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ALFRED N. GOLDSMITH, Ph.D.

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On page 268 of the June, 1916, "PROCEEDINGS," in heading of third column of the numerical table, for

"Audio Current"

read

"Audibility/Current."

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RECENT STANDARD RADIO SETS*

By

HARRY SHOEMAKER

(RESEARCH ENGINEER, MARCONI WIRELESS TELEGRAPH COMPANY OF AMERICA)

The standard sets to be described are made in two sizes; namely, the 2-kilowatt, 500-cycle set, known as type "P-4," and the ½-kilowatt, 500-cycle set, known as type "P-5." As the ½-kilowatt size is practically the same as the 2-kilowatt size, except in detail, I will confine my description at present to the 2-kilowatt set and later on point out the slight differences. These set are made at Aldene, New Jersey, by the Marconi Wireless Telegraph Company of America.

In designing the set, our first consideration was given to meeting all government requirements and next to our own commercial requirements. As these sets were to be used on shipboard, it was necessary to construct them so as to occupy a minimum space—especially floor space. After careful consideration, the panel type of equipment was decided on and the sets constructed accordingly.

As these sets were required to operate on a current furnished by the ship's dynamo, it was necessary to use a motor generator which would successfully operate on a direct current having varying voltages over wide limits, and deliver a 500-cycle, single phase current. As this motor generator would necessarily be of considerable size and weight, we found it necessary to make provision for mounting it on the floor of the operating room.

All the other appliances, with the exception of the transformer and starting resistance, we were able to mount either directly on the front of the panel or on the back of the panel. In this way we were able to get a set which would occupy a minimum floor space.

All switches and handles necessary for the control and manipulation of the set are mounted on the front of the panel so as to be readily accessible to the operator. All the radio frequency and high potential circuits and appliances are mounted

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on the back of the panel and supported by insulators. The panels are made of "bakelite dilecto" which has been found to be the most suitable material for this purpose on account of its great strength and good insulating properties. The insulators or rods which support the radio frequency circuits and appliances are also made of this material. All wood-work and inflammable material has been entirely eliminated, where possible.

As the circuits used in these sets are so well known, I will not attempt to describe them in any great detail but will endeavor to confine such description to the novel points. The radio frequency circuits consist of a closed oscillating circuit, and an open oscillating or radiating circuit which are coupled inductively.

The closed oscillating circuit consists of an inductance, a condenser, and a spark gap which are connected in series. In these sets, two types of spark gaps are provided either of which can be used as desired. A double throw double pole switch is provided so that either spark gap can be inserted in the circuit. One type of spark gap used is known as the quenched gap. The other type is known as the rotary synchronous gap. In practice, the quenched gap is used almost entirely and the rotary gap merely serves as a spare.

The condenser used consists of six Leyden jars connected in multiple, each having a capacity of 0.002 μf. and a total capacity of 0.012 μf. As it is desired to transmit three different wave lengths; namely, 300, 450, and 600 meters, provision is made for connecting in the proper inductance to produce these wave lengths. The inductance of the circuit consists of a copper strip wound in a spiral and mounted on a bakelite dilecto plate. Taps at the proper points are provided which, in conjunction with a switch known as the primary wave changing switch, enables the wave length or natural period of this circuit to be readily changed. As the capacity used is of too great a value to reach the 300-meter wave length and still maintain sufficient inductance in the primary coil for coupling purposes, the wave-changing switch is so constructed that the capacity used on the 300-meter wave length is reduced to 0.006 μf. This requires only three jars and, consequently, the power used at this wave length is reduced to one-half or one kilowatt.

The secondary circuit consists of the aerial, the aerial inductance which is variable, the loading inductance, the wave-changing switch, the secondary, and the heating element of the radiation meter. These parts are all connected in series. A series condenser known as the short wave condenser is provided for the purpose of shortening the aerial circuit when its natural period is too high to operate on the 300-meter wave length.

The coupling or inductive relation between these two circuits can be varied by varying the distance between the primary and secondary—the primary being movable with respect to the secondary.

On the front of the panel, commencing at the top, are mounted the following instruments and appliances:

A radiation meter, a wattmeter, a motor field rheostat, a generator field rheostat, a handle for varying the aerial inductance, a handle for operating the wave changing switch, a switch for operating the set on low power, a handle for varying the coupling between the closed oscillating circuit and open oscillating circuit, and two bushings thru which the leads to the quenched gap are brought. These are all mounted on the upper section of the panel. The quenched spark gap is mounted on a separate panel which is mounted on the frame-work by means of hinges so that the panel can be opened from either side. This permits the replacement or inspection of the condenser jars which are mounted directly behind this panel. On the lower panel are mounted the automatic starter, together with the D. C. line switch, generator field switch, and A. C. line switch. An over-load release relay is also mounted on this panel which protects the D. C. circuit from over-loads. A row of studs mounted at the lower edge of this panel permits all connections from the panel to the motor generator and external circuits to be made. On the back of the panel, commencing at the top, are the following appliances:

A variable inductance, known as the tuning inductance, a loading coil, the secondary wave changing switch, the primary wave changing switch, a heating element for the radiation meter, the secondary coil, the primary coil, the condenser jars, the change-over switch and an air duct.

The motor generator, the transformer and starting resistance units are mounted on the floor of the operating room directly back of the panel.

The closed oscillating circuit is adjusted for the three wave lengths at the factory and the open or radiating circuit is adjusted when the apparatus is installed and connected to the aerial. The wave changing switches of both circuits are controlled by a single handle so that both circuits are changed simultaneously. This not only changes the wave length of each circuit but also varies the coupling between the two circuits by the proper amount so that it is not necessary to re-tune the two circuits when changing the wave length. This is accomplished by varying the amount of inductance in the secondary while maintaining the total inductance of the radiating circuit constant. This latter method is the one used when operating with the quenched spark gap.

The radiation meter used in this set is of a comparatively new design and is constructed as follows. A number of thin strips constructed of a platinum silver alloy are connected between two terminals which are inserted in series with the aerial circuit. These strips are heated by the aerial current. They are of such thickness and so disposed that they have practically a constant resistance for any frequency. The number of these strips used depends on the amount of current which the instrument has to measure. A thermo junction, consisting of two small wires of different materials, is soldered to the center of one of these strips. The other two ends of the thermo junction are connected to two terminals which have practically the temperature of the surrounding air. These terminals are in turn connected to a very sensitive indicating instrument of the D'Arsonval type. When the strips are heated by the antenna current, the thermo junction is heated and current flows thru the indicating instrument. The deflection of the indicating instrument will be proportional to the square of the current flowing thru the heating strip. The thermo junction and heating strips are made in a separate unit which can be mounted in any convenient place. Connection between the thermo junction and the indicating instrument is made by means of lead covered wire with the covering properly grounded. In the later type of instrument the indicating instrument has the heating strip and thermo junction mounted inside its case.

The condenser of the primary circuit has its terminals connected to the secondary terminals of the transformer. The primary of this transformer is connected to the terminals of the generator thru the necessary controlling appliances.

This transformer is of the closed core, non-leakage type. The coils are placed inside an iron case and the terminals are brought out thru the top of this case. All the windings are immersed in an oil which is solid at ordinary temperatures. A safety gap is provided to protect the secondary against excessive potentials. This transformer is designed to operate with a total capacity of 0.012 giving one discharge per half cycle, or 1,000 discharges per second. When operating on the 300-meter wave length and with a capacity of 0.006 μf., it is necessary to use a reactance in series with the generator and transformer primary. This reactance is of such value that two discharges per cycle are obtained. When operated on other wave lengths, this reactance is automatically short-circuited by the wave changing switch.

Figure 1 is a front view of the set complete, Figure 2 is a side view and Figure 3 is a back view. The different parts are numbered and are as follows:

FIGURE 1

1 is the radiation meter which measures the antenna current. This instrument is of the D'Arsonval type and is operated by means of a thermo junction which is heated by the aerial current.

2 is a wattmeter which measures the A. C. watts at the terminals of the transformer primary.

3 is the generator field rheostat which permits variation of the generator voltage.

4 is the motor field rheostat which permits speed variation of the motor generator.

5 is a scale which indicates the number of turns in the variable tuning inductance.

6 is the handle for varying this inductance.

7 is a handle which permits the transmitted wave lengths to be changed and at the same time indicates this wave length.

8 is the low power switch which cuts in sufficient resistance to operate the set on a sufficiently low power to reduce interference to a minimum. This reduces the power of the transmitted wave to approximately 10 watts.

9 is a scale which indicates the proper coupling for the different wave lengths when using the rotary gap. This coupling is not varied when operated on the quenched gap as the switch controlled by handle 7 takes care of the coupling adjustments as well as the wave length adjustments.

10 is a handle which permits the varying of the coupling between the closed oscillating circuit and the open oscillating circuit.

11 and 12 are flexible leads which connect the quenched gap 13 in the closed oscillating circuit.

14 and 15 are hinges which permit the panel carrying the quenched gap to be swung open from either side.

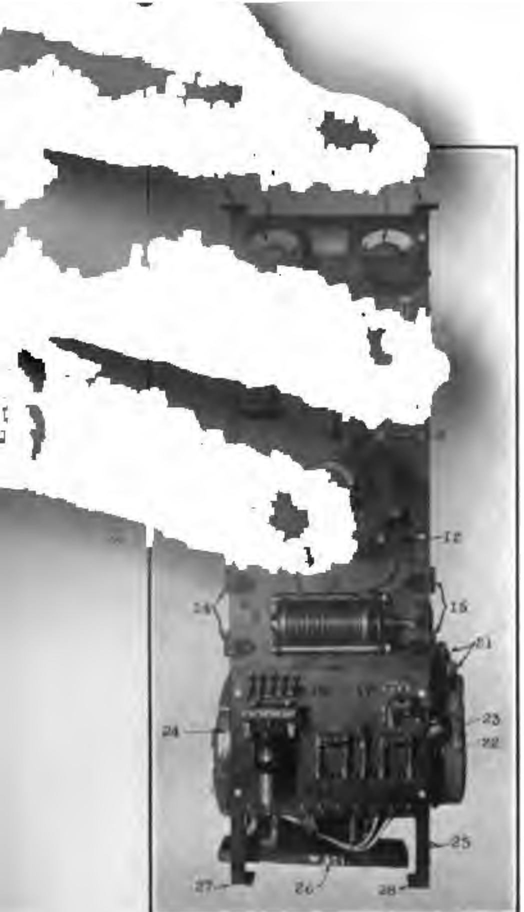

FIGURE 1

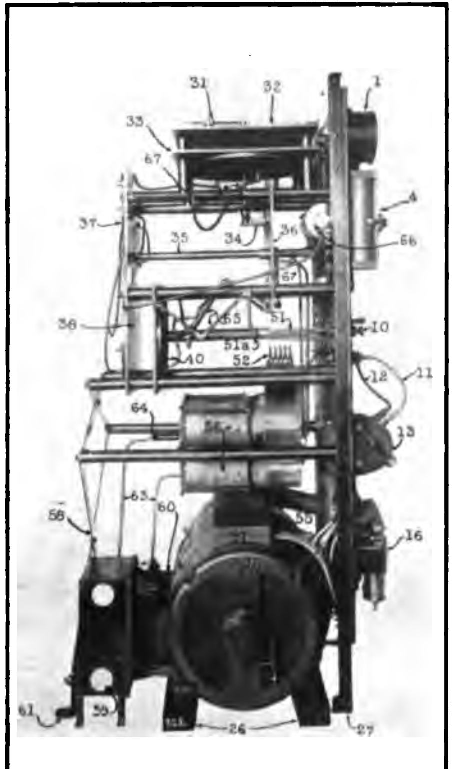

FIGURE 2

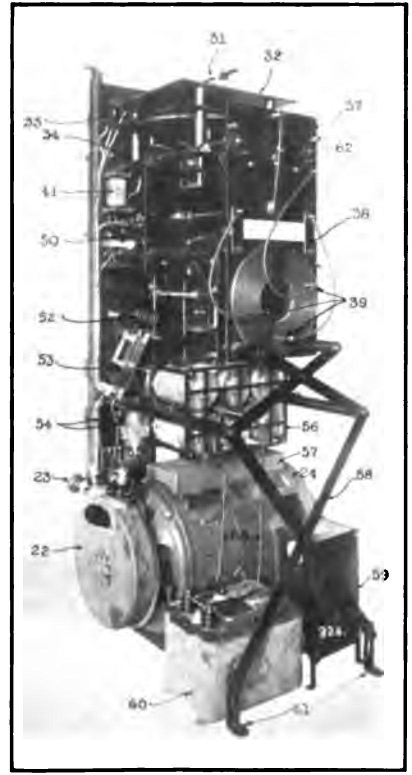

FIGURE 3

16 is the automatic starter movement which permits the motor generator to be started and stopped by means of a single pole switch situated on the operator's table. This movement also serves to open and close the D. C. circuit, cut out the starting resistance in proper order, and connect in the generator field after all starting resistance has been cut out. This last mentioned function prevents the operator from transmitting until the motor generator is up to full speed.

17 is an overload relay which is so constructed that when the set is overloaded the starting movement is released which, in turn, opens the motor circuit. This circuit remains open until the control switch is opened and again closed in which case the motor will again start unless there is a permanent short circuit on the line.

18 is the D. C. line switch which permits opening or closing the D. C. line.

19 is a generator field switch which permits opening or closing the D. C. generator field.

20 is the A. C. line switch which completely connects or disconnects the A. C. generator from the transformer primary.

21 are the rotary spark gap terminals.

22 is the rotary spark gap casing.

23 is a handle which permits the rotation of the spark gap casing and terminals for phase adjustment.

24 is the motor generator.

25 is the ground terminal which is directly connected to the panel frame.

26 is one of the skids on which the motor generator is mounted. These skids are secured to the floor of the operating room by lag screws.

27 and 28 are the lower ends of the panel frame which permits the panel to be secured to the floor by means of lag screws.

29 and 30 are extension angles which slide in the panel frame and which permit the panel frame to be secured to the ceiling of the operating room. The height of these angles can be adjusted to suit the height of the operating room.

FIGURES 2 AND 3

31 is a movable contact which is controlled by the handle 6 and permits the variation of inductance in the aerial or opened oscillation circuit.

32 is the antenna inductance which is of spiral form and mounted on a plate of bakelite dilecto.

33 is a spiral inductance mounted on a plate of bakelite dilecto and is called the loading coil. This inductance is in series with inductance 32 and is so located that connection can be made to any part of it by means of flexible connections and clips.

34 is a bevel gear which gears the handle 6 to the movable contact 31 so as to permit its rotation.

35 is an insulating rod which transmits the motion of the handle 7 to the arm 62 of the wave length switch 37. This also transmits the motion of the handle 7 to the arm 67 of the primary wave length changing switch.

36 is the primary wave length changing switch.

38 is the secondary coil or inductance and consists of a spiral mounted on a bakelite dilecto plate. Connection can be made to any portion of this inductance by means of the clips and flexible leads 39.

40 is the primary coil or inductance which consists of a spiral mounted on a bakelite dilecto plate. This plate is movable with respect to the secondary coil by means of the screw 51 and handle 10. This movement permits the variation of coupling between the primary and secondary. Connection is made between this movable coil and the switch 36 by means of the links 65.

51–a is a bakelite dilecto tube rigidly connected to the plate carrying the primary 40, the other end having a collar adapted to engage the screw 51.

41 is an impedance coil which is automatically connected in series with the primary of the transformer when the handle 7 is set for the 300 meter wave length.

50 is a series resistance which is thrown in series with the generator field when switch 8 is open for the purpose of operating on low power.

52 is a compensating inductance which is connected in series in the closed oscillating circuit when the quenched gap is being used. This inductance compensates for the inductance in the leads 54 when the rotary spark gap is being used.

53 is a change-over switch which permits cutting out the quenched spark gap and connecting in the rotary spark gap in the closed oscillating circuit.

55 is the air duct which carries the air from the combined rotary gap and blower to the quenched gap.

56 is the condenser of the closed oscillating circuit which consists of 6 jars connected in multiple, each having a capacity

of 0.002 μf. making a total capacity of 0.012 μf. These jars are mounted in a cast iron rack which, in turn, is supported by 2 bakelite dilecto rods.

57 is a cast iron cover which covers the terminals of the motor generator and the protective condensers used for protecting the low potential circuit from the radio frequency potentials.

58 is a support which supports the rods carrying the radio frequency appliances.

59 is the starting resistance unit which is mounted on the floor.

60 is the transformer which transforms the generator voltage from 140 volts to approximately 12,000 volts.

63 are the secondary leads which connect the secondary of the transformer 60 to the terminals of the condenser 56.

61 are adjustable feet for securing support 58 to the floor.

Figure 4 is a diagram of connections of complete set and shows the relative positions of the different parts of the apparatus. In this drawing all the different parts are so named that the reader will readily understand it.

The motor generator of this set was especially designed to operate under our service conditions which, in most cases, require a motor which will run at practically constant speed with a voltage variation of from 95 volts to 120 volts. This was accomplished by making the motor of such size that it could be operated with the field below saturation when operating on the highest voltage. The motor is also differentially compounded to insure constant speed with varying load. In practice this motor showed a maximum speed variation of 5 per cent. with a variation of voltage from 95 to 120. The variation of speed from no load to full load was within 5 per cent. The speed of the motor can also be controlled over a limited range by means of a field rheostat. This field rheostat enables the operator to get the proper speed for best tone. The generator is of the wound armature type having an open circuit voltage of approximately 350 and a load voltage of 140. The synchronous impedance of this machine was found to be approximately 17 ohms and inductance 15 ohms. The voltage of this generator is controlled within working range by a field rheostat. This field rheostat enables the operator to adjust voltage for best tone. The windings of both motor and generator are protected from the radio frequency induction by means of condensers. Each terminal of a winding is grounded thru a condenser.

An automatic starter of the remote control type is provided, which enables the motor to be started and stopped either by means of the antenna switch or a separate control switch. A dynamic brake is also provided which quickly brings the motor to a stop when the control switch is open. Wtih this type of starter the motor can be brought up to full speed in approximately 10 seconds and completely brought to a stop in approximately 15 seconds. This starter is so designed as to operate with a voltage varying from 95 to 120. An overload relay is provided which opens the motor circuit when the current becomes excessive. This relay automatically holds the circuit open until the control switch is opened. When the control switch is again closed, the overload relay automatically closes the motor circuit so that the motor will immediately start. In case of a short circuit, this overload relay will immediately open the circuit again.

A switch is provided which, when opened, inserts a high resistance in the generator field. This reduces the voltage of the generator so that the set can be operated with one gap of the quenched gap in the circuit. Under these conditions the set radiates about 10 watts. This arrangement was provided for the purpose of operating over short distances with a minimum of interference. In practice it has been found that the sets will work easily 50 miles on this low power adjustment and, in some cases, it has been reported that the sets have worked over 100 miles. For the purpose of signalling, a small hand key, known as the type "C" key, is used, and serves to open and close the A. C. circuit. A switch known as the type "S. H." antenna switch is provided which permits the operator to connect in the receiving circuits or transmitting circuits at will. When in the transmitting position, it starts the motor generator, closes the generator field, closes the A. C. line, and connects the antenna to the transmitter. It also, when in this position, protects the receiving circuits. When in the receiving position, the antenna is connected to the receiver and the transmitter circuits are opened so that it is impossible to transmit.

The receiver used with these sets is of the coupled circuit type and is known as the type "106" receiver. There are two circuits in this receiver, the one circuit known as the open or antenna circuit, and the other as the closed tuned circuit. These two circuits are coupled inductively and means are provided for varying the inductive relation of the two circuits. The primary circuit consists of the antenna, a loading coil, a primary

coil, a series condenser, and a ground connection, all being connected in series. By means of a switch any amount of the loading coil in the primary can be thrown into circuit at will. This enables the operator to adjust readily this circuit to the received signals. In case the wave length of the received signal is shorter than the natural period of the antenna, the series condenser is thrown in the circuit which brings this circuit to the desired period. The secondary circuit consists of a secondary coil or inductance which is movable with respect to the primary. This coil is in series with a variable condenser. A switch is provided which permits any amount of the secondary to be thrown in the circuit. The variable condenser permits the variation of the capacity of this circuit so that it may be adjusted for resonance with the primary circuit. By having both the inductance and capacity of this circuit variable, the ratio of capacity to inductance can be varied while keeping the period of the circuit constant. This enables the operator to obtain the best adjustment for operating the detector. The detector used in this receiver is of the crystal type. A battery and potentiometer are provided so that a crystal can be operated either with or without battery as desired. The detector circuit consists of the potentiometer, a stopping condenser and the telephones. The potentiometer and stopping condenser are connected in series with each other and in shunt to the variable condenser. The telephones are connected in shunt with the stopping condenser. A test circuit is provided which enables the operator to excite the antenna circuit at will so that he can adjust the detector for maximum sensitiveness. These circuits are all shown in Figure 4. A careful consideration of this drawing will enable the reader to understand fully the complete circuits of both transmitter and receiver.

Figure 5 shows a section of the motor generator and the combined rotary spark gap and blower. The different parts of this motor generator are indicated by the table and reference numbers.

Figure 6 shows the details of the combined rotary spark gap and blower. This type of spark gap is so well known that it does not need any detailed description. This figure also shows the method of grounding the shaft of the motor generator to prevent currents flowing thru the bearings.

Ref	Detail
1	Cap Screw for removing end shield
2	Terminal Nuts for removing lead
3	Thrust nut which holds bearing in place
4	Set screw for loosening thrust nut
5	Bearing
6	Pin which holds bearing from turning
7	Oil ring
8	Screw which holds oil ring in place
9	Pole shoe which holds motor field coil in place
10	Motor field Coil
11	Armature winding
12	Generator armature coil
13	Generator field coil

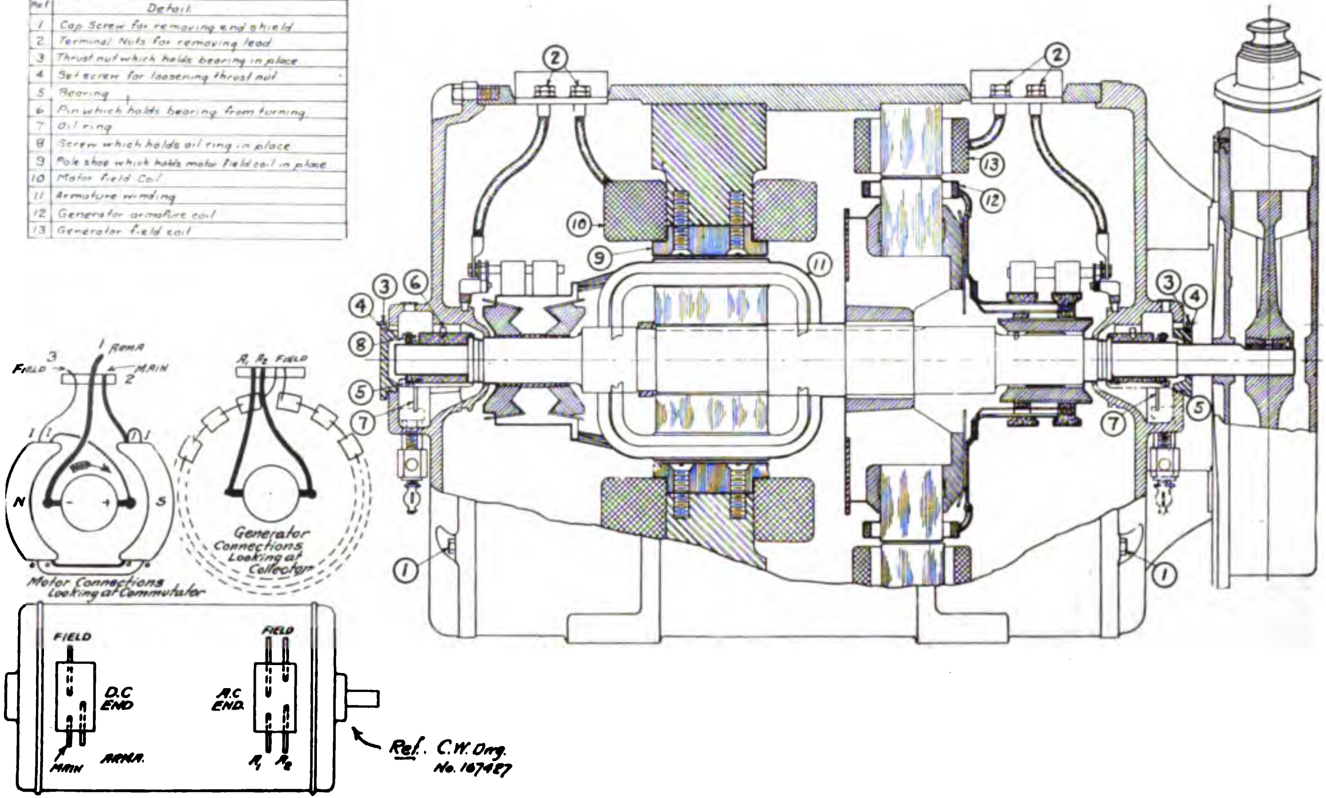

FIGURE 5

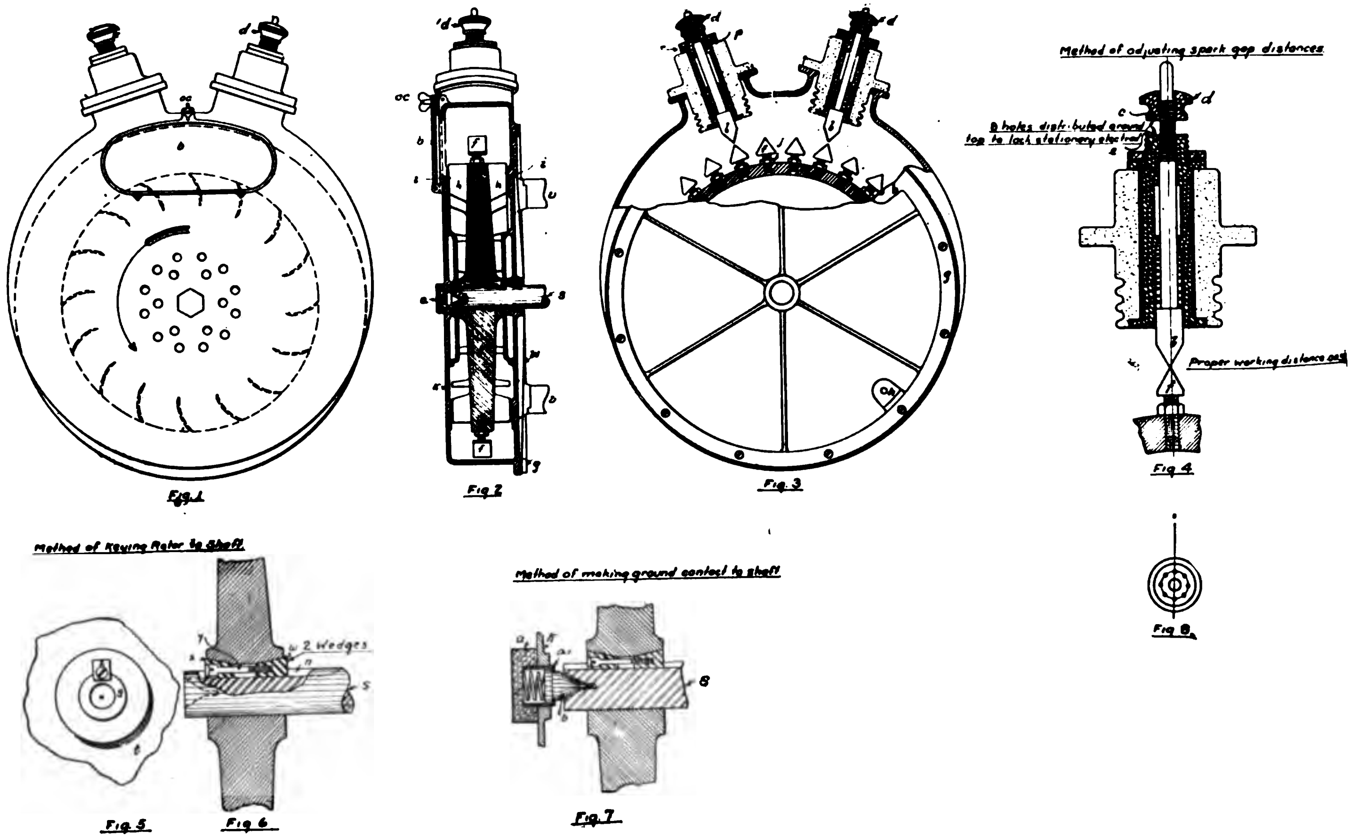
Fig. 1
Fig. 2
Fig. 3
Method of adjusting spark gap distances
8 holes distributed around top to lock stationary electrode
Proper working distance
Fig. 4
Fig. 8
Method of Keying Rotor to Shaft
w 2 Wedges
Fig. 5
Fig. 6
Method of making ground contact to shaft
Fig. 7

FIGURE 6

Figure 7 shows the signalling key used with these sets.

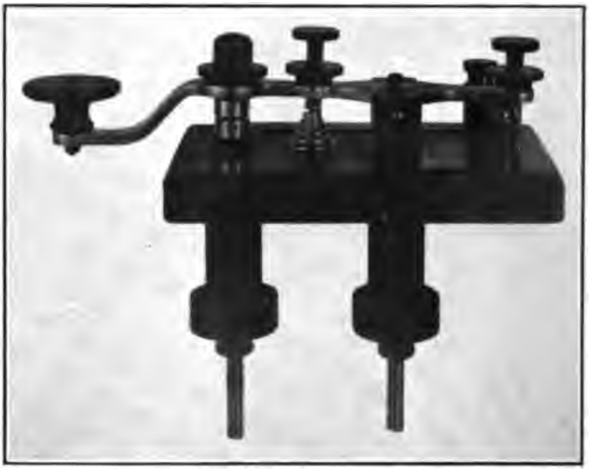

FIGURE 7

Figure 8 shows the complete receiver.

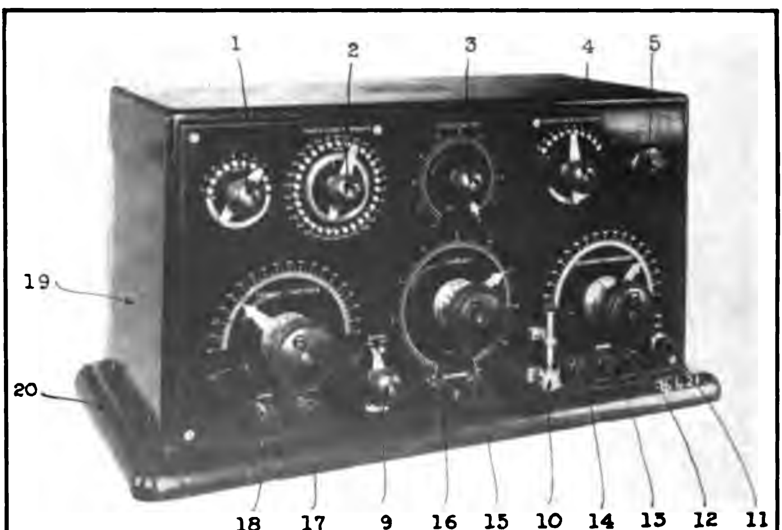

FIGURE 8

1 is the unit switch which permits 1 turn variation in the primary.

2 is the primary switch which permits 10 turns variation in the primary and at the same time cuts out the unused portions of the primary.

3 is a potentiometer.

4 is the secondary of the transformer. This switch enables the operator to cut in the necessary amount of inductance properly to tune the secondary to the primary circuit.

5 is the test buzzer.

6 is the primary condenser. When in the "out" position, it is short-circuited.

7 is the coupling mechanism for varying the inductive relation between the aerial and closed circuit.

8 is the secondary condenser.

9 is the battery switch.

10 is the detector.

11 is a switch for operating the buzzer or test circuit.

12, 13 and 14 are battery posts for the receiver and buzzer.

15 and 16 are the telephone posts.

17 and 18 are the ground and aerial posts.

19 is the case and 20 the base of the receiver.

Figure 9 is the quenched gap showing part in section.

k and *c* are the end plates.

dd etc. are bolts holding end and plates together.

b is the clamp nut.

a is a lock nut.

ee are tubes of bakelite dilecto which cover the clamp nuts, and serve to hold the plates in position.

nn, etc., are the gaskets or separators which keep the plates the proper distance apart and at the same time excludes the air from the sparking surface.

hh, etc., are the spark plates which are made of copper.

j is the sparking face of the spark gap which is made of pure copper and carefully soldered to the larger plates.

oo, etc., are the coupling flanges.

ff are plates of insulating material which insulate the end plates from the frame.

p and *q* are the terminals which serve to connect the spark gap in the closed oscillating circuit.

Figure 10 is a front view and Figure 11 is a rear view of the ½-kilowatt set.

1 is the motor field rheostat.
2 is the generator field rheostat.
3 is the wattmeter.
4 is a handle controlling the aerial inductance.
5 is a low power switch.
6 is the wave length changing switch.
7 is the radiation meter.

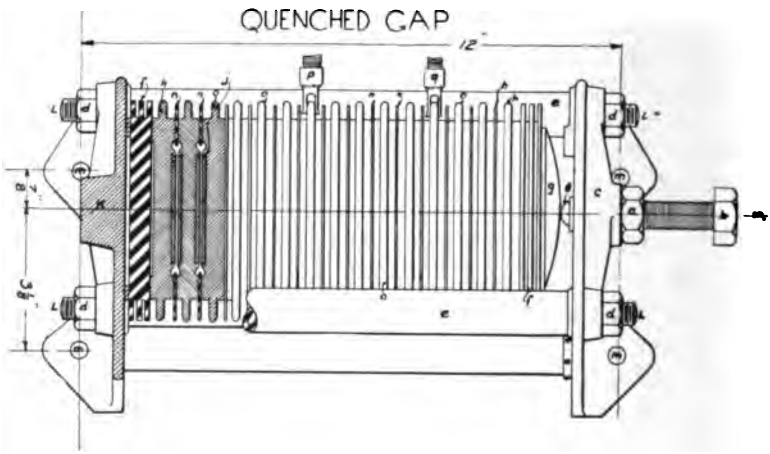

FIGURE 9

8 is a lightning switch which permits the grounding of the antenna when desired.

9 is the handle for varying the coupling.

10 and 11 are the flexible leads for connecting the quenched spark gap in the closed oscillating circuit.

12 is the quenched spark gap.

13 is the automatic motor starter.

14 is the D. C. line switch.

15 is the generator field switch.

16 is the A. C. generator line switch.

17 is a handle for adjusting the rotary spark gap for proper phase relation.

18 is the casing of the rotary spark gap.

19 are the terminals of the rotary spark gap.

20 is the motor generator.

21 is the resistance unit of the motor starter.

22 is the frame work supporting the panel.

23 and 24 are extension angles for securing the set to the ceiling of the operating room.

25 is the variable inductance.

26 is the loading coil.

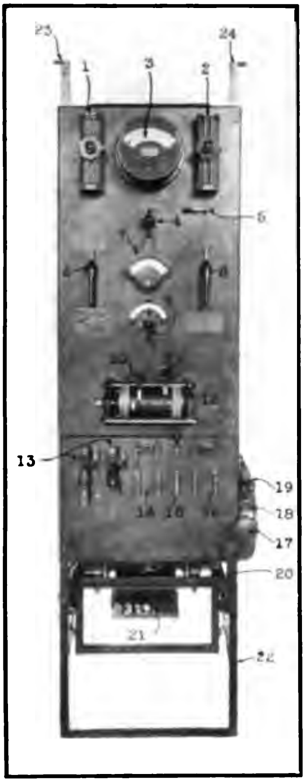

FIGURE 10

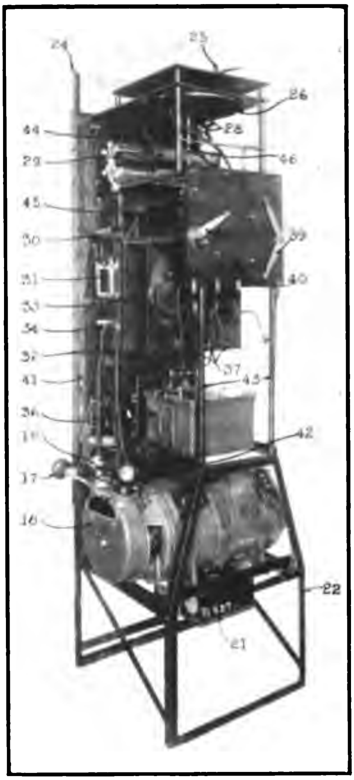

FIGURE 11

28 are adjustable contacts for making connections with the loading coil.

29 is the primary condenser.

30 is the compensating inductance.

31 is the switch for changing over from quenched gap to rotary gap.

32 are the quenched gap leads.

33 is the primary inductance.

34 is the secondary which is movable relative to the primary.

36 is the transformer.

37 are the links for connecting the movable secondary with the switch 40.

38 is the lightning switch arm.

39 is the wave length changing switch arm.

41 is an air duct carrying the air from the combined rotary gap and blower to the quenched spark gap.

42 are the protective condensers mounted on the back of the panel.

43 are rods of bakelite dilecto supporting the switch 40.

44 are the terminals of the wattmeter.

45 is a gear which enables the coil 25 to be varied by the handle 4.

It will be seen from Figures 10 and 11 that the ½-kilowatt set is practically the same as the 2-kilowatt set.

Figure 12 is a complete diagram of connections of this set, which needs no detailed description.

TUNING

The tuning of these sets is quite simple when the method is properly understood. As the closed oscillating circuit is adjusted for the three wave lengths used, the set can be completely tuned without the use of a wave meter. It will, however, require the use of a wave meter to determine the logarithmic decrement of the oscillations.

In tuning the set, it is necessary to bear in mind the fact that a certain definite amount of inductance must be included in the open radiating or aerial circuit to bring its period up to the required wave length and that the coupling between this circuit and the closed oscillating circuit is obtained, not by varying the distance between the secondary and primary inductances, but by means of varying the amount of inductance in the secondary circuit in such a manner as to obtain the proper mutual inductance between the two circuits. When the inductance in the secondary circuit is varied, the amount of inductance in the loading coils must be varied also to keep the total inductance constant. The primary inductance is made movable with respect to the secondary so that the coupling can be varied within limits. The scale which indicates the coupling has a mark which indicates the normal setting for use with the quenched gap. The coupling can either be increased or decreased from this normal setting. This is necessary for the tuning-up operation.

In tuning a set, the wave changing switch is set to the desired

wave length, say, 600 meters. An approximate setting is made by means of the adjustable contact on the secondary inductance. Another contact is made on the loading coil in such a manner that the aerial circuit includes a certain number of turns in the loading coil. The set is then operated and the variable inductance in the aerial circuit is varied while the indications on the radiation meter are noted. If the amount of inductance is too small in the antenna circuit, then an increase of inductance will give an increased amount of current. If the inductance in the antenna circuit is too large, then an increase of inductance will give a decreasing current in the antenna circuit. Inductance is then adjusted until a maximum current is obtained; and at the same time, the coupling is varied within limits, so that by means of varying the inductance in the antenna circuit, and varying the coupling, a maximum current is obtained in that circuit. Now the position of the coupling indicator is noted. If the coupling is less than the normal amount it indicates that there is too much inductance in the secondary. If it is greater than the normal amount it indicates that there is too small an amount of inductance in the secondary. The amount of inductance in the secondary is then either increased or decreased as desired and the amount in the loading coil is varied accordingly so as to keep the total amount equal. The exact amount is generally obtained by two or three trials. The 450 and 300-meter wave lengths are adjusted in the same manner.

In tuning up the sets it is generally advisable to use low power; that is, adjust the set so that it operates with two or three plates in the quenched gap. It is also advisable to adjust the power so that a half note is obtained during the tuning operation. This prevents the gap from being subjected to excessive heating caused by the two circuits being out of tune a considerable portion of the time. After these sets have been tuned up all that is necessary to change from one wave length to the other is to throw the wave length switch to the desired position. It has been found that sets which have been tuned at the dock generally are out of tune when the ship moves away from the dock. This is probably due to the increased capacity of the antenna due to the close proximity of the dock's structure. The operator can easily compensate for this by varying the variable inductance in the radiating circuit until the maximum current is indicated in the radiation meter.

When using the rotary gap it is necessary to use a much looser coupling than with the quenched gap and as this rotary gap is not intended for continuous use, it is necessary to vary the coupling for each different wave length. When the set has been tuned for operation with the quenched gap, it is then operated on the rotary gap and the position for the proper coupling with the different wave lengths is marked on the scale of the coupling indicator. This enables the operator to adjust for proper coupling without the use of the radiation meter.

In most cases, storage batteries are provided for operating the motor generator in case of emergency. The set can then be operated continuously from 4 to 8 hours on these batteries.

SUMMARY: The most recent standard 2-kilowatt and ½-kilowatt (transformer input) sets of the Marconi Company are described fully. Details are given of the design of the switchboards, gaps, condensers, radiation thermo ammeter, motor generator, transformer, automatic starter, overload relay, low power switch, wave changer, and receiver. The adjustment of these sets is carefully considered.

DISCUSSION

J. Zenneck: There is only one objection that I can raise in connection with this paper, and that is to the name "radiation meter." This instrument measures effective current in the antenna, and not true radiation. Indeed, were a true radiation meter to be invented, it would be a most useful and valuable instrument.

However, it must be admitted that "radiation meter" is not the only misnomer which has been applied to instruments of this type. In Germany, an instrument of this sort calibrated to read currents squared has been called a "watt meter." Of course, this name is quite as incorrect as "radiation meter," since the instrument indicates watts absorbed in the instrument itself and not at all in the outside circuit.

I suppose that the use of an auxiliary source of potential or battery across the detector by the Marconi Company is to enable working at a special point of the detector characteristic. The superposition on the alternating current in the telephone of a direct current certainly changes the sensitiveness of the telephone, but probably decreasingly. This, however, is a more or less secondary effect compared with the total increase in sensitiveness of the detector, resulting from working at the proper point of the detector characteristic.

Louis R. Krumm: A discussion of the new panel sets being installed by the Marconi Company is a very practical question with me. Mr. Shoemaker states in his paper that the first intention was to comply with the Government requirements, and I am pleased to be able to say that they do this and more. The 2-kilowatt set can communicate considerably more than the 100 miles (160 km.) required by the Radio Laws, and the decrement obtained is considerably better than that required.

However, there is a practical side to this set to which I would like to invite attention. The development of the panel set appears to have been carried somewhat to the extreme in this case. A primary object of the panel arrangement is to bring all the equipment into the most compact form, so that all the switches and other apparatus are readily available to the operator, as well as shortening or lengthening the wave length of all the circuits. In the case of these 2-kilowatt sets, the physical dimensions (that is, the width and depth), are determined mostly by the motor-generator, which is installed at the bottom. This has resulted in a panel set of a size which does not always meet the space requirements of the radio room in which it must be installed.

Radio engineers may appreciate the advantages of a panel set, but ship companies using them are not so well informed, and in many cases provided radio rooms of such size that the 2-kilowatt panel equipment cannot be properly arranged. Its lack of flexibility has produced some curious results. One case I have in mind is where the panel had to be installed in such a manner that it was very difficult to get at the switches, and it was necessary for the operator to go outside and look thru the window of his cabin if he desired to read his instruments. Such conditions, of course, entirely nullify the advantages of a panel equipment, and it occurs to me that there would be several advantages if the motor generator had been separated from the panel, permitting a more compact and flexible arrangement of the remaining equipment. Even the ability to move the motor generator 5 to 10 feet (3 meters) would have greatly improved the conditions under which many of these sets were installed, and the difficulties of running the high-tension circuits to the synchronous rotary gap are not insurmountable. In a word, unless the radio company also provides the quarters, a 2-kilowatt panel set is hardly practicable for a ship set under present conditions.

Altho the three wave lengths provided, namely, 300, 450 and 600 meters, are easily obtained by means of one switch, I doubt very much if the operators are taking proper advantage of these wave lengths.

The Traffic Department of the Marconi Company can no doubt inform you much better than I how much their operators are using the wave lengths other than 600 meters. This would have a direct bearing on the practicability of adopting a common calling wave length and then passing to another one as a transmitting wave.

Another objection might be made to 2-kilowatt sets on ships. I believe that there is more power provided than is necessary for a large proportion of the vessels on which they are installed. Many of the ships in coastwise trade never get more than 50 or 75 miles (120 km.) from land stations, nor into the region of heavy strays. This results in the operator being the determining factor in the amount of interference which will be created by the use of unnecessary power, and experience indicates that operators are inclined to use full power at all times.

Ralph H. Langley: This paper is very interesting in that it discusses fully the mechanical details of the design of quenched spark apparatus of the latest Marconi type. There are two or three questions I should like to ask Mr. Shoemaker. The first is concerned with the continuously variable inductance supplied in the antenna circuit. This set is arranged for three wave lengths. Is a separate inductance, independently variable, supplied for each wave length, or is there but one inductance supplied? It is evident that with but one inductance to make final adjustment of each wave length, it will usually happen that this inductance, or variometer, as we call it, must be adjusted each time the wave length is changed. If separate inductances are supplied, each remains in proper adjustment, and is not effected by changes in the inductance for another wave length.

In all quenched spark transmitters, it is found that there are two or more points of coupling at which proper tuning can be obtained. In other words, there are two or more points of coupling that give current maxima in the antenna circuit. I should like to ask Mr. Shoemaker whether in this transmitter, where the inductance of the coil is varied, and not its position in space, the same points of near-resonance are found, and if so, at which one of these points is it found most advantageous to work. While the method of coupling variation is by inductance rather than motion of the coil, it is apparently found necessary to provide in addition a method of moving the coil. I should like to ask Mr. Shoemaker whether it is possible to move the coil sufficiently to reach all of the two or more points of coupling mentioned above, with any given adjustment of the remaining variables in the circuits remaining constant.

Harry Shoemaker: As regards the inductance available for exact tuning and slight correction when changing from one wave length to another, this was not exactly described in the paper. It consists of approximately ten turns, and the normal setting is at about five turns. There is therefore room for increase or decrease if necessary. Any effect which influences the antenna tuning after the set has been adjusted can be compensated for by this means. Of course, in the original tuning of the set, this inductance is set at its normal mid-way position.

It is interesting to note that if a ship be tuned while in dock and then goes out to sea, the change in antenna current may be an ampere or an ampere and a half. While this would not interfere with the working of the set to any marked extent, it might be desirable to bring the radiation back to full value, and this can readily be done by the use of the compensating inductance mentioned.

As regards the term "radiation meter," I must disclaim responsibility for this term which originated elsewhere in this country. Professor Zenneck's criticism of the term is fully justified.

SOME SMALL DIRECT CURRENT SETS*

By

Bowden Washington

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

Altho many radio engineers are undoubtedly familiar with the action of the Chaffee gap as used in the sets which are to be described, a short description of its behavior and characteristics may not be out of place.

This gap, originated by Dr. E. Leon Chaffee of Harvard University, consists of a copper anode and an aluminum cathode, in an atmosphere of moist hydrogen.† Figure 1 is a photo-

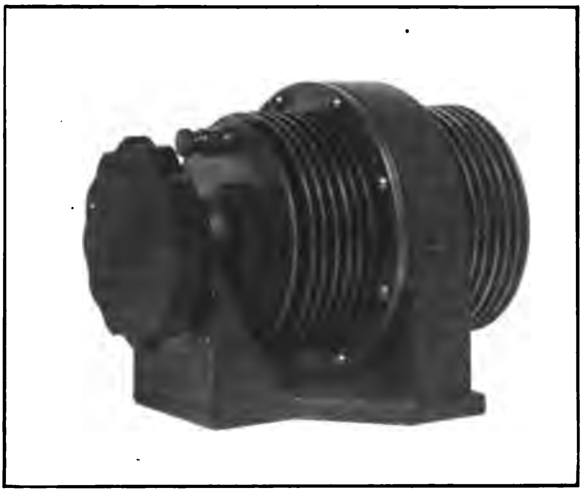

Figure 1

graph of our standard gap; Figure 2 a section. We have found it extremely difficult to build a gap which is adjustable for gap length, and is also hydrogen-tight. All manner of threads and

* Received by the Editor, February 5, 1916.

† "A New Method of Impact Excitation of Undamped Oscillations, and Their Analysis by Means of Braun Tube Oscillographs," by E. Leon Chaffee, "Proceedings of the American Academy of Arts and Sciences," November, 1911.

stuffing boxes have been tried, without great success. The total adjustment required is very small, probably never being over 1/16 inch (1.5 mm.), so we have adopted the thin phosphor-bronze diafram shown in the section at "A." This pushes in and out like the bottom of an oil-can, and we have found it very satisfactory. The periphery of this diafram is clamped against

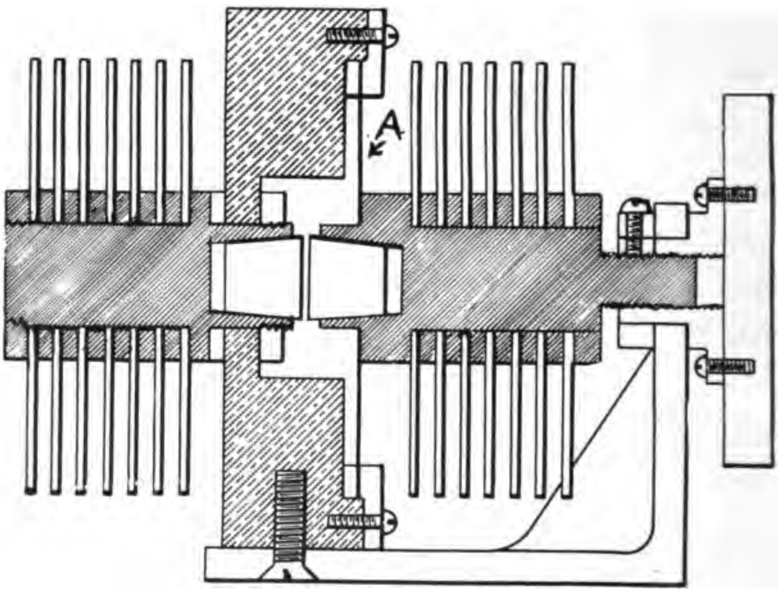

FIGURE 2

a soft rubber packing by a brass ring, held to the bakelite gap chamber by eight "10–32" machine screws. The base is a small composition casting. Cooling fins and the adjusting handle are shown.

The connections are as in Figure 3. When the direct current feed circuit is closed, the primary condenser, C_1, is charged until a potential is reached which is sufficient to break down the gap, G. The condenser discharges thru the gap in a single loop, or half-cycle. The gap then goes out, and leaves the secondary circuit free to oscillate at its own period. Meanwhile, the condenser, C_1, is being recharged from the generator. When it has reached a potential almost sufficient to break down the gap again, the e. m. f. induced in the primary circuit by the oscillating antenna is sufficient to "trigger off" the gap in the proper phase-relation to the antenna; which process continues indefinitely. The number of antenna oscillations which occur between gap discharges, called by Dr. Chaffee, the "Inverse Charge Frequency," and indicated hereafter by the abbreviation I. C. F., can be varied from two to almost any number, depending on the amplitude of the feed current, the size of the primary con-

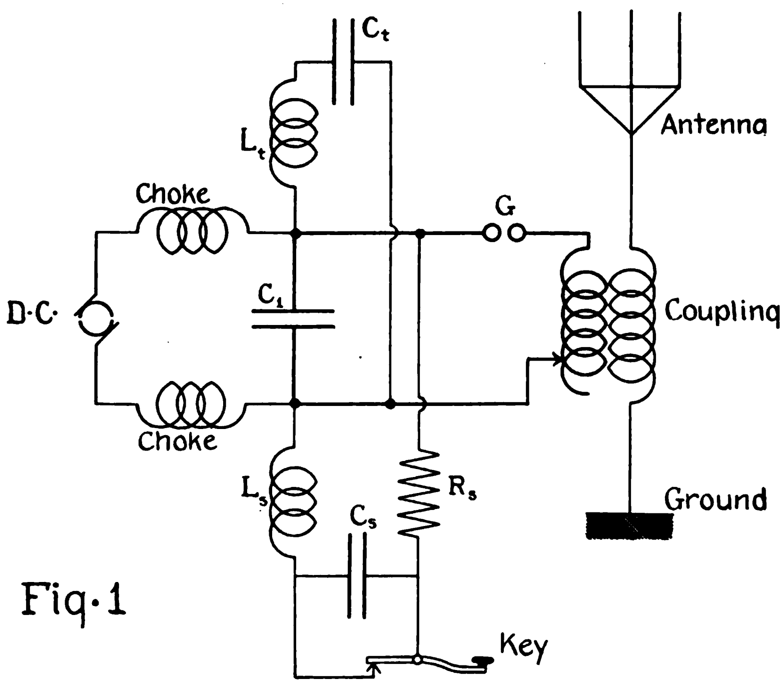

FIGURE 3

denser, the length of the gap, etc. It will be readily seen that with an antenna of normal resistance, and an I. C. F. of 2 to 6, a sustained, and in fact practically undamped, oscillation will be maintained in the secondary. To illustrate this more clearly, the following Braun tube oscillograms may be helpful.

Figure 4 illustrates the current-voltage characteristic of the gap, the current vertical, and the voltage horizontal.

Figure 5 shows the primary half-loop, with an I. C. F. of 2, and was taken by deflecting the beam vertically with the primary current, and horizontally with the secondary current.

Figures 6 and 7 show the secondary wave-train, with an antenna resistance of 40 ohms and an I. C. F. of 9 and 6 respectively.

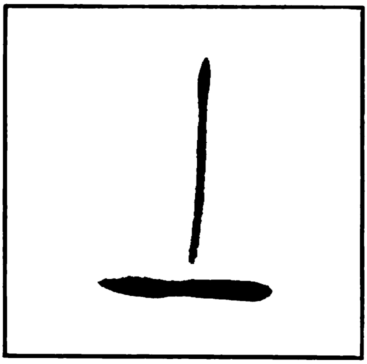

FIGURE 4

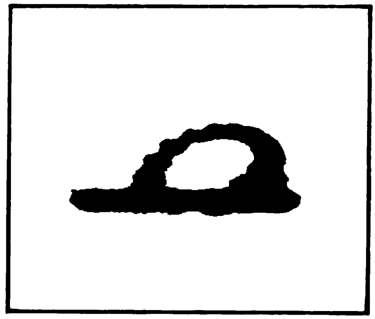

FIGURE 5

Figures 8, 9 and 10 show the secondary wave-train with an I. C. F. of 4, 3 and 2, and an antenna resistance of 5 ohms. These were taken by deflecting the beam vertically with the secondary current and horizontally with the potential of the primary condenser. It will be apparent that when the gap discharges, the spot returns, and one antenna oscillation occurs during this return.

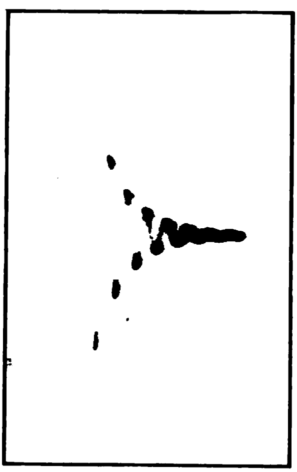

FIGURE 6

FIGURE 7

Figure 11 is the potential current curve of the secondary, with an I. C. F. of 4, and a resistance of 40 ohms.

Figure 12 shows the production of beats, and was made with two secondary circuits.

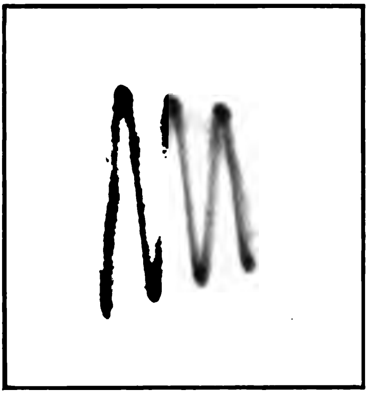

FIGURE 8

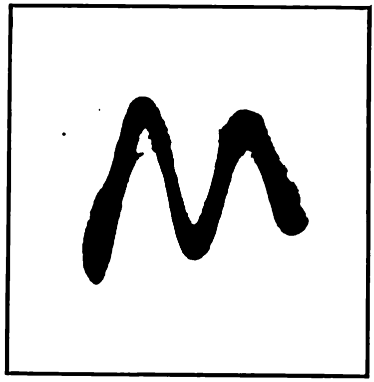

FIGURE 9

The power and efficiency curves for changing feed current, Figure 13, taken from Dr. Chaffee's paper referred to above, may be of interest, and require no explanation. One gap is capable of efficiently handling about 200 watts input. We find that when two or three gaps are used, with the same primary condenser as with one, it is advisable to double or triple, as the case may be, both current and voltage, thereby keeping the I. C. F. the same, so that it may be roughly stated that the

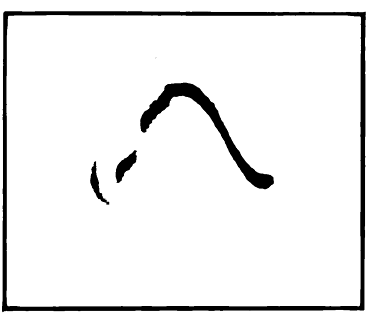

FIGURE 10

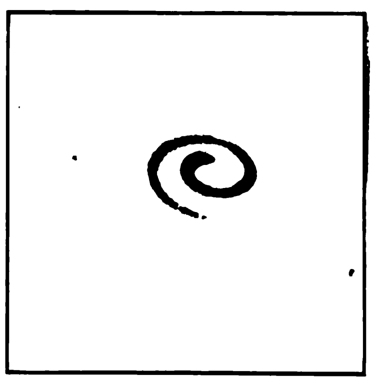

FIGURE 11

power increases with the square of the number of gaps. However, when powers of 1/2 kilowatt or larger are required, we use a later development of the Chaffee gap, which consists of a rapidly rotating aluminum disc from which the spark passes to a stationary copper electrode, running in an atmosphere of hydrocarbon vapor; and used in conjunction with the Cabot high-

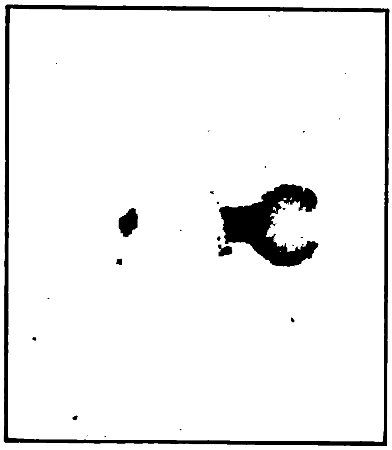

FIGURE 12

voltage, direct current machine. We have shown with the Braun tube that the action of these gaps is identical, as is to be expected; but the efficiency of the rotary type is remarkably high, from 60 per cent. to 70 per cent.

There is no resonance between the primary and radiating circuits; and to obtain the best energy transfer it has been found advisable to tune the primary to a wave-length 1.5 to 2 times that of the secondary. However, the smaller the I. C. F., the more desirable it becomes to tune the two circuits to a ratio of 1.7 to 1. It will be seen that the efficiency from generator to antenna of these sets is quite low, judged by modern standards; however, rather remarkable distances have been covered with small powers, due probably to the radiation of a single wave, and to its maintained nature.

Some tests were made not long ago with a single-gap aeroplane set, which I will describe in detail later. The input was about 150 watts, and the antenna used consisted of two vertical or nearly vertical wires 130 feet (40 m.) long, spaced 4 feet

(1.2 m.) apart, and having a natural period of 205 meters. The wave-length was 480 meters, and the radiation meter showed 1.5 amperes. This test was not pre-arranged in any way. The stations with which we obtained communication were simply called in the ordinary manner. Communication was established with Highland Light, a distance of about 51 miles (80 km.),

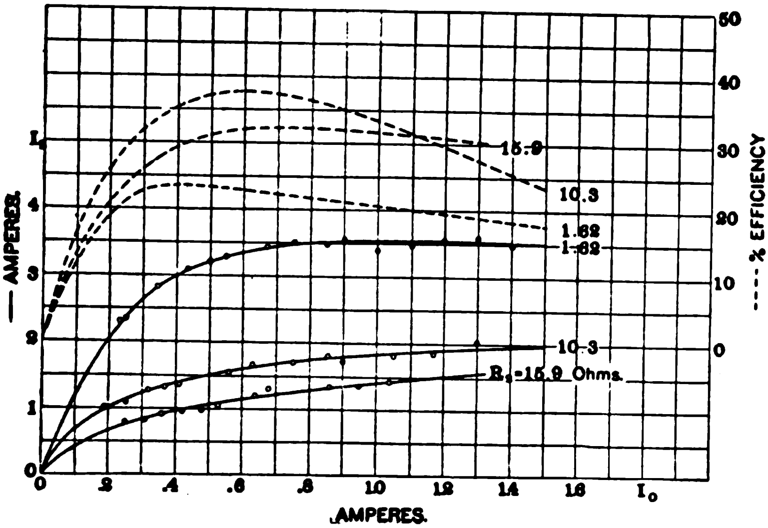

FIGURE 13

and our signals were reported strong. We then worked with the S. S. *Virginian*, which reported 78 miles (125 km.), signals good. Then we got the U. S. S. *Gresham*, presumably between 40 and 50 miles. We also worked several other stations at about these distances, with equal success.

ONE-QUARTER KILOWATT PANEL SET

Figures 14 and 15 are the front and side views, respectively, of a ¼- kilowatt panel set, as used in the Cruft Laboratory at Harvard University. The panel is ⅜-inch (9.5 mm.) bakelite, and is 14 inches (35 cm.) wide, and 24 inches (60 cm.) high. It is bolted to the 1 inch (2.5 cm.) by ⅛-inch (3 mm.) angle-iron frame with black-oxidized cap screws. In the upper left-hand corner will be seen the direct current ammeter, which is in the feed circuit, and has a full scale deflection of 1.5 amperes. In the right-hand corner is a hot-wire radiation meter. Below

FIGURE 14

FIGURE 15

are the handles for the two variometers, which are situated at the back of the board. These are wound with separately insulated, stranded wire. The large coil of each is form-wound, and held on the inside of the wooden frame, so that there need be only a sufficient air gap between the two coils to keep them from rubbing, thus giving very close coupling, and therefore a low minimum inductance. One of these is common to both circuits, the other in the antenna. Below the variometer handles are seen the two gaps, which are connected in series.

The large box filling the whole lower part of the frame contains the "tone circuit," which consists of a circuit, shunted across the primary condenser, containing such capacity and inductance as to be of an audible frequency ($C_T L_T$, Figure 3). Its action is similar to that of the tone circuit in the Rein "Multitone" sets.* The inductance is tapped in three places, and provided with a switch so the three tones can be obtained. This box also contains a "starting circuit" ($C_s L_s R_s$, Figure 3). These gaps, of course, require a good deal higher potential in starting than the average drop across the gap, which latter is all the generator need supply. If one uses a generator with a high initial voltage and a very steep falling characteristic, the operation of the generator is apt to be unstable, for the load "kills" the field, and the voltage drops below that necessary to keep the gap in operation, builds up and starts again. A moderately falling characteristic, however, seems to be desirable, as apparently the gap is in the most stable state when the generator and gap characteristics cross at nearly right angles at the working point. This starting circuit consists of an inductance of the order of 0.1 henry, and a capacity of, say, 0.06 μf. (microfarad), and a resistance approximately equal to the average resistance of the gaps. The key is shunted across this condenser, and open circuits when depressed. The current from the generator flows thru the key, inductance and resistance. When the key is opened, it breaks the current quickly, owing to the condenser, and thus the energy stored up in the choke coils and the "starting inductance" produces a high voltage (which the Braun Tube showed in one case to be about 1,500 volts, while the average gap drop is about 150 volts per gap), sufficient to start the gaps, which continue to operate in a normal manner. The resistance in this circuit is, by the way, sufficient to keep it from causing a tone effect.

*See PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, Volume 1, 1913.

The small box at the rear of the set contains the choke coils: a closed magnetic (iron) circuit wound with two coils, one of which is connected in each side of the line, and having a total inductance of about 40 henries. Placed beside this is the primary condenser, consisting of aluminum plates in oil, contained in an oil-tight steel tank, and having a capacity of about 0.006 μf.

The connectors accompanying this set, one of which is shown leading to the key at the right, consist of two stranded silk-covered wires, sewn in a thin leather strap and terminating, when convenient, in small so-called stage connectors. There are two of these from the key to the panel, one from the receiving set to the panel and one from the generator or line to the panel.

A detailed photograph of the key is shown in Figure 16. The pair of contacts attached to the key lever at the back, and insulated from it, are led to the antenna binding post thru a piece of Belden braid. The upper adjustable contact is connected

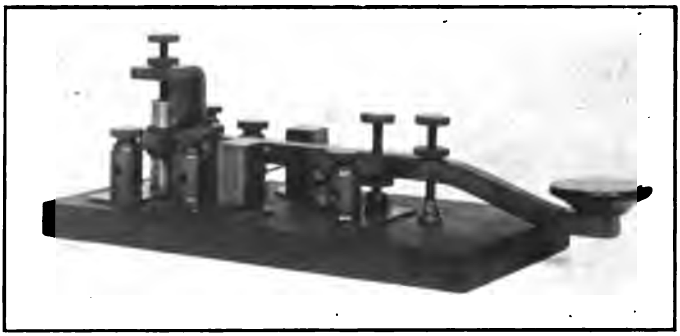

FIGURE 16

to the antenna side of the transmitter; the contact on the base to the antenna side of the receiver. Thus the key acts as an antenna transfer switch when operated. The spring contact, which, unfortunately, is concealed in the photograph behind one of the trunnion posts, opens the starting circuit as described above. This key, which is virtually a break-in key, is made practicable by the low potentials developed with these sets. In one instance, with a current of 3 amperes in an antenna of which the natural period was 540 meters, and which was working at 1,000 meters, the R. M. S. potential, observed with an electrostatic voltmeter between the top of the coupling coil and the ground, was 375 volts. This set will put 2.7 amperes into the two-wire vertical antenna referred to above, at 500 meters, and nearly 4 amperes into a large flat-top antenna of which the natural wave length is 540 meters, when working at 1,000 meters.

All metal parts of this set are black-oxidized, the box is dead black oak, the name-plate black-oxidized with white lettering.

ONE-SIXTH-KILOWATT AEROPLANE SET

Figure 17 shows a ⅙-kilowatt aeroplane set. The case is white pine, and is only a temporary arrangement, to be used until we secure something more suitable. On the right will be seen the complete receiving set, consisting of the tuner, variable

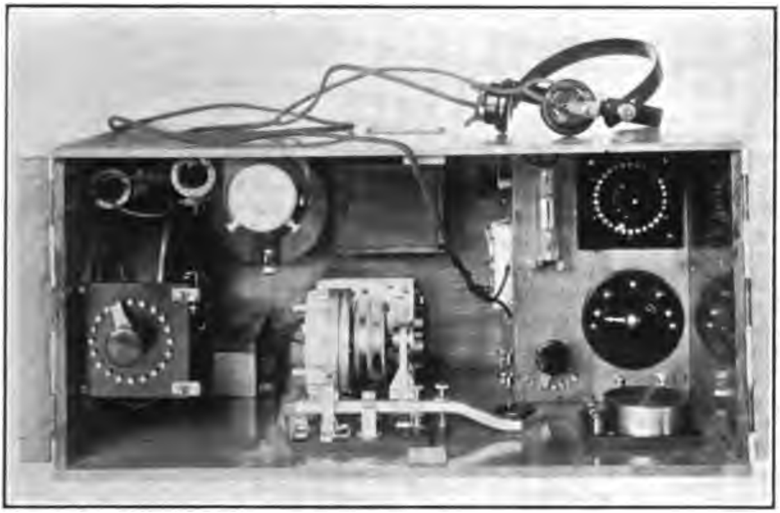

FIGURE 17

condenser, stoppage condenser, audion, audion potential battery with switch, audion heating current rheostat, and audion heating current switch, all mounted as a removable unit. In front of the receiving set will be seen the chopper, which consists of a buzzer, the armature carrying an insulated contact which breaks up the sustained oscillations into audible groups.

The key, of the break-in type described above, is made largely of aluminum, and weighs 12 ounces (0.35 kg.). Details of the key are shown in Figure 18. Behind the key is the gap (Figure 19), embodying the same phosphor-bronze diafram used in the standard gaps, but constructed principally of aluminum castings, weighing complete 2.5 pounds (1.1 kg.). Behind the gap is a cast aluminum frame, holding two mica condensers (Figure 20), one of which is the primary condenser, the other the starting circuit condenser. The starting circuit inductance is seen behind the radiation meter, the starting circuit resistance in the upper left-hand corner. To the left-hand side of the

FIGURE 18

box is secured the coupling coil (Figure 21), wound with number 16 double-cotton-covered, shellacked wire* on well varnished wooden forms, and provided with switches to vary both the primary and secondary inductance; which weighs 2 pounds, 6 ounces (1.1 kg.). The small iron-core choke coil is behind this. The small box above the condensers contains the audion heating

FIGURE 19

FIGURE 20

* Diameter of number 16 wire = 0.051 inch = 0.129 cm.

battery, which consists of one of the ordinary large 3-cell flashlight batteries. Spring binding posts are used almost altogether, as they would seem less likely to become loose from vibration. The box complete weighs 31.5 pounds (14.3 kg.).

The generator (Figure 22) accompanying this set is a small 3,300 R. P. M. direct current machine, giving 350 volts on no load, and 150 volts, and 1.2 amperes at its working point. It

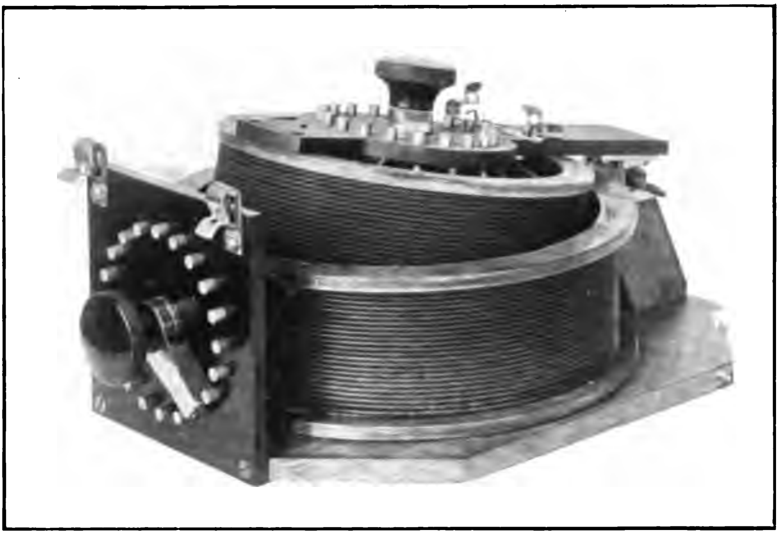

FIGURE 21

weighs 15 pounds (6.8 kg.). It is driven by the wind which operates a small aluminum air propeller mounted on the end of the generator shaft, and connected to the generator thru a centrifugal clutch. The clutch keeps the generator at its proper speed when the aeroplane speed is 50 miles (80 km.) per hour, or beyond. The entire generating unit weighs 20 pounds (9 kg.).

The antenna consists of 50 meters of number 16 phosphor-bronze wire, wound on a ball-bearing wooden reel, and is to be trailed behind. The engine, strut wires, etc., will be used as ground. The weight of the complete outfit is 55 pounds (25 kg.).

We have not as yet made any tests from a plane. The tests of a single-gap set referred to previously in this paper were made with this set. The inductance, capacity, and radiation resistance of the above aeroplane antenna were calculated, the latter by

Dr. G. W. Pierce, and a similar artificial antenna was made up. The radiation current was from 1.5 to 2 amperes, or about the same as in the test referred to above.

The hydrogen for these sets is supplied compressed to a high pressure in steel tanks. The tanks for the panel set are approximately 6 inches (15 cm.) in diameter, 5 feet (1.5 m.) long,

FIGURE 22

holding 50 cubic feet (140 liters) of gas, while those for the aeroplane set are 1.5 inch (3.8 cm.) in diameter and 6 inches (15 cm.) long, holding 1.5 cubic feet (4.3 liters) of gas. Altho the hydrogen plays a necessary part in the action of the gap, it must go thru a complete chemical cycle of some sort, as it does not appear to be consumed; the writer having run a carefully sealed gap well over ten hours without renewal. The tanks are necessary only to supply gas lost thru any small leak that might develop.

The Chaffee Gap seems on the whole to have a wide range of commercial and laboratory applications. In the laboratory its use would include the production of sustained oscillations for the measurement of radio frequency inductance, resistance or capacity, and of dielectric and magnetic hysteresis at radio frequencies. It seems to be eminently fitted for short distance radio telephony, and its range can undoubtedly be increased when a suitable controlling device or transmitter is found. When used as a radio telegraph transmitter, it has the advantages of lightness, extremely low potentials, absolute quiet, one wave, adaptability for beat reception, and, in the rotary type, exceptionally high efficiency.

Since writing the above portion of the paper, I have discovered that alcohol vapor can be substituted for hydrogen in the stationary gaps with great success, if the alcohol is fed into the bottom of the gap chamber thru a ¼-inch (6 mm.) round cotton wick from a small oil cup of the ordinary wick type. The carbon seems to distil off around the wick, and form a light flaky soot—which can be cleaned out occasionally. The electrodes remain free from soot, which was not the case when alcohol was dropped in from above, and enough carbon did not collect in a twenty-hour continuous run (key down) to interfere with the operation of the gap. The gap sometimes starts with a slight explosion, but operates normally and without waiting. It uses about 2 c. c. of alcohol per hour. This, of course, adds considerably to the commercial value of the apparatus, as hydrogen is sometimes hard to obtain.

In conclusion, I wish to thank Professor George W. Pierce, whose kindness has enabled me to do a large part of the development work connected with these sets in the Cruft Laboratory of Harvard University.

SUMMARY: The construction of a commercial Chaffee gap (copper and aluminum electrodes in hydrogen) is described. The use of such gaps in connection with "starting" and "tone" circuits for the production of sustained waves modified into groups of audio frequency is considered. The phenomena are illustrated by Braun tube oscillograms. Impulse excitation is obtained.

The construction and operation of a ¼-kilowatt panel set and a ⅛-kilowatt aeroplane set of this type are given in detail, together with performance data.

DISCUSSION

John L. Hogan, Jr.: It is interesting to compare the two types of heterodyne response described by Mr. Washington and Dr. De Forest. The base note produced in the heterodyne receiver when listening to radiation from a well adjusted Chaffee arc, is stated to be purely and regularly musical, but to have a slight hiss overlaid upon it. The pitch is constant, in spite of the fact that the wave lengths used were comparatively short and that, consequently, an extremely small percentage change of wave frequency would produce a large variation in heterodyne-tone. The sound produced in the heterodyne receiver when listening to radiation from "quenched-arc" set, such as described by Dr. De Forest, is said to be a strong hiss. Presumably the successive wave trains are of approximately the same persistence in the two cases, and presumably the group or discharge frequency may be made approximately the same in either the Chaffee or de Forest arrangements.

This brings us to consideration of an explanation which has been given to describe just such heterodyne-tone phenomena. It appears that when wave trains occur at a group frequency which is a comparatively large fraction of the wave frequency, a pure heterodyne-tone will be produced if the successive groups have the proper phase relation. If the first half-wave of the second group coincides in phase with the third, fifth, seventh, ninth, etc., half-wave of the first group, and if a similar relation exists between the third and second group, and between the fourth and third, etc., the result will be a pure sustained wave having a boundary curve the amplitude of which changes slightly at the group frequency. The main energy of the wave is purely sustained and this portion results in a pure heterodyne-tone. The slight amplitude variation sets up irregularities which cause the overlaid hiss described by Mr. Washington. Phase conditions of this sort seem to be secured in the Chaffee arrangement, when each wave train is "triggered off" by reaction from that which preceded it.

In the case of the "quenched arc," where no provision is made for phasing up successive wave trains, the high group frequency results in groups of waves which overlap each other and which have random phase relations. Sometimes the new group destroys partially or totally the effective energy of that which preceded it, and sometimes the two energies are added.

The constantly varying phase of the resulting antenna current causes an irregularity in the beats produced at the heterodyne receiver, and the signal sound, altho loud, is hissing and not musical.

The comparison outlined above forms an interesting application of the physical principle that regularity of impulse application, as regards time, is essential if true musical tone of the impulse frequency is to be produced. Much the same effect has been noticed in connection with maintaining the tone quality of signals produced by spark transmitters.

Lee De Forest: Concerning the paper by Mr. Washington, it may be of interest to state that I have been working for some time on an arc in air between two flat tungsten electrodes three-quarter of an inch (1.8 cm.) in diameter, the circuits being practically the same as those used by Mr. Washington and Dr. Chaffee. The electrodes are clamped into ordinary aluminum cooling flanges. As far as my measurements go, I found very marked similarity between this arc and the one in the Chaffee gap. The efficiencies were also very much like those Mr. Washington described. In the matter of sustained radiated waves, however, not having had much experience with the Chaffee arc, I was much surprised to learn that one got a clear note from it in the ultraudion receiver. With the tungsten quenched arc transmitter one does not get a clear note, but a very loud hissing noise like escaping steam, or like that from a tikker. This would seem to show that the radiation from the antenna energized from the Chaffee arc is much more nearly continuous than when energized by the quenched arc with tungsten electrodes in air.

Benjamin Liebowitz: Mr. Washington's paper is of special interest to me because it illustrates the fact that, to obtain high efficiencies with arc oscillators, a rapidly responsive generator with a sharply falling voltage characteristic is necessary. The reasons for this were explained in a paper published not long ago in the "Physical Review,"[1] in which I showed that if the arc characteristic "with oscillations" is an equilateral hyperbola, (as is approximately the case, generally), and if the generator voltage is constant, the efficiency cannot exceed 50 per cent. I showed also that this efficiency limitation could be overcome by the use of a generator with a sharply falling voltage-current characteristic, provided the response was sufficiently rapid.

[1] December, 1915.

The truth of these statements can be seen from the following graphical analysis: The relation between mean arc voltage (P) when the arc is oscillating, and mean arc current (x_m) is, as already mentioned, approximately an equilateral hyperbola in most practical cases, i. e., $P x_m = \text{constant}$. But, since the pulsations in the supply current are small, due to the large series inductance, the product $P x_m$ gives the average rate at which power is drawn by the arc.[2] Hence, arc oscillating systems tend to draw power at a constant rate, so far as variations in the mean supply current are concerned. This is illustrated by Curve III of the accompanying curve-sheet. The *useful* power supplied to the system, however, is very variable. Let E be the generator voltage, assumed constant, and R the resistance of the entire supply circuit, exclusive of the arc. Then the average useful power supplied is $E x_m - R x_m^2$, since the pulsations in x are small. For the total power input is $E x_m$ and the losses are $R x_m^2$. It should be noted that the losses in the arc are not included in $R x_m^2$, for the arc resistance drop is included in the mean arc voltage, P. The graph of the total power is Curve I, and of the useful power is Curve II.

For operation, useful power supplied must equal power drawn by arc, i. e., the possible operating points are the intersections r and r', of curves II and III. If we could operate at r', we should have an efficiency of $\frac{s' r'}{s' p'}$, since $s' r' = \text{power}$ drawn by arc, and $s' p' = \text{total power input}$. At r however, the efficiency is $\frac{s r}{s p}$. In other words, a given arc output (including arc losses) can be obtained at two values of supply current, one below $\frac{1}{2} \cdot \frac{E}{R}$, the other an equal amount above $\frac{1}{2} \cdot \frac{E}{R}$; and operation at the low value of current would give high efficiency, at the high value, low efficiency. But operation at the low current is unstable, because if anything should happen to decrease the current ever so slightly, the power drawn would exceed the useful power supplied and the arc would go out.

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[2] Average power $= \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} e x \, dt$. But since x is nearly steady and equal to x_m, this becomes $\frac{x_m}{t_2 - t_1} \int_{t_1}^{t_2} e \, dt$. But $\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} e \, dt = \text{average of } e = P$, hence Average Power $= P x_m$.

It follows that we must operate with mean supply currents equal to or greater than $\frac{1}{2} \cdot \frac{E}{R}$. If by suitable adjustment, the point K were brought into coincidence with n, the equilibrium would be neutral and the efficiency would be a maximum,

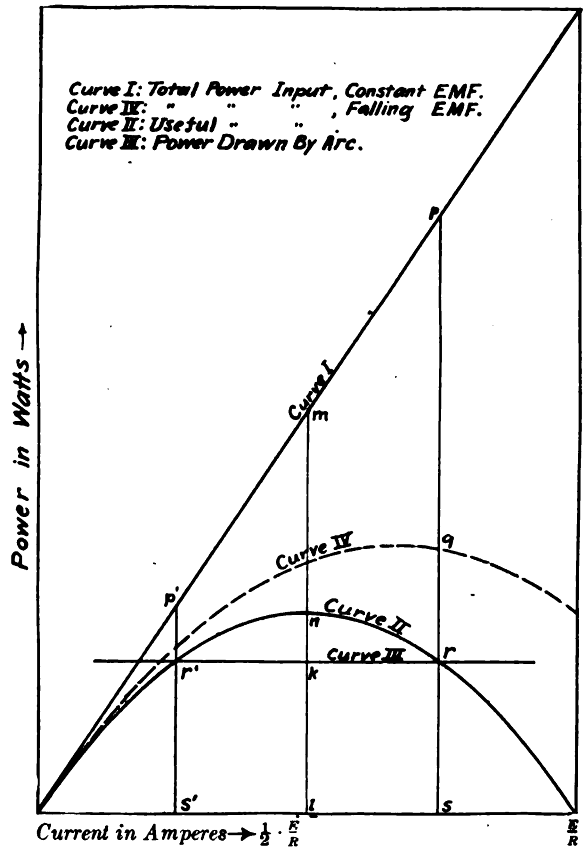

FIGURE 1

viz: $\frac{ln}{lm} = \frac{1}{2}$. Hence it follows that if the generator e.m.f. is constant and the arc characteristic is an equilateral hyperbola, the efficiency cannot exceed 50 per cent. It should be noted that the losses in the arc itself are not included, a fact which will more than counterbalance such departures from the equilateral hyperbola law which may exist in practice. We are on the safe side, therefore, in saying that the efficiency cannot exceed 50 per cent.

Suppose, now, that the impressed e. m. f., instead of being constant, falls off linearly with increase of current, i. e., let the generator voltage be $E-h\,x_m$, and let the resistance of the supply circuit now be R'. Then the useful power supplied is $(E-h\,x_m)\cdot x_m - R'x_m^2 = E\,x_m - (R'+h)\,x_m^2$. If we choose R' and h so that $R'+h=R$, the original resistance of the supply circuit, then the useful power supplied will have the same graph as before: viz: Curve II. The power input, however, will now be $E\,x_m - h\,x_m^2$, whose graph is Curve IV, and the efficiency when operating at r becomes $\frac{s\,r}{s\,q}$ instead of $\frac{s\,r}{s\,p}$. By letting h approach R and R' approach zero, curve IV can be made to approach Curve II and the efficiency (exclusive of the arc) can be thus brought as close to 100 per cent. as desired.

Hence, by using a generator with a sharply falling voltage characteristic, the efficiency limit of 50 per cent. can be overcome. The voltage changes of the generator, however, must follow the current changes very rapidly, i. e., the generator must be quickly responsive, for if the current ever falls below the critical value $\frac{1}{2}\frac{E}{R'+h}$, a very short time is sufficient for extinction.

The results of this analysis appear to be contradicted by the high efficiencies obtained in some of the large Poulsen stations, where efficiencies above 60 per cent. have been measured. The discrepancy may be due to a very marked departure of the arc characteristic from the equilateral hyperbola law, or to experimental error. That the departure from said law, however, should be sufficient to more than counterbalance the arc losses, seems very unlikely. The discrepancy, on the other hand, seems too large to be attributed to ordinary experimental error. Hence we are led to seek something peculiar about the circumstances of the measurements.

This peculiarity, I believe, lies in a hitherto unsuspected variation of antenna resistance, which is measured with very small current and is tacitly assumed to be the same at very large currents.

The potential gradient in the soil in the neighborhood of a large antenna is very minute at measuring currents, so that, if the soil conduction is due to moisture, the ground may act as a dielectric at these extremely small gradients, i. e., as an electrolytic condenser. At the higher potential gradients due to operating currents, however, there can be no doubt that the soil is a fairly good conductor. Thus there may be substantial changes in the effective resistance due to ground losses in passing from measuring currents to operating currents. The same may be true to a certain extent of the surrounding dielectrics, which Miller[3] has just shown to play such a prominent part. I submit, therefore, that the efficiencies of our large stations are, at the present time, unknown quantities, because we cannot assume the antenna resistance measured at very small currents to be the same at very large currents, without further proof.

[3] "Effect of Imperfect Dielectrics," Bulletin Bureau of Standards, March 20, 1916.

(Further Discussion on "Experiments at the U. S. Naval Radio Station, Darien, Canal Zone" By Louis W. Austin)

ON TELEPHONIC MEASUREMENTS IN A RADIO RECEIVER

COMMUNICATED BY

J. Zenneck

(Professor of Experimental Physics, Technische Hochschule, Munich, Germany)

Attention has already been called to some difficulties connected with the interpretation of the audibility factor. The following general remarks on the question of telephonic measurement of the received current may be of interest altho I am well aware that they do not point out anything new.

1. THE MEASUREMENT OF THE AUDIBILITY

The current in the detector circuit generally is a pulsating current, the frequency of which is identical with the group-frequency produced in the transmitter or the receiver. The movement of the telephone diafram is determined by the *A. C.* component of this pulsating current; only this component therefore can be determined by any telephonic measurement. This *A. C.* component or audio-current may be assumed at first to be sinusoidal.

The idea in measuring the audibility is to measure the amplitude of this audio-current; but not to measure it in amperes but in an arbitrary unit, namely that amplitude which just permits the individual observer to distinguish between dots and dashes. Accordingly the audibility is defined as the ratio of the amplitude of the actual audio-current to the amplitude just permitting distinguishing between dots and dashes.

This indeterminedness of the basic unit implies a serious difficulty when audibility measurements have to be made by different observers or by the same observer at different times. The unity may be different for different measurements. The amplitude which just enables one to distinguish dots and dashes is different for different individuals, and, for the same person, depends on physiological and psychological conditions. It will certainly be smaller when, apart from the signals, the telephone is absolutely quiet, than when continuous strong noises are produced by strays in the telephone. In these two cases, if the audio-currents due to the signals were exactly the same, in the latter case a much smaller audibility would be measured than in the former. Therefore the plain statement, that for a special transmitter and receiver an audibility of 200 had been measured, does not mean much for the measuring physicist, important as it may be for the installing engineer.

The following method for measuring the audibility is generally adopted. The telephone is shunted by a non-inductive resistance R, which is so adjusted as to make dots and dashes just distinguishable. How accurately this critical resistance can be measured largely depends on the skill and experience of the observer. The main disadvantage is that the disappearance of a gradually diminishing tone and not a sharply defined minimum, as is obtained with the A. C. Wheatstone bridge, has to be determined.

The critical value of the shunt resistance having been measured, the value of the audibility factor is to be calculated. The amplitude I_o of the audio-current in the telephone is given by the equation

$$I_o = I' \frac{R}{\sqrt{(R+R_t)^2+(2\pi N L_t)^2}} * \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

I' being the amplitude of the audio-current in the branches AA' and BB' in Figure 1, R_t the audio-frequency resistance of the telephone, L_t its audio-frequency inductance and N the group-frequency. The shunt resistance R being removed, the amplitude of the telephone current may be $=I''$. Then according to the definition mentioned above the audibility

$$A = \frac{I''}{I_o} = \frac{I''}{I'} \cdot \frac{\sqrt{(R+R_t)^2+(2\pi N L_t)^2}}{R}.$$

In order to make

$$A = \frac{\sqrt{(R+R_t)^2+(2\pi N L_t)^2}}{R} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and therefore only dependent on the constants of the telephone and its shunt, the condition

$$I'' = I'$$

* Assuming that the reaction of the vibration of the telephone diafram on the telephone circuit can be neglected. If this is not the case, the effective resistance R_t of the telephone as well as its effective inductance L_t may also depend on the amplitude of the audio-current and not only on its frequency.

has to be fulfilled; that is, the current in the unshunted branches AA' and $B'B$ ought not to be changed by shunting the telephone. This implies that

(*a*) The radio-frequency current flowing thru the detector must not be affected by shunting the telephone, otherwise the

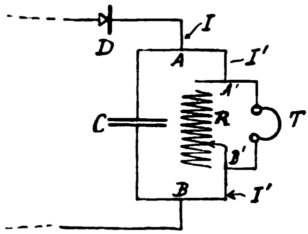

FIGURE 1

audio-current produced by the detector would also be changed. This can be avoided by making the radio-frequency reactance of the condenser C small compared with the radio-frequency impedance of the branched circuit R, T.

(*b*) The ratio of the audio-currents I'' and I' must be independent of R.

This can be done by making the audio-frequency reactance of the condenser C great compared with the audio-frequency impedance of the telephone. Even in this case, when the telephone is unshunted, and much more so, when it is shunted, practically all the audio-current flows thru the branch $AA'B'B$. But if a long wave be used in connection with a relatively high group-frequency, this condition may be contradictory to the condition (*a*).

Then the arrangement of Figure 2 may be employed supposing, however, the audio-frequency impedance of the telephone to be great compared with any value of the resistance R used. The shunt R, therefore, cannot be disconnected, as this would mean making $R = \infty$. In consequence of this, only the *ratio* of two audibilities A_1 and A_2 can be measured, not the audibility itself. According to equation (2)

$$A_1 : A_2 = \frac{\sqrt{(R_1+R_t)^2+(2\pi N L_t)^2}}{R_1} : \frac{\sqrt{(R_2+R_t)^2+(2\pi N L_t)^2}}{R_2},$$

if R_1 and R_2 are the values of the shunt resistance R necessary in both cases to make dots and dashes just distinguishable and if R_1 as well as R_2 are small compared with the audio-frequency impedance of the telephone.

It seems to be very general usage to substitute for equation (2) the relation:

$$A = \frac{R + R_t}{R}.$$

This, of course, is correct only if the audio-frequency inductance of the telephone is very small compared with $R + R_t$, which is

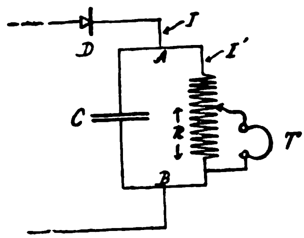

FIGURE 2

not the case in the telephones generally used for radio-telegraphic work. (A. H. Taylor and A. S. Blatterman, PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, 4, 135, 1916.)

2. THE RELATION OF THE AUDIO-CURRENT IN THE TELEPHONE TO THE RECEIVED ANTENNA CURRENT

It may first be assumed that a quenched gap system be used as a transmitter emitting groups of exponentially damped waves of one frequency.

In the first place the amplitude of the audio-current depends on the characteristics of the detector, on whether the detector response depends on the amplitude of the radio-frequency current or on its square or on any other function of it. It depends further very largely on the sensitiveness of the individual detector at the time of the measurement. Therefore, the detector should be calibrated.

But the calibration ought not to be done by means of a galvanometer. This would mean measuring the *D. C.* component of the detector current, and not its *A. C.* component which determines the audibility. This latter is very much affected by the "inertia" of the detector. The inertia of two detectors being different, one of them may give an audibility twenty times greater than the other and still the deviation of a galvanometer produced by these detectors may be the same for the same radio-frequency current.

Also the capacity of the condenser C shunting the telephone (Figure 1) comes into consideration. As soon as the audio-frequency reactance of the condenser is not great compared with the impedance of the telephone, an increase in the capacity of the condenser diminishes the audibility in the same way as an increase in the inertia of the detector.

All these difficulties, as well as those involved in the uncertainty of the unit of audibility and in the variable sensitiveness of the detector, are met by comparing the audibility produced by the incoming signals with that due to a *standard circuit* of the same group-frequency extremely loosely coupled with the receiving antenna. As a standard circuit, a condenser circuit with an instrument measuring the R. M. S. current (such as a sensitive hot wire ammeter or a thermo-element) may be used. How to excite free oscillations of a known and variable initial amplitude and having the natural decrement of the circuit, using a rotating or vibrating switch (Figure 3) or an interrupter (Figure 4) is shown in the figures mentioned. The condenser C is periodically charged to the potential produced by the battery B and regulated by the potentiometer P, and discharges thru the circuit.

By means of this standard circuit, which, in general, is to be tuned to the frequency of the incoming waves, the entire receiving device can be calibrated. The coupling of the standard circuit with the antenna may be kept constant, and, by varying the voltage to which the condenser C (Figures 3 or 4) is charged, the R. M. S. current in the standard circuit varied. Then the audibility corresponding to each R. M. S. value of the current may be measured. Or the oscillations in the standard circuit may be kept constant and its coupling with the antenna (that is, the coefficient of mutual inductance, M, between the antenna and the standard circuit) may be varied. In this way, the audibility is measured as a function of M and of the amplitude of the oscillations induced in the antenna by the standard circuit, this being proportional to M.

If the constants of the arrangement are known, by this method the amplitude of the oscillations, which are set up in the antenna by a distant transmitter can be measured in absolute units or in amperes (*F. Braun*, "Jahrbuch der drahtlosen Telegraphie," **8**, 132, 212, 1914). But for this measurement, the decrement of the standard circuit should be equal to that of the incoming waves. Assuming, for instance, a thermo-detector to be used, the indication of which depends on the square of the current and therefore on the energy of the oscillations, the amplitude of the audio-current (and therefore the audibility) will be different for different decrements even when the energy of the antenna current is the same. Whether or not the decrement of the standard circuit is the same as that of the incoming waves, can easily be checked if, for instance, a resistance is inserted in the antenna, or the antenna is detuned by a certain amount. The decrease of audibility must be the same for excitation by

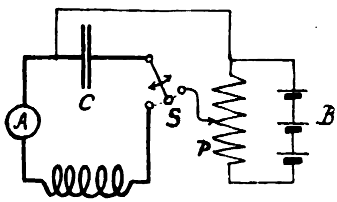

FIGURE 3

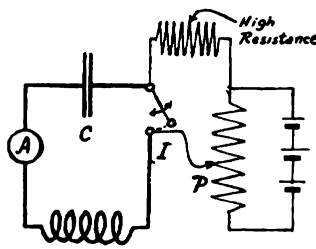

FIGURE 4

the standard circuit and for excitation by the incoming waves.

If the decrements be the same, it is desirable to adjust the amplitude of the oscillations produced in the antenna by the standard circuit so as to give the same audibility as the incoming waves by varying the amplitude of the oscillations in the standard circuit or by varying its coupling with the antenna. Then the E. M. F. induced in the antenna by the incoming waves is the same as that produced by the standard circuit. This amplitude can be easily calculated from the constants of the arrangements and the value of the R. M. S. current in the standard circuit. In this modification, the method is independent of the characteristics of the detector, of the capacity of the condenser in shunt to the telephone, and is also independent of the conditions mentioned in the first section of this discussion. It can be employed regardless of whether or not an amplifier is used.

3. THE RECEPTION OF UNDAMPED WAVES

If the transmitter emits continuous waves and a tone is produced in the receiver by one of the well known methods, generally the amplitude of the audio-current in the telephone is not only dependent on the amplitude of the incoming waves, but also on the device which produces the tone in the receiver. For instance, it is well known that in the beat method, the amplitude of the audio-current depends just as much on the amplitude of the locally produced oscillations as on that of the incoming waves. Therefore there does not exist any definite relation between the amplitude of the audio-current and the amplitude of the oscillations set up at the receiving antenna.

In this case also the difficulty can be overcome by using a standard circuit. But it would be incorrect to use the same type of standard circuit as that described above. The damped oscillations produced in the antenna by such a circuit would be affected by the receiving device (amplifier, beat reception) in quite a different way from the undamped oscillations set up in the antenna by the incoming waves. It is absolutely necessary to use as a standard circuit a continously oscillating system of exactly the same frequency as that of the transmitter. Such a standard circuit can very easily be had by means of an oscillating electron relay, such as the audion, and its R. M. S. current and therefore also the current amplitude can be easily measured by a sensitive hot wire ammeter or a thermo-element. Otherwise the method for measuring the amplitude of the oscillations set up in the receiving antenna by the incoming waves, is exactly the same as that explained in section 2 of this discussion for damped waves. It is still simpler in that no complications are introduced by the damping.

SUMMARY: If the audibility method is to be used for measuring the amplitude or energy of the incoming waves, useful results can be obtained only by making comparative tests with a properly constructed standard circuit for each measurement, or at least for each set of measurements.

ARC OSCILLATIONS IN COUPLED CIRCUITS*

By

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CHARACTERISTIC CURVES

Before entering upon a description of the phenomena in coupled circuits, it may not be entirely useless to review briefly some of the arc phenomena in single circuits and to recall the usual method of studying them.

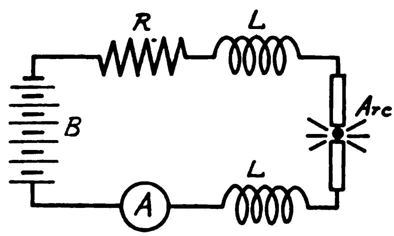

FIGURE 1

The energy is usually supplied from a D. C. source of several hundred volts thru a resistance and a large inductance. The inductance prevents the radio frequency oscillations from going into the battery or dynamo circuit and tends to keep the supply current constant.

If, as in Figure 2, we plot the potential across the arc against the steady current flowing thru the arc for different values of the current, we obtain what is called the "static characteristic" of the arc. The slope of the curve, or the value of $\frac{dv}{di}$, is negative and the characteristic is said to be "falling." The fall of the curve is much more abrupt when the arc is immersed in hydrogen or some hydrocarbon gas.

If, now, we replace the battery of Figure 1 by an A. C.

*Presented before the Boston Section of The Institute of Radio Engineers, January 27, 1916.

source, then the terminal potential and the current are functions of the time, and the instantaneous values of v and i do not have the same relation to one another as the relation found from the

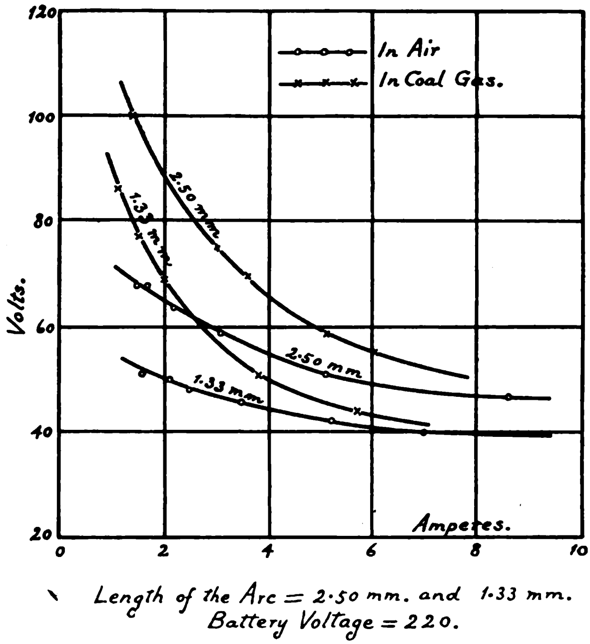

FIGURE 2—Static Characteristics

static characteristic. The curve of v against i with the alternating impressed E. M. F. has been called "dynamic characteristic" by Professor H. Th. Simon.[1]

Professor Simon explored this by means of a Braun tube arranged so that the cathode ray pointer was deflected in the horizontal direction by the current and in the vertical direction by the potential difference. The diagram that he obtained with the alternating impressed E. M. F. is a closed curve of the form of Figure 3, and shows a phenomenon called "arc hysteresis."

While the P. D. is going up from zero to the value corresponding to the point a, there is a small current flowing, but at a the current begins to increase very rapidly while the P. D. drops and the spot on the screen comes to the point b along the curve ab. During the succeeding decrease of the current the spot does not

[1] H. Th. Simon, "Phys. Zeitschr." VI, p. 297, 1905. "Phys. Zeitschr." VII, p. 423, 1906.

follow back the path ba, but the P. D. remains much lower as represented by bc. From the point c the current and voltage drop almost linearly to zero and then reverse, so that a symmetrical curve is traced in the third quadrant.

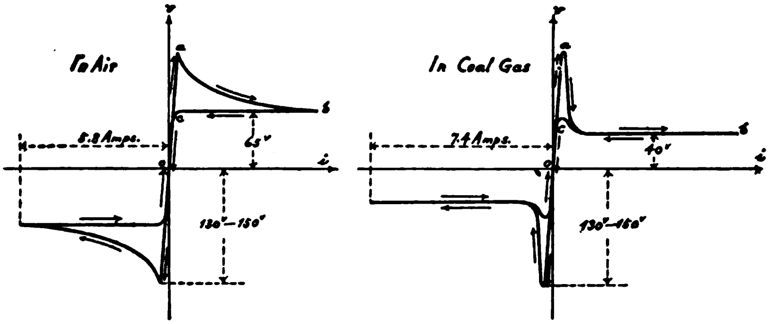

FIGURE 3—Arc Hysteresis Curves

In 1900, Mr. Duddell[2] showed that a D. C. arc gave out a musical note when it was shunted by a condenser and inductance. He gave as one of the necessary conditions of oscillation a negative resistance of the arc or the negative value of $\frac{dv}{di}$.

The most extensive and valuable study of the dynamic

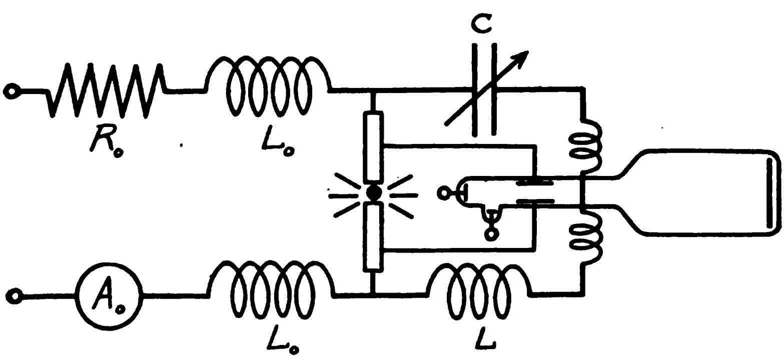

FIGURE 4—Connection of Braun Tube for Taking the Dynamic Characteristics

characteristics of the oscillating arc was made by Simon and his students. The Braun tube arrangement used by him and his followers is as shown in Figure 4.

[2]W. Duddell, "Journal I. E. E.," Vol. 30, p. 232, 1900.

If there were no oscillations, the current thru the arc, i_0, would be nearly constant. The condenser discharge thru the arc tends to superpose a sinusoidal current and make the current pulsating. So long as i_0 is larger than the amplitude of pulsation, there is no extinction of the arc and the oscillation is called an "oscillation of the first type." The oscillation of this type is generally obtained in musical arcs.

When the fluctuation becomes larger than i_0, there will be a duration of no current and the arc will be extinguished for a moment. If the arc extinguishes, a constant current i_0 will flow into the condenser and charge it up until its potential becomes sufficiently high to cause the next discharge across the arc gap. This is called the "oscillation of the second type" and is most readily obtained in practice at radio frequencies, especially when there is any dissimilarity of the electrode material or other electrode conditions.

Since the condenser is charged by a constant current, the

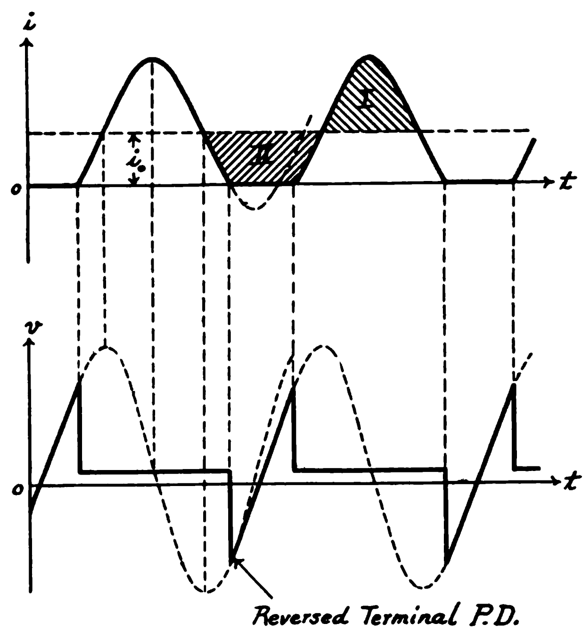

FIGURE 5—Oscillation of the Second Type

current in the oscillation circuit can no longer be sinusoidal with time. The two shaded areas of Figure 5 must evidently be equal, for the electric quantity discharged thru the arc (I) must have been stored in the condenser during its charging (II).

Altho the condenser potential is to vary in a sinusoidal manner during the discharge, as shown by the dotted lines in Figure 5, the terminal P. D. of the arc is never harmonic, but it remains nearly constant while the arc is burning and becomes equal to the condenser potential at the extinction. During the extinction of the arc, the P. D. goes up along a straight line until the next discharge takes place.

If the supply current i_o is small and the capacity of the condenser comparatively large, then a longer time will be needed to charge up the condenser and the consecutive discharges will take place at longer intervals so that the behavior of the arc discharge will resemble more or less that of quenched sparks of one-half cycle each. (Figure 6.)

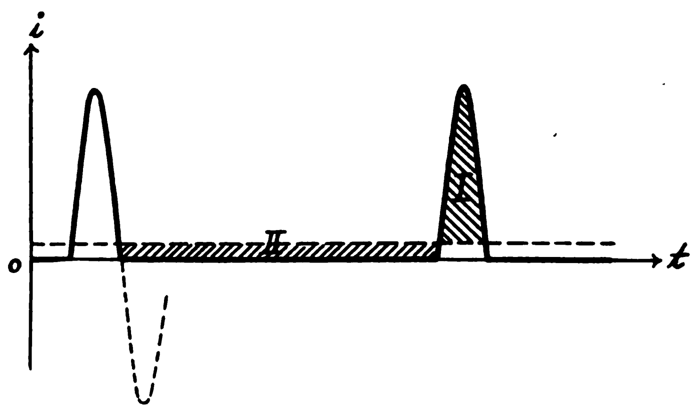

FIGURE 6—Discharges at Long Intervals

If the terminal P. D. which becomes reversed at the extinction (Figure 5) is large enough to cause a discharge across the gap, it will light a small arc in the opposite direction. The oscillation with such a reverse discharge is called an "oscillation of the third type."

The dynamic characteristics observed on the Braun tube screen look as shown in Figure 7.

These diagrams enable us to study the several quantitative relations of the oscillatory arcs and sparks.

The important points which can be noted from the above are that the oscillation is usually non-sinusoidal, and that the frequency cannot be determined by the oscillation constants alone, but varies because of a slight variation of the supply current or the arc condition.

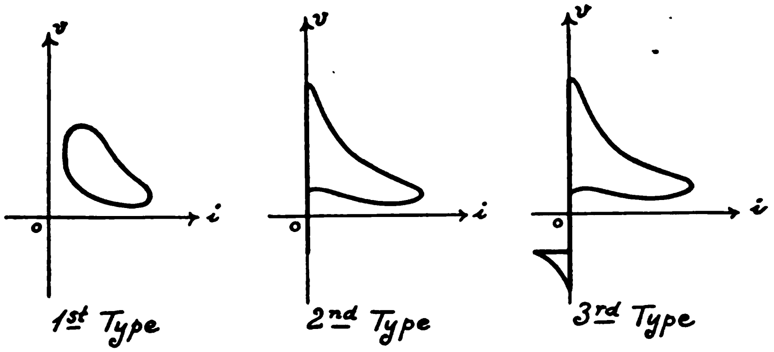

FIGURE 7—Dynamic Characteristics of Arc Oscillations

CYCLIC CURRENT DIAGRAMS

The object of the following experiments is to show, by means of a Braun tube oscillograph, the reacting effect of a coupled secondary circuit upon the oscillation of a carbon arc.

Tho many observations have been made with Braun tube on the arc oscillation, the action of the coupled secondary oscillation has seldom been demonstrated. Jones and Owen's[3] elaborate experiments on musical arcs were made only on the oscillation of the first type with particular combinations of circuit constants, i. e., with a large capacity and a small inductance in the primary and a very small capacity and a large inductance in the secondary, so that the oscillation resistance $\sqrt{\frac{L}{C}}$ was comparatively small in the primary and exceedingly large in the secondary.

Figure 8, Figure 9, and Figure 10 show diagramatically the arrangements of the writer's experiments:

Figure 8 is the arrangement for obtaining the dynamic characteristic with a secondary circuit coupled with the primary oscillation circuit. The arrangements of Figure 9 and Figure 10 are made to obtain what the writer will call "cyclic current dia-

[3] E. T. Jones and M. Owen, "Phil. Mag." 18, p. 713, 1909.
E. T. Jones, "Phil. Mag." 17, p. 28, 1909.

grams," in which the horizontal scale measures the strength of current i, and the vertical scale corresponds to $e = L\frac{di}{dt}$, or the first derivative of the current*.

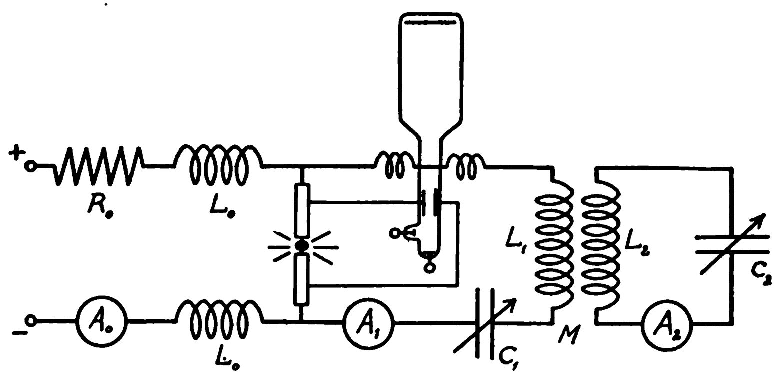

FIGURE 8—Connection for Obtaining Dynamic Characteristic of Arc Oscillations

As this diagram gives us the value of $\frac{di}{dt}$ with respect to i, it is useful for the exploration of the variation of currents and consequently of potentials with respect to time. In order to

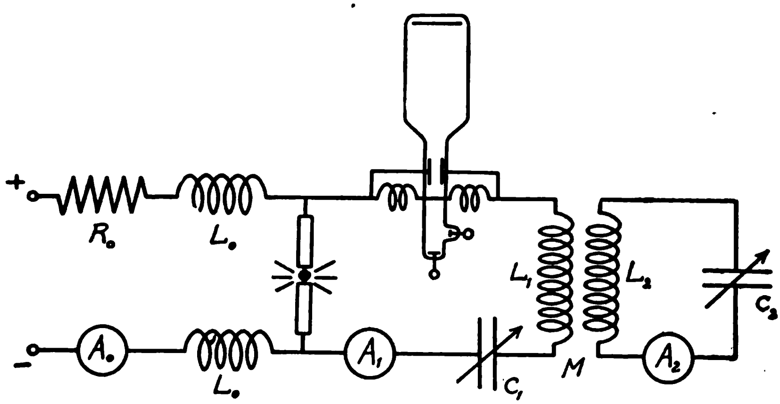

FIGURE 9—Connection for Obtaining Cyclic Current Diagram of the Primary Oscillations

make its use clear, let us take for example the oscillation without the secondary circuit. Figure 11 shows the cyclic current diagrams of the oscillations in single circuits.

*Here L is the small inductance of the current coil of the Braun tube whose terminals are connected to the pressure plates of the tube.

In Figure 12, the curve of i is developed against time by the aid of the corresponding cyclic current diagram of oscillation of the third type. At a the $\frac{di}{dt}$ starts from zero, i. e., the current

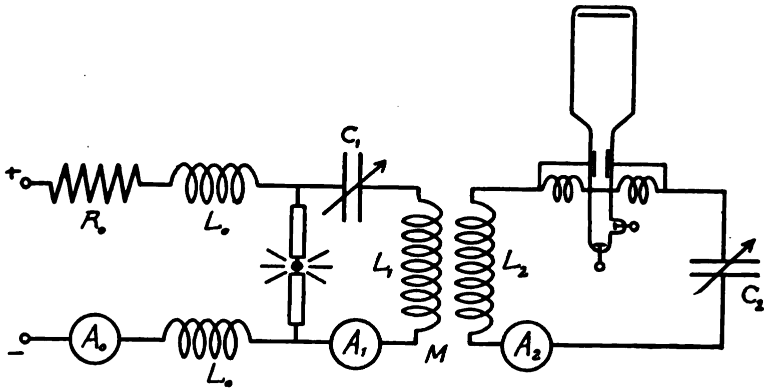

FIGURE 10—Connection for Obtaining Cyclic Current Diagram of the Secondary Oscillations

time curve starts horizontally at a_1 and increases continuously and rapidly. Now $\frac{di}{dt}$ reaches a maximum at b, decreases again to zero at c corresponding to the current-time curve becoming horizontal again at its maximum point c_1. The curve is nearly similar on the other side, but at e, $\frac{di}{dt}$ does not go back to zero,

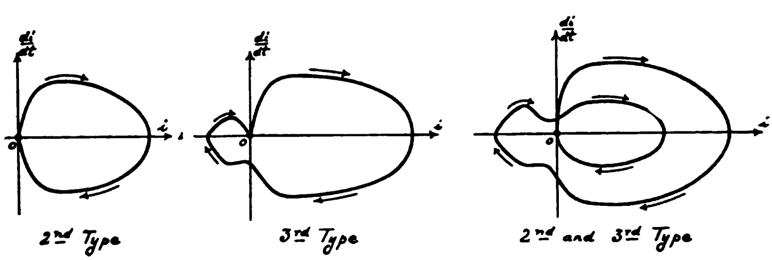

FIGURE 11—Cyclic Current Diagrams of the Oscillations in Single Circuit

which shows that the current-time curve is not horizontal at e_1, but has a certain slope. The curve of i against time becomes again maximum at f_1 and its slope becomes maximum at g_1. h_1 the i-t curve is once more horizontal. The length of time between h_1 and a_2 cannot be determined by the cyclic current diagram, but it can be estimated from the relation of the two shaded areas in Figure 12 being equal. Now that the current

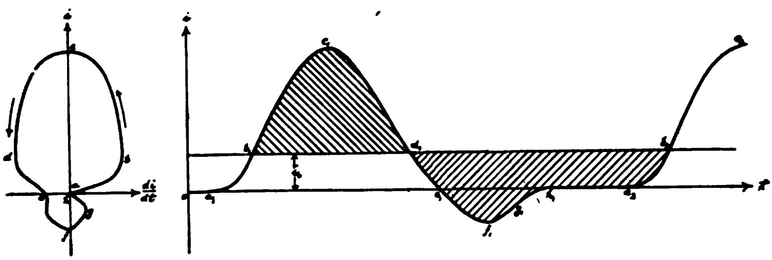

FIGURE 12—Development of i-t Curve from Cyclic Current Diagram of the Oscillation of the Third Type

curve with time is obtained, the potential curve with time can also be plotted by means of the dynamic characteristic.

REACTION OF THE SECONDARY OSCILLATIONS

The arc was lighted between solid carbons, in a glass chamber filled with coal gas, from a battery of 440 volts, with large resistance and inductance in series, to keep the supply current at about 4 amperes. C_1 and C_2 were 0.0297 microfarad each and L_1 and L_2 55 microhenrys each.

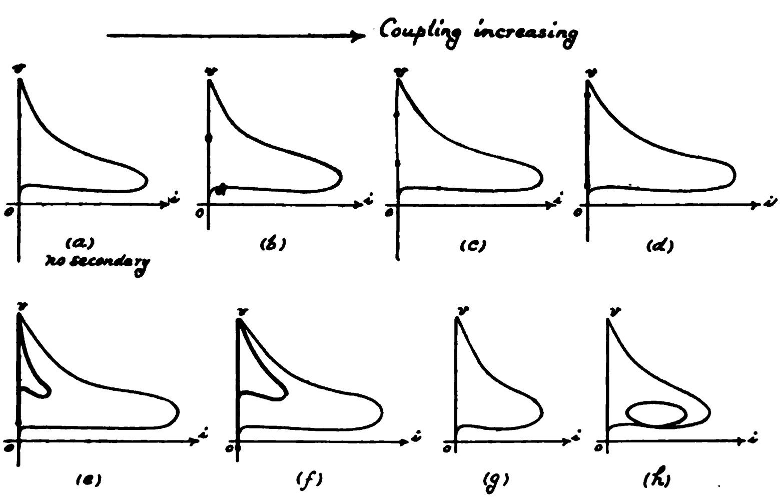

FIGURE 13—Variation of Dynamic Characteristic with Coupling Observed by the Arrangement of Figure 8.

Figure 13 shows the change of the dynamic characteristic of the primary oscil ation obtained by the connection of Figure 8 when the coupling was varied from zero to the closest possible degree.

In (*b*), (*c*) and (*d*) of Figure 13, the brighter portion of the vertical line shows the fluctuation of potential during the charging of condenser, and in (*e*) and (*f*) this fluctuation of potential causes a feeble discharge which is revealed by the appearance of the smaller closed curve. (*f*) changes suddenly to (*g*) and then to (*h*) when the coupling is made very close.

By a slight loosening of the coupling from (*h*), the diagram, especially its loop, shows a tendency to enlarge a little and then changes suddenly to the shape (*f*) without passing the stage (*g*). All three conditions (*f*), (*g*) and (*h*) appeared within a very slight variation of coupling or of the arc condition, and it was sometimes noticed that (*f*) became (*g*) and then (*h*) and suddenly returned to (*f*) again and repeated the cyclic change, while everything was left untouched and unaltered.

Corresponding cyclic current diagrams of the primary and the secondary oscillations were taken by the arrangements of Figure 9 and Figure 10, which are given in Figure 14.

The probable mode of change of E. M. F. and currents with time corresponding to the four cases (*d*), (*f*), (*g*) and (*h*) of Figure

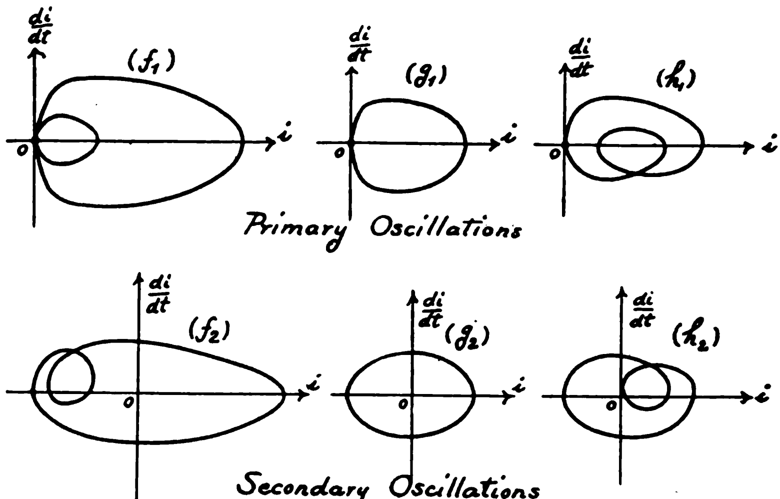

FIGURE 14—Cyclic Current Diagrams of Secondary Oscillations Corresponding to (*f*), (*g*) and (*h*) of Figure 13.

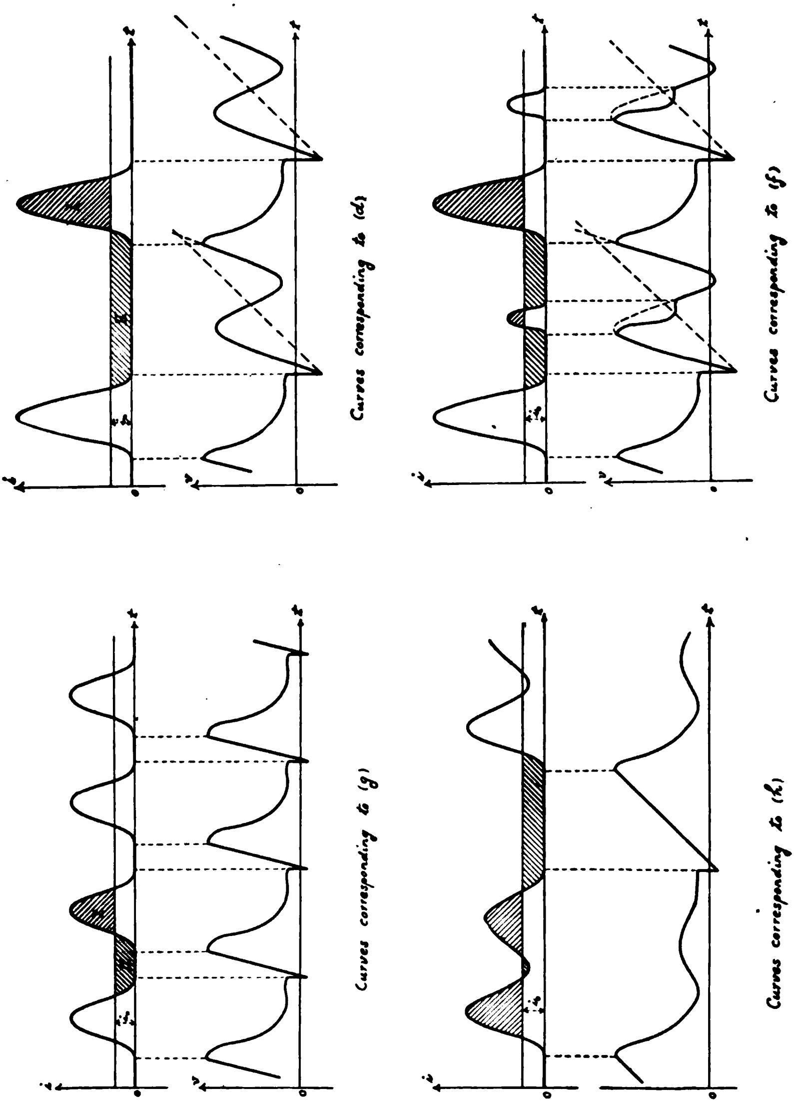

FIGURE 15—Curves of v and i Against Time, Corresponding to (*d*), (*f*), (*g*) and (*h*) of Figure 13

13 is given in Figure 15, which was plotted by the aid of the cyclic current diagrams, Figure 14 and the dynamic characteristics, Figure 13.

In Figure 13 and Figure 15

(*d*) is a case in which a reaction from the secondary oscillation induces a hump of E. M. F. in the primary while the primary condenser potential is going up along a straight line shown by the dotted line in Figure 15, that is to say while the arc is extinguished.

(*f*) is a case in which the reaction not only induces a hump of potential but also causes a separate feeble discharge to take place.

(*g*) The separate discharge is no longer feeble and the reaction makes the similar discharges occur with nearly double frequency.

(*h*) is a case in which a hump is induced by the reaction of the secondary while the current is flowing across the arc and its potential is nearly constant.

EFFECT OF VARYING THE FREQUENCY RELATION

The following is the result of observation with variable secondary capacity. C_1 was kept constant at 0.0297 microfarad and C_2 was varied from zero up to 5,900 micro-micro-farads. The supply current was about 4.2 amperes.

Figure 16 shows the deformation of the dynamic character-

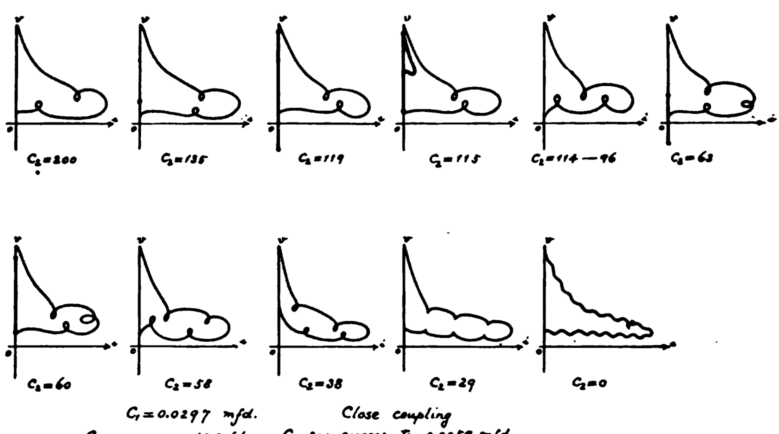

FIGURE 16—Variation of Dynamic Characteristics When the Reaction of the Secondary Oscillations at Higher Frequencies is Inducing Ripples in the Primary Oscillations

istics when the frequency of the secondary circuit was gradually increased.

Figure 17 shows the corresponding variation of the cyclic current diagrams of the primary oscillations.

Following the increase of the secondary frequency, the reaction upon the primary creates many ripples in each oscillation. One of the diagrams of Figure 17 is developed in Figure 18.

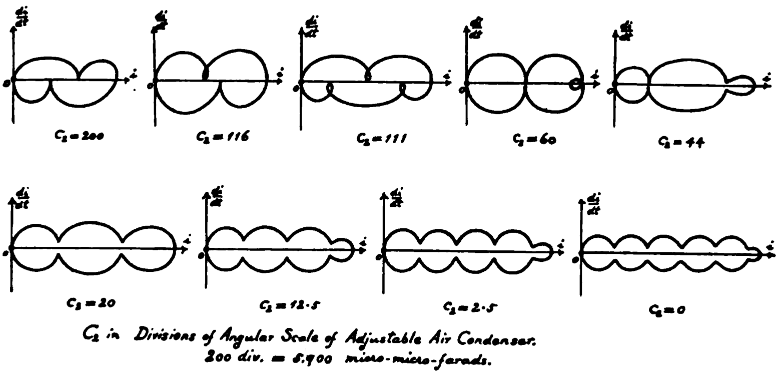

FIGURE 17—Cyclic Current Diagrams Corresponding to Figure 16

The effect of changing the distance between the primary and secondary coils is shown in Figure 19. There is no change of the number of ripples induced from the secondary, but their intensity and phase relation undergo slight change.

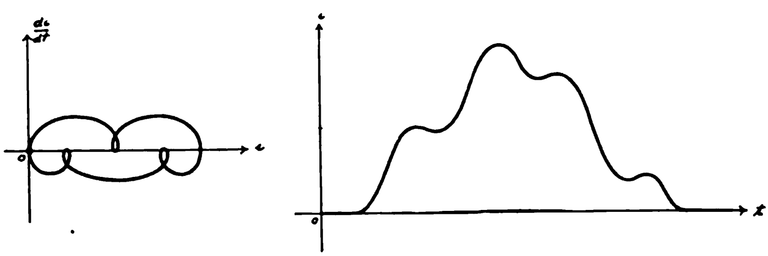

FIGURE 18—Developed *i-t* Curve Showing Ripples

Figure 20 shows the variation of the cyclic current diagram of the secondary oscillation, when its frequency is varied by varying C_2. It shows that the oscillation is not always purely harmonic. It is also plain from Figure 20 that there are several maxima and minima of the intensity of secondary oscillation. This is exactly what the writer experienced with the discharge between metallic electrodes.[4]

Figure 21 gives the results of measurement of the secondary current by means of a hot wire ammeter.

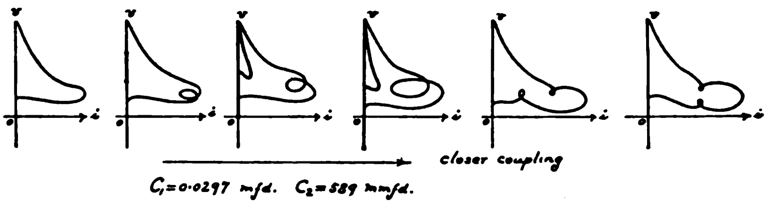

FIGURE 19—Variation of Ripples in Dynamic Characteristic Due to the Variation of Coupling

Another observation, with C_1 varying from zero to 2,750 micro-micro-farads and C_2 from zero to 3,175 micro-micro-farads and a small supply current of 0.43 ampere, proved the existence

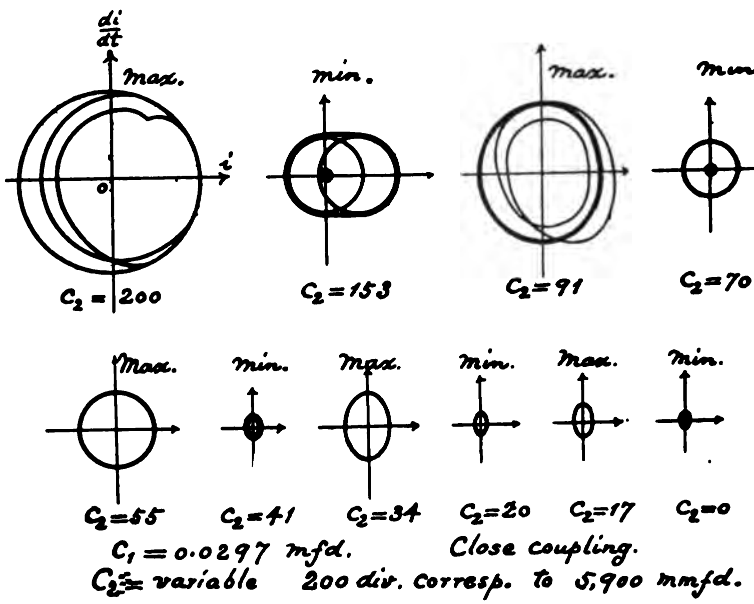

FIGURE 20—Cyclic Current Diagram of the Secondary Oscillation

[4] H. Yagi, "Electrician," Vol. LXXVI, p. 195, 1915.

of the same kind of reaction and also the peculiar fluctuation of the secondary current. (Figure 22).

In Figure 21 and Figure 22 the maxima of the current effect with respect to C_2 occur with regularly increasing intervals.

Let τ_1 be the period of the fundamental oscillation of the primary, or the time interval between two consecutive impulses which are given by the primary to the secondary, and τ_2 the period of the secondary free oscillation; then, when $\gamma = \frac{\tau_1}{\tau_2}$ is an integer, there are maxima of the secondary current. The

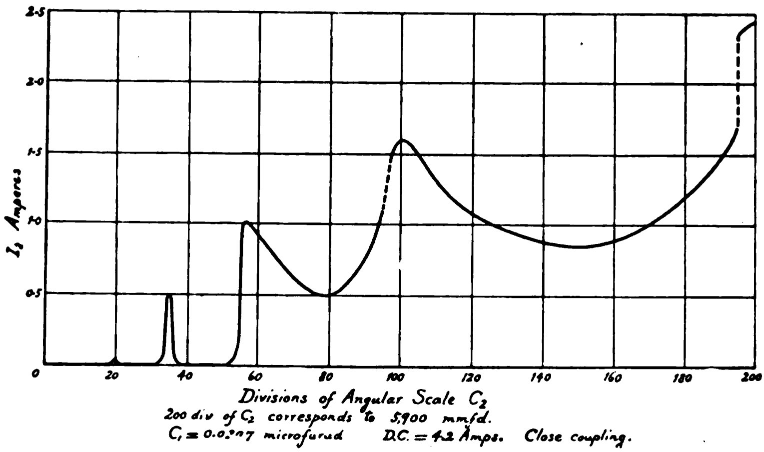

FIGURE 21—Variation of Secondary Current

reasoning is quite analogous to that for the production of sustained oscillation by means of quenched sparks[5], namely, the intensity of the secondary oscillation is the greatest when each fresh impulse from the primary occurs at such time as to be in step with the persistent oscillation already created in the secondary circuit.

As long as the period between two successive discharges in the primary is kept constant, the interval between maxima of Figure 21 and Figure 22 must depend only upon the period of the secondary oscillation which is proportional to $\sqrt{C_2}$.

Figure 22 also shows the dependency of these intervals upon C_1.

It was confirmed by experiments that there can be neither

[5] H. Yagi, loc. cit.

the reaction nor the periodic fluctuation as described, when the primary frequency is larger than the secondary frequency. The dynamic characteristic has shown no ripples and the cyclic

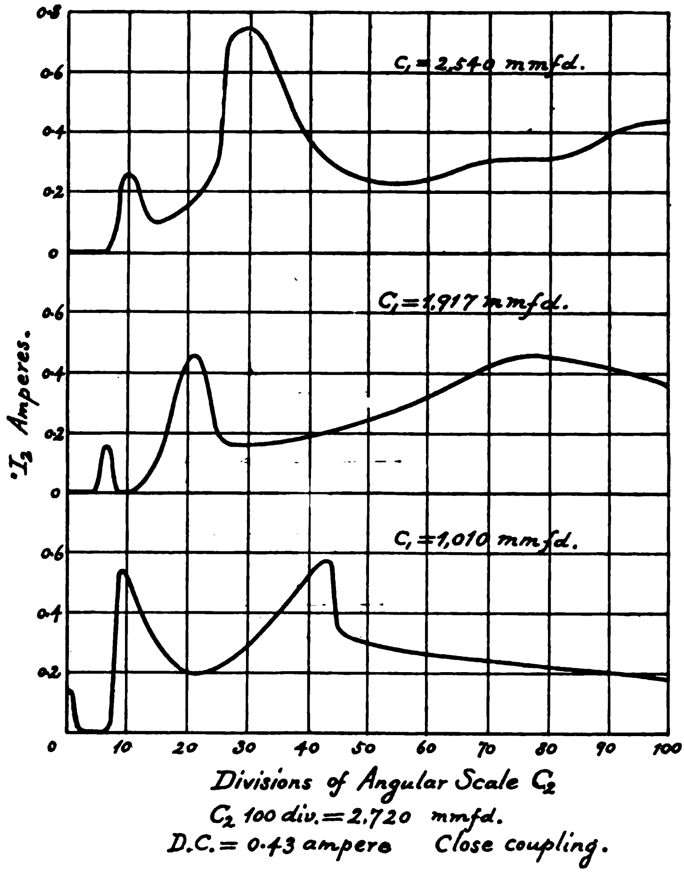

FIGURE 22—Variation of Secondary Current

current diagram of the secondary oscillation was a smooth circle.

When C_1 was further reduced, the arc oscillation of the second type became one of the first type and then ceased to oscillate.

EXPERIMENT WITH SMALL ARCS

In order to bring the carbon arc nearer to a state of spark, a higher resistance was introduced into the supply circuit, which brought the supply current down to less than 0.4 ampere.

C_1 and C_2 were 0.0297 micro-farad each, and L_1 and L_2, 55 micro-henrys each.

Now the arc was very often mixed with sparks, which could be recognized by the following facts.

Figure 23 shows the cyclic current diagrams of the primary oscillation, in which thicker lines correspond to arcs and finer

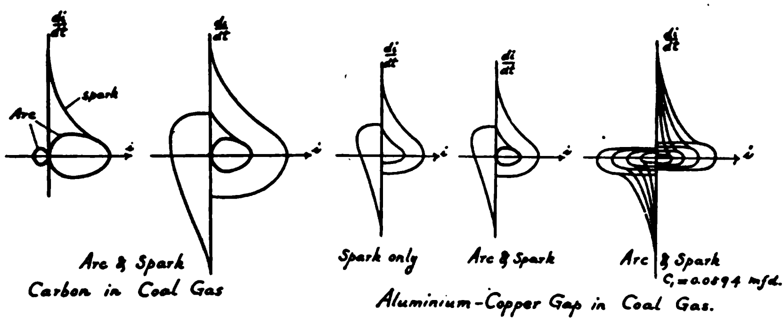

FIGURE 23—Cyclic Current Diagrams of the Primary O cil:ation Showing the Mixed Occurrence of Arcs and Sparks

lines to sparks. The diagrams of metallic arcs and sparks are given for comparison to show the similarity. Spark could generally be noticed by hissing sounds, and, when only sparks occurred, there was no glow of the carbon electrode.

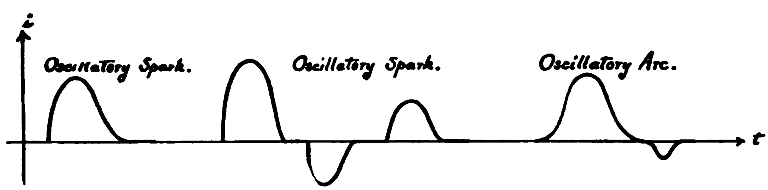

FIGURE 24—Variation of Current with Time in Oscillatory Arc and Spark

In the cyclic current diagram of Figure 23, the initial value of $\frac{di}{dt}$ is very large for a spark and it shows that the current increases very suddenly as shown in Figure 24.

It may be noticed from Figure 23 that, in cases of metalic arcs, the initial value of $\frac{di}{dt}$ is not zero, but has a certain magnitude; in other words, the current curve with respect to time does not start in a horizontal direction.

Figure 25 shows the cyclic current diagram of the secondary oscillation. The cyclic current diagram of a sustained harmonic oscillation is to appear as a circle or an ellipse upon the screen, and Figure 25 shows clearly that sustained oscillations are created in the secondary. The method was found very convenient by the writer[6] for the demonstration of damped and sustained harmonic oscillations.

It may also be seen from Figure 25 that a spark can produce

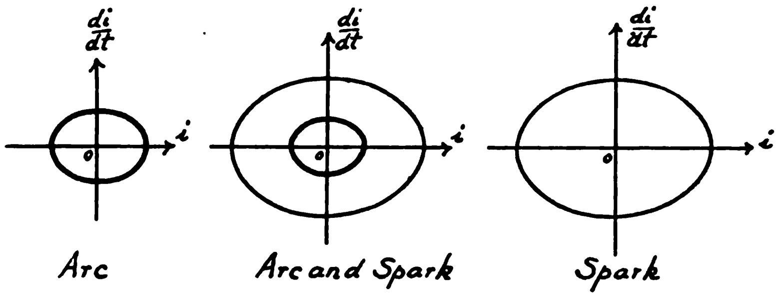

FIGURE 25—Cyclic Current Diagrams of the Secondary Oscillation Produced by Small Arcs and Sparks

oscillations of larger amplitudes in the secondary than an arc under the same conditions.

Many thanks are due to Professor J. A. Fleming for enabling me to carry out experiments in his research laboratory; and to Professor George W. Pierce and Dr. E. L. Chaffee for giving me valuable advice while working out this paper in the Cruft Laboratory, Harvard University.

SUMMARY: 1. When a secondary circuit is closely coupled, its reaction causes variation in the primary oscillations and consequently in the secondary oscillations themselves.

2. The cyclic current diagrams afford a means of studying the variation of current with time, which cannot be easily done by the dynamic characteristics.

3. There are favorable conditions for maximum current effect in the secondary. They depend on the ratio of the frequency of the separate discharges to that of the secondary oscillation.

4. A spark creates more powerful oscillations than an arc of the same current strength, tho the former are not quite as steady, owing to the necessarily higher discharge potential.

The above principles are fully illustrated by a number of experimentally obtained dynamic characteristics and cyclic current diagrams.

[6] H. Yagi, loc. cit.

DISCUSSION

Jonathan Zenneck: Some six years ago one of my students, S. Subkis, made an investigation into the behavior of coupled arc generators along the same lines and using almost the same experimental methods as Professor Yagi. His paper has been published in the "Jahrbuch der drahtlosen Telegraphie," Volume 5, 1911, pages 507 and 545.

The work of Subkis was restricted to audio frequency currents. The present paper therefore goes beyond what Subkis did in dealing with far higher frequencies and therefore approaching much more nearly the practical working conditions.

The method of Professor Yagi, which consists in having the cathode ray beam of a Braun tube plot the derivative of the current with respect to the time against the current itself may prove useful for analyzing the form of radio frequency currents. The question of whether a radio frequency current is sinusoidal or not cannot generally be answered by the inspection of instantaneous photographs on a moving photographic plate, since the phosphorescent spot on the screen of the Braun tube is not bright enough. In this case, the method of Professor Yagi may be employed, making use of the well-known principle of having the curve on the phosphorescent screen repeated every period, thereby furnishing a curve bright enough to give a good photograph permitting analysis of the current curve.

Cyril F. Elwell (by letter): I have read the paper with much interest and the author is to be commended on a very painstaking piece of work. However from the point of view of working installations the very variable factor of the strength of the magnetic field is left out of count and there is no doubt that if the author continues his study, taking account of the strength of the magnetic field, speed of rotation of carbon, arc length, etc., he will delve into a very useful and profitable field. The range of secondary capacities taken was good for the size of arc experimented with, but what I would like to see some light on is the problem of the very large arc on large capacities. It is not easy to obtain a large arc on which to experiment, so that the experiments on a small arc should take into consideration all the variables which have to be taken into consideration in large arcs, in order to throw any light on the large arc problem. Then again factors which would disturb the quality of emitted oscillations in a small arc would be inconsequential in a large one. One of the troubles with the critics of the Poulsen arc is that they base their opinions as to the continuity of the oscillations on home-made arcs, and from the same data decry the possibility of building large arcs, as witness even recent writers who give as their opinion the impossibility of building arcs of 100 kilowatts and upward. In my opinion there is no difficulty in building an arc as large as required, the difficulty being to build an antenna to radiate a useful part of the energy. The radio art is indebted to Mr. Hidetsugu Yagi for his valuable contribution to theory. It is to be hoped that he will continue his investigations and contribute the results in the near future.