

A. Press

(Consulting Engineer, New York, N. Y.)

In reality, the theory of the voltage and current distribution in a vertical grounded antenna should be based not only on the fact that the inductance and capacity are distributed; but, what is equally important, on the fact that such capacity and inductance are of variable distribution. It is this latter type of antenna that will be investigated.

In a former paper the following formula was developed giving the inductance in henrys per centimeter of a vertical grounded antenna where r was the radius of the wire and x the height of any given point from the ground, also in centimeters:

$$L = \frac{2}{10^9} \log_\epsilon \frac{\sqrt{x^2+r^2}+x}{r} \tag{1}$$

It is found that with a sufficient degree of exactness, up to 200 feet (60 m.), the above formula can be replaced by

$$L = \frac{7}{10^9} x^{0.13} \quad \text{henrys per cm.} \tag{2}$$

Evidently before one obtains a solution of the differential equations controlling the current and voltage relations in the aerial conductor, it will be necessary to obtain a formula similar to the above for the capacity per centimeter of the vertical grounded antenna as a function of the same distance x as before. The above differential equations of condition are

$$L \frac{d\,i}{d\,t} = -\frac{d\,v}{d\,x} \tag{3}$$

$$C \frac{d\,v}{d\,t} = -\frac{d\,i}{d\,x} \tag{4}$$

where L and C may be functions of x.

---

* Received by the Editor, December 27, 1917.

With wires having uniformly distributed inductance and capacity, the speed of propagation, neglecting the effect of resistance and conductance leakage, leads to the relation

$$L_o C_o = \frac{1}{V^2} \tag{5}$$

where V is the velocity of light in centimeters per second, and L_o and C_o are respectively the inductance and capacity in centimeters per centimeter. This is the same relation as obtains for free ether waves. The thought occurs to one that since the velocity of wave propagation along a straight vertical grounded antenna is practically the same quantity V, that, over the infinitesimal parts of the aerial wire, formula (5) should hold and be generalized[1] to read

$$LC = L_o C_o = \frac{1}{V^2} \tag{6}$$

which would give

$$C = \frac{1}{2 \times 9 \times 10^5 \log_\epsilon \dfrac{\sqrt{x^2+r^2}+x}{r}} \quad \mu\text{f. per cm.} \tag{7}$$

which is of the right order. Practically one may take over the same working range of 200 feet (60 m.)

$$C = \frac{1}{4.6 \times \log_{10}\left(\dfrac{4x}{d}\right) \cdot 9\,(10)^5} \quad \mu\text{f. per cm.} \tag{8}$$

The latter formula should account for a good deal of the work of of Professors Slaby and Howe.[2] If the formula (8) is compared with that obtaining for an antenna horizontally arranged with respect to the earth's surface, it will be seen that so far as vertical antennas are concerned, one can estimate antenna capacities on the assumption that the individual elements are made up of independent infinitesimal parts of horizontally disposed antennas.

The following set of expressions can therefore be said to prevail:

$$LC = \frac{1}{V^2} \tag{6}$$

---

[1] Compare Dr. Louis Cohen, "Calculation of Alternate Current Phenomena," page 108. In another place, I have indicated how for helices the equation (6) should be generalized to read $LC = L_o C_o = \frac{\mu}{V^2}$, where μ represents the equivalent magnetic loading of the medium giving an inductance axially to correspond with a straight wire having the same inductance per cm.

[2] See reference to above in Fleming's "Electric Wave Telegraphy," 1916, pages 204 and 642.

$$L = L_o x^n \tag{9}$$

$$C = \frac{C_o}{x^n} \tag{10}$$

$$LC = L_o C_o \tag{11}$$

Conditions (9) and (10) lead to the solution of a Bessel's antenna in precisely the same manner as Heaviside[3] has treated the corresponding Bessel's cable.

To arrive at the resultant characteristic from equations (3) and (4), following the symbolical methods of Heaviside let

$$t_1 = \frac{d}{dt}$$

$$x_1 = \frac{d}{dx}$$

then equations (3) and (4) can be written

$$L t_1 i = -x_1 v \tag{12}$$

$$C t_1 v = -x_1 i \tag{13}$$

and by non-commutative algebraic processes, so far as the coefficients L and C alone are concerned, one obtains by solving for v and i in succession

$$L t_1 i = x_1 \frac{1}{C t_1} x_1 i$$

which, interpreted back again, gives:

$$\frac{d^2 i}{d t^2} = \frac{1}{L} \frac{d}{dx} \cdot \frac{1}{C} \frac{d}{dx} \cdot i \tag{14}$$

$$C t_1 v = x_1 \frac{1}{L t_1} x_1 v$$

$$\frac{d^2 v}{d t^2} = \frac{1}{C} \frac{d}{dx} \cdot \frac{1}{L} \frac{d}{dx} \cdot v \tag{15}$$

It is the equations (14) and (15) that can be thrown into the usual Bessel's form with constant coefficients L_o, C_o by means of the relations (9) and (10) mentioned above and in consequence

$$\frac{d^2 i}{d x^2} + \frac{n}{x} \cdot \frac{di}{dx} = L_o C_o \frac{d^2 i}{d t^2} = q^2 i \tag{16}$$

$$\frac{d^2 v}{d x^2} - \frac{n}{x} \cdot \frac{dv}{dx} = L_o C_o \frac{d^2 v}{d t^2} = q^2 v \tag{17}$$

with the understanding that the operation $L_o C_o \frac{d^2}{d t^2}$ has been

---

[3] Compare Heaviside, "Electromagnetic Theory," Volume II, page 239.

symbolized by q^2. These latter equations are to be solved in order to determine the true current and voltage relations which enable stationary waves to be set up in straight vertical grounded antennas with variably spaced nodes and antinodes.

The general solution of (16) is[4]

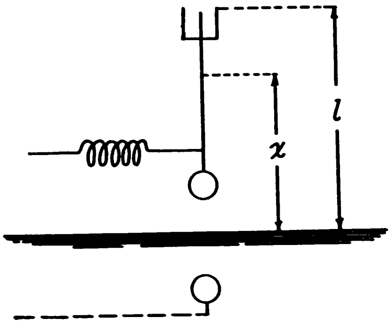
$$i=\frac{I_m(qx)}{x^m}A+\frac{I_{-m}(qx)}{x^m}\cdot B \tag{18}$$

given that $m=\dfrac{n-1}{2}$ and where

$$\frac{I_m(qx)}{x^m}=\frac{\left(\frac{q}{2}\right)^m}{0!\,m!}+\frac{\left(\frac{q}{2}\right)^{m+2}x^2}{1!\,(m+1)!}+\frac{\left(\frac{q}{2}\right)^{m+4}x^4}{2!\,(m+2)!}+\cdots \tag{19}$$

$$\frac{I_{-m}(qx)}{x^m}=\frac{\left(\frac{q}{2}\right)^{-m}x^{-2m}}{0!\,(-m)!}+\frac{\left(\frac{q}{2}\right)^{-m+2}x^{-2m+2}}{1!\,(-m+1)!}+\frac{\left(\frac{q}{2}\right)^{-m+4}x^{-2m+4}}{2!\,(-m+2)!}+\cdots \tag{20}$$

In the case at hand $n=0.13$, whence $m=\dfrac{0.13-1}{2}=-0.435$, showing that m is negative and therefore the indices of the x's in $\dfrac{I_{-m}(qx)}{x^m}$ are all plus.



To satisfy the simplest boundary conditions, by way of example, one may take

$$i=I \text{ when } x=0 \tag{21}$$

$$i=0 \text{ when } x=l, \text{ the antenna height} \tag{22}$$

---

[4] See Heaviside, previous citation, page 244 and page 240.

Thus for the first boundary condition when

$$x=0, \quad \frac{I_{-m}(qx)}{x^m}=0,$$

and therefore, by (18),

$$I=\frac{\left(\frac{q}{2}\right)^m}{0!\,m!}A$$

$$A=\frac{0!\,m!}{\left(\frac{q}{2}\right)^m}I \tag{23}$$

Again, for $x=l$,

$$0=\frac{I_m(ql)}{l^m}A+\frac{I_{-m}(ql)}{l^m}B$$

$$B=-\frac{I_m(ql)}{I_{-m}(ql)}A \tag{24}$$

and therefore, for the above set of boundary conditions, the complete solution is

$$i=\frac{0!\,m!}{\left(\frac{q}{2}\right)^m}\left\{\frac{I_m(qx)}{x^m}-\frac{I_m(ql)}{I_{-m}(ql)}\cdot\frac{I_{-m}(qx)}{x^m}\right\}\cdot I \tag{25}$$

and I is the impressed current function of the time for $x=0$. The current function I is that produced directly by the exciting or oscillation circuit, and therefore dependent on the constants in that circuit. On the other hand, the voltage distribution in the antenna is obtainable thru the fundamental equation:

$$C\frac{dv}{dt}=-\frac{di}{dx} \tag{4}$$

and thus one may obtain a relation between the current at $x=0$ and the maximum antenna voltage at $x=l$, that is, at the top of the antenna. Another way would be to assume a definite impressed voltage function where the lead of the primary circuit attaches to the antenna.

Substituting (25) in (4), there obtains[5]

$$C\frac{dv}{dt}=\frac{0!\,m!}{\left(\frac{q}{2}\right)^m}\left\{\frac{I_m(ql)}{I_{-m}(ql)}\cdot\frac{I_{-(m+1)}(qx)}{x^m}-\frac{I_{m+1}(qx)}{x^m}\right\}\cdot I \tag{26}$$

---

[5] By formula (27) in Heaviside, previous citation, page 245.

and therefore since

$$q^2=LC\frac{d^2}{dt^2}$$

$$\frac{d}{dt}=\frac{q}{\sqrt{LC}}=Vq \qquad (27)$$

whence

$$I=\frac{CVq\left(\frac{q}{2}\right)^m}{0!\,m!}\left\{\frac{x^m I_{-m}(ql)}{I_m(ql)\,.\,I_{-(m+1)}(ql)-I_{-m}(ql)\,.\,I_{m+1}(qx)}\right\}v \qquad (28)$$

If then we write v_l for the maximum voltage at $x=l$ and C_l for the capacity per centimeter at $x=l$ the relationship between the maximum voltage and the maximum current is as follows

$$I=\frac{C_l Vq\left(\frac{q}{2}\right)^m}{0!\,m!}\left\{\frac{l^m I_{-m}(ql)}{I_m(ql)\,.\,I_{-(m+1)}(ql)-I_{-m}(ql)\,.\,I_{m+1}(ql)}\right\}v_l$$

$$I=\frac{C_l Vq\left(\frac{ql}{2}\right)^{m+1}}{0!\,m!}\left\{\frac{-\pi}{2\,sin\,m\,\pi}\right\}I_{-m}(ql)\,v_l \qquad (29)$$

For steady impressed sinusoids the function $I_{-m}(ql)$ becomes a real Bessel's of oscillating character and then, because q is imaginary, one may use the formula[6]

$$i^{2m}=(cos+j\,sin)\,m\,\pi$$

This would indicate that for Poulsen circuits, the maximum current amplitude is in general always out of time phase with the maximum voltage.[7]

SUMMARY: By taking account of the variable distribution of inductance and capacity along a vertical grounded antenna, the general expression for the current at any point of the antenna is obtained.

For the case of an antenna having zero current at the top and maximum current at the (unloaded) bottom, the particular solution for current and voltage distribution is obtained.

---

[6] Heaviside, previous citation, page 245.

[7] Heaviside, previous citation, page 253.

ON THE POSSIBILITY OF TONE PRODUCTION BY ROTARY AND STATIONARY SPARK GAPS*

By

HIDETSUGU YAGI

(PROFESSOR OF ELECTRICAL ENGINEERING, TOHOKU IMPERIAL UNIVERSITY, SENDAI, JAPAN.)

INTRODUCTION

In a previous paper on resonance transformers,[1] the author has shown that the tone phenomena are possible only for certain values of discharge voltage, and he has considered how the possible range varies with the ratio of the natural frequency β of the circuit to the forced frequency ω of the source.

A remarkable result was obtained, namely, that with a stationary spark gap, the possibility range vanishes at absolute resonance, $\beta = \omega$, if the damping of the circuit is negligibly small.

The possibility range will naturally be quite different when a rotary spark gap is employed.

An admirable paper has been published by Lieutenant L. Bouthillon[2] on the combined system of a high voltage, direct current generator and a rotary spark gap. So the author finds it hardly necessary to go into the details of the fundamental principles of tone production both for the alternating current resonance transformer method and for the high tension direct current method.

In what follows, an attempt is made to determine the possibility range of the regular discharge, or the tone phenomenon, in the two systems above mentioned when equipped with a rotary or a stationary spark gap. Part I deals with the discharge characteristic of a rotary gap, and enables the drawing of conclusions concerning the stationary gap since this is but one particular case of the rotary gap. In Part II, the possibility ranges are considered for the resonance transformer method

---

* Received by the Editor, September 20, 1917.

[1] H. Yagi, PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, Volume 5, Number 6, December, 1917.

[2] L. Bouthillon, PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, June, Volume 5, Number 3, 1917.

with both kinds of spark gap; and in Part III, the same is done for the high tension, direct current method.

PART I. CHARACTERISTICS OF A ROTARY SPARK GAP

Whatever the shape of the rotary gap, the variation of the gap length with time may be deduced from the following simple formulas.

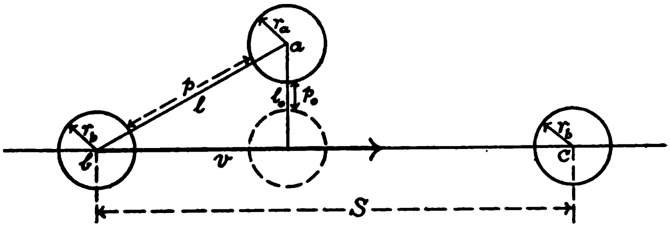


FIGURE 1

Suppose that the point a is fixed and b moves along a straight line $b\ c$ with a constant velocity v. Other points c, d, and so on, similar to b, move in unison with b and with a constant distance S between them.

If b, c, d, and so on, form one electrode and a the other, then the gap length between two poles varies periodically. Let t_o be the time at the moment when b lies at the minimum distance l_o from a, and t the time at any other position distant l from a. Then

$$l^2 = l_o^2 + v^2\,(t_o - t)^2$$

This is an hyperbola like A in Figure 2, the asymptote of which has an inclination v to the horizontal axis.

When a, b, c, and so on, are mere points, or the gap is a needle gap, l denotes the gap length itself. In actual gaps, however, the electrodes are not points but have various shapes which may for convenience be taken to be spheres. Assuming their radii to be r_a and r_b respectively, the true gap length p is

$$p = l - r_a - r_b$$

and the minimum gap length is given by

$$p_o = l_o - r_a - r_b.$$

Or,
$$(p + r_a + r_b)^2 = l_o^2 + v^2\,(t_o - t)^2 \qquad (1)$$

Now r_a, r_b, l_o, v, and t_o are all constants, and p as a function of t traces an hyperbola with its center C displaced r_a+r_b from the t axis. (B in Figure 2.)

The period T is given by

$$T=\frac{S}{v}.$$

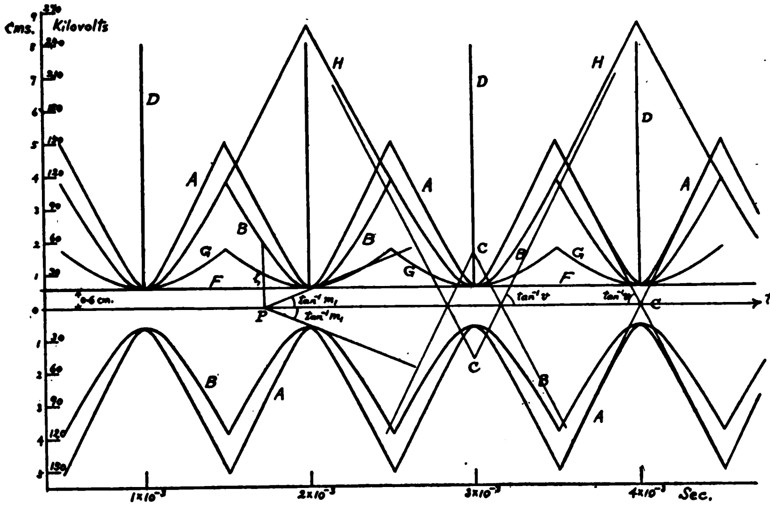


FIGURE 2—Characteristics of Rotary Spark Gaps

T is determined by the proposed spark frequency and then S is proportional to v. As v is proportional to the diameter of the wheel, or the diameter of the path of b, the number of knobs (or studs) around the circumference for this condition is independent of the diameter when the number of revolutions per minute of the wheel is constant.

With increasing v, the hyperbola becomes more and more peaked and the characteristic feature of a rotary gap becomes more manifest. It has usually been supposed that a rotary gap is an arrangement which enables the discharge to take place with ideal exactness at intervals independent of the terminal potential at the moment. However, from the consideration of the mechanical stress due to centrifugal force, there is a practical limit to the peripheral speed v, and the rotary gap can never be so ideal an arrangement as is usually supposed. For an ideal gap, the characteristic curve must coincide with the straight lines D in Figure 2.

The most efficient way of improving the discharge characteristic is to divide the gap into many series gaps, each one being a rotary gap of the highest permissible speed.

When $v=0$, as a particular case, S must also be zero, and the gap is nothing but a stationary gap. (F in Figure 2.)

In Figure 2, A and B represent the discharge characteristics for $r_a=r_b=0$, or $l_o=0.6$ cm. (needle gap) and for $r_a=r_b=0.8$ cm., or $l_o=2.2$ cm. (spherical gap) respectively. For both of them

$v=10^4$ cm. per sec. (100 m. per sec. or 330 feet per sec.)
$p_o=0.6$ cm.
$T=0.001$ sec.
$S=T\,v=10$ cm. (4 inches).

G is the curve of the spherical gap for $v=5\times 10^3$ cm. per sec. (50 m. per sec. or 165 feet per sec.) or $S=5$ cm. (2 inches). H is drawn for $T=0.002$ sec. and $v=10^4$ cm. per sec.

The relation between the air gap length and the disruptive voltage is not truly linear, but they may practically be assumed to be proportional to each other, and Figure 2 may at the same time be taken as a diagram representing the relation between the sparking voltage and the time.

In cases of alternating current operation, in which alternate discharges may take place, the image of the characteristic curves must be drawn below the horizontal axis as in Figure 2. Whenever the terminal voltage passes beyond these upper and lower limiting curves, there will be a spark discharge across the gap.

It is plain from these examples that even at the high speed of 100 meters per second (330 feet per second), with 10 cm. (4 inches) distance between consecutive knobs, the rotary gap is not an arrangement which causes the discharge to occur as sharply as presupposed.

PART II. POSSIBILITY RANGE OF TONE PHENOMENA WITH THE RESONANCE TRANSFORMER METHOD

The performance of a spark gap is not to be defined by the magnitude of current thru it, but is determined simply by its disruptive voltage; and consequently the explanation of its operation should be more suitably developed from voltage considerations. It is true that the introduction of current terms in the equations makes the forms of some expressions simpler; nevertheless, a method of solution that might be called a "current method" is no more convenient than the "potential method" used by the author to deduce directly the most important relations.

Let us restrict the subject as hitherto[3] to the two sorts of regular discharge, namely:

Alternate discharge—one discharge per half cycle;

Unidirectional discharge—one discharge per cycle.

The terminal voltage e_2 of the condenser is given by the following expression for alternate discharge:

$$\left\{\begin{aligned}
&e_2 = E_c \sin(\omega t + \phi) - K E_o \varepsilon^{-\alpha t} \cos\left(\beta t - \theta - \tan^{-1}\frac{\alpha}{\beta}\right) && (2)\\
&K = \frac{1}{\sqrt{1 + 2\left(\varepsilon^{-\alpha\frac{\pi}{\omega}}\right)\cos\beta\frac{\pi}{\omega} + \left(\varepsilon^{-\alpha\frac{\pi}{\omega}}\right)^2}} && (3)\\
&\tan\theta = \frac{\varepsilon^{-\alpha\frac{\pi}{\omega}}\sin\beta\frac{\pi}{\omega}}{1 + \varepsilon^{-\alpha\frac{\pi}{\omega}}\cos\beta\frac{\pi}{\omega}} && (4)
\end{aligned}\right.$$

and for unidirectional discharge:

$$\left\{\begin{aligned}
&e_2 = E_c \sin(\omega t + \phi) - K E_o \varepsilon^{-\alpha t} \cos\left(\beta t + \theta - \tan^{-1}\frac{\alpha}{\beta}\right) && (5)\\
&K = \frac{1}{\sqrt{1 - 2\left(\varepsilon^{-\alpha\frac{2\pi}{\omega}}\right)\cos\beta\frac{2\pi}{\omega} + \left(\varepsilon^{-\alpha\frac{2\pi}{\omega}}\right)^2}} && (6)\\
&\tan\theta = \frac{\varepsilon^{-\alpha\frac{2\pi}{\omega}}\sin\beta\frac{2\pi}{\omega}}{1 - \varepsilon^{-\alpha\frac{2\pi}{\omega}}\cos\beta\frac{2\pi}{\omega}} && (7)
\end{aligned}\right.$$

where t is measured from the instant of a discharge.

When α is negligibly small in comparison with β, we have

$$\left(\frac{d e_2}{d t}\right)_{t=0} = \left(\frac{d e_2}{d t}\right)_{t=T}$$

This corresponds to the assumption in the current method that the current i_o at discharge must remain constant during the momentary short circuit. It will later be seen that $\left(\frac{d e_2}{d t}\right)_o$ is an important term in deciding the possibility of tone phenomena from the characteristic of the spark gap.

---

[3] H. Yagi. Previous citation.

Another initial condition is

$$e_2 = 0 \text{ at } t = 0,$$

or

$$\sin\phi = \frac{E_o}{E_c} K \cos\theta \qquad (8)$$

K and θ are constants for a given $\frac{\beta}{\omega}$,and when E_c is held constant, there is a value of $\sin\phi$ corresponding to each E_o. As $\frac{1}{K\cos\theta}$ is never greater than 2, E_o can never be larger than $2E_c$[4].

In actual rotary gaps, tho not in ideal ones, in order to have discharges at a definite E_o, the wheel must be rotated in such phase relation that the gap length becomes that corresponding to E_o at the proper instants.

From equation (1),

$$E_o = qp = q\sqrt{l_o^2 + v^2 (t_o - t)^2} - q(r_a + r_b) \qquad (9)$$

where q is the disruptive strength per cm. or nearly 30,000 volts per cm. (75,000 volts per inch) in the air.

If t is measured from the instant of a discharge, then t_o is the time interval between the discharge and the time corresponding to the minimum length of the rotary gap. Putting $\psi = \omega t_o$, we know that there is a definite t_o or ψ corresponding to the given E_o.

Now the time interval between the discharge and the zero of the fundamental sine wave, $E_c \sin(\omega t + \phi)$, is $\frac{\phi}{\omega}$, and therefore the time interval between this zero condition and the minimum length of gap condition is

$$\frac{\phi + \psi}{\omega}$$

where

$$\phi = \sin^{-1}\frac{E_o}{E_c} K \cos\theta$$

and

$$\psi = \frac{\omega}{v}\sqrt{\left[\frac{E_o}{q} + (r_a + r_b)\right]^2 - l_o^2} \qquad (10)$$

Hence the phase difference between the alternator position[5]

---

[4] In Lieutenant Bouthillon's paper, the coefficient in his equation (19) and the value in Figure 8 correspond to what is denoted by $\frac{1}{K\cos\theta}$ in the present paper.

[5] The phase difference between $E_c \sin(\omega t + \phi)$ and the alternator E.M.F. is determined by the circuit constants.

and the position of the rotary gap must be adjusted to accord with E_o. ψ and ϕ are plotted in Figure 3 as the functions of E_o. It may be recognized therefrom that $\frac{\psi+\phi}{\omega}$ is nearly proportional to E_o within a certain intermediate region of E_o when the discharge takes place at $o < \phi < \frac{\pi}{2}$, whereas $\frac{\psi+\phi}{\omega}$ is nearly constant (equal to T) when $\frac{\pi}{2} < \phi < \pi$.

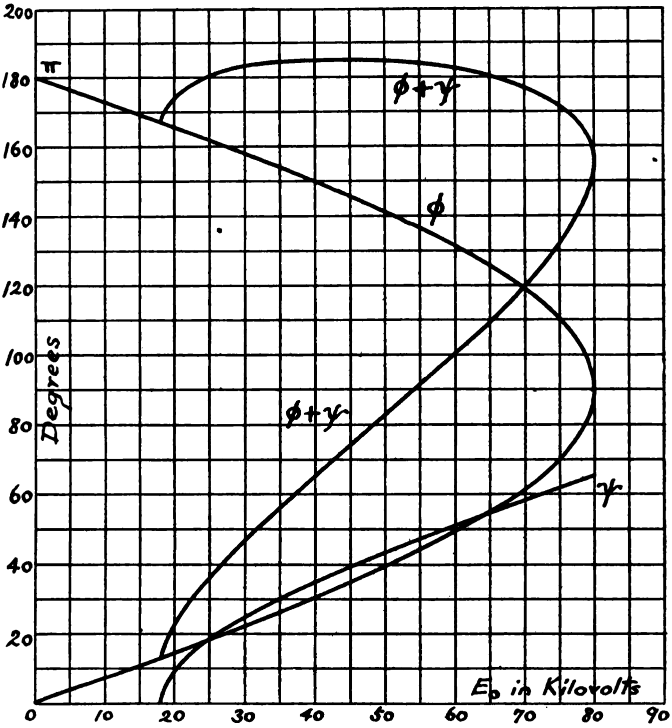


FIGURE 3

POSSIBLE RANGE

From (2) and (5) we have

$$\left(\frac{d\,e_2}{d\,t}\right)_o = \omega E_c \cos\phi \mp \sqrt{\alpha^2+\beta^2}\, K E_o \sin\theta,$$

or, substituting in (8),

$$\left(\frac{d\,e_2}{d\,t}\right)_o = \omega\sqrt{E_c{}^2 - E_o{}^2\ K^2 \cos^2\theta} \mp \beta\, K E_o \sin\theta, \qquad (11)$$

taking the $-$ sign for alternate discharge and the $+$ sign for unidirectional discharge.

When the circuit constants are all given and E_c and ω are fixed, there will be a definite $\left(\frac{d e_2}{d t}\right)_o$ corresponding to E_o, and when E_o is varied from zero to $2E_c$, $\left(\frac{d e_2}{d t}\right)_o$ varies also according to the equation (11). (See Figures 5 and 6.)

Whether this $\left(\frac{d e_2}{d t}\right)_o$ is permissible or not will be determined by the characteristic of the spark gap.

As we have too many variable quantities, it is not easy to determine very accurately the boundary of the possibility region of tone phenomena. In the following, conventional methods, tho not strictly exact, are resorted to; thus enabling us to solve the problem very simply.

ROTARY GAP

The permissible range of $\left(\frac{d e_2}{d t}\right)_o$ is limited by the following relations:—

(1) Suppose a discharge to take place at P (Figure 2). The condenser potential e_2 becomes instantly zero and then rises from zero, whereby the curve of e_2 against t must not cut the characteristic curve before the next regular discharge. The limit is reached when these two curves touch each other. One of the curves is an hyperbola and the other a sine curve, so that the solution is not quite simple. It is assumed that the upper and the lower limits of $\left(\frac{d e_2}{d t}\right)_o$ are given by the inclination of the tangents (straight lines) drawn to the hyperbolas thru the point P.

If P is the point corresponding to the gap length l_1, the inclination m_1 which the tangent to the hyperbola makes with the horizontal axis is given by

$$m_1 = \frac{v}{l_1^2} \left\{ (r_a + r_b) \sqrt{l_1^2 - l_o^2} \pm l_o \sqrt{l_1^2 - (r_a + r_b)^2} \right\} \qquad (12)$$

This value of m_1 is graphically represented in Figure 4 as a function of E_o, E_o being equal to $q\,p_1$, or $= q\,(l_1 - r_a - r_b)$.

The curves above the horizontal axis are for $r_a + r_b = 0$, 0.8, 1.6, and 2.4 cms. (0, 0.3, 0.6, and 0.9 inch). Below the axis are drawn only two of them, i. e., $r_a + r_b = 0$ and $= 1.6$ cm. (0.6 inch).

These curves show that the possible range is more restricted for larger electrodes (r_a+r_b), when the minimum gap length is to be constant. If v is made smaller, the relative proportion is unaltered but all the limits as a whole are lowered in proportion to v.

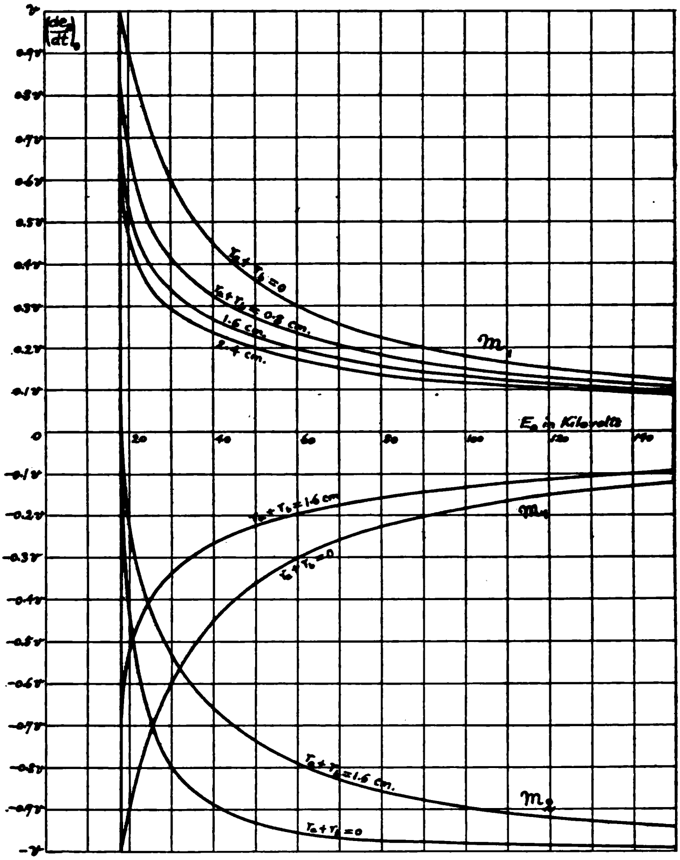
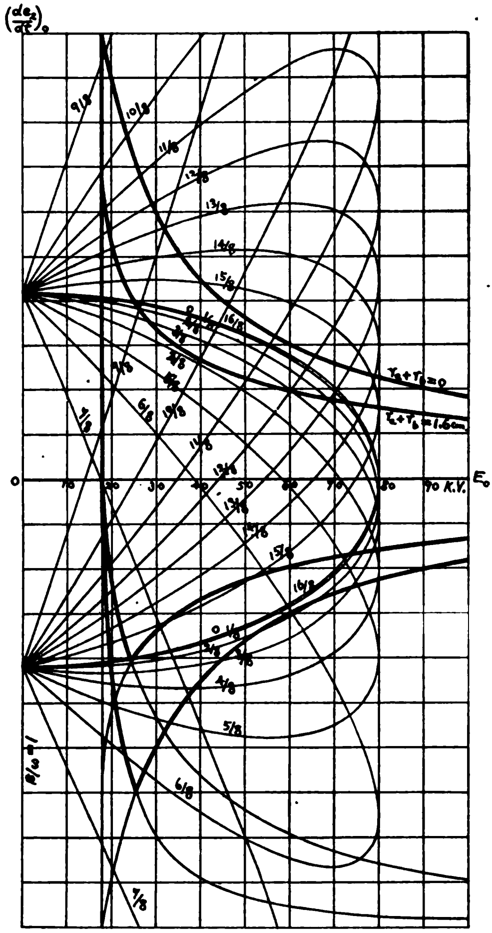


FIGURE 4—A. C. Method

(2) $\left(\frac{d\,e_2}{d\,t}\right)_o$, which is always positive in stationary gaps may be negative in the case of rotary gaps, and its negative limit is given by the condition that $\left(\frac{d\,e_2}{d\,t}\right)_T$ coincides with the inclination of the tangent to the hyperbola at the moment of

discharge. This inclination m_2 is given by

$$m_2 = v\sqrt{1-\left(\frac{l_o}{l_1}\right)^2} \qquad (13)$$



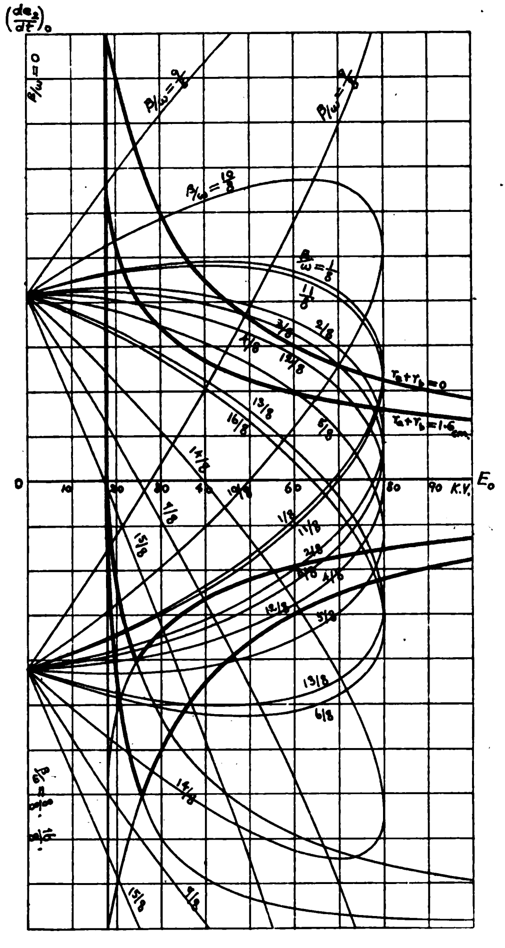
$E_c = 40000^V \qquad \omega = 1000\pi$

FIGURE 5—Alternate Discharge

The m_2 curves in Figure 4 are plotted for $r_a + r_b = 0$ and $= 1.6$ cm. (0.6 inch). The large part of these m_2 curves lie beyond the first limit m_1.

The same limits m_1 and m_2 apply also for unidirectional discharges, provided that the stud number is halved and the wheel rotated at the same speed as before.

On the other hand, the curves of $\left(\frac{d e_2}{d t}\right)_0$ corresponding to E_0 are computed by equation (11) for various β's on both sides of absolute resonance, assuming $\omega = 1000\pi$ and $E_c = 40{,}000$ volts.



$E_c = 40000^V$ $\omega = 1000\pi$

FIGURE 6—Unidirectional Discharge

These are plotted in Figure 5 and Figure 6.

In computing the values of K, $\sin\theta$, and $\cos\theta$, e^{-aT} has always been taken equal to 1, so that $K\cos\theta = \frac{1}{2}$, and the first term of (11) is independent of β (which is not rigorously true).

Now if $\left(\frac{de_2}{dt}\right)_0$ thus determined is without the possible limits m_1 and m_2, the presupposed sorts of regular discharge will be impossible.

For two kinds of gaps, namely $r_a+r_b=0$ (needle gap) and $r_a+r_b=1.6$cm. (0.6 inch) (spherical gap), the range of E_o has been determined from Figure 5 and Figure 6, which makes the tone phenomena possible.

In Figures 7, 8, 9, and 10, two classes of possible areas are distinguished by their hatchings, one corresponding to discharges at $0<\phi<\frac{\pi}{2}$ and the other to $\frac{\pi}{2}<\phi<\pi$. That is, they differ according as the discharge takes place on one or the other side of the maximum of the fundamental sine wave, $E_c \sin(\omega t+\phi)$.

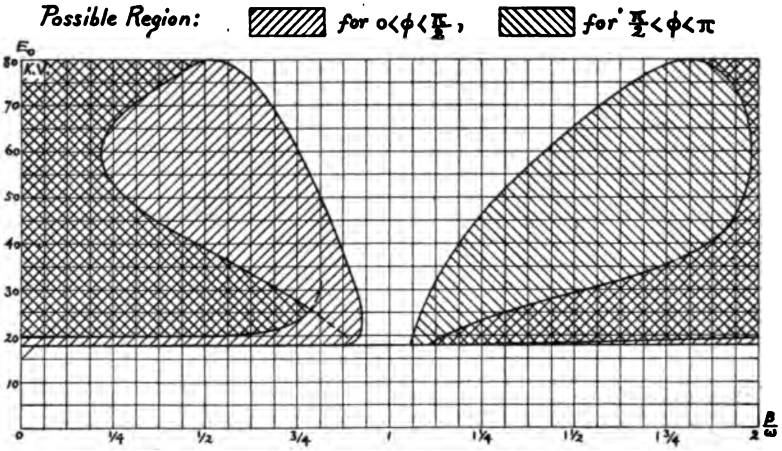


FIGURE 7—Alternate Discharge—Rotary Ideal (Needle) Gap

As seen from these figures, the possibility range is more restricted in actual rotary gaps with spherical electrodes. At $\beta<\omega$, the possible area is much larger for $0<\phi<\frac{\pi}{2}$ and at $\beta<\omega$, for $\frac{\pi}{2}<\phi<\pi$.

STATIONARY GAP

The limiting condition is somewhat different in stationary gap operation; and there is only one condition, namely,

$$\left(\frac{d\,e_2}{d\,t}\right)_0 \geqq 0$$

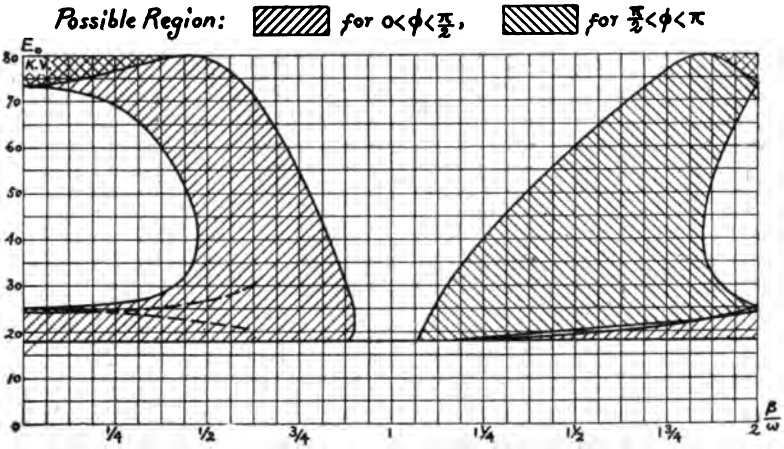


FIGURE 8—Alternate Discharge—Rotary Spherical Gap($r_a = r_b = 0.8$ cm.)

The possible ranges of E_0 corresponding to $\frac{\beta}{\omega}$ are shown in Figures 11 and 12. These curves, representing the limit

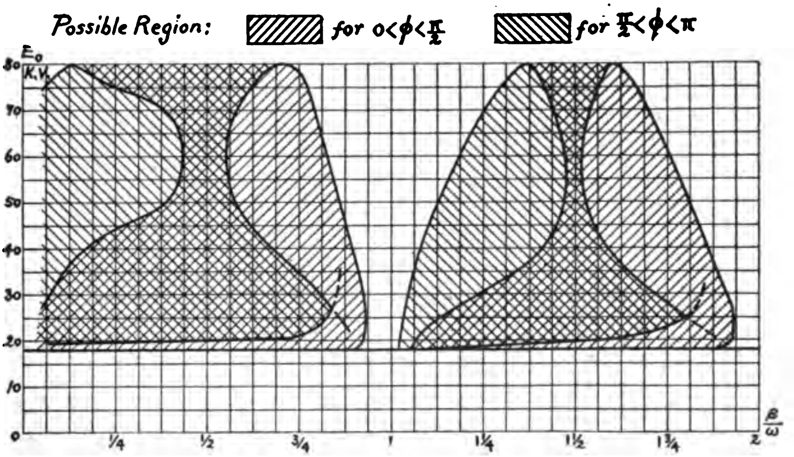


FIGURE 9—Unidirectional Discharge—Rotary Ideal (Needle) Gap

$\left(\frac{de_2}{dt}\right)_0 = 0$, have been determined from Figures 5 and 6, and coincide exactly with the curves obtained by the author in his previous paper.

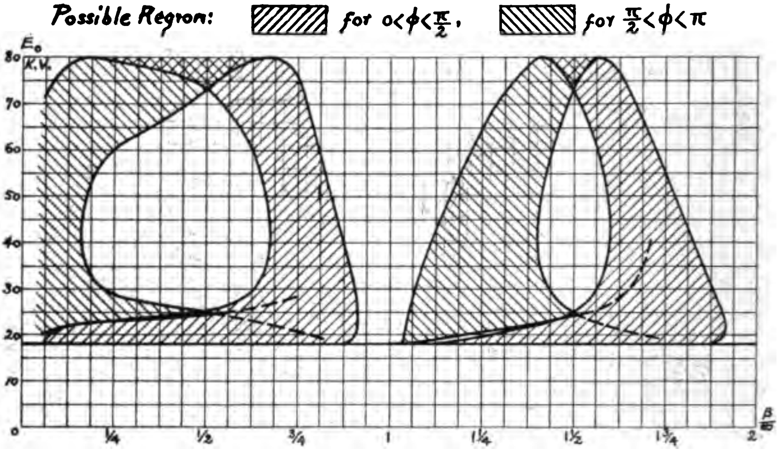


FIGURE 10—Unidirectional Discharge—Rotary Spherical Gap ($r_a = r_b = 0.8$ cm.)

Another limiting factor was considered in connection therewith, which is reproduced here, for comparison, by the dotted curves. The possibility areas given on that occasion lie entirely within the possible range determined in the present paper.

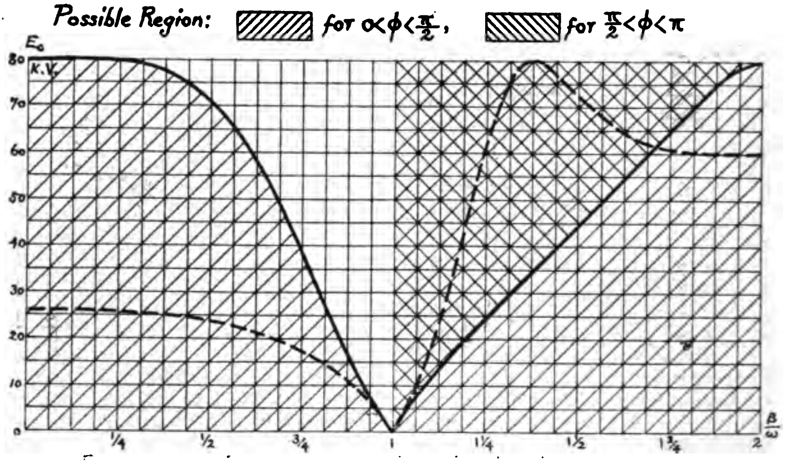


FIGURE 11—Alternate Discharge—Stationary Gap

PART III. POSSIBILITY RANGE OF TONE PHENOMENA IN THE HIGH VOLTAGE D.C. METHOD

Altho Lieutenant Bouthillon's solution is made without neglecting the damping, the author nevertheless regards it as convenient and important to treat the d. c. operation by a potential method analogous to that of the above calculation, even tho some approximation are introduced for the sake of simplicity.

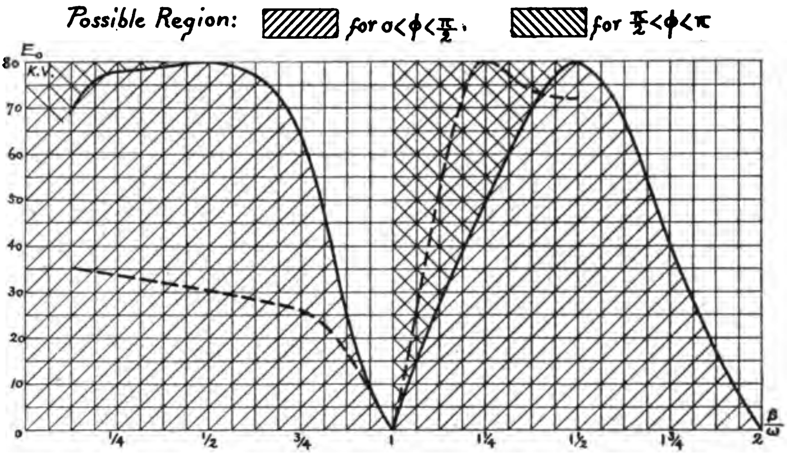


FIGURE 12—Unidirectional Discharge—Stationary Gap

The transient term due to one spark discharge is given by[6]

$$\begin{cases} i_2 = -\beta C E_o \varepsilon^{-\alpha t} \sin \beta t \\ e_2 = E_o \varepsilon^{-\alpha t} \cos\left(\beta t - \tan^{-1}\dfrac{\alpha}{\beta}\right) \end{cases}$$

and the sum of the transient terms becomes

$$\sum_{n=0}^{\infty} E_o \varepsilon^{-\alpha(t+nT)}\left(\cos\beta(t+nT) - \tan^{-1}\frac{\alpha}{\beta}\right)$$

$$= K E_o \varepsilon^{-\alpha t} \cos\left(\beta t + \theta - \tan^{-1}\frac{\alpha}{\beta}\right) \tag{14}$$

where

$$K = \frac{1}{\sqrt{1 - 2\,(\varepsilon^{-\alpha T}) \cos\beta T + (\varepsilon^{-\alpha T})^2}} \tag{15}$$

$$= P_o(\cos\beta T) + \varepsilon^{-\alpha T} P_1(\cos\beta T) + \varepsilon^{-2\alpha T} P_2(\cos\beta T) + \varepsilon^{-3\alpha T} P_3(\cos\beta T) + \;.\;.\;. \tag{16}$$

---

[6] H. Yagi, previous citation.

and
$$\tan\theta=\frac{\varepsilon^{-\alpha T}\sin\beta T}{1-\varepsilon^{-\alpha T}\cos\beta t} \tag{17}$$

Hence, if E_c is the E. M. F. of the source, the terminal voltage e of the condenser becomes

$$e=E_c-KE_o\,\varepsilon^{-\alpha t}\cos\left(\beta t+\theta-\tan^{-1}\frac{\alpha}{\beta}\right) \tag{18}$$

Curves of e are drawn in Figure 13 for various β's assuming $\alpha=0$.

From the terminal conditions

$$(e)_{t=0}=0$$

and
$$(e)_{t=T}=E_o,$$

we obtain

$$\frac{E_c}{E_o}=K\cos\theta \tag{19}$$

When βT and E_c are definitely given, the assumed form of regular discharge may occur only at a definite E_o as given by the above equation. That is, in the case of rotary gaps, which require T to be constant, only one E_o is possible for a given β. It must be noted at the same time that a single value of $\left(\frac{de}{dt}\right)_o$ or $\left(\frac{de}{dt}\right)_T$ is determined corresponding to this E_o and β; for

$$\left(\frac{de}{dt}\right)=\sqrt{\alpha^2+\beta^2}\,KE_o\,\varepsilon^{-\alpha t}\sin(\beta t+\theta)$$

and
$$\left(\frac{de}{dt}\right)_o=\beta KE_o\sin\theta \tag{20}$$

Whether or not the tone phenomenon is possible at this E_o and $\left(\frac{de}{dt}\right)_o$ has to be decided with reference to the characteristic of the spark gap.

ROTARY GAP

(I) After leaving zero potential, the e curve must not cut across the characteristic curve of the gap before the next discharge, so the same m_1 as in the a. c. method gives the upper limit of $\left(\frac{de}{dt}\right)_o$.

(II) Exactly as in the a. c. method, the negative limit of $\left(\frac{de}{dt}\right)_T$ is given by m_2 which is the inclination of the tangent drawn to the hyperbola.

(III) As shown in Figure 13, the e curve approaches a straight line when βT becomes very small. Therefore, $\left(\frac{de}{dt}\right)_o$ may never become larger than $m_3 = \frac{E_o}{T}$.

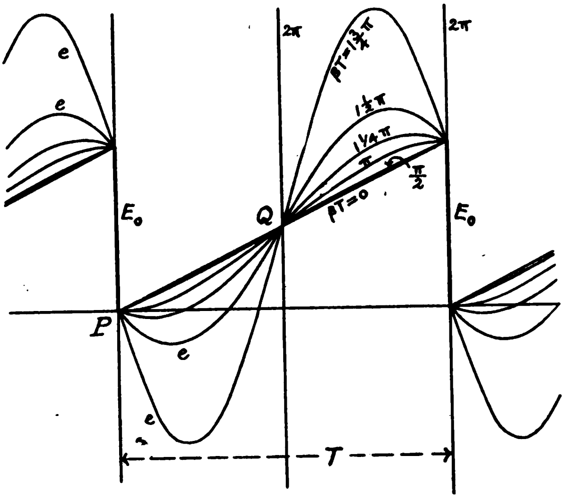


FIGURE 13—Curves of Condenser Potential e with Regular Discharge—High Tension D. C. Method

(IV) In a. c. operation, the curvature of the e_2 curve after a discharge is comparatively small and the positive and negative limits of $\left(\frac{de_2}{dt}\right)_o$ were obtained by assuming e_2 to vary nearly along a straight line.

The same relation does not hold for the e curve in d. c. operation when $\left(\frac{de}{dt}\right)_o$ is negative, because the e curve will soon reach a minimum and reverse its direction, and consequently the same m_1 cannot be considered to indicate the negative limit of $\left(\frac{de}{dt}\right)_o$.

It was determined by trial that the curve of e will touch the gap characteristic on the negative side when $\left(\frac{de}{dt}\right)_o$ exceeds the values m_4 shown in Figure 14.

As this occurs at $\beta T > \frac{3}{2}\pi$, it does not give rise to any very serious restriction in practice.

(V) When E_0 is chosen larger than a certain value E_0', the point Q in Figure 13 will lie beyond the gap characteristic and the tone phenomena are impossible beyond E_0', irrespective of the value of βT. This limit is much higher for a needle gap than for a spherical gap.

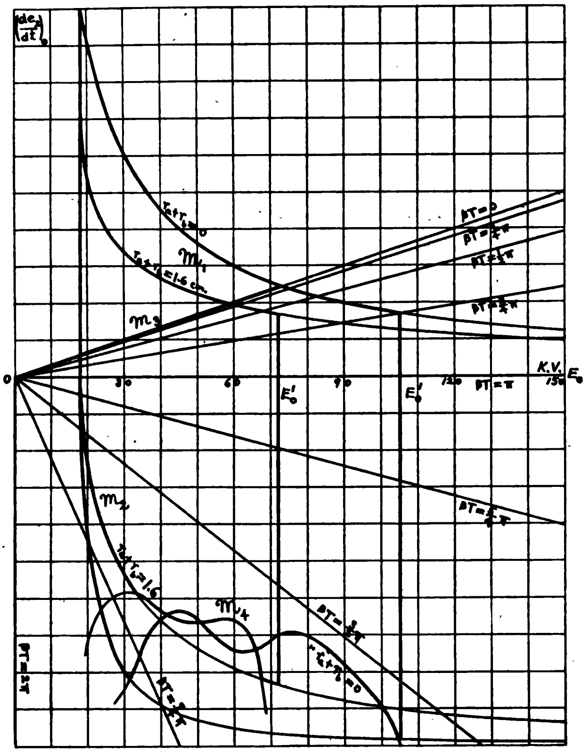


Figure 14—High Tension D. C. Method

All these limits are shown in Figure 14. The straight lines radiating from a point in this diagram show the relation between E_0 and $\left(\frac{de}{dt}\right)_0$ as given by equation (20) for different values of βT.

From Figure 14, the permissible E_0 for tone phenomena may be determined at various values of βT both for the case of a needle gap and that of a spherical gap.

The results are plotted in Figure 15, and Figure 16.

When E_c is fixed, E_o must also have a definite value

$$E_o = \frac{E_c}{K \cos\theta} \, (=2E_c),$$

and whether or not this E_o is well suited to tone production must be checked by these diagrams. If the answer be negative, E_c or the gap ought to be adjusted.

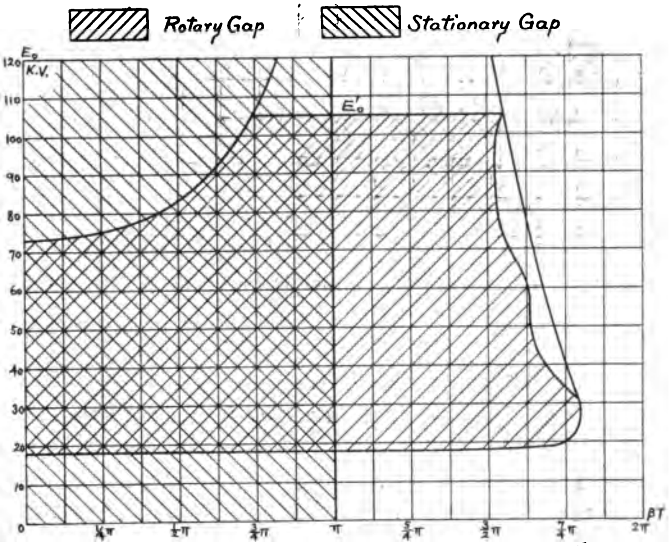


FIGURE 15—D. C. Method—Ideal (Needle) Gap

STATIONARY GAP

The special condition for stationary gaps is

$$\left(\frac{de}{dt}\right)_o \geqq 0$$

or, by equation (20) $\quad \sin\theta \geqq 0$

i. e., the tone phenomena are possible within the region

$$0 < \beta T < \pi$$
$$2\pi < \beta T < 3\pi$$
$$\cdots\cdots$$

and no "late sparking" is possible for stationary gaps.

Any value whatever may be assigned to E_o, provided that E_c is so adjusted that $E_c = E_o K \cos\theta$, or in other words, when E_c is held constant, the tone phenomenon is possible with $E_o = \dfrac{E_c}{K \cos\theta}$ only.

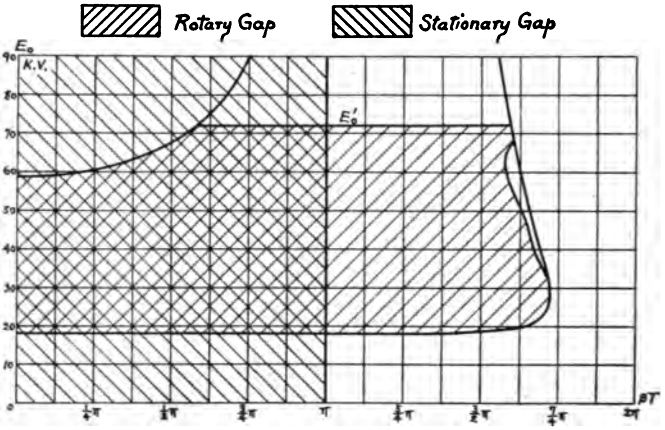


FIGURE 16—D. C. Method—Spherical Gap ($r_a = r_b = 0.8$ cm.) (0.3 inch)

TRANSIENT STATE

No attempt is made in this paper to determine the phenomena in the transient state preceding the establishment of the true tone phenomenon. Nor is it easy to do so, especially for rotary gap operation. A short survey, at least, will not be out of place when appended to this paper.

The only condition which determines the phenomena during this transient state is that "a spark discharge will take place without fail as soon as the terminal potential difference reaches the value determined by the characteristic of the spark gap, no matter what the current at the moment."

With stationary gaps, this disruptive voltage is constant and the time interval T between consecutive discharges is variable. With rotary gaps, T is supposed to be nearly constant, nevertheless, if the solution were developed merely from the current relations without considering the above-stated voltage condition, there would be the possibility of an entirely false assumption, since the discharge might have missed when e was too small.

Again, the conclusions that regular discharge will follow the first spark if the initial current is equal to that corresponding to the tone phenomenon, and that the tone phenomenon will be established automatically regardless of the current at the beginning of the first charge need to be justified from the above mentioned voltage condition, because a rotary gap is not an appliance which guarantees that the spark discharge shall occur at regular intervals regardless of the potential at the moment.

The phase relation between the charging oscillation and the rotation of the rotary gap has an important bearing upon the matter, and unless the stud comes to its proper position at the very moment when the potential difference has reached the assigned value, the events will not continue as desired.

Figure 17 shows the plainest example of this sort. If, in this case, $E_c < V$, where V = minimum disruptive voltage of the gap, then the tone phenomenon has failed to start, and the main switch or the key must be closed anew at a proper instant.

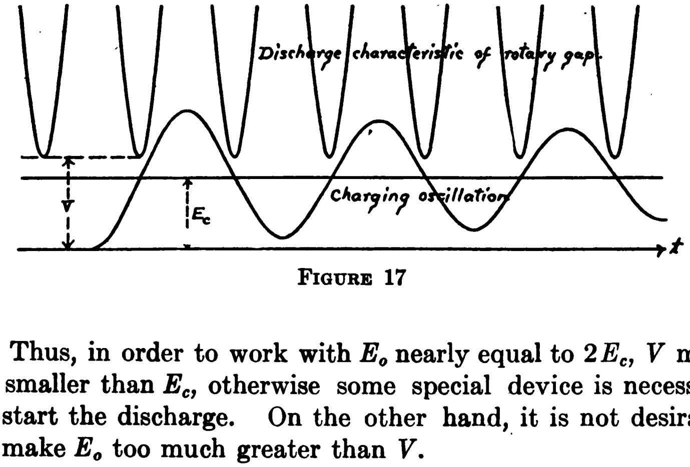


FIGURE 17

Thus, in order to work with E_0 nearly equal to $2E_c$, V must be smaller than E_c, otherwise some special device is necessary to start the discharge. On the other hand, it is not desirable to make E_0 too much greater than V.

The author has already stated in his previous paper, on the a. c. method, that unless some special means is provided to start the discharge in stationary gap operation, E_0 cannot be made larger than E_c, while it is quite desirable to work with E_0 ranging between E_c and $2E_c$.

SUMMARY: The possibilities of securing tone phenomena with the a. c. resonance transformer, spark gap method, and with the high tension d. c. spark gap method, are considered.

There are treated a. c. rotary spark gaps, resonance transformer effects on tone production, and the effects produced respectively by needle and spherical gaps. The results of using rotary, needle, and spherical gaps with high tension d. c. are also considered.

Finally a brief treatment is given of the transient conditions existing before the establishment of a stable tone regime.

INDEX TO VOLUME 6

1918

All references to any individual, company, or radio station are fully listed in the index. Answers to points brought out in the Discussions will be listed under the name of questioner. With the exception of the names of companies, all topics will be listed in general under the ***noun*** **referred to. The numbers correspond to pages in the text. The following abbreviations are used: r. f.—radio frequency; a. f.—audio frequency; l. v.—low voltage; h. v.—high voltage.**