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TELEPHONY WITHOUT WIRES

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PREFACE

Soon after the early discoveries of Hertz and Lodge had been turned to practical use by Marconi, and successful wireless communication had been established over appreciable distances, many suggestions were put forward for various other applications of wireless signalling. One of the earliest and most frequently recurring of these was to the transmission of human speech. Time after time during the subsequent development of the Art have various devices been tried with this end in view—with at first but little success. Better results, however, followed as the proper principles became more fully understood. It is therefore somewhat surprising to find the comparatively small attention that is given to the subject in most Text-books on Wireless. Usually it is relegated to one or two concluding chapters.

An attempt has been made in this volume to collect together as much information as possible on the various ideas that have been proposed and experimented with, and to classify them into groupings as far as practicable. In the opening chapters, the simplest, and now historical, methods of speech communication using Induction, or Earth Conduction, as well as Light Wave Transmission, have been briefly dealt with—more with a view to covering all the methods, than from their modern practical utility. In fairness to the inventors of these systems, however, it should be mentioned that these long-despised schemes have of late years again found useful scope of work in the light of recent improvements, and especially under the exigencies of war-time conditions. Following this, speech

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transmission by the customary "wireless" aether waves is dealt with in its various aspects—from the earliest spark systems with their imperfect results, to the modern and eminently successful continuous wave generators such as the Arc and Valve. The problems of Microphonic Control, Reception, and Interference Prevention are dealt with in turn, while the scope of Radiotelephony is discussed in the concluding chapter.

It is hoped that this collection of results achieved may be of some use to students of the subject, and to others engaged in its development, both as indicating how much has already been accomplished, as well as the difficulties encountered, and the possible lines of advance. With this object in mind, the Bibliography of References has been made as complete as possible, and has been classified into the same groupings as the main text. Doubtless this list does not contain every useful reference to the subject, but the author hopes that it will, together with the accompanying text, be of some little assistance to those engaged in the furthering of our knowledge in this interesting branch of Science.

PHILIP R. COURSEY.

LONDON, *March* 1919.

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CHAPTER I

INTRODUCTION

From the earliest times the need for communicating thought has urged itself upon man's notice. The means employed for this purpose have advanced with the progress of civilisation, resulting towards the end of the last century in the development of the Electric Wire Telephone. Wires, however, are liable to breakage, so that intercourse between point and point is delayed, while it is not always possible to erect or maintain them, or even to utilise them for telephonic purposes when they have been erected or laid. Long submarine cables, for instance, are quite unsuitable for the transmission of speech.

The problem before us is therefore the development of the methods of telephony without these connecting wires.

In the early development of the art, however, the results obtained by various complicated electrical methods did not surpass either in effectiveness or range of communication the ordinary transmission of speech by sound waves through the natural media—air, water, etc.—especially when any devices such as the megaphone are used to aid the latter. These methods are of course easily affected by atmospheric conditions—for instance, as a general rule, the distance over which a sound is audible depends upon its intensity, yet, under some circumstances at present not completely understood, there seem to be certain more or less well-defined regions in which sounds cannot be heard, even comparatively near to their source, while at greater distances they can again be heard quite distinctly. The causes of this irregular variation appear to lie in the meteorological conditions prevailing at the time.[1]

Submarine sound signalling installations, often fitted to ships for communication purposes and to help in avoiding collisions in fog and thick weather, utilise some form of sound generator attached to the ship's hull for transmitting the speech or other impulses, and some sound detector under the water surface for receiving them.[2] These methods are capable of transmitting speech over distances of three or four miles when the Fessenden transmitter is employed.[3]

Modern developments have brought about enormous increases in the available speaking range of wireless telephone apparatus until it has now surpassed even the wire telephone in this respect.

The various practicable methods for the wireless transmission of speech that have been proposed from time to time, may be divided up into three main groups :

1. Conduction and Induction methods, employing the conductive connection of the earth or sea ; or the simple magnetic induction between circuits.

2. Photophone and Thermophone methods, employing light or heat waves as the transmitting medium.

3. Wave methods, employing aether waves of the same kind as those used in ordinary modern wireless telegraphy.

Of these three groups, the first two are now more or less historical, while the third includes all the methods employing aether waves as in wireless telegraphy. To this last group belong all the arrangements and proposals properly included in the term MODERN WIRELESS TELEPHONY.

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[1] Reference Nos. 9 and 10.

[2] Reference Nos. 4, 7, and 8.

[3] Reference Nos. 1 and 2.

CHAPTER II

CONDUCTION AND INDUCTION METHODS

The Conduction System

The first transmission of intelligible electrical signals from place to place without the employment of a continuous metallic circuit between the two places takes us right back to the beginnings of wire telegraphy itself, in fact, when Steinheil showed that half of the ordinary electrical circuit between the two stations could be dispensed with by using the earth (or water) as the return conductor. This was long before telegraphy became in any sense the valuable adjunct to commerce that it is to-day,[1] and almost before it had emerged to any great extent from the seclusion of the laboratories in which the original discoveries were made (Fig. 1).

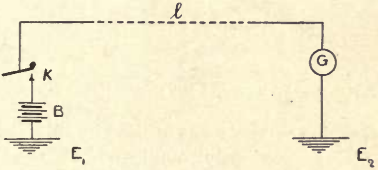

Fig. 1.—Simple Telegraph Circuit with "Earth Return."

The best-known instance in which it was shown to be possible to dispense not only with one wire, but with both of them, occurred in 1842 when S. Morse was arranging some demonstrations of the ordinary electric telegraph (as then known), using wires laid across the bed of the Susquehanna River. Through an accident these wires were broken, but this misfortune led to the discovery of the conduction method of wireless signalling, for Morse immediately set about to devise a plan whereby such accidents could be avoided in future experiments. The result was the arrangement dia-

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[1] In 1838 to be more precise.

grammatically depicted in Fig. 2. P_1, P_2, P_3, and P_4 represent four copper (or other metallic) plates immersed in the river, two on each bank, and connected respectively to the receiving galvanometer G, and to the transmitting battery B, and signalling key K.

These and similar early experiments were all concerned merely with telegraphic signalling, for it was not until about 1876 that the first really successful telephone receiver was invented by A. G. Bell, and the practical microphone transmitter by D. E. Hughes about two years later.[1] Almost as soon as these instruments became available for experimental purposes, however, it was realised that they could be applied to the above conduction method of signalling. In the first place, the great sensitiveness of the telephone receiver to varying currents was utilised by substituting it for the galvanometer previously employed at the receiving station. A revolving commutator, or buzzer and battery, or other source of varying or interrupted currents was used at the transmitter with this arrangement. Thus, for instance, in 1889, F. W. Melhuish and others in the Indian Telegraph Department demonstrated the great superiority of the buzzer and telephone method over the older battery and galvanometer method for signalling across flooded rivers, and other similar places where the maintenance of cables or telegraphic lines proved unusually difficult. Incidentally it may be mentioned that their experiments indirectly became the forerunners of the modern vibratory or buzzer telegraph so extensively used at the present day for military purposes in which its great ability to signal through leaky or broken lines is of the utmost value.

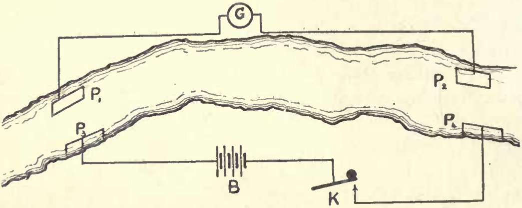

FIG. 2.—Arrangement of "Conduction" Telegraph across a River (S. Morse).

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[1] See Reference 18.

Actual experiments in the transmission of speech by this conduction system had, however, been made prior to this. W. H. Preece in 1882 obtained satisfactory communication across the Solent, though at the same time he found that speech communication was not quite so good as the buzzer telegraph over the same distance. Later experiments, for example, at Loch Ness, and at the Skerries (in 1899), proved completely successful, and speech was satisfactorily and clearly transmitted without any direct connecting wires between the two stations. Fig. 3 depicts the method in outline, and Fig. 4 shows one arrangement by which the separate transmitting and receiving apparatus at each station may be combined together for communications in both directions. The transformer L_1L_2 is used for this purpose much as in a modern wire telephone instrument. The current from the battery B is modulated by the microphone M in accordance with the speech waves, and induces corresponding varying currents in the circuit E_1, T, L_2, E_2, feeble portions of which are picked up by the like arrangement at the receiving station, and there flowing

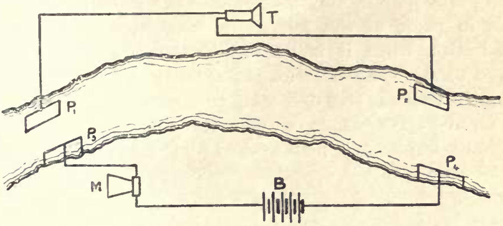

FIG. 3.—Arrangement of "Conduction" Telephone across a River (W. H. Preece).

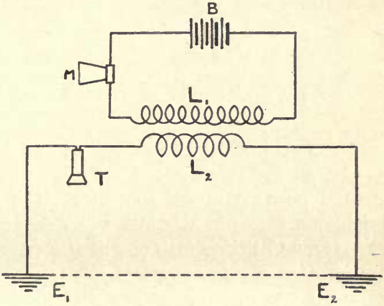

FIG. 4.—Conduction Telephony—Combined Transmitter and Receiver.

through the receiving telephone are heard by the person using the apparatus.

As a matter of fact, however, it has usually been found more satisfactory to retain the transmitter and receiver at each station in separate circuits, so arranged that the transmitting microphone may be put into the circuit of the earth plates in place of the telephone receiver, by depressing a push button when it is desired to speak. The connection scheme used at the Skerries installation is shown in Fig. 5. This installation is still operating to the mainland of Anglesea over an average distance of about three miles, and is the only one of any importance now worked by this method.[1]

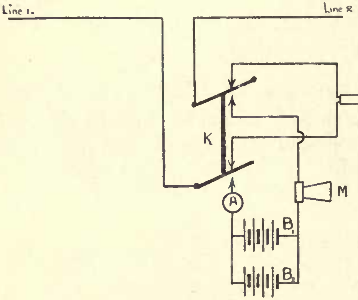

FIG. 5.—Connection Scheme for Conduction Wireless Telephone Installation at the Skerries.

The two line wires running out to the earth connections are led to the terminals of a double pole key K which in its normal position serves to connect the lines directly to the telephone receiver T; but when depressed, it cuts off the receiver, and brings into circuit the "solid-back" microphone transmitter M, and battery B_1B_2.[2] A stand-by telegraph arrangement with morse key and motor-driven transmitting interrupter is also provided in this instance (not shown in above diagram) as a reserve method of communication for use under certain conditions when speech cannot be maintained—such, for instance, as when there is considerable induction by "earth-currents" or other atmospheric dis-

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[1] Reference No. 14.

[2] Two sets in parallel, of twenty cells each, are used on the mainland; and two similar sets, but of twelve cells each only, at Skerries.

turbances which render the circuit "noisy" and drown out the faint speech sounds in the receiving telephones.

The distance over which apparatus of this type is available for successful communication is, on the whole, very limited (as a rule not more than a few miles); although it is probable that the range of effective communication could be considerably increased if the modern telephone relays and amplifiers were employed for receiving purposes.

In many of the early experiments alluded to above, rough laws were determined as to the influence of various factors on the range of communication. The general trend of the conclusions arrived at is to the effect that the energy picked up at the receiving station varies approximately as the distance between the "base" plates at each station; that it is approximately proportional to the area of these contact plates buried in the earth, or immersed in the water, and inversely proportional to the square of the mean distance between the stations.[1] The method would thus appear to be scarcely practicable for distances between the stations greater than from three to four times the length of the "base" employed—that is, from three to four times the distance between the pair of earth plates used at one station.

Considerable discussion has taken place at one time and another as to the true mechanism of the transference of the energy from one station to the other in the above system. The phenomena at the receiving station were at first attributed entirely to the actual conduction of the current from the transmitting station across to the receiver; but it has since been suggested that a by no means negligible portion of the energy passes across by direct magnetic induction from the circuits at one station to those at the other. This view is further supported by assertions often made that the results obtained by this method may be improved and the speaking range increased by placing the wires to the earth plates on poles, thus transforming the transmitting and receiving circuits into a form more of the nature of very open coils.

THE INDUCTION SYSTEM

The above considerations bring us to a discussion of the pure Induction System in which large coils of wire are used

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[1] Reference Nos. 13, 15.

at both transmitter and receiver with no earth connections at either station.[1] For telephonic purposes a microphone and battery are inserted in the transmitting coil circuit, and a telephone receiver at the second station is likewise connected to the receiving coil[2] (Fig. 6).

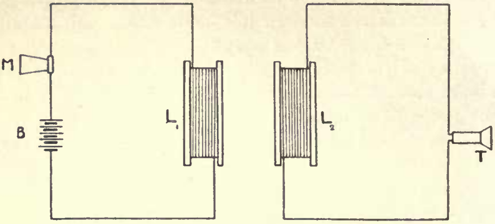

Fig. 6.—Outline Scheme of Induction Wireless Telephone.

The most notable investigator in this field was W. H. Preece, who succeeded in telephoning over a distance of a few hundred yards in 1886, using the induction method, although, as in the Conduction System, much greater distances have been covered using a buzzer transmitter and a telephone receiver for telegraphic purposes by the same method.

Practical Applications

The most important practical application of these systems has, however, been made comparatively recently for the purpose of communicating between the different levels and parts of mines and similar places.[3] The apparatus for this purpose has the advantage of great portability and simplicity in use; while the ranges of communication that are required are comparatively speaking quite short, so that little power is needed. Merely as an example of this application, J. H. Reineke's method may be mentioned.[4] He has proposed a combined conduction and induction method in which use is made of any pipes, haulage cables, rails, etc., that there may be in the locality as a conducting medium between the two stations—one or both of which may be in motion if so desired. For transmission purposes a microphone and battery are

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[1] Reference No. 19.

[2] Reference Nos. 20, 21.

[3] Reference No. 22.

[4] Reference No. 24.

connected in series with the primary of an induction coil, or step-up transformer, one terminal of the secondary of which is put in communication with the pipe, rails, or whatever else may be employed for the purpose ; and the other terminal either left free, or preferably connected to a small insulated counter capacity of wire-netting or similar material. For the receiving station the telephone may be connected between the pipe, rails, or other conductor, and the earth or a balancing capacity ; between two points along the length of the same pipe or rail ; or to a closed coil " induction " type of receiver placed in the vicinity of the pipe-line or conductor. This last arrangement is of special use for movable stations on account of its greater portability. It would seem that the method might possibly be of greater safety in mines than some of the ordinary signalling systems now in use, on account of the absence of high voltages, sparks, etc., which might fire an accumulation of inflammable gas, although difficulties would be experienced in the provision of any suitable calling arrangement for the other station.[1]

Installations on these lines have been employed with some success in collieries when all reasonable precautions are observed. One at the Carolinenglück Pit in which speaking ranges of about a mile have been obtained may be instanced in this connection.[2] An especial feature of these simple methods is their suitability for use by rescue parties in cases of accidents in mines, for in such instances it is very probable that the more usual means of communication will be more or less dislocated or completely useless. A rapid, reliable, and portable method of communication may in such circumstances be the means of saving many lives.

A somewhat analogous method has been suggested for telephonic communication with captive observational balloons, by utilising a " conduction " transmission along the mooring cable.[3]

The conduction system has also been employed to a very

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[1] Explosions have been caused in collieries through the small sparks arising at the contact of bare wires used for bell signalling purposes, so that quite low voltages must be maintained in any bare or unprotected circuits. See *The Electrician*, lxxv. pp. 130, 132; and lxxvii. p. 638. Reference No. 23.

[2] Reference No. 25.

[3] This arrangement and the preceding one for mines is somewhat analogous to an " electrostatic " method described below—p. 29, also Reference No. 11.

limited extent for communicating with ships, but the chief difficulty that is met with, apart from the limited length of "base" line available on shipboard, is the short-circuiting of the impulses by the metal hull of the ship which is in such close proximity to the terminal electrodes.[1]

Still another use to which the induction method has been put is for telephoning to and from moving railway trains. Experiments were carried out in this direction by A. C. Brown, T. A. Edison, and others about 1885, but although successful scientifically, the arrangements did not meet with sufficient use to warrant their commercial development. However, modern conditions of "hustle" and rapid communication have changed the outlook in this direction, so that a distinct field may be said to exist for wireless telephone apparatus on railway trains.[2] As evidence of this, various applications of the induction method for such purposes have recently been re-evolved,[3] while some headway has also been made with the use of more modern wireless methods under similar conditions.

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[1] Reference No. 12.

[2] See also Chap. XXIV. p. 357.

[3] Reference No. 26.

CHAPTER III

PHOTOPHONES AND THERMOPHONES

Turning now to the second of the above groups into which we have classed wireless telephone apparatus (p. 2), we come to those systems utilising light or heat waves through the aether as the mechanism for the communication from one station to another. In brief outline these methods all comprise some means at the transmitter of setting up a beam of light, the intensity of which can be varied by the sound waves or voice ; and some apparatus at the receiver for reconverting the varying beam of light back into sound waves—that is to say, either some detector that emits a sound depending on the light intensity falling upon it ; or, more usually, some substance whose electrical properties depend upon the illumination to which it is subjected. The transmitting apparatus is therefore under the control of the speaker's voice, either directly or else through the medium of an ordinary pattern of microphone transmitter and local circuit ; while the person at the other station hears the transmitted speech in an ordinary telephone connected to the receiving apparatus. A considerable number of different types of transmitters and receivers have been devised, and a workable form for a complete installation may be made up by using almost any one of these various transmitters in conjunction with almost any pattern of receiver. Certain exceptions to this generalisation, that is to say, types of receivers which are more particularly adapted to working with a special form of transmitter, will be noted in connection with the description of those receivers.

Photophone Transmitters

(1) *Mirror Transmitters*

In the simplest forms of transmitter a constant source of light is employed, and its intensity is modulated *en route* from the source to the receiving station. Such modulation in accordance with the speaker's voice may be very simply effected by reflecting the light at the transmitter from a very thin flexible mirror which may be influenced by the sound waves to cause it to vibrate and thus to vary the intensity of the light falling upon the receiver[1] (Fig. 7).

For the mirror a piece of very thin silvered glass, such as a microscope cover glass, may be employed. A circular diaphragm of this material about 2 inches diameter, and $\frac{1}{100}$ to $\frac{1}{200}$ inch thick will give satisfactory results. Somewhat better is a very thin mica diaphragm. In either case the surface of the material should be rendered reflecting by silvering upon the outside (front) surface.

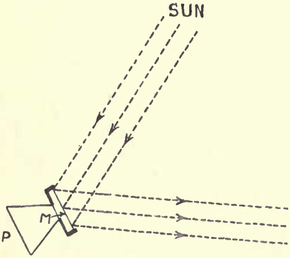

Fig. 7.—Flexible Mirror Photophone Transmitter (Bell & Tainter).

When the diaphragm, M, Fig. 7, is spoken to through the trumpet P it is thrown into vibration by the varying pressure of the air waves, thus changing it from its original plane form to a concave or convex one. Hence the light waves which in the first place passed to the receiver as a parallel beam, become convergent or divergent respectively, and as a consequence the intensity of the light at the receiver is diminished in either case from its original value. Such an arrangement was used by A. G. Bell in his original experiments with the photophone about 1878.

A slightly simpler form to construct may be a diaphragm of thin mica or thin stretched rubber[2] clamped across the small end of the trumpet, and having attached to it a small mirror which will therefore be tilted from its original position of rest, when the diaphragm is set into vibration by the sound waves. The reflected beam will thus be thrown on and off the receiver at a varying frequency and to a varying degree depending upon the sounds influencing the diaphragm.

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[1] Reference No. 27.

[2] Toy "balloons" form a convenient source of diaphragm material for experimental purposes.

In Fig. 8, P represents a small trumpet into which the speaker directs his voice; D is the diaphragm clamped in place over the end of the trumpet tube by the ring R. M is the small mirror attached to the diaphragm by a suitable cement. This mirror must be fastened to the diaphragm at some point other than its centre, otherwise the beam of light will not be tilted when the diaphragm vibrates, as the mirror would merely be moved inwards and outwards (Fig. 9).

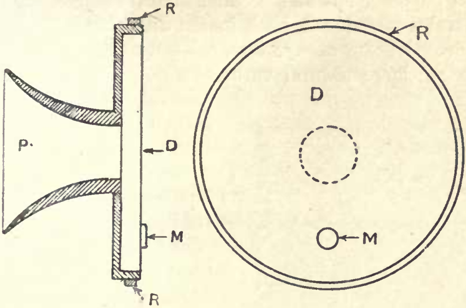

FIG. 8.—Simple Mirror Transmitter for Photophone.

Many alternative methods of supporting or arranging the mirror so that it can be deflected by the movements of the transmitting diaphragm, may evidently be employed if desired. It becomes possible in this manner to make use of a larger mirror than is feasible when it is directly mounted upon the diaphragm itself. A more intense beam of light can thus be reflected to the receiver and the range thereby increased.

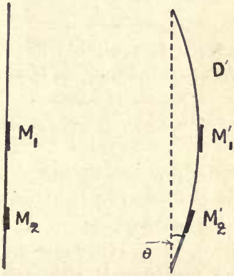

FIG. 9.—Diagram illustrating effect of Mirror Position upon the angle θ through which the mirror is tilted when the diaphragm, D, is extended a given amount. $\theta=0$ when mirror is in centre of diaphragm, as at M_1 M_1'.

Any such arrangements as the above, however, all suffer from the great disadvantage that the beam of light that can be employed, even with the largest possible mirrors, is relatively feeble, and the range thus very limited. They may perhaps be of some interest for experimental purposes over short distances.

As source of light the sun may, and often has been employed for this purpose, but at the same time further disadvantages are thereby introduced, both in the difficulty in maintaining the reflected beam always directed towards the receiver, and also in the large natural variations in intensity such as are caused by clouds and other atmospheric influence. It is therefore preferable, whenever possible, to employ some form of artificial source of light which may be maintained in a fixed position and of constant intensity. Artificial light is of course essential if the apparatus is to be used at night. Any bright source of light may be used, such as acetylene, oil, lime-light, electric arc, etc., although if the latter source is available it may be utilised in a very much more efficient manner, as is set out below (pp. 16-19).

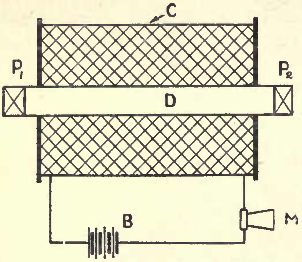

FIG. 10.—Polarised Light Photophone Transmitter.

(2) *Polarised Light Transmitters*

A number of other methods of controlling the intensity of the beam of light, such as by vibrating shutters, etc., will at once be evident, but need not be entered into in detail here. One other novel and important method may, however, be mentioned, although it does not appear to have been utilised for much practical work. It is based upon the fact that the plane of polarisation of a beam of light may be rotated by passing it through certain transparent substances when they are placed in a magnetic field.

A beam of light is said to be plane polarised when the transverse vibrations of which it is composed are all taking place in a single plane passing through the axis of transmission, as distinct from an ordinary beam in which the transverse vibrations are taking place in all planes passing through and arranged round the axis of transmission. The effect of the beam upon one's eye is the same whether or not the beam is polarised. The extent of the rotation of the plane of polarisation brought about in the above manner is dependent upon the strength of the magnetic field, so that if we arrange two "Nicol prisms" P_1P_2 (Fig. 10), as "polariser" and "analyser" on opposite ends of a coil of wire C, so that the first one serves to polarise the beam of light, while the second is so placed that under normal conditions with no current flowing through the coil, all light is cut off; we are thus provided with a means of controlling the intensity of the beam of light emitted from the analysing prism by control of the current in the coil C.

In the centre of the coil D should be placed some substance having a high rotary power—such as carbon bisulphide, CS_2; or carbon tetrachloride, CCl_4—as by this means the effects may be much increased. When a current is passed through the coil C, from the battery B, the plane of polarisation of the light beam will be rotated, and therefore some light will pass out from the second prism P_2. Hence if this current is modulated by the microphone M, the light intensity will be correspondingly varied depending upon the speech waves affecting the microphone, and a method of achieving speech communication by light waves is obtained.

A great many other methods of modulating the intensity of a fixed beam of light have been devised from time to time, but space will not permit of their discussion in detail here.

The other main class of photophonic transmitters comprises those in which the modulation is effected in the source of light itself instead of between the source and the receiver. These are considered in the succeeding sections.

(3) *Manometric Flame Transmitters*

One of the earliest forms of variable light source photophonic transmitters consisted of a manometric flame which was directly influenced by the speech waves to be transmitted.[1] For this purpose a small chamber is inserted in the gas supply pipe to the jet, one side being closed by a flexible diaphragm D, Fig. 11, which may be caused to vibrate by speaking in at the mouthpiece M. The vibrations of the diaphragm alter

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[1] Reference No. 30.

the pressure of the gas in the chamber A, and hence produce variations in the intensity of the light emitted by the flame at P_2. If so desired, the diaphragm D in such an arrangement may be influenced by a telephone receiver, instead of directly by the voice, in which case the receiver would be connected in circuit with a microphone transmitter and battery in the usual manner.

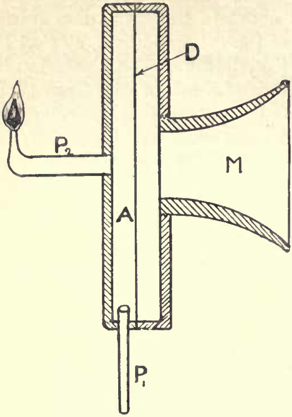

FIG. 11.—Manometric Flame Photophone Transmitter.

Even when acetylene gas is employed, these methods do not yield a beam of light of sufficient intensity to enable telephonic communication to be carried on over distances much greater than a few hundred yards.[1] For greater distances more powerful light sources must be employed.

(4) *Electric Arc Transmitters*

The electric arc furnishes a more intense and concentrated light source than any other illuminant, and at the same time possesses the valuable property that the intensity of the emitted light may be very easily varied by producing changes in the current passing through the lamp.[2] Alterations in the current strength cause alterations in the temperature of the carbons, and hence in the light emitted. Incidentally, of course, these temperature variations give rise to changes in the volume of the arc, thus setting up sound waves as well. This constitutes the well-known phenomenon of the "talking arc." There is in general a certain amount of hysteresis or lagging between the current change, and the change in the emitted light, but this is not of a sufficient magnitude to hinder the transmission of speech.[3]

The most generally useful, and most commonly employed

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[1] Reference No. 29.

[2] Reference Nos. 31 and 32.

[3] Reference No. 33.

method for electrically influencing the light of the arc is shown in Fig. 12.[1] In this diagram, the arc is represented at A, with its series resistance R_0 in the supply leads. One coil L_1 of a small transformer is inserted in one of the leads to the arc, and the other coil L_2 is connected in series with a microphone M and battery B of a few cells, so that a current of say 0·1 to 0·25 ampere flows through the microphone. The microphone used may be of any of the well-known commercial types. The variations in the resistance of M caused by the speech waves vary the current flowing through L_2 and hence induce E.M.F.'s in the winding L_1. These being alternating will alternately oppose and strengthen the current flowing through the arc, and so cause variations in its light, as described above. The effectiveness of the results obtained depends to a certain extent upon the size of the carbons used, and on the strength of current passing through the arc.[2]

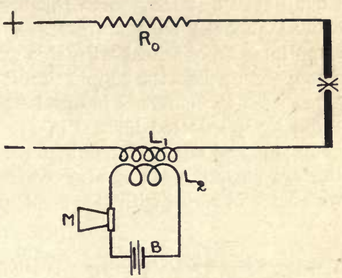

FIG. 12.—Simple form of Electric Arc Photophone Transmitter (H. Hayes, and A. G. Bell).

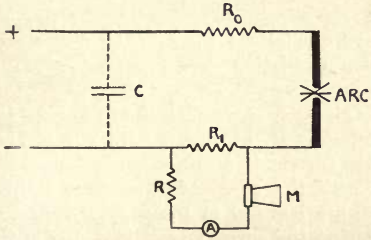

FIG. 13.—Control of Arc by Microphone in Shunt to a Series Resistance or Inductance.

An alternative method of modulating the emission of light by the arc, is to connect the microphone (in series with a suitable resistance to limit the current through the microphone to a safe value to avoid overheating) across a small resistance or inductance in the supply circuit to the arc. This allows the series transformer used in the previous arrangement to be dispensed with. The diagram of connections is shown in Fig. 13. R_0 is the usual resistance in series with the

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[1] Reference Nos. 34, 35, and 36.

[2] Reference No. 38.

arc, and R_1 is a small extra resistance (or inductance may be used instead), across which the microphone M is shunted. The current A must be carefully adjusted to prevent overheating of the microphone. With ordinary pattern "solid-back" type of microphones this current should generally not exceed about $\frac{1}{4}$ to $\frac{1}{2}$ ampere. A slight improvement may sometimes be obtained with this arrangement by connecting a condenser across the supply circuit to the arc so as to provide a path for the currents induced by the microphone, as indicated by the dotted lines C in Fig. 13, and preventing their being damped out by the inductance of the dynamo supplying the arc current.[1] It is also generally advisable to insert a resistance in series with this condenser in order to prevent its setting up low-frequency oscillations through the arc, after the manner of ordinary oscillating arcs (compare p. 110 *et seq.*).

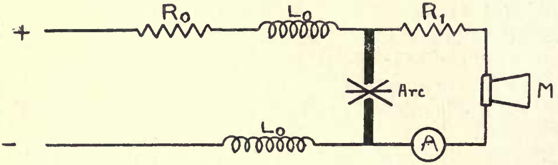

FIG. 14.—Control of Arc by Shunt Microphone.

Another arrangement giving good results is shown in Fig. 14. In this case the microphone M, in circuit with a suitable resistance R_1 to limit the current to a safe value as before, is connected in parallel with the arc.[2] Choking coils L_0 of considerable inductance are inserted in the supply leads to the arc, in order to confine the current variations produced by the microphone to the arc circuit rather than allowing them to be wasted in the supply leads—these choking coils offering no appreciable impedance to the direct supply current to the arc, but opposing the passage of the rapidly varying currents passing through the microphone.

Still another method is available if the arc can be supplied direct from a special dynamo not having any other load upon it. The microphone can then be arranged to influence the field current of the machine, either by connecting it directly

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[1] Reference Nos. 39 and 40.

[2] Reference No. 42.

in circuit with the field windings if the current is sufficiently small; or by one of the above control arrangements. The variations in the resistance of the microphone thereby produce large variations in the E.M.F. generated by the dynamo armature, and therefore also in the current passing through the arc. Fig. 15 shows one such arrangement for a separately excited machine. A trouble experienced with this method arises through the very great impedance possessed by the field coils of the dynamo, which prevents any large rapid modulations of the current passing through such coils. Matters may be improved by employing a machine having laminated field magnets, but this entails a special machine. The method, therefore, does not usually give such good results as might at first sight be expected, and although generally workable, it is in no way superior to the other methods described above.

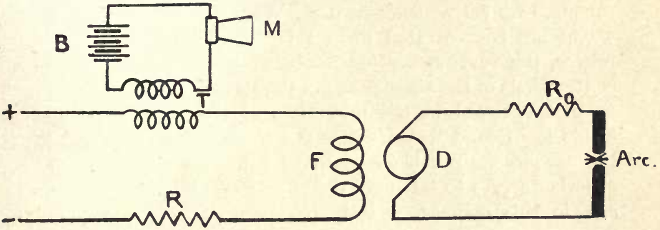

Fig. 15.—Microphonic Control of Exciting Current for Supply Dynamo of Arc Transmitter.

(5) *Incandescent Lamp Transmitters*

Another source of light which might in utility be placed intermediate between the gas flame transmitters and the electric arc transmitters, is the ordinary metallic filament electric glow lamp. The current passing through such a lamp, and therefore also the intensity of the light emitted, may be modulated by a microphone by any of the methods outlined above, and it has been demonstrated that such lamps may even (in high candle-power units) be caused to emit audible sounds just as in the case of the "talking-arc."[1] The effects obtainable are, however, much inferior to those when using the arc arrangements.

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[1] Reference No. 45.

PHOTOPHONIC RECEIVERS

(1) *Direct Receivers*

The earliest used photophonic receivers really responded to the heating effects of the beam of light, rather than to pure light action. In 1893, A. G. Bell and others used small pieces of charred cork enclosed in glass tubes placed in the focus of a parabolic mirror.[1] Mica or glass coated with lamp-black may also be employed. The free end of the glass tube was connected by a rubber, or other flexible tube to a suitable ear-piece for convenience in use. When the light (and heat) waves are concentrated upon this device by the parabolic mirror, the varying heating produced causes expansions and contractions of the air enclosed in the glass tube and especially in that enclosed in the interstices of the porous material inside it. Sound waves are thus set up which are heard in the ear-piece. The black charcoal being an excellent heat absorber serves to intensify the effects. The light variations are, in this manner, directly reconverted back into sound waves.

One very simple and effective form of this receiver consists of a small flat glass disc that has previously been smoked in a lamp flame, and enclosed inside a flat box with a glass front through which the beam of light is admitted. The box is provided with a tube leading to an ear-piece by means of which the received sounds may be detected.

The great disadvantage of all forms of this class of receivers lies in the fact that the energy of the sound waves must *all* be derived exclusively from the energy contained in the beam of light falling upon the receiver. The received sounds will therefore diminish very rapidly with increasing distance from the transmitter. More satisfactory results may be obtained from some of the Electrical Receivers which act after the manner of relays, and the energy of the sound waves that are set up is drawn largely from a local source. The received light waves serve merely to control the energy furnished by this local source in the form of sound waves.

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[1] Reference No. 46.

(2) *Electrical Receivers*—(*a*) *Selenium Cells*

General Remarks.—The most successful Photophonic Receivers are those employing some material such as selenium whose electrical properties are influenced by the intensity of the illumination to which it is subjected.[1] These materials operate somewhat after the manner of relays, in that the light energy of the incident beam is not directly expended in producing sounds at the receiver, but serves to release and control additional energy derived from a local source for that purpose.

The electrical conductivity of selenium, stibnite, antimonite, and a number of other substances—notably the haloid salts of silver, and especially silver iodide—depends very considerably upon the intensity of the illumination to which they are subjected. The original discovery of this change of conductivity with illumination was made about 1873, in the case of selenium, and opened up a large field for experiment in connection with these photophones.[2] Their use over ranges of several miles was thereby rendered possible.

The sensitiveness of stibnite to light was discovered in 1907;[3] and more recently still A, H. Pfund has shown that copper oxide (the cuprous variety, Cu_2O) possesses considerable sensitiveness to light action—the maximum effect occurring with ultra-violet light.[4] A suitably constructed cell containing this latter material is capable of following rapid light fluctuations such as occur in telephony. Carbon, lampblack, etc., are also sensitive to light, but not nearly to so great an extent as selenium. A deposit of soot between conducting electrodes upon glass or mica, as used for the simple photophonic receivers (p. 20), will also show changes of electrical conductivity on illumination.[5]

The specific resistance of selenium is very high; an average figure often quoted for the crystalline variety is about 60,000 ohms per centimetre cube, but very little reliance can be placed upon this figure, as it is found to vary enormously according to the mode of preparation of the material. It also depends to some extent upon the voltage applied to it in making the measurement.[6]

Consequently, it is necessary to construct a special form

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[1] Reference No. 56.

[2] Reference Nos. 47, 52, 57, and 64.

[3] Reference No. 55.

[4] Reference No. 53.

[5] Reference Nos. 46 and 56.

[6] Reference Nos. 48 and 49.

of "cell" which presents a very large cross-sectional area to the current, while at the same time the length traversed by the current, or the distance between the electrodes of the cell, is kept as short as possible. At the same time we are faced with the difficulty that the action of the light on the conductivity of the selenium does not penetrate far into the interior of the mass of the substance. F. C. Brown, who has carried out very extensive experimental investigations of the electrical and other properties of this material,[1] has reached the conclusion that the usual depth of effective penetration is about 0·014 mm.,[2] but some other observers incline to the view that the effects extend deeper than this.[3] In any case, however, it is evident that for good results the selenium should be exposed to the light action over as large and shallow an area as possible, or otherwise the resistance of the mass of the material in the interior remaining unchanged by the light will to a certain extent mask the effect of the change of resistance of the surface film.

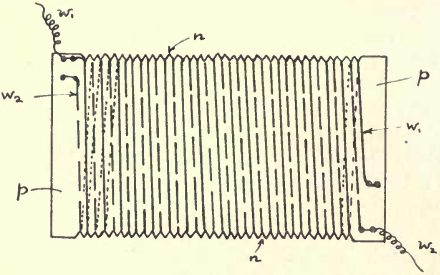

FIG. 16.—Flat type of Selenium Cell (Ruhmer).

Constructional Details.—Several forms of "cells" or "bridges" have been devised in order to satisfy these conditions as fully as possible.[4] One of the most useful is constructed as follows: A flat piece of unglazed porcelain, slate, ground glass, or similar insulating material (preferably having a slightly roughened surface) has two metallic wires W_1W_2 (Fig. 16) wound round it in notches N cut in its edges. These wires (of size about = No. 30 or No. 36 S.W.G.) are preferably

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[1] Reference No. 54, etc.

[2] Reference No. 51.

[3] Reference No. 50.

[4] Reference Nos. 59, 60, and 61.

of platinum, as this does not oxidise when heated, nor combine with the selenium. Other materials, such as nickel or copper, may, however, be employed. The wires should be kept spaced apart throughout their length, at a distance about equal to their own diameter, and one end of each led out to a terminal connection. The plate and wires are then heated, and a *thin* film of selenium is smeared over the whole to form a bridge between the two wires for the passage of the current between them. When completed the cell must be annealed by heating to about 200° C., when the selenium becomes plastic and changes over into the grey crystalline form which is sensitive to light.

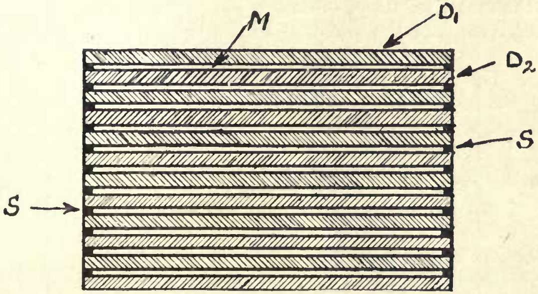

Fig. 17.—Cylindrical Type of Selenium Cell.

The final value of the resistance of the cell depends very largely upon the temperature and duration of the annealing process; and it is stated that a preliminary heating to a higher temperature, and subsequent annealing for several hours at a slightly lower temperature—say about 190° C.—produces cells of lower resistance which are more sensitive to feeble illuminations.[1]

Another pattern—one that is specially convenient for use with parabolic mirrors—consists of a pile of thin brass or copper discs, D_1, D_2, etc., alternating with discs of mica M having a slightly smaller diameter.[2] The alternate brass discs are connected together, and to the two terminals, while the selenium S is smeared over their edges, thus forming a number of thin concentric rings of the material which are all connected in parallel (Fig. 17).

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[1] Reference No. 58.

[2] Reference No. 64.

A great many other forms have been devised from time to time, and for detailed descriptions of them the reader is referred to the original papers on the subject.

"*Light-Negative*" *and Insensitive Cells.*—As a general rule the effect of light upon selenium is to cause an increase in its conductivity on illumination; but in some cases it has been found that the conductivity falls on illumination.[1] The exact reasons for and causes of this change are not very well known, but F. C. Brown has shown that the presence of mercury-vapour may give rise to this particular variety.[2] The addition of the metal tellurium often has the effect of diminishing the sensitiveness of the selenium to the light action, and should therefore be rigorously avoided.[3] Care should also be taken to avoid the presence of moisture on selenium cells, as this frequently gives rise to a considerable decrease in their sensitiveness. A damp atmosphere is for this reason detrimental to their action, so that some advantages are obtained by sealing up the completed cell in a glass bulb or tube which is subsequently exhausted.[4] Alternatively the sensitive surface of the cell may be covered with a thin sheet of mica or film of transparent wax.

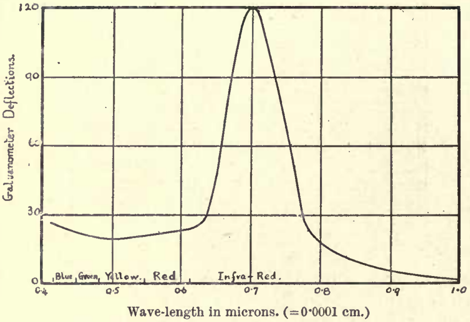

FIG. 18.—Sensitiveness Curve for Selenium Cell.

Sensitiveness of Selenium Cells.—When suitably prepared such selenium cells, or selenium bridges as they should more properly be called, are found to be much more sensitive to

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[1] Reference No. 67.

[2] Reference Nos. 66 and 69.

[3] Reference No. 68.

[4] Reference No. 74.

light than the human eye, not only for the purpose of detecting weak illuminations, but also for giving indications of minute changes in an existing illumination.[1] It is this latter property which renders them of such special value in wireless telephony by means of light waves. In use the cells are generally subjected to a more or less intense and constant illumination, upon which is impressed the small variations set up at the transmitter by the sound waves as described above.

The sensitiveness of selenium is not a fixed and invariable quantity for any particular cell, but depends upon the temperature of the cell,[2] usually increasing for low temperatures; nor is it uniform for light of different colours, but reaches a maximum value for a particular colour or wave-length.[3] Fig. 18 shows a typical curve illustrating this variation of sensitiveness with the wave-length of the incident light. The particular colour for which the maximum sensitiveness is obtained depends to some extent upon the method of annealing to which the cell has been subjected. In the example illustrated the maximum sensitiveness is reached in the infra-red region of the spectrum.

Use of Colour Screens in Photophony.—The above brings us to a consideration of the possibility of so screening the source of light at the photophone transmitter that only one particular colour is emitted. A colour screen may then be placed in front of the selenium cell to render it insensitive to other colours. In this manner it even becomes possible to combine together two or three differently coloured beams, and to carry on a separate conversation along the beam of each colour. With such an arrangement an unselective receiver will pick up merely a jumble of all the conversations, while each individual receiver provided with its proper colour filter will pick up its proper message undisturbed by the others. Such a combination is conducive to a certain amount of secrecy of transmission.

A further possibility is to screen off all the visible light, and to utilise merely the invisible ultra-violet or infra-red rays.[4] The beam between the two stations is thus rendered quite invisible to an outside observer. Ultra-violet light, however, suffers under the disadvantage for this purpose, of being rather rapidly absorbed by the atmosphere, causing a

[1] Reference Nos. 70 and 72.

[2] Reference Nos. 73 and 75.

[3] Reference Nos. 62 and 63.

[4] Reference No. 78.

diminution of the speaking range over that obtainable with visible light or infra-red rays.

As colour screens, solutions of some of the aniline dyes, or other coloured compounds, held in suitable flat cells, are very suitable both for definite wave-length ranges in the visible spectrum; and also in some instances, by suitable combinations of such filters, for certain ranges outside the visible part of the spectrum.[1] A thin sheet of ebonite may also serve as a filter to allow infra-red rays to pass, while cutting off all visible light.[2] A solution of iodine in carbon bisulphide is likewise of value as a filter for the long rays of this end of the spectrum.[3]

Most forms of selenium cell exhibit considerable inertia in returning to their initial resistance after illumination. This is more particularly noticeable when the light is very intense. Fig. 19 shows a typical resistance curve for prolonged strong illumination—5 minutes—and the comparatively slow recovery after the illumination is cut off.

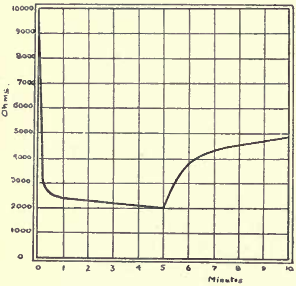

Fig. 19.—Resistance Curve showing Inertia of Selenium under Illumination.

This sluggishness would appear at first to render it unsuitable for telephonic transmission, but in practice it is found that *variations* of a steady and not too strong illumination are faithfully and rapidly followed by the resistance changes. In reality one is working on the steep initial part of the above curve, where the rate of change of resistance with time is very large.

Arrangement of Selenium Cells for Photophonic Receiver.—In order to utilise the above properties of selenium and selenium bridges for the purposes of photophonic reception of speech it is merely necessary to mount the selected cell in a suitable holder usually at or near the focal point of a parabolic mirror which may be directed towards the transmitter and serves to concentrate as much light as possible upon the cell. With this end in view the aperture of the mirror should be made as large as is conveniently possible in order to increase the speaking range of the instrument.

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[1] Reference No. 77.
[2] Reference No. 76.
[3] Reference No. 617; see also No. 28.

The selenium cell should be connected up in series with a suitable battery and a telephone receiver. The voltage of the battery must be chosen according to the average resistance (measured in the dark) of the cell in use, so that a convenient current is passed to operate the telephone. Generally the sensitiveness of the combination increases with increase of voltage of the battery, though this must not be chosen so high as to cause any appreciable heating of the selenium, nor to damage the telephones. With high resistance selenium cells 100 to 150 volts is often permissible. For best results the resistance of the telephones should be chosen, whenever possible, to be of the same order of magnitude as that of the cell in use.

(*b*) *Photoelectric Receivers*

Another detector that it is possible to use, but one particularly adapted for use with ultra-violet light, consists of some photoelectrically sensitive substance—such, for example, as the liquid alloy of sodium and potassium—which emits (negative) electrons when it is illuminated. The above-mentioned alloy is spontaneously inflammable when exposed to the air, and must therefore be kept hermetically sealed in an exhausted tube, with an insulated electrode mounted just above the surface of the liquid alloy.

For use the " cell " is connected in series with a battery and a telephone receiver, by joining the negative pole of the battery to the liquid, and the positive pole, through the telephones, to the insulated electrode. The sensitiveness of the arrangement is usually, however, inferior to that of the selenium cells, although in some instances quite sensitive cells have been devised (and used, for example, in stellar photometry, and similar instances where very feeble illuminations are involved).[1]

The hydrides of the alkali metals, when enclosed in suitable gases, such as hydrogen or neon, and with the proper value of the polarising voltage applied from the local battery, are usually quite sensitive.[2] The rubidium-hydride cell in neon gas in particular possesses the valuable property from the telephonic point of view that the current passing through the cell is almost exactly proportional to the incident energy in the light beam thrown upon it. Any distortion of the transmitted speech is thus avoided.

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[1] Reference No. 79.

[2] Reference Nos. 80 to 84.

THERMOPHONIC RECEIVERS

A delicate thermopile, or series of contacts between dissimilar metals, may also be employed as a receiver. Its action depends upon the heat energy received from the beam falling upon it, so that it is specially adapted as a receiver for the infra-red and heat waves. Under the most favourable conditions, however, its sensitiveness is considerably less than that obtainable with selenium.

The thermopile, when warmed by the rays, generates its own E.M.F., so that it is merely necessary to connect it to a low-resistance telephone receiver when required for these purposes. A thermopile having an extremely small heat capacity must be chosen, in order to enable its changes of temperature to follow the rapid variations in the energy of the received beam that constitute the speech waves.

SPEAKING RANGE OF PHOTOPHONE APPARATUS

In order to increase as much as possible the transmission range of all photophonic apparatus, it is advisable to employ parabolic mirrors at both the transmitter and receiver. These mirrors should be large in order to obtain and utilise as powerful a beam as possible—in fact the transmitter is best made in the form of a powerful arc searchlight.

With such arrangements it has been found possible to transmit intelligible speech over distances up to about twenty miles, although this distance is naturally much reduced in foggy and bad weather. The practical utility of such apparatus is therefore extremely limited; and they have not been employed for anything very much beyond merely experimental purposes. A great deal of work has been done upon them by E. Ruhmer, and those desiring further information and details of his work could not do better than consult his book upon the subject.[1]

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[1] *Wireless Telephony*, by E. Ruhmer. English translation by J. Erskine-Murray (Crosby, Lockwood and Sons).

CHAPTER IV

EARLY ATTEMPTS AT TELEPHONY BY LONG ELECTROMAGNETIC WAVES

THE third group of wireless telephone methods referred to in the Introduction (p. 2) includes all the practical and modern methods involving the use of long aether waves of the same kind as those commonly utilised for ordinary wireless telegraphy—that is to say, waves of length within what is customarily called the " wireless range " of say 200 or 300 metres up to about 10,000 metres wave-length (frequencies from 1 or $1\frac{1}{2}$ million down to about 30,000 per second).

ELECTROSTATIC METHODS

Dolbear's Transmitter.—The germ of these modern systems seems to have originated about 1882 when A. E. Dolbear and others first put forward the " electrostatic " methods of wireless telephony.[1] Dolbear's patent provides for two elevated

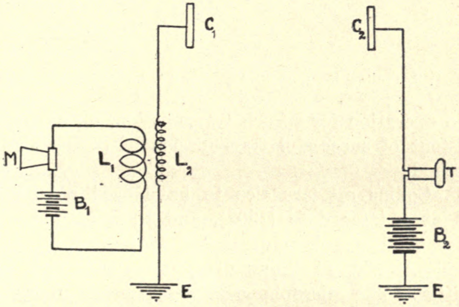

FIG. 20.—Electrostatic Wireless Telephone (A. E. Dolbear).

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[1] Reference No. 85.

capacity areas, one at each station—the transmitter being connected to earth through a high voltage battery and a microphone, and the receiver to earth through a telephone (Fig. 20).

The variations in the resistance of the microphone M vary the potential of the elevated conductor C_1, and these potential variations influence the second similar capacity area C_2 placed within the radius of the electrostatic field of the first conductor. The potential variations of C_2 cause varying currents to flow through the telephone receiver T to earth.

There is little evidence that this arrangement was ever put into operation for speech transmission, although records are existent of successful transmission of buzzer signals by this method.

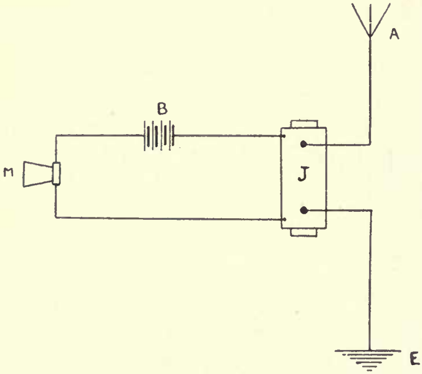

FIG. 21.—A. F. Collins' Form of Electrostatic Wireless Telephone Transmitter.

A. F. Collins appears also to have used a very similar method at a later date (1902), and to have succeeded in obtaining good speech transmission over distances of about three miles.[1] Fig. 21 shows diagrammatically this form of transmitter. The microphone M is connected in the circuit of the induction coil J, of which the secondary is arranged to vary the static potential of the elevated aerial A.

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[1] Reference No. 86.

Early Hertz Wave Methods

Much more serious attempts at the solution of the problem of speech transmission through the aether were made as soon as the outlines of wireless telegraph signalling by aether waves were laid by H. Hertz in 1888, and by G. Marconi about ten years later.

The broad idea worked upon was to modulate the emission of aether waves from one of the early forms of wireless transmitters, not abruptly, as in the dot and dash of the Morse alphabet, but continuously and in accordance with the sound waves spoken before the transmitting instrument.

To this end two main lines of experiment were followed up, viz.:

(1) The control of the *generation* of the waves in accordance with the speech to be transmitted; and

(2) The control of the *intensity* of what would otherwise be a steady stream of waves.

In both methods the early wireless transmitter using an induction coil and open spark-gap were at first retained. Fig. 22 gives an idea of the principle involved in the many proposals made about this time (1900–1906), which belong to the first of the above classes.[1] It consists merely in the addition of a microphone M in the primary circuit of the induction coil J, which supplies the spark-gap S in the aerial circuit A–E of a simple wireless telegraph transmitter, on what is now known as the "plain aerial" method.[2] The customary hammer-break or other interrupter in the primary

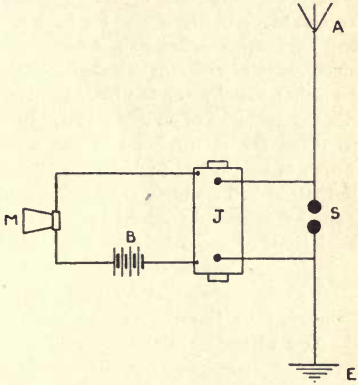

Fig. 22.—Simple Form of Early Spark Telephone Transmitter.

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[1] Reference No. 87.

[2] Alternatively the microphone may be inductively coupled with the primary circuit of the induction coil (or transformer). Reference Nos. 90 and 91.

circuit of the induction coil is dispensed with. The idea is that the changes of current through the induction coil primary caused by variations of the resistance of the microphone produced by the sounds spoken near it would induce voltages in the secondary coil and cause sparks to pass at the gap S, whose frequency and intensity would correspond with the speech waves. Thus aether waves of varying group frequency would be set up, and rendered audible in the receiving telephones by the use of a suitable auto-decohering coherer or microphonic contact detector at the receiving station.[1]

A certain measure of success was obtained, in that rhythmic sounds or notes could be transmitted, but articulate speech was practically out of the question.[2] The wave form of speech is far too irregular for such a combination of induction coil and open spark-gap to reproduce with much success, since some of the current variations of the microphone would be either too slow or too brief to give rise to any sparks at all. Similar remarks of course also apply to the analogous proposal to place the microphone in one arm of a Wheatstone bridge which is connected in between the supply generator and the induction coil or high voltage transformer feeding the spark-gap, so that only currents corresponding to the resistance variations of the microphone are allowed to flow through the transformer primary.

A system proposed by F. Majorana may also be taken as belonging to the first group. He suggested that the production of the oscillations could be controlled in accordance with the speech waves, by causing the voice to vary the sparking distance at the spark-gap. One fixed electrode was used for this purpose, while the other was arranged in the form of a jet of mercury, and was caused to be set in motion by the voice by means of a suitably placed diaphragm attached to the jet. In this manner the intensity of the oscillations set up in the transmitting aerial circuits, which depends upon the spark length, was controlled to a certain extent by the speaker's voice. An obvious disadvantage of using such a method in conjunction with an induction coil transmitter is that the regularity of the sparks depends upon the interrupter, or alternator, used with the coil, while in any case the number

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[1] The modern crystal detectors were not in use at the time these proposals were made.

[2] Reference Nos. 88 and 89.

of spark discharges taking place per second will be comparatively small—too small to allow of the finer details of the speech to be reproduced. In addition, too, the fact that these sparks are taking place at a low rate per second means that they will of themselves give rise to sounds in the receiving telephones corresponding to the pitch of the interrupter or the frequency of the alternator employed.

A proposal belonging to the second of the above classes was to insert an ordinary microphone into the earth lead of the above type of spark transmitter, in the manner shown in Fig. 23, so that the changes in its resistance produced by the speaker's voice would modify the strength of the current flowing in the aerial circuit, and so control the emission of the waves in accordance with the spoken words. This method also suffers from the same disadvantages as the preceding. It may perhaps be mentioned in passing that this mode of connection of the controlling microphone in the aerial circuit of the transmitter is one now commonly employed with success with the modern transmitters producing continuous waves—the fault in this instance was in the type of oscillation generator, the induction coil, when used at such low spark frequencies.

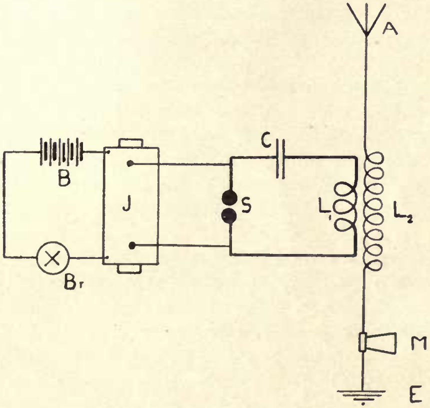

FIG. 23.—Early Spark Transmitter with Microphone in Earth Lead to control Intensity of Emitted Waves.

It was found that these several methods, imperfect though they were, were capable of transmitting musical notes and simple sounds; but that speech was out of the question on account of the irregularity of the sparks and the noise at the receiver caused by the low spark frequency.

CHAPTER V

THE CONDITIONS FOR SUCCESSFUL WIRELESS TELEPHONY BY AETHER WAVES

THE above outline of the earlier attempts made to solve the problem of the wireless communication of speech by aether waves shows that the problems presented are rather different from those of ordinary wireless telegraphy, although the same medium of transmission (the aether) is employed in both cases. A sketch of the requirements for radiotelephony may be given as follows :—

At the transmitter must be set up a stream of aether waves suitable for affecting the distant receiver, as in an ordinary wireless telegraph transmitter. This stream of waves will give rise to a certain continuous effect at the receiver. As mentioned above it was this "continuous effect" at the receiver that was one of the causes of the failure of the early attempts at radiotelephony, since with the low spark frequencies employed it meant the production of a continuous sound or note in the receiving telephones, apart altogether from any speech transmission.

The trouble is lessened if the pitch of the note thus produced at the receiver is raised by correspondingly increasing the spark frequency of the transmitter. The sensitiveness of the ear (and more especially of the combination of telephone receiver and ear) begins to fall off for notes above a certain pitch, generally for normal ears about 600 to 700 per second [1] (Fig. 24). The ideal to be aimed at is therefore not merely to increase the spark frequency to say 2000 per second or so, but to increase it very much more still until the upper acoustic limit is passed and the note becomes completely inaudible.

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[1] Reference Nos. 92, 93, and 95.

This limit is generally reached at frequencies between 20,000 and 30,000 per second, depending upon the observer.[1]

When dealing with the signals received from spark transmitters, however, it has been shown on several occasions that there is not nearly so great an increase in sensitiveness of the combination, telephone + ear, as the above tests (made with sine wave alternating current) would lead one to expect to occur in the neighbourhood of about 600 to 700 per second. L. W. Austin, for instance, has shown that the apparent telephone sensitiveness is about the same for signals from a 60 ∿ and from a 500 ∿ spark station.[2] In any case, however, there is bound to be a large falling off in ear sensitiveness for very high note frequencies.

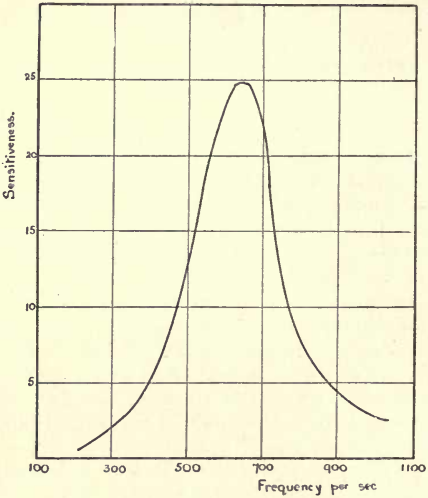

FIG. 24.—Variation of Sensitiveness of Ear and Telephone with the Sound Frequency.

It is then necessary to modulate this continuous stream of waves in accordance with the speech or sound waves, just as the light in the photophone transmitter was so modulated, in

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[1] Some people and many animals (dogs, etc.) can often hear notes of a much higher pitch.

[2] Reference No. 94.

order to produce at the receiver effects which are a more or less faithful copy of the speech or sound waves impinging on the transmitter, and which may be made audible by the use of suitable detectors and the customary telephones.

The practical realisation of the above is not, however, as simple as it might appear at first sight, especially when we try and raise the spark frequency to such high limits by merely modifying ordinary apparatus. To such an extent is this the case that another group altogether of wave generators has sprung up as being more suitable for the problems in hand. These aim at producing a *perfectly continuous* stream of oscillations (and waves), after the manner of an ordinary alternating current, but with the frequency raised at least until it is above the acoustic limits set out above.

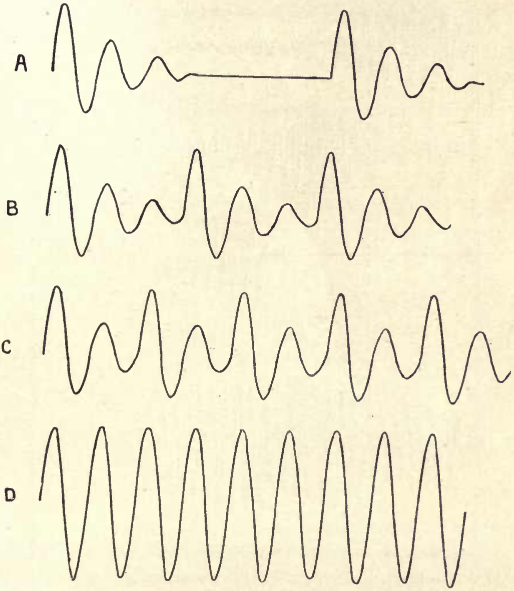

FIG. 25.—Effect of Group Frequency upon the Type of Waves.

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The transmitting apparatus for long aether wave wireless telephony may be roughly divided into these two main groups :

(1) Apparatus producing continuous waves.

(2) Apparatus producing discontinuous groups of waves, of a very high group frequency.

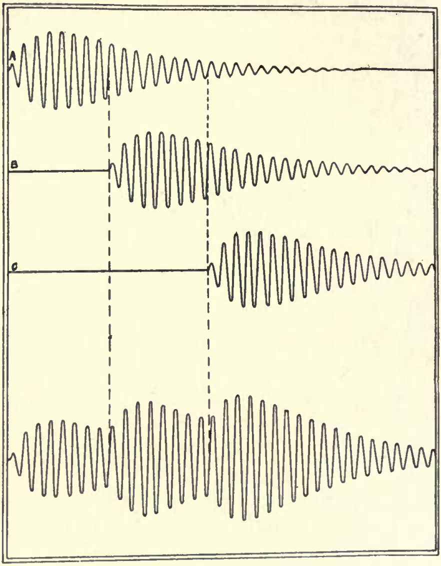

Fig. 26.—Diagram showing Correct Synchronisation of Wave Trains with the Oscillations.

The first of the above groups may be subdivided into the following types of apparatus :

(1) Oscillating arc apparatus.

(2) Alternator and frequency raising apparatus.

(3) " Vacuum " methods, involving the employment of an electrical discharge through a rarefied gas or vacuum.

The group of discontinuous wave generators comprises practically only one type of apparatus, viz., the short spark methods employing some form of quenched spark-gap.

This classification, however, cannot be looked upon as an absolutely rigid one, as we find, for instance, that several of the available pieces of apparatus do not strictly belong to either class. As an example of this it is usually understood that the expression "discontinuous groups of waves" implies a succession of waves trains, each of which dies out completely before the succeeding one commences; whereas some of the short-spark methods usually referred to this class really produce a rapid series of trains of oscillations which run into one another, giving rise to waves of fluctuating amplitude which do not actually die out at any time. Fig. 25 indicates how such a state of affairs may arise through an increase in the group or spark frequency of the waves, (A) showing damped waves of low group frequency; (B) the effect of an increase in group frequency causing the waves to run into one another; and (C) the same effect carried still further, so that a fresh impulse is obtained every four half waves. It is easily seen that such a wave would be very similar in its general properties, and in the effects produced at the

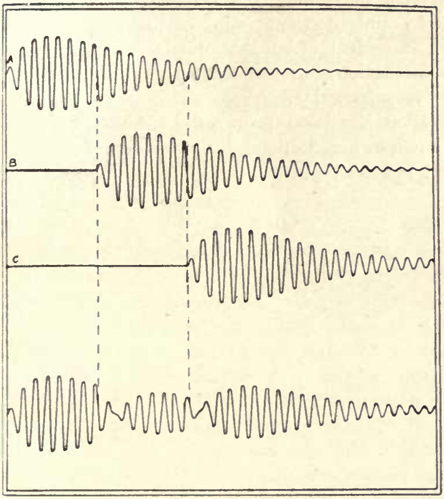

Fig. 27.—Diagram showing Incorrect Synchronisation of Wave Trains with Oscillations.

receiver, to the perfectly continuous or undamped wave shown at (D).

In passing it may be noticed that an exact synchronism is required in cases (B) and (C), between the group and oscillation frequencies, that is to say, each fresh impulse must take place at such an instant that it reinforces the existing oscillation. If the phase becomes slightly displaced the resulting oscillation will be weakened instead of strengthened.

Fig. 26 shows a proper addition of successive impulses (A), (B) and (C), in which each occurs at precisely the exact moment to reinforce the existing oscillation ; while in Fig. 27 is shown the effect of a phase displacement of half a period (of the oscillation), to the left so that the resultant wave becomes very irregular.

A method has been proposed by Marconi to secure the result shown in Fig. 25 (C), by means of suitable rotary spark-gaps. It is described more fully later (see p. 86).

CHAPTER VI

DISCONTINUOUS WAVE GENERATORS FOR RADIOTELEPHONY OR "SPARK" GENERATORS

In endeavouring to overcome the difficulties arising through the irregular and low spark frequencies yielded by induction coils (see Fig. 28), many attempts were made from time to time to increase the spark frequency by replacing the induction coils and batteries by alternating current transformers and alternators. The spark-gaps are so arranged that a considerable number of discharges takes place in each half cycle of the voltage wave. If the curve shown in Fig. 29 represents the voltage wave of the alternator, and the spark-gap is so arranged that a discharge can take place as soon as some such voltage as represented by V is attained, then it is evident that more than one discharge should take place per half cycle of the voltage wave ; for as soon as the voltage reaches the value V, a spark will pass and discharge the condenser. But if the spark-gap is so arranged (as, for instance with a suitable air blast) that the discharge does not persist as an arc after the oscillation is completed, then the spark-gap will be in a condition to allow another discharge to pass as soon as the condenser voltage again reaches the sparking value $=$V. This it should do rapidly, since the voltage impressed upon the condenser circuit from the transformer secondary is now higher than that required to spark across the gap. In this manner a number of such discharges may be obtained in each half cycle, such as at the points shown at A, B, C, etc., in the above diagram. It should also at once be evident that these sparks will not be evenly spaced ; that they will succeed one another most rapidly when the alternator voltage is greatest, *i.e.* near the peak of the E.M.F. wave ; and that there will be much longer intervals when the voltage is passing through its zero values. Fig. 30 is a reproduction of a spark photograph showing such multiple discharges. It was taken with

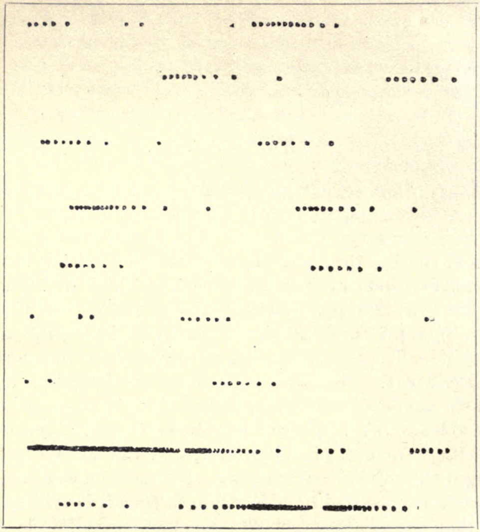

FIG. 28.—Spark Photograph showing Irregular Discharges yielded by an Induction Coil (J. A. Fleming).
(Each dot in this photograph represents a discharge across the gap.

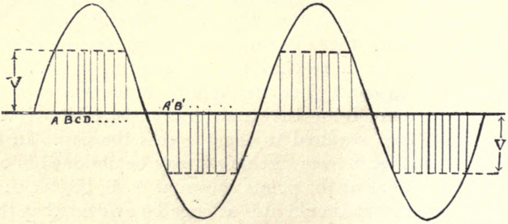

FIG. 29.—Voltage Wave illustrating the Production of Multiple Discharges.

an open spark-gap supplied from an alternator and high voltage transformer, the length of the gap being so adjusted that the maximum voltage yielded by the transformer was considerably in excess of that required to break down the air at the spark-gap. It will be noticed from the photograph that three or four sparks occurred during each half cycle of the voltage wave with this particular arrangement, and that there was a comparatively long pause free of sparks when the transformer voltage was passing through the zero values.

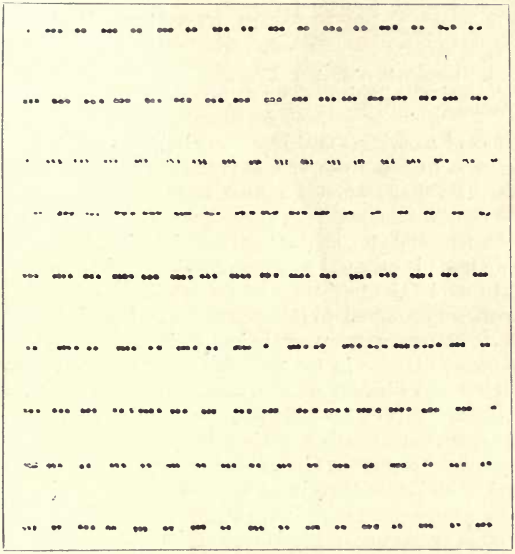

FIG. 30.—Spark Photograph showing Multiple Discharges during each Alternation (J. A. Fleming).

The employment of a choking inductance of considerable value in series with the supply transformer (primary) generally proves of considerable use with such arrangements in order to prevent the formation of an arc discharge across the spark-gap, with a consequent cessation of oscillatory discharges until the arc is extinguished when the alternator E.M.F. falls to zero. The presence of this inductance also improves the regularity of the discharges.[1]

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[1] Reference Nos. 102, 103, and 104.

A greater regularity of the discharges may generally be obtained if an alternator is employed that does not give the usual sine wave of E.M.F., but one that is much more "rectangular" in shape (Fig. 31), as has been proposed by A. Blondel, since in this case a much more constant voltage is impressed upon the condenser circuit for a longer portion of the whole period.[1]

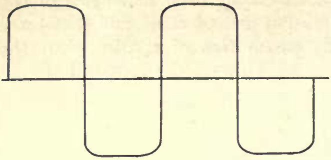

FIG. 31.—Rectangular-shaped E.M.F. Wave for increasing the Regularity of the Multiple Discharges.

A much more ideal method of securing the desired regularity in the spark discharges is to make use of high voltage continuous current, since the voltage applied to the condenser circuit is then quite constant and a very regular succession of discharges becomes possible.[2] The use of sufficient inductance in the supply leads is essential to secure regularity of the discharges and to avoid the formation of an inactive arc at the gap. A spark-gap adapted to the passage of such rapid discharges without becoming permanently ionised is also a desideratum.

A great advance in the direction of improving the spark-gap for rapid discharges was made in 1906, when M. Wien published the results of his researches on the properties of short spark-gaps.[3] His experiments showed that the decrement[4] of the oscillations in a circuit containing a short spark-gap is much higher than in one with an ordinary gap. These short spark-gaps therefore have a high spark resistance. The discharge across such a gap is very rapidly quenched out after a very few oscillations. On this account these sparks are frequently referred to as quenched discharges, and the gaps as quenched spark-gaps.

The effect of a quenched discharge upon a secondary circuit coupled with the main oscillation circuit across the spark-gap depends to a considerable extent upon the number

[1] Reference No. 99.

[2] Reference No. 101, also Nos. 618, 620.

[3] Reference No. 107.

[4] The decrement of an oscillation is the "natural" or Naperian logarithm of the ratio of two successive semi-amplitudes of the oscillation measured on the same side of the zero, *i.e.* two successive positive, *or* negative semi-oscillations.

of oscillations that occur before the primary discharge is damped out. When, as is often the case, there are four or five semi-oscillations in the primary discharge, the secondary circuit should be tuned approximately to the same frequency as the primary, in order that the energy may be built up in the secondary during the successive oscillations in the usual manner. The coupling between the two circuits should be sufficiently close to enable as much as possible of the primary energy to be handed over into the secondary circuit during the continuance of the discharge. The quenching out of the primary discharge prevents the energy of the secondary circuit from being passed back again into the primary, and so leaves the secondary free to oscillate with its own natural period. On the other hand, with certain types of quenched spark-gap, the decrement of the circuit may be increased to such an extent that the primary discharge becomes quite aperiodic—that is to say, it is quite dead beat and does not oscillate at all. The effect of such a highly quenched discharge upon the secondary circuit is practically that of an electrical blow that sets the secondary oscillating and leaves it quite free to continue with its own free period quite irrespective of whether or not this free period is the same as that of the primary circuit itself (as given by the usual formula—neglecting the effect of the spark-gap in rendering the circuit aperiodic). In this case therefore the two circuits need not be tuned, and the coupling between them can be closer.

These two types of quenched discharge are sometimes referred to as "beat" and "impact" excitation respectively.[1]

The best-known application of these researches on the quenching action of short spark-gaps has been to ordinary musical note spark telegraphy, employing an alternating current supply. The gap is then arranged to discharge regularly, once in each half cycle of the E.M.F. wave of the alternator.

The well-known Telefunken apparatus is an example of such use. The quenching out of the primary oscillation prevents the energy which has been accumulated in the secondary circuit from being handed back again to the primary and giving rise to the double frequency wave usually obtained with ordinary spark-gaps. This effect is shown in Fig. 32, which illustrates the form of the oscillations obtained

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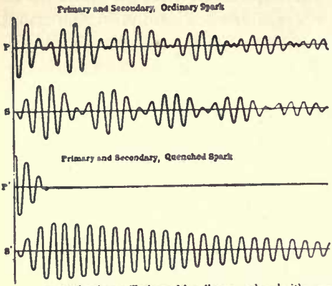
[1] Reference No. 176.

with ordinary and quenched spark-gaps respectively. In the latter case it is seen that the primary current is quenched out exactly at that point when all the energy has been transferred to the secondary circuit, and when the amplitude of the oscillation in the primary is a minimum. This leaves the secondary circuit free to continue to oscillate (with its own natural period), unimpeded by reaction with the primary. On account of this action it is possible to utilise a much closer coupling between the primary and secondary circuits than is advisable with ordinary spark-gaps—the maximum value allowable usually ranging between 0·3 and 0·5, depending upon the particular construction of gap in use. For best effects the exact value to be chosen for any particular arrangement must be found by experiment. It usually lies between certain fairly well defined limits for each particular spark-gap.[1] Numerous experiments upon the conditions of operation of these gaps have also shown that in addition to the critical coupling a certain small percentage detuning of the secondary circuit from the position of resonance with the primary is often of some advantage.[2]



Curves showing oscillations with ordinary spark and with quenched spark.

FIG. 32.

These effects of variation of the coupling between the primary and secondary circuits become more pronounced as the spark frequency is raised, and therefore are specially important when a direct current supply is used for the high spark frequencies of radiotelephony (Fig. 33). The reasons for this are to be found in the overlapping in the secondary circuit of the wave trains induced by each spark at the gap. With " beat " excitation, apart from the constants of the gap itself, the coupling will determine the interval of time that elapses between the commencement of the discharge and the completion of the transference of all the energy of the discharge into the secondary circuit. It is at this instant that

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[1] Reference Nos. 113 and 114.

[2] Reference No. 108.

the current amplitude in the primary reaches its minimum value, and that the discharge should be quenched out at the gap. The number of oscillations in the secondary circuit between each discharge will therefore depend upon the value of the coupling, and it may consequently so happen that when a fresh discharge occurs it may either help or hinder the existing oscillation in the secondary. Figs. 26 and 27 may perhaps serve to make this point clearer. The former can represent the state of affairs that may be imagined to take place when the coupling has been so adjusted that the time t_1 occupied by the discharge, together with the time t_2 taken by the condenser to recharge, is an exact multiple of the periodic time T of the oscillation. In other words, a second discharge occurs at such an instant that the resulting E.M.F. induced in the secondary assists the oscillation already existing there, and so augments the amplitude of the resulting secondary oscillation. In the second diagram (Fig. 27) the time t_1 has been slightly shortened (as by an alteration of the coupling) so that the time $t_1 + t_2$ is no longer an exact multiple of the periodic time T, and the current induced by the fresh discharge does not come in phase with the existing oscillation. The resulting oscillation as a consequence becomes irregular, and its effective value is much reduced.

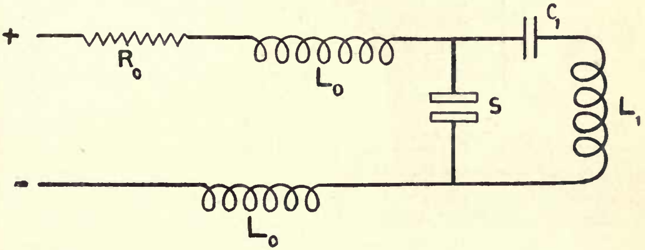

FIG. 33.—Arrangement of Quenched Spark-Gap with Direct Current Supply to obtain High Spark Frequencies.

S = Quenched Spark-Gap; R_0 = Series Resistance; L_0 L_0 = Series Choking Inductances; C_1 = Main Oscillation Circuit Condenser; L_1 = Main Oscillation Circuit Inductance.

It is therefore evident that the coupling between the two circuits should be so adjusted that the former state of affairs is realised rather than the latter.[1] Another way of compen-

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[1] Reference No. 117.

sating for the bad conditions shown in Fig. 27 would obviously be to slightly alter the value of the condenser C_1 in the primary circuit, or of the condenser C_2 in the secondary, or of both, so as to alter the periodic time T. As an example of the effect of the latter, the curve shown in Fig. 34 gives the current in the secondary circuit of such an arrangement plotted against the value of the capacity C_2 in the same circuit. It will be noted that the secondary current reaches a succession of "maxima." These are found to occur under those conditions when the successive impulses assist one another in maintaining the resultant secondary oscillation; and the minima, at the intermediate points when the successive trains of oscillations are not in phase with one another (as in Fig. 27).

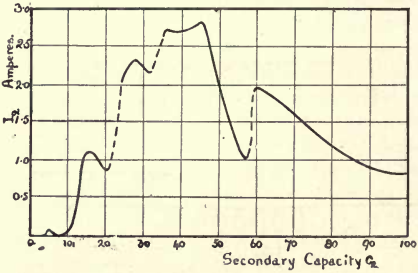

FIG. 34.—Effect of Variation of Secondary Circuit Capacity upon the Oscillatory Current obtained from a Quenched Discharge Spark-Gap (H. Yagi).

It is abundantly evident, therefore, that all these variables must in practice be adjusted to a nicety in order to obtain the best results out of the spark-gap, and the steadiest oscillations in the aerial, which latter are essential to successful speech communication.

It will also be noticed from the above diagrams that the oscillations set up in the secondary circuit with this arrangement no longer consist of discontinuous groups of waves separated by relatively long intervals, but of a continuous oscillation of fluctuating amplitude owing to the joining up and overlapping of the successive groups. Evidently, therefore, if means can be provided for still further increasing the discharge rate, until successive impulses occur every two or three half-waves of the oscillation, a practically undamped oscillation should be maintained in the secondary circuit. This method has been employed by E. L. Chaffee, H. Yagi, and others.[1]

The metal that was at first most commonly employed for the electrodes of these quenched short spark-gaps was copper. Later experiments have shown that much better results may be obtained with other materials. The surface of copper when used as an electrode of a spark-gap very rapidly becomes pitted with the discharge, and the gap length consequently becomes irregular. This effect is more noticeable when the gap is in use for prolonged periods. The phenomenon of the quenching action does not appear to be very closely connected with the facility, or otherwise, with which an *arc* may be struck between poles of the material in question, as might at first be supposed. In many cases materials which do not readily form arcs give poor results in a quenched gap.[2] The advantages of some metals over others are to be found in their being less oxidisable, and less changed or pitted by the passage of the discharges.[3]

E. Taege has investigated the effect of various materials for the electrodes of quenched spark-gaps, and also of various dielectrics between the electrodes.[4] Best effects are found with silver, platinum, or copper, while magnesium and aluminium are least effective. Zinc gives fair results, but does not approach copper or silver. The best results of all are to be obtained with platinum-iridium, or with tungsten electrodes, very largely on account of their greater hardness.[5] When tungsten electrodes are used very much shorter gap lengths may be employed owing to the hardness of the metal, without any risk of short-circuit or fusing together of the electrodes. Better quenching action is thereby obtained, and closer couplings may be employed. Very good results may be obtained with molybdenum electrodes, but they are not nearly so satisfactory as tungsten. In commercial apparatus silver-plated copper electrodes have been very largely employed.

The most efficient quenching action is obtained when the electrodes are kept thoroughly cool. The thermal conductivity of the dielectric between them is of some importance

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[1] See pp. 67 and 78.

[2] Reference No. 109.

[3] Reference No. 120.

[4] Reference No. 121.

[5] Reference Nos. 119 (and 118).

in this connection. Best results are yielded by hydrogen or coal gas,[1] while such gases as nitrogen and chlorine have least influence. Good results are, however, said to be obtained with iodine-vapour.

An air blast, as a rule, is of little use with quenched spark-gaps, except under very special conditions.[2]

Artificial cooling of the electrodes will hinder the formation of an arc discharge between them, and consequently improve the quenching action by reducing the number of free ions[3] in the gap and so assist its rapid deionisation after the passage of each discharge. This feature is of special importance for securing high sparking rates.[4]

With an ordinary "open" spark-gap the maximum permissible sparking rate is very seriously limited by the characteristics of the gap and of the gas between the electrodes. For instance, it has been shown by K. Rottgardt that the natural time of deionisation of a gap having zinc electrodes and operating in air is of the order of 0·001 second.[5] This factor alone would therefore limit the maximum possible spark frequency with such a gap to something less than about 1000 per second, a value which, as we have already seen, is far too low for the purposes of wireless telephony. Any attempts to push up the sparking rate with such a gap would result in a permanent ionisation of the gap and the establishment of an arc discharge unless the deionisation time of the gap were shortened by some artificial means. Artificial cooling of the electrodes would assist in shortening this time. Quenched spark-gaps as a whole have a much shorter deionisation time than open sparks, and are therefore more suited to rapid sparking rates.

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[1] Reference No. 111.

[2] See p. 71, also Reference No. 108.

[3] With a discharge between two metallic electrodes the current is carried mainly by ions derived from the material of the dielectric while it is in the form usually referred to as a "spark"; but almost entirely by ions derived from the (heated) electrodes themselves when it is in the "arc" form. This distinction is borne out by the spectrum of the discharge which shows only the "lines" due to the materials of the dielectric for a pure spark, and the "lines" due to the electrode material when an arc is passing.

[4] A summary of the influence of the above factors upon the quenching properties of spark-gaps is given in Reference No. 621.

[5] Reference No. 124.

CHAPTER VII

"SPARK" GENERATORS (*continued*)—PRACTICAL FORMS OF QUENCHED SPARK-GAP

THE most usually adopted form of quenched spark-gap consists of two or more electrodes of fairly large surface area, separated by a very short air space, the whole design being such as to favour very rapid cooling and to hinder the production of any arc discharge. The actual gap length, and surface area of the electrodes, depend upon the particular design in use, the efficiency of the cooling arrangements, and especially upon the material of the electrodes and on the power to be handled by the gap. The following descriptions of special forms of quenched spark-gap will serve to illustrate these points.

Many patents have been taken out from time to time concerned with various forms and modifications of these spark-gaps, and considerable controversy has raged over their respective priority and invention.[1]

In the following pages an attempt has been made to give an account only of the most important varieties that have been used for commercial work or for experimental purposes, while details of some others may be obtained from the list of references to original papers, included at the end of the book. It should be understood, however, that the number of possible forms of such spark-gaps is almost unlimited, depending largely upon the ingenuity of the designer. It is therefore quite impossible to give an adequate account of all the many varieties in a work of this description.

THE TELEFUNKEN SPARK-GAP

This is perhaps the best known among the quenched spark-gaps, largely on account of its extensive use for musical note

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[1] See, for example, Reference Nos. 132, 133.

wireless telegraphy, using alternating current at 500-1000 ∼ .[1] It may, however, also be employed with direct current, or with higher frequency alternating currents to obtain increased sparking rates for telephone purposes.

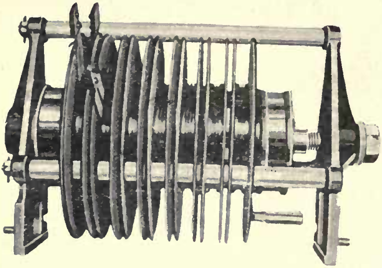

FIG. 35.—Telefunken Quenched Spark-Gap.

The gap consists (Fig. 35) of a series of flat copper discs provided with cooling flanges, and separated from one another by mica rings round their edges. A single spark-gap is thus formed between each adjacent pair of plates. The complete series of gaps is mounted in any convenient insulating stand and clamp. A sectional diagram showing four discs is given in Fig. 36. A, B, C, D are the four copper discs provided with cooling flanges F, F, and separated from one another by the mica rings M, M. Grooves G, G are turned in the discs near their edges and prevent the sparks always passing across the edge of the mica rings. The sparking spaces are S, S. The thickness of the mica rings M determines the spark length. This should be between 0·1 and 0·25 mm. The usual supply voltage under these conditions is from 600 to 800 volts per gap.

Many modifications of this gap have been brought out from time to time. In one of the most useful of these, due to R. Pfund,[2] an attempt has been made to avoid any irregularity in the spark length over the surface of the discs due to variations in the thickness of the mica rings, by constructing the discs with raised central portions for the sparking surfaces, with thicker rings of insulation permanently attached to each side of the disc and provided with metal facings. The whole disc, including the metal facings to the insulating rings, may then be turned up perfectly true, and *metal* washers or rings used for spacing purposes to determine the length of the gap. Much more uniform results may thus be obtained.

In the modern forms of the Telefunken spark-gap the

[1] Reference Nos. 127 to 131.

[2] Reference No. 125.

original copper discs have been replaced by silver-plated ones, with greatly improved results. The silver is much less oxidisable than the copper and tends to consequent greater regularity in the operation of the gap.

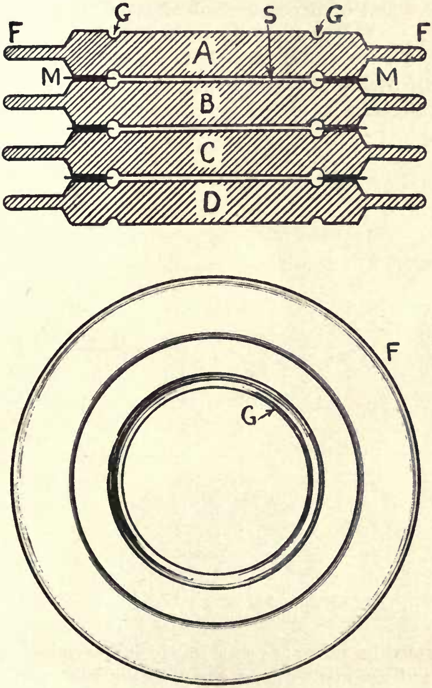

Fig. 36.—Section of Telefunken Spark-Gap.

When in use, this gap merely takes the place of the ordinary spark-gap of an inductively coupled transmitter (Fig. 37). With a direct current supply to obtain high sparking rates, R_0 and L_0 are the series resistance and choking inductance respectively, in the supply leads to the spark-gap S.

THE LEPEL SPARK-GAP

The Lepel quenched spark-gap possesses several features in common with the Telefunken gap just described, the chief differences being the customary use of water-cooling for the electrodes, and of paper instead of mica for separating the electrodes.[1] A diagrammatic section of the gap is given in Fig. 38. The two discs D_1 and D_2, which form the electrodes proper, are each provided with shallow metallic boxes through which water can be passed for cooling purposes.[2] The discs are separated by a disc of paper P, which determines the spark length, and gradually burns away as the gap is used, while the sparks which originally cross the gap through a small hole in the centre of the paper gradually pass towards the outside edges of the discs. When this is reached the paper must be removed and replaced by a fresh one. Fig. 39 is a photograph of a paper that has been used in one of these gaps. The irregular outline of the hole arises through the gradual burning away of the paper by the discharge. Not only does

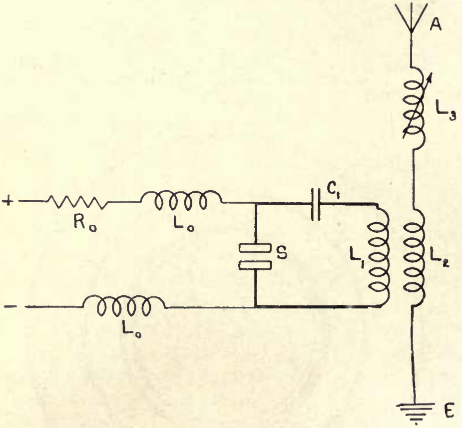

FIG. 37.—Arrangement of Quenched Spark Transmitter using Direct Current Supply.

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[1] Reference Nos. 136, 138, also 132 and 133.

[2] Rubber connecting tubes must obviously be employed for insulation purposes; and sea- or salt-water must not be used.

the paper form a convenient means of determining the length of the spark-gap, but through its burning away by the discharge a hydrogenous atmosphere is produced which favours the production of steady oscillations. To this end, different varieties of paper have slightly different effects. Impregnation of the paper with certain substances, such, for example, as paraffins, etc., is also often of some advantage. The most convenient thickness for the paper is as a rule between 5 and 10 mils. (=0·005″ to 0·01″).

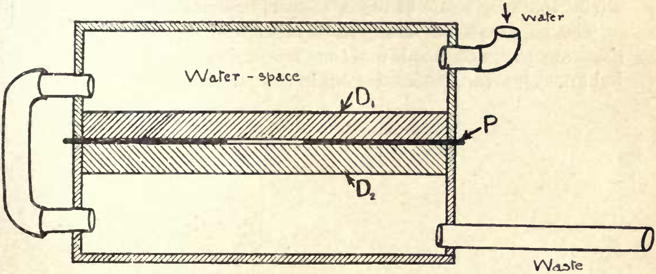

Fig. 38.—Diagrammatic Section of Lepel Quenched Spark-Gap.

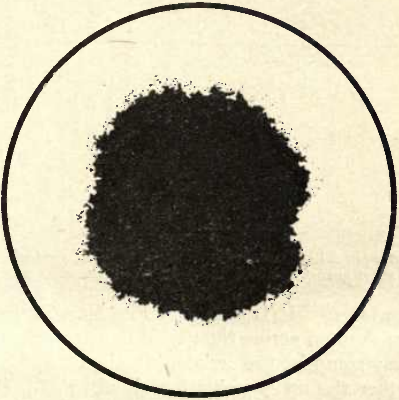

Fig. 39.—Paper Separator after use in a Lepel Spark-Gap.

A single gap of the above type may be connected to a direct current supply circuit of about 400 to 600 volts. When very thin papers are used voltages down to about 250 may be used. The electrodes may be from 3″ to 5″ diameter, and are customarily made of brass, copper, or delta metal.[1]

The gap may be arranged in much the same manner as that already described for the Telefunken gap (Fig. 37); but another arrangement, set out in the patent claims, possesses some advantages.[2] It is shown in Fig. 40. Two oscillation circuits are shunted across the gap in this arrangement. One of these may comprise the aerial-earth circuit A, L_2, S, C_2, E; and the other the main oscillation circuit, S, L_1, C_1. These two are also coupled together by the coils L_1, L_2. The direct current supply, represented by V_0, feeds the gap S through the series resistance R_0 and the choking inductances L_0.

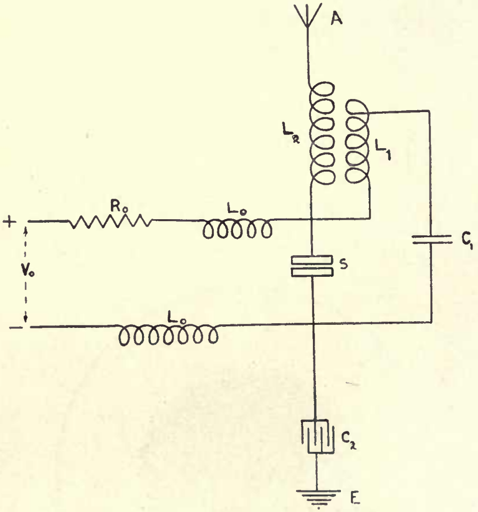

Fig. 40.—Arrangement of Quenched Spark-Gap with Double Oscillation Circuit to assist quenching of Discharge (E. von Lepel and others).

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[1] A hard brass containing a small percentage of iron.

[2] Reference No. 136; see also Nos. 134, 135.

The special advantage of this arrangement is that the gap is capable of starting up the oscillations in the two circuits, which are afterwards free to continue oscillating in series [A, L_2, L_1, C_1, C_2, E] with their own natural frequency,[1] as soon as the discharge is quenched out. The presence of the double circuit across the gap may greatly assist this rapid quenching action, provided that the electrical constants of the two circuits have been properly chosen.[2] The nature of this phenomenon is well illustrated in Fig. 41.

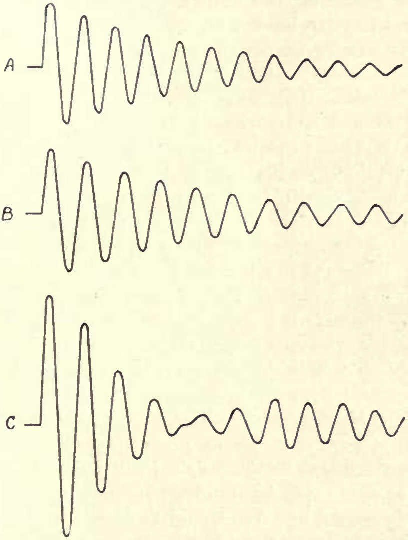

FIG. 41.—Mode of Operation of Double Shunt Oscillation Circuit across Spark-Gap.

This diagram shows the increased rapidity of quenching obtained when the two shunt circuits are adjusted to slightly different oscillation frequencies.

This diagram shows the effect of the addition of two

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[1] When two tuned circuits are connected in series with one another their combined natural frequency is the same as that of either of them taken separately.

[2] To such an extent is this the case that even an ordinary spark-gap not having any special quenching properties may be made, by this arrangement, to yield feebly damped oscillations like those furnished by a quenched gap. Reference No. 139.

oscillations A and B to one another—the two having the same initial amplitude, but slightly differing frequencies. They represent the curves of current in the two circuits which are shunted across the spark-gap. The sum of these two currents, curve C, therefore represents the total oscillatory current passing across the spark-gap. It will be noticed from the diagram that this curve rapidly dies down to a small amplitude. The quenching of the discharge can take place at this instant, and the gap become open-circuited. In other words, the current passing across the gap can cease entirely, while yet a considerable oscillatory current is flowing in each of the two circuits. The path of this oscillatory current is therefore through the two circuits in series, and, since the spark-gap resistance has been eliminated from this path, the damping of these oscillations will be much reduced. The above diagram illustrates the necessity for the small percentage detuning of the two circuits in order to increase the rapidity of the quenching out of the discharge across the gap. The frequency difference must not be made too great, however, in attempting to still further shorten the duration of the oscillations through the gap, or an oscillation will be built up again across the spark-gap before the quenching has been completed. A certain definite period of zero or small amplitude current across the gap must be allowed for the gap to become deionised, and the discharge quenched out. This period that is necessary depends upon the design of the spark-gap. It corresponds to the " deionisation-time " of the gap. If it can be made sufficiently great an ordinary type of open gap may be used,[1] but this would limit the spark frequency to a considerable extent.

THE PEUKERT OSCILLATION GENERATOR

In this spark-gap, due to W. Peukert, oil is used as the dielectric in place of air, by immersing the complete gap in oil, or by allowing oil (or other liquid) to be fed into the sparking space between the electrodes by some suitable arrangement.[2] To prevent the carbonisation of the oil, brought about by the heat of the discharge, from causing short-circuiting of the gap, it is necessary to maintain a circulation of the oil between the discs of the spark-gap.

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[1] Reference No. 139.

[2] Reference Nos. 140, 141, and 142.

This may be secured either by the help of a small auxiliary pump; or the oil may be run in by a gravity feed from a small reservoir, or by a "drip-feed" lubricator arranged with a pipe leading into the space between the electrodes through a hole in one of them. The oil rotates with the discs, and as a result of the centrifugal force upon it, is flung out radially to form a thin film on the electrode surfaces. The sparks pass through this oil film. An electromotor is commonly employed to maintain the discs in rotation (Fig. 42). The spark-gap should be supplied with from 600 to 900 volts, direct current, with currents up to a maximum of about 3 or 4 amperes. The gap is very steady in operation under these conditions. Silver-plated copper, brass, or steel electrode discs may be used. They are usually spaced about $\frac{1}{250}''$ apart ($=0{\cdot}1$ mm.), or slightly more for high voltages. In the most recent forms of this gap alcohol is usually employed in place of oil, as it yields more satisfactory results.

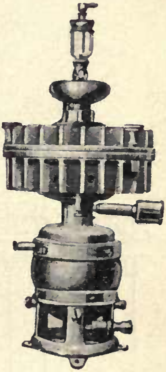

Fig. 42.—Peukert's Quenched Spark-Gap.

J. A. Fleming and G. B. Dyke have devised a modification of this spark-gap, that has proved successful for use over long periods, and for generating very steady oscillations.[1] An oil dielectric is used with rotating metal discs for the electrodes of the gap. Fig. 43 is a diagram (in part section) of the arrangement. A_1, A_2 are the two discs of "case-hardened" steel ground perfectly flat. The upper one, A_1, is mounted upon the end of a spindle B, running in ball-bearings through the upper supporting plate H, on which all the parts are mounted. The lower disc A_2 is carried on three adjusting screws C, C, C, passing through the plate G which is supported by pillars (but insulated) from the upper plate H. By means of these screws the two electrodes may be set in perfect parallelism. The lower disc (A_2) has a hole F in the centre through which fresh oil is sucked into the spark space between the discs to replace that which is flung out from between them by centrifugal force. The revolving disc may be belt-driven from a small electric motor at a speed of about 2000 r.p.m.

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[1] Reference No. 142*a*.

When several gaps of this type are used in series with high voltages, they may, if desired, all be belt-driven from the same motor, since the leather belt provides sufficient insulation between them. The complete gap is placed in a suitable vessel containing paraffin oil. The spacing of the discs should be about 0·25 mm., and the voltage required per gap is of the same order as for the Peukert gap.

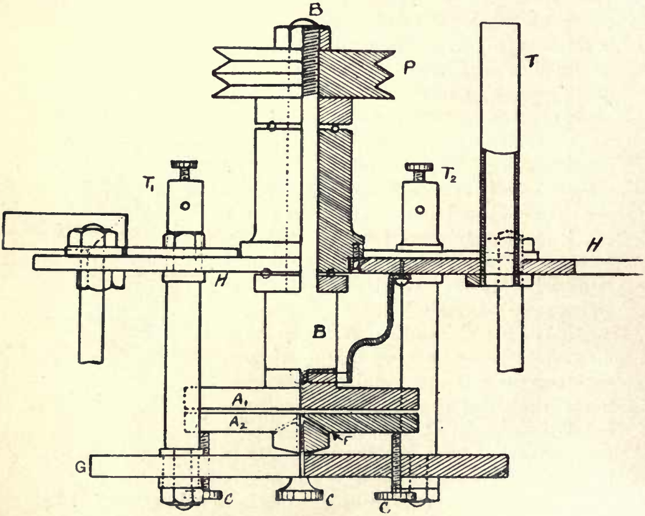

FIG. 43.—Fleming and Dyke Rotary Quenched Spark-Gap.

THE DUBILIER ROTARY SPARK-GAP

Another rotary quenched spark-gap is due to W. Dubilier.[1] In this instance the gap is usually operated with an air dielectric. It consists of a conical-shaped electrode mounted upon a spindle and capable of being rotated by an electromotor at a speed of 1000 to 2000 r.p.m., either by belt-drive or through an insulated coupling or gearing. In Fig. 44, A is the revolving electrode mounted on the shaft B running in the bearing C. The second electrode D is coned internally

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[1] Reference No. 144.

to the same angle as the revolving electrode A. The length of the gap between A and D can be varied by screwing the part D into or out of the fixed casing E. Voltages from 250 volts may be used on each gap.

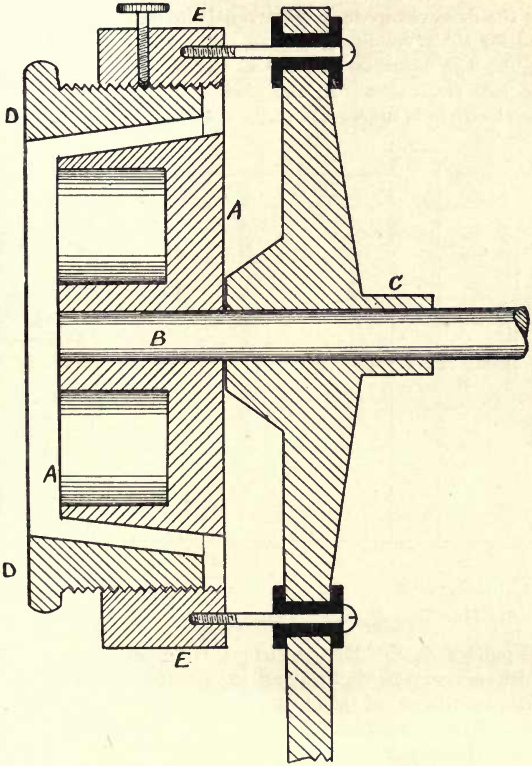

Fig. 44.—Dubilier Rotary Quenched Spark-Gap.

Water-cooled Rotary Spark-Gap

In order to obtain more efficient quenching action the electrodes of the spark-gap may be water-cooled (as in the Lepel gap, p. 55). A rotary quenched spark-gap, with water-cooled electrodes, that has been designed by the author is shown diagrammatically in Fig. 45. A and B are the two hollow water-cooled electrodes, one of which, A, is fixed to the insulating framework C, D, E, and the other, B, can be driven round on the shaft F, G. Cooling water circulation for the fixed electrode A is provided through the tubes R, S; and for the revolving electrode, through the hollow shaft at Q, T. The spark takes place in the narrow gap V between the two electrodes. In the particular arrangement shown the electrode is driven round on the fixed shaft by means of the pulleys X, X. The gap length is varied by the screw P, which moves the shaft along in the framework C, D, E. Strict parallelism of the electrodes may be secured by adjustment of the electrode A; but once accurately set and fixed very little further alteration should be required.

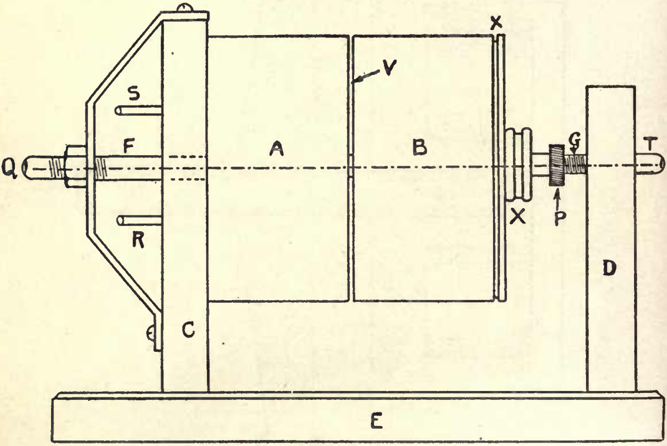

Fig. 45.—Water-cooled Rotary Quenched Spark-Gap (P. R. Coursey).

Revolving Disc Spark-Gap

Still another type of discharge gap differing from those already described is Marconi's smooth disc spark-gap. Gaps of this type are very suitable for high sparking rates, although they may also be employed in a special manner for the generation of continuous oscillations (see p. 99). It consists, as shown in Fig. 46, of a metal disc D, which is revolved rapidly between two other smaller discs or electrodes B, B, by means of the motor M. An insulated coupling or gearing must be placed between the motor and disc shafts. The discs B, B, may either be stationary or preferably be rotated by a motor through suitable insulated gearing or by belt drive. The connections of the disc for use in a similar manner to an ordinary quenched spark-gap are shown in the same diagram.

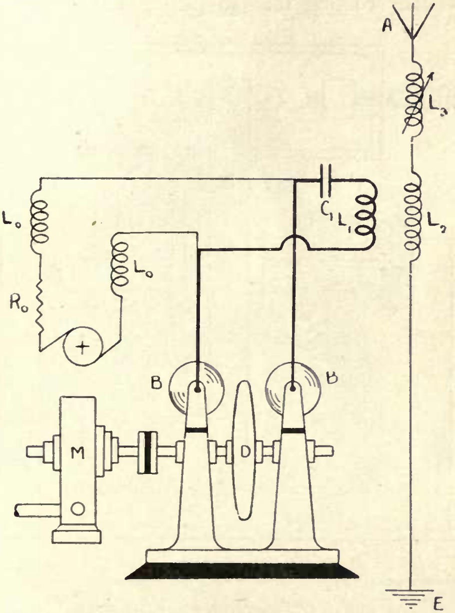

FIG. 46.—Marconi Smooth Disc Spark-Gap.

For experimental work with low power input a simple form of this gap may be constructed as shown in Fig. 47. The revolving disc D is belt-driven by the pulley G. The side electrodes A and B may be solid knobs (provided with adjustments to vary the gap length); or may be water-cooled for handling larger power inputs.

MULTIPLE CYLINDER QUENCHED SPARK-GAP

The forms of quenched spark-gap that have been described above, in common with practically all spark-gaps, are subject to irregular working through pitting and wearing of the electrode surfaces. This necessitates comparatively frequent removal of the electrodes for cleaning and re-surfacing. The employment of the hard metals, platinum-iridium alloy, tungsten, etc., for the electrode surfaces diminishes very considerably the wear caused by the spark, and thus considerably lengthens the useful life of gap (see p. 49).

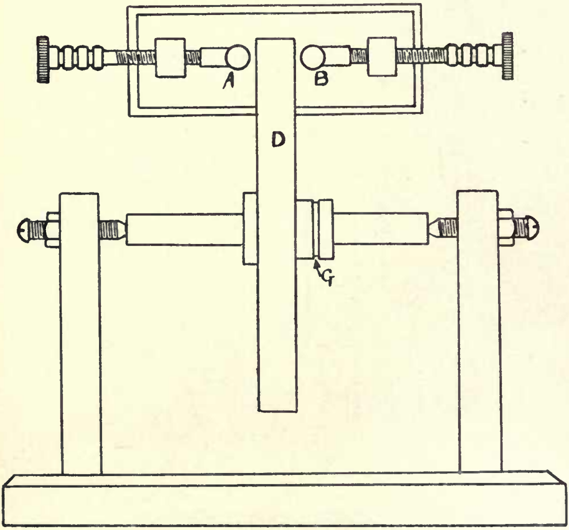

FIG. 47.—Revolving Disc Spark-Gap.

A form of gap in which the active surfaces of the electrodes can be renewed when they become worn, without removing the gap from service, is shown in Fig. 49. The electrodes are made in the form of parallel cylinders, so that the sparks pass between the adjacent edges; as at S in the diagram. The series of cylinders, A, B, C, etc., are mounted in any convenient insulating framework F, and each cylinder is provided with a small insulating handle H so that it may be rotated to present a fresh surface to the sparks from time to time as may be necessary. When the whole surface of the cylinder has been used in this manner it is but a moment's work to replace it by a fresh one.

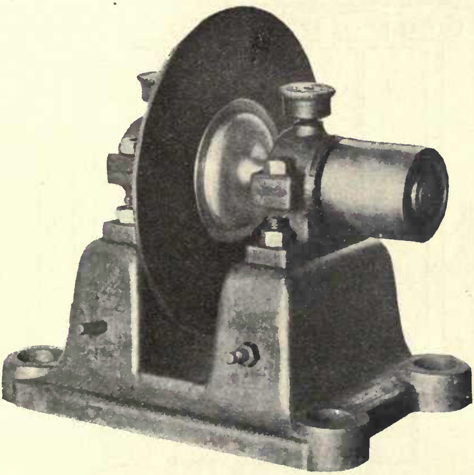

Fig. 48.—First Disc Discharger ever made (Smooth Disc).

The spark length S between adjacent cylinders should be a small fraction of a millimetre, and the number of gaps required must be adjusted to suit the voltage employed as in the cases already described.

Any of the usual materials may, of course, be employed for the cylinders—brass, copper, silver, tungsten, etc.—although as in other cases best results are usually obtained with tungsten on account of its hardness. A coating of tungsten on the surfaces of the cylinders is sufficient to secure the advantages of this material.

In a very similar construction adopted by the Compagnie

Générale de Radiotélégraphie[1] the cylinders are mounted in a framework in such a manner that the rectangular frame can be skewed more or less into a parallelogram shape by means of a screw adjustment, thus varying the gap length between the cylinders, as indicated diagrammatically in Fig. 50. A, B, C, D, E represent five such cylinders held in suitable clips between the two insulating strips F_1, F_2. Of these F_1 is fixed to the outer frame F; while F_2 can be moved laterally in guides by means of the adjusting screw G. The gap length S, between adjacent cylinders, can thus be regulated. The terminals T_1, T_2 are connected to the two outer cylinders.

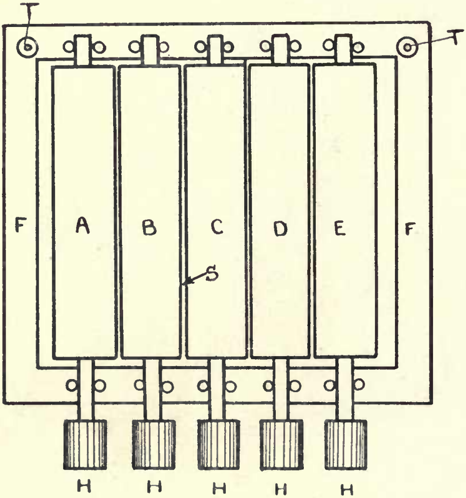

Fig. 49.—Parallel Cylinder Quenched Spark-Gap.

B. Thieme has described[2] various modifications of this spark-gap with the idea of retaining its advantages in the shape of easy renewal of the active surfaces, while overcoming the disadvantage under which it suffers, of having a very small effective surface area over which the sparking can take place.

[1] Reference No. 145.

[2] Reference No. 147.

The limited surface area of these gaps is responsible for a considerable restriction of the maximum power with which they can be loaded, without causing excessive wear of their surfaces. The same restriction also applies to the gap shown in Fig. 51, which is composed of a number of parallel metal strips arranged so that the sparks pass between their edges. Fairly effective cooling is obtained, provided that only small powers are used. The chief merit of the construction lies in its extreme simplicity and cheapness for experimental purposes.

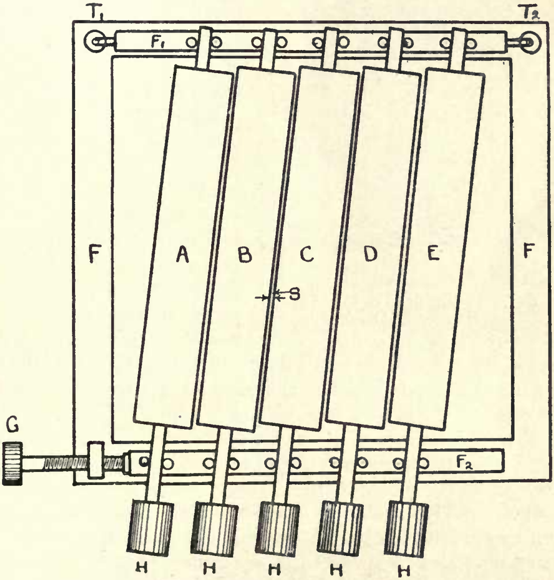

FIG. 50.—Multi-Cylinder Quenched Spark-Gap (Compagnie Générale de Radiotélégraphie).

CHAFFEE'S COPPER-ALUMINIUM QUENCHED SPARK-GAP

In 1911 E. L. Chaffee discovered that a quenched spark-gap formed between electrodes of copper and aluminium possessed novel and valuable properties, especially when it is worked in an atmosphere of hydrogen gas.[1] Still more recently H. Yagi has shown that a gap formed of aluminium and brass electrodes used in an atmosphere of coal gas yields similar, but slightly improved results.[2] A special feature of both these gaps is the relatively small surface area when compared with the Telefunken and similar gaps. The electrodes in size resemble almost those of an arc lamp—the usual size in the Chaffee gap being about $\frac{1}{2}''$ diameter, while those used by Yagi were still smaller. The small electrode area causes great limitations of the available power input. At the same time, however, under the conditions of extremely high sparking rates for which they seem particularly adapted the power input is further limited by other considerations unless the supply voltage is very largely increased.

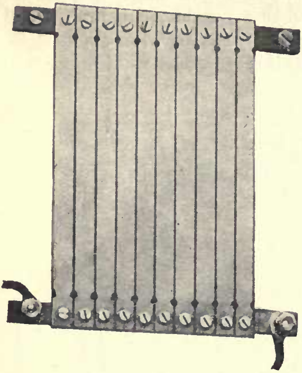

FIG. 51.—Parallel Strip Quenched Spark-Gap (W. Dubilier).

Fig. 52 is a diagram of Chaffee's gap showing the electrodes A, B, mounted in massive metal terminal blocks C, D, which are provided with radiating flanges as shown, for cooling purposes. The insulating handles H_1, H_2, serve to vary the gap length between the electrodes. The holders E, F, which carry the terminal blocks C, D, are clamped together with the insulating ring of fibre, G, between them. The hole in the centre of this ring serves as a container for the hydrogen atmosphere round the spark. T_1 and T_2 are inlet and outlet tubes for the gas.

The usual length of spark-gap lies between 0·04 and 0·1 mm., and under these conditions the voltage across each gap, when in operation, is about 150 volts. Direct current is used to enable high sparking rates to be secured. With a 400 volt supply circuit two gaps may be used in series, and four in series on an 800-1000 volt circuit. The gap as described

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[1] Reference No. 146.

[2] Reference No. 175.

above is only effective when the direct current passing through it is limited to 1 ampere or less, in order to prevent the formation of an inactive arc discharge with consequent cessation of the high-frequency oscillations.

A slightly simpler and somewhat modified form of this gap is due to B. Washington.[1] Fig. 53 is a diagram of his arrangement. The chief simplification lies in the replacement of the insulating ring G (in Fig. 52) by a closed metal cavity provided with a bronze diaphragm A over its front surface. The electrode C is clamped through the centre of this diaphragm, so that the adjusting handle H serves to push it towards or draw it away from the other electrode B, by bending in or out the central part of the diaphragm. A gas-tight joint between the moving electrode and the fixed casing is much more easily secured with this arrangement. Fig. 54 shows the complete gap.

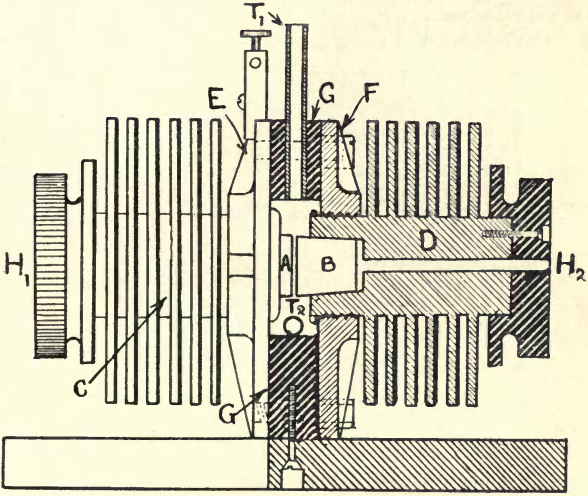

FIG. 52.—Chaffee's Copper-Aluminium Quenched Spark-Gap in Part Section.

For further details of the results obtainable with this gap see Chapter VIII. p. 78.

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[1] Reference No. 118.

Another pattern of this gap in which the electrodes are made in the form of discs, arranged so that one of them can be driven round by a small motor, has also been used, and yields improved results with higher efficiencies of operation. W. T. Ditcham has successfully employed a gap of this type for wireless telephone purposes over short distances.[1] This type of spark-gap closely resembles the Peukert gap (p. 58), except for the particular electrode materials employed, and in the use of hydrogen gas instead of oil or alcohol between the electrodes.

The operation of these gaps is essentially dependent upon the aluminium electrode (which should be connected to the negative pole of the supply circuit), rather than upon the anode (positive electrode). Changes in the material of the latter electrode produce but slight changes in the general properties of the gap. Researches show that the formation of some oxide skin upon the surface of the aluminium electrode is intimately connected with successful operation. The gap can be operated without the hydrogen atmosphere, but then yields inferior results. A thin film of oil upon the surface of the aluminium electrode is sometimes beneficial under these conditions. The pressure of the hydrogen is of some importance, and should not be raised much above ordinary atmospheric pressure. It is possible that the action of the film or

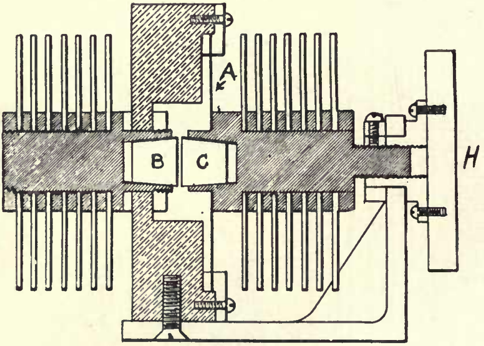

FIG. 53.—Section of Modified Chaffee Quenched Spark-Gap (B. Washington).

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[1] Reference Nos. 148 and 149.

skin upon the aluminium electrode materially increases the quenching action. A similar phenomenon occurs in the "T.Y.K." spark-gap,[1] and in the aluminium electrolytic valve rectifier. The same action is also exhibited by the aluminium electrolytic lightning arresters often used on power transmission lines.

The effect of various gases upon the operation of spark-gaps of the above type has been studied by E. Yokoyama. He has found the most favourable operation with ammonia gas when using copper and aluminium electrodes. The pressure of the gas is also of some importance.[2]

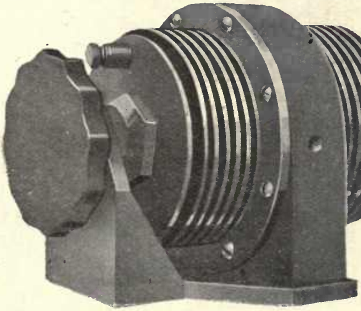

FIG. 54.—Modified Chaffee Quenched Spark-Gap (B. Washington).

SHAW'S QUENCHED SPARK-GAP

A peculiar form of spark-gap well adapted to the impulse excitation of a secondary or aerial circuit has been patented by A. Shaw (1912), and used to some extent in Australia.[3] Its properties depend upon the use of a very high velocity air blast between the electrodes.

It has already been mentioned (p. 50) that the use of an air blast is usually of little value with quenched spark-gaps. The ordinary air blast as often used with open spark-gaps serves mainly to clear away the ionised air between the electrodes and permit of more regular sparking. To this extent such an air blast has little action with quenched gaps except at very high sparking rates, since the deionisation time

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[1] See p. 151.

[2] Reference No. 623.

[3] Reference No. 150.

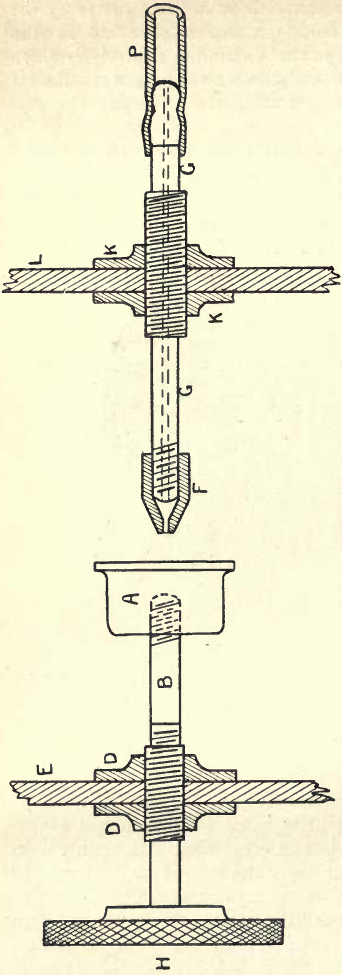

Fig. 55.—Sectional Diagram of Shaw's Quenched Spark-Gap with Air Blast.

of such gaps is already very short under normal conditions. An air blast also has some action towards raising the voltage across a spark-gap and so increasing the amount of energy drawn from the supply.

With the Shaw gap, the advantages of the air blast are not shown up until a very high velocity blast is obtained. The construction is shown diagrammatically in Fig. 55. It consists of a flat metal plate A, for one electrode, and a conical-shaped jet F, for the other. An aperture is made along the axis of this conical electrode to admit the air blast to the sparking space between the electrodes. The electrodes are carried on screwed rods B, G, G, with the insulating handle H for adjusting the length of the gap. The air is supplied through the pipe P, and so is admitted right into the sparking space where it can be most effective. The air pressure must be carefully adjusted to yield the best results, but is usually in the neighbourhood of 100 lbs./in.^{2} with a jet of diameter about $\frac{1}{64}''$. The electrodes are preferably constructed of copper or silver. The length of gap may be $\frac{3}{8}''$ to $\frac{1}{2}''$ without destroying the quenching action.

The usual circuit diagram employed with this type of gap is given in Fig. 56. Very high sparking rates are said to be obtainable.

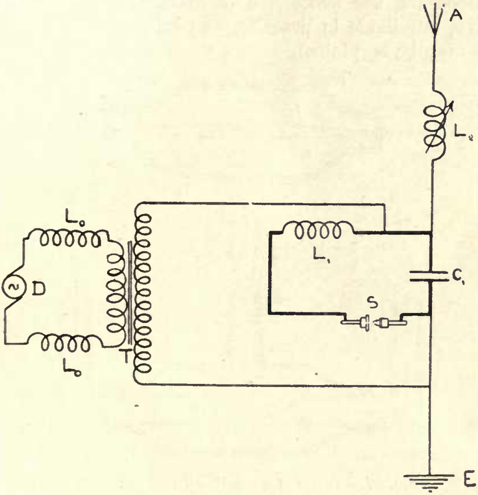

Fig. 56.—Circuit Diagram for Shaw's Quenched Spark-Gap.

Miscellaneous Methods for Impact Excitation

A great many experiments have been carried out from time to time concerned with other methods of securing the results of impact excitation apart from the use of such spark-gap arrangements as have been already described. The majority of these are of little value except for experimental investigations, and consequently a bare mention of them will suffice here. Further details are obtainable, if desired, from the original papers which are classified at the end of the book.

S. Eisenstein has proposed the use of a rectifying spark-gap comprised of one hot and one cold electrode in order to quench out the second half-wave of each discharge and thus to impulsively excite the secondary circuit.[1] A very similar arrangement has been used by B. Glatzel with two nickel wires for the spark-gap electrodes, placed in an atmosphere of hydrogen.[2] With certain electrode materials some workers have claimed good results by maintaining a permanent ionisation of the dielectric between the electrodes—such as by a Bunsen flame, etc.—with a view to securing more regular conditions for the successive discharges.[3] The method is, however, unreliable in practice, and but very limited energy inputs may be employed.

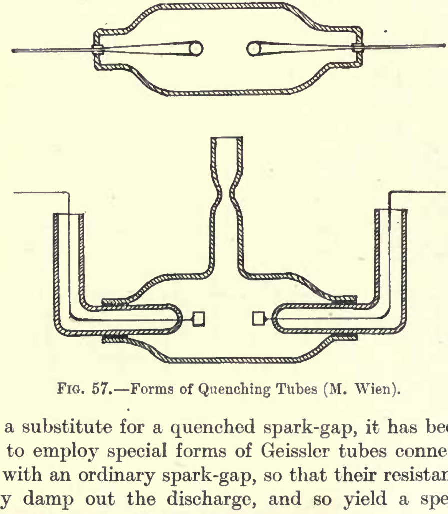

FIG. 57.—Forms of Quenching Tubes (M. Wien).

As a substitute for a quenched spark-gap, it has been proposed to employ special forms of Geissler tubes connected in series with an ordinary spark-gap, so that their resistance will rapidly damp out the discharge, and so yield a species of quenching action. M. Wien has described several special forms of these " quenching tubes " designed so as to be capable of handling the heavy condenser discharge currents without overheating (Fig. 57).[4] Vacuum tube condensers have also been used with a similar object. In this case the passage of

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[1] Reference No. 159.

[2] Reference No. 157.

[3] Reference No. 158.

[4] The electrodes of these tubes are best made of silver; and the gas pressure inside should be between 0·1 and about 1·0 mm. of mercury. Hydrogen gives the most satisfactory results. Reference No. 152.

the discharge sets up a certain amount of ionisation between the condenser plates and thus throws the primary and secondary circuits partly out of tune with one another.[1]

A more practical arrangement for securing a similar result is achieved by using a number of extra spark-gaps in the oscillation circuit, and bridging these extra ones by means of choking coils which allow the passage of the charging current through them, but possess sufficient impedance to stop the oscillatory discharge current and to force it to jump across the gap or gaps with which the coils are in parallel[2] (Fig. 58). In this way very little extra impedance will be offered to the charging up of the condenser from the supply circuit, but a much greater number of spark-gaps will be suddenly thrown into the circuit as soon as the discharge commences, thus promoting a more rapid quenching action.

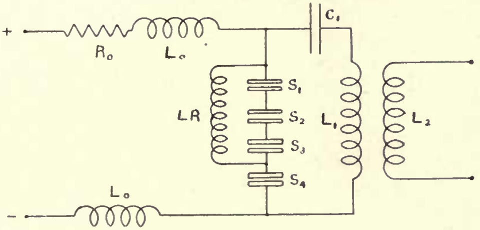

FIG. 58.—Additional Shunted Spark-Gaps to improve Quenching Effect.

One other form of quenched gap arrangement deserves mention here, as very good results may be obtained from it, especially in the direction of securing a very rapid succession of discharges and of generating continuous oscillations. The properties of a discharge through rarefied mercury vapour are involved in these arrangements. It is well known that the deionisation time of conducting mercury vapour is extremely short. This fact is shown up in the case of mercury vapour arc lamps,[3] in which a cessation of the current for an extremely minute fraction of a second results in a complete extinction of the arc. If such a lamp is connected up as a spark-gap with the usual oscillation circuits it becomes possible to obtain very efficient generation of high-frequency oscillations

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[1] Reference No. 151.

[2] Reference Nos. 153, 154, 155.

[3] Such as the Cooper-Hewitt and similar patterns.

on account of its effective quenching properties. Very high spark frequencies are thus readily obtainable.[1] G. W. Pierce has demonstrated that it is easily possible to obtain 100,000 or more discharges per second through such a gap without setting up a continuous arc discharge.[2] In addition to yielding very rapid and regular discharges this gap permits of much higher voltages being employed than with the usual quenched spark-gaps—as much as 10,000-15,000 volts being obtainable across a single gap.

Spark or discharge gaps of this type may also be used in other ways to yield continuous oscillations. Their use in this connection is dealt with more fully in the next chapter (p. 83).

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[1] Reference Nos. 162, 163, 185.

[2] Reference No. 174.

CHAPTER VIII

THE GENERATION OF CONTINUOUS OSCILLATIONS BY MEANS OF QUENCHED AND OTHER SPARK-GAPS

THE possibility of obtaining not merely a discontinuous series of damped oscillatory wave trains which may or may not run into one another, but oscillations which are either actually undamped, or at least very nearly so, has already been touched upon in the initial discussion of the uses of quenched spark-gaps.[1] It is evident from what has already been said that this necessitates an extremely high rate of sparking at the gap, when the customary oscillation frequencies are employed. The desired conditions will therefore be more readily secured the lower the frequency of the oscillations used, that is to say, the longer the wave-length that is employed in transmission. On the other hand, it is impossible in practice to increase the wave-length of transmission to an indefinite extent. This is the case for several reasons: firstly, it cannot be made to exceed about 10,000 metres (which corresponds to an oscillation frequency of 30,000 $\sim$ per second), or a continuous note would be heard in the receiving telephones, since lower frequencies are within the acoustic limit. In the second place, the longer the wave-length that is used, the larger must be the aerial that is utilised for its radiation and reception if any practical efficiency is to be obtained. The radiation falls off rapidly when the wave-length is increased to any great extent above the fundamental wave-length of the aerial. It is therefore very uneconomical to employ small aerials for the radiation of very long wave-lengths. Large and high aerials, however, involve heavy constructional and maintenance costs, which are not justifiable except for very long distance communications. Thirdly, it is customary to reserve long wave-

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[1] See pp. 38, 39, etc.

lengths for long-distance work. To transmit signals over great distances involves the employment of very considerable power at the transmitting station. Most especially is this the case when commercial work is to be handled, with its more exacting demands as to reliability of communication under all conditions.[1] The generation of large oscillatory power by the "spark" methods is, however, a difficult matter, while its control and modulation in accordance with the speaker's voice also presents some difficulties.[2] The spark methods in general do not therefore appear to be very well suited in their present forms for any but short-distance low-power work.

THE CHAFFEE GAP FOR CONTINUOUS OSCILLATIONS

The simplest method of obtaining continuous undamped (or nearly so) oscillations from a quenched spark-gap will perhaps best be appreciated from a description of Chaffee's experiments upon this subject.[3] The spark-gap that he employed has already been described.[4] One or two of these gaps may be run in series off a direct current supply circuit at about 400 volts with suitable resistance in series to limit the supply current to about 1 ampere, or preferably much less. Choking coils of large inductance must also be inserted in each lead, as shown at L_0 in Fig. 33 (p 47).

Under these conditions of operation the mode of working is as follows:

The choking inductances L_0 in the supply leads serve as a means of maintaining the current drawn from the direct current source at practically a constant value. Hence if the condenser circuit were not connected across the gap this current

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[1] Take, for instance, Trans-Atlantic communication. The first signals across the ocean were obtained in December 1901, with an expenditure of energy of less than 15 h.p. at the transmitter. Modern commercial stations to operate across the same distance contain plant running into 500-1000 h.p. The reason is to be found in the enormous variations in signal strength that take place from hour to hour and from day to day due to variations in the electrical properties of the atmosphere, and of the "absorption" that it causes; and also in the prevalence of interference due to natural electric waves or X's. An ample reserve of power is therefore needed to secure absolute reliability of communication.

[2] See Chapter XVI. p. 238, on "Modulation of the Transmitted Energy."

[3] Reference No. 146; see also No. 176.

[4] See p. 67 *et seq.*

would flow between the electrodes as an ordinary arc discharge. The capacity of the condenser used in the shunt oscillation circuit (usually about 0·005 mfd. or less), is sufficient to draw a charging current from the mains whose initial value is of the same order of magnitude as the normal supply current. Hence when the condenser circuit is connected across the gap the charging current that it draws almost entirely robs the spark-gap of the current that was previously passing through it, since the supply current from the mains is maintained practically constant by the series inductances L_0. The discharge across the gap therefore ceases, and the condenser is enabled to charge up nearly to the full supply voltage before a spark again crosses the gap, and the condenser is discharged through the primary inductance L_1 in the usual manner. While this is happening the supply current, previously serving to charge the condenser, is now diverted and passes across the gap, until the condenser is ready to be recharged.

Owing to the particular properties of the gap the discharge that passes is practically a " dead-beat " one, that is to say it consists, as a rule, of one half oscillation only. (Under certain circumstances two or three half-waves are obtained instead of one only, but the latter is more usual.[1]) The reasons for this probably lie in the special properties of the aluminium oxide film that is formed upon the surface of the negative electrode, as such a film usually possesses very marked rectifying properties [2] and would therefore quench out the second half of the oscillation. The gap is therefore very quickly ready for the passage of a fresh discharge, and if the condenser can charge up sufficiently quickly, this may occur after the lapse of half a period only of the oscillation induced in the secondary circuit. Under these conditions therefore the secondary oscillation would receive an impulse once in each complete period, so that it would become practically an undamped oscillation.

The frequency of the discharges at the gap is governed by the size of the condenser and the magnitude of the current drawn from the supply mains, for if $C =$ the capacity of the condenser in the oscillation circuit in microfarads, and V is

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[1] See also Reference No. 176.

[2] These properties are made use of, for instance, in the Aluminium Electrolytic Rectifier.

the maximum voltage to which it is charged in volts, then the charge Q, stored up in the condenser each time it is charged, is $Q=\frac{CV}{10^6}$ coulombs. Further, if $I=$ the current drawn from the supply mains in amperes, the quantity of electricity flowing into the condenser circuit per second $=I$ coulombs. Hence the number of times that this quantity will suffice to charge up the condenser in one second is given by $N=\frac{I}{CV\times 10^{-6}}$. This therefore is the maximum possible number of discharges per second that can be obtained under these conditions.

As an example, suppose that $C=0{\cdot}002$ mfd., $V=200$ volts, and $I=0{\cdot}2$ ampere, then we have

$$N=\frac{0{\cdot}2\times 10^6}{0{\cdot}002\times 200}=0{\cdot}5\times 10^6 \text{ per sec.}$$

Chaffee has shown by means of wave-meter readings that discharges quite as rapid, and even more rapid than this are obtainable with these arrangements.

It is evident from the above that the number of discharges per second is directly proportional to the current supplied to the gap. This conclusion has been verified with various types of spark-gap, by E. Mosler, G. W. Nasmyth, and others,[1] by employing such arrangements as enable the actual discharge frequency to be recorded photographically. It is therefore of the utmost importance that with any particular arrangement, the supply current should be correctly adjusted so that the right number of discharges is obtained per second to properly reinforce the secondary circuit oscillations. In practice it will be found that there is more than one value for the supply current which yields persistent oscillations in the secondary, corresponding to adjustments giving the secondary oscillation a fresh impulse every two, four, or six half-waves. When there is considerable absorption of energy by the secondary circuit (such as by radiation, etc.), it is advisable to secure a fresh impulse once in *every complete period*, in order that the oscillations may be as persistent as possible. As a matter of fact, it is found that the reactions between the secondary and primary circuits considerably aid the production of a regular succession of discharges in the correct phase relation to the existing oscillation.[2] In

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[1] Reference Nos. 122, 123.

[2] Reference Nos. 175, 177.

Fig. 59 is shown a typical curve obtained by Chaffee illustrating this effect of varying the supply current to the gap, and consequently also the number of discharges per second. The other circuit constants were held unaltered during the experiment. It is noticeable that the current in the secondary circuit fluctuates as the number of discharges per second is altered, and consequently either helps or hinders the existing oscillation. The maximum current A (Fig. 59) was shown, in this particular instance, to correspond with a discharge rate of one-third of the oscillation frequency in the secondary circuit, the peak B to one-fifth, and the peak C to one-seventh of the same frequency.

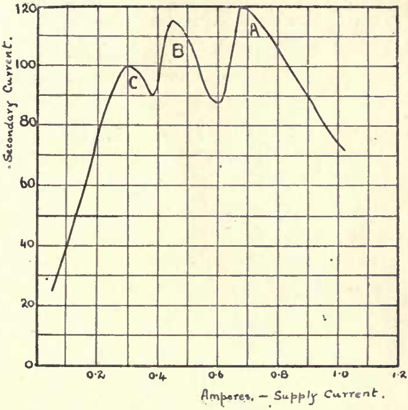

FIG. 59.—Variation of Secondary Oscillatory Current with Continuous Supply Current to Quenched Spark-Gap (E. L. Chaffee).

Apparatus worked in this manner is, however, only available for comparatively small power inputs, and it yet remains to be seen whether it will be possible to construct it on similar lines but on a much larger scale, so as to be suitable for handling larger amounts of energy. The chief difficulties in this direction are twofold, the limitation in the permissible size of the condenser in order to retain high discharge frequency, and the difficulty of constructing either gaps to handle large currents, or very high voltage direct current generators for use with a number of spark-gaps in series.

The storage of energy by a small condenser is very limited, when the voltages customarily used with these gaps are concerned. To charge up a condenser of capacity $= C$ mfds. to a voltage of V volts, requires an average amount of energy $= \frac{1}{2}QV$, where $Q =$ the charge stored up in the condenser, and $\frac{1}{2}V =$ the average potential of the condenser during its charge (starting at zero and ending at V volts). But, as we have already seen, $Q = CV \times 10^{-6}$ coulombs, therefore the energy stored up in the condenser per charge

$$= \tfrac{1}{2}\,V \cdot CV \times 10^{-6} = \tfrac{1}{2}\,CV^2 \times 10^{-6} \text{ joules.}$$

If N = the number of such charges per second = the number of discharges per second at the spark-gap, we have the power stored up in the condenser

$$= \tfrac{1}{2}CV^2N \times 10^{-6} \text{ watts.}$$

Taking the case we have already dealt with, viz., $C = 0{\cdot}002$ mfd., $V = 200$ volts, and $N = 0{\cdot}5 \times 10^6$ per second,[1] then

$$\begin{aligned} W &= \tfrac{1}{2} \times 0{\cdot}002 \times 200^2 \times 0{\cdot}5 \times 10^6 \times 10^{-6} \\ &= 20 \text{ watts.} \end{aligned}$$

This value is evidently too small for much practical work.[2]

The most useful way of increasing this quantity is to increase V and to use a larger number of spark-gaps in series, at the same time reducing the size of the condenser C so as to maintain the same number of discharges per second. It is evident from the formula for the discharge frequency given on p. 80 that the product CV must be maintained constant if the same sparking rate is to be retained, while employing the same supply current as must be the case while the same type of gap is used. Let us therefore examine the effect of using four gaps in series under a higher voltage in place of the single gap in the example taken above. With four gaps, the supply voltage V may be raised to 800 volts; and therefore to retain the product CV at the same value as before, C must be reduced to $\tfrac{1}{4} \times 0{\cdot}002 = 0{\cdot}0005$ mfd. The discharge frequency N remains at the same value as before.

Therefore, we have,

$$\begin{aligned} W &= \tfrac{1}{2} \times 0{\cdot}0005 \times 800^2 \times 0{\cdot}5 \times 10^6 \\ &= 80 \text{ watts.} \end{aligned}$$

This means that the output of high-frequency energy has been approximately quadrupled by using the greater number of gaps.[3]

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[1] See p. 80.

[2] Unless amplifiers are used at the receiving station. See Chapter XXII. p. 332.

[3] This result might also be expected from simpler reasoning; viz. the supply current remains the same, and the supply voltage has been quadrupled, therefore, if the efficiency remains the same the output should be quadrupled also.

In practical working it becomes difficult to increase the direct current supply voltage to a higher value than about 10,000 to 15,000 volts, since the generation of very high voltage direct current is a much more serious problem than the simple step-up transformation of alternating current.[1]

MERCURY-VAPOUR SPARK-GAPS FOR THE GENERATION OF CONTINUOUS OSCILLATIONS

The use of a mercury-vapour spark-gap as an ordinary quenched discharger has already been referred to on p. 75. Its extremely rapid quenching properties render it specially suited for use in the same way as the Chaffee gap just dealt with, to generate continuous oscillations[2] from a direct current supply source.

The general features of the arrangement are indicated in Fig. 60. Several special constructions for the mercury vapour tube have been described at various times, notably by E. Weintraub, and P. Cooper-Hewitt,[3] with the object of improving the efficiency and effectiveness of the apparatus. In the pattern shown in the diagram it consists of two bulbs G, H, of glass or quartz, united by a narrow bore tube T. The lower bulb H contains the mercury cathode K (negative electrode), and the upper one, G, the main anode F. Best effects are obtained when this anode is maintained as cool as possible, as, for instance, by constructing it in the form of a copper tube, closed at both ends, and provided with cooling water circulation through the pipes P_1, P_2. The lower bulb H is provided with an auxiliary side electrode M which serves as a local anode, and is connected with a battery B_1, and a resistance R_1, so that a small mercury vapour arc is maintained between the cathode K and the anode M. The cathode is best provided with a small copper wire or other similar solid projection above the surface of the mercury in order to locate the point from which the arc springs, and to prevent it from wandering about over the surface of the mercury K. When a sufficient voltage is applied between F and K, a mercury vapour arc will be set up between them, provided that F is connected to the positive pole of the supply circuit, since the rectifying properties of such a mercury vapour tube

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[1] See also Chapter XX. p. 299.

[2] Reference Nos. 182, 185, 186, 187, 188.

[3] Reference Nos. 180, 183, 184.

would suppress any appreciable current flow in the reverse direction.

On connecting the oscillation circuit C_1L_1 across this arrangement, the charging current flowing into the condenser robs the arc of some of its current (since the inductances L_0L_0 serve to maintain the supply current nearly constant as in Chaffee's arrangement), If therefore this charging current is sufficiently large, the arc will be completely extinguished,

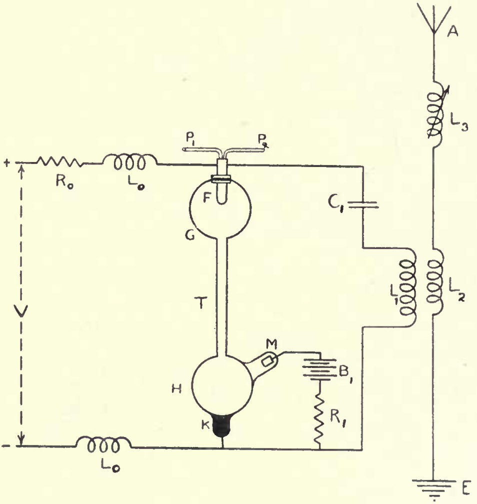

FIG. 60.—Mercury Vapour Discharge Tube arranged for the Generation of Continuous Oscillations (E. Weintraub).

provided that the vapour in the tube T can be deionised sufficiently quickly to bring about this extinction during the brief interval during which the condenser is charging. In order to help this action it is especially advantageous to maintain the whole apparatus as cool as possible, such as by employing a powerful air blast to cool the tube, or by immersing it completely in an oil bath which is maintained at a low temperature.

When the condenser has become charged up nearly to the line voltage V, the arc will be restruck again through the tube, and a low resistance path thus provided for the discharge of the condenser C_1 through the coil L_1. Owing to the rectifying property of the tube this discharge will be unidirectional only, and *not* oscillatory, so that the condenser is then immediately ready to be recharged from the mains, and the whole cycle repeated. By tuning the secondary circuit A, L_3, L_2, E to the frequency of these successive impulsive discharges, sustained oscillations will be set up in that circuit.

The efficiency of generation of high-frequency oscillations, and the output from this arrangement, is increased by making the bore of the tube T very small, such as $\frac{1}{16}''$ or even $\frac{1}{32}''$, for a length of 6″ or 8″, and the walls of the tube very thin, in order that the cooling may be as effective as possible in rapidly deionising the enclosed mercury vapour.

Powerful high-frequency oscillations suitable for wireless telephony may be obtained with a direct current supply voltage V of about 12,000 volts, and a condenser C of about 0·01 mfds. From $\frac{1}{2}$ to 1 kw. may be handled by a single tube.

It has been shown by F. K. Vreeland[1] that very similar results may be obtained without the employment of a tube having a constricted bore, if the tube is subjected to an axial magnetic field to serve the purpose of concentrating the discharge into a narrow arc stream down the centre of the tube. The use of hydrogen, nitrogen, or other similar inert gas inside the tube, at pressures up to 1 or 2 mms. of mercury, is also advantageous in securing the same results, and in raising both the maximum permissible voltage across the tube, and also the maximum current that can be passed through it, consistent with the setting up of oscillations in the shunt circuit. Very efficient cooling means must be employed when the tube is handling these large outputs. For instance, as an example of the quantities involved with this type of tube, currents up to 10 or 15 amperes can be passed through a tube about 2″ diameter × 6″ long with the electrodes placed about 3″ apart. If the gas pressure inside the tube is raised to about 2 mm. of mercury, a p.d. of from 300 to 500 volts would be obtained across the terminals of such an arrangement.

[1] Reference No. 183.

THE MARCONI MULTI-DISC DISCHARGER FOR GENERATING CONTINUOUS OSCILLATIONS

Methods are available for the generation of continuous oscillations by spark discharges, other than the simple use of quenched gaps that has already been described. Of these, the most important one is a modification of the well-known Marconi studded disc discharger (Figs. 61 and 62), so largely used in musical note spark telegraphy.

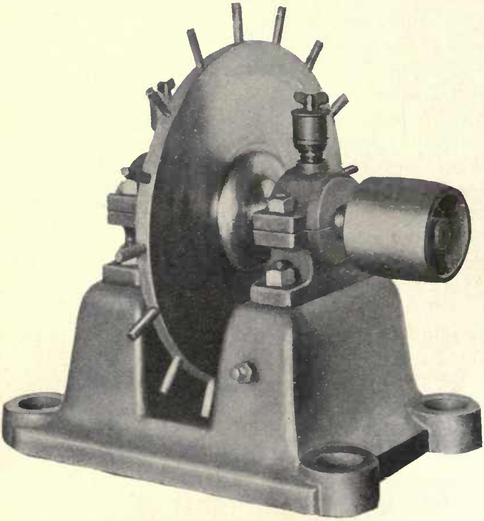

FIG. 61.—Early Form of Disc Discharger with Radial Teeth.

In the usual arrangement of the rotary studded spark-gap there is a relatively long interval between the successive trains of oscillations set up by each spark discharge (except in the case of the long distance stations using long wavelengths). We may, however, imagine the spark frequency to be considerably increased until it becomes comparable with the oscillation frequency, so that a fresh impulse is given to the secondary circuit every two or three oscillations, just as in the simple cases that have already been dealt with. This

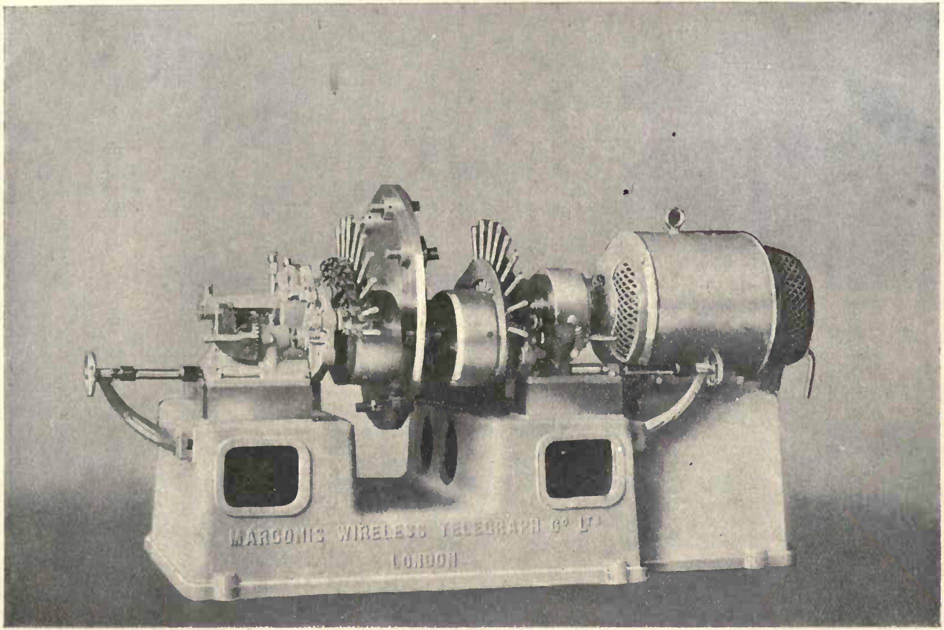

FIG. 62.—Rotary Disc Discharger for 75 kw. Installation.

arrangement of a studded spark-gap would, however, have very limited utility, since it is impossible to increase indefinitely either the number of teeth or studs on the revolving disc, or its speed of rotation, for mechanical reasons. Also the spark would be liable to jump to more than one tooth simultaneously if they are placed too close together (see p. 98).

A great improvement in this method is obtained by splitting up the spark so that it takes place on a number of discs, so arranged that they discharge in succession. The time interval between successive sparks on the same disc is thereby increased with advantageous results. The method then constitutes what is usually known as the Marconi multi-disc discharger.[1]

A number of similar studded disc spark-gaps are mounted upon a common shaft, with their electrodes so arranged with respect to one another that sparking takes place in regular succession at each of the discs, the sparks occurring at the following discs filling up the spaces, at equal intervals, between the successive sparks on the first disc. Fig. 63 will perhaps make the idea clearer. D_1, D_2, D_3, D_4 represent four such similar discs mounted upon a common axis. Each disc would, in actuality, have many studs or sparking projections upon it, but for simplicity in the diagram four only are shown on each disc. If then, under these conditions, one disc only, say D_1, were connected up, there would be four sparks during each revolution of the shaft. The studs on the other discs, D_2, D_3, D_4, are, however, set at equal angular intervals behind one another, so that when all the discs are connected up a spark will pass first on D_1, then after a certain interval (represented in this instance, as shown in the diagram, by the time of $\frac{1}{16}$ of a revolution of the shaft), on D_2; again, after the same interval, on D_3; similarly on D_4; and, after a fourth equal interval, again on D_1, after which the cycle will be repeated indefinitely. In this way, instead of obtaining merely 4 sparks per revolution as would have been the case with but one disc, we get $4 \times 4 = 16$ sparks. In general, the number of sparks obtainable per second with this arrangement = (no. of studs per disc) × (no. of discs) × (revs. per second of the shaft).

In this manner, if each disc has its own oscillation circuit connected across its electrodes, as shown in the above

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[1] Reference No. 189.

diagram, it is possible to get a second discharge occurring (on a second disc) before the train of oscillations due to the first spark has died away, so that if the respective primary circuits are caused to influence the same secondary circuit, including an aerial system, it becomes possible by driving the discs at the correct speed to arrange that the impulses obtained from the successive sparks shall assist one another and set up a steady continuous oscillation in the aerial circuit.[1]

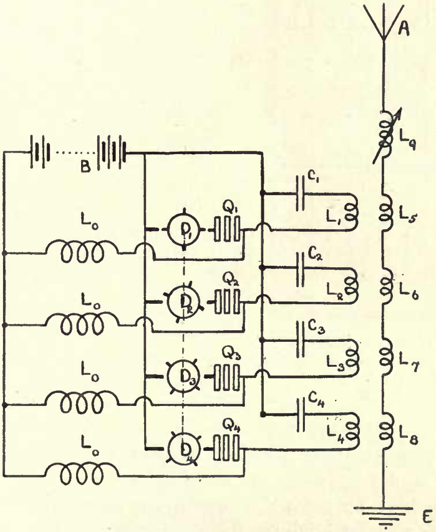

FIG. 63.—Circuit Arrangement for Multi-Disc Discharger for Continuous Oscillations.

Fig. 64 diagrammatically represents these conditions. The first four lines show the oscillations due to each of the four discs in turn, displaced in phase by an equal amount from one another. The lowest line gives the sum of these successive wave trains, and therefore represents the resulting oscillation in the secondary (aerial) circuit. It is evident that under the conditions shown, this is a continuous undamped

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[1] Reference No. 190.

oscillation,[1] although the ordinates, positive and negative, on opposite sides of the zero line are not quite equal.

The essential feature of this method of generating continuous oscillations therefore consists in driving the discs at such a speed that the successive spark discharges will exactly synchronise with the oscillation frequency in the manner shown in Fig. 64. This further means that the speed of the discs must be maintained extremely constant or an irregular wave will be generated, and the energy output will be greatly diminished.

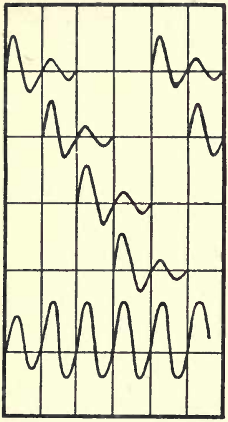

FIG. 64.—Diagram of Mode of Operation of Marconi Multi-Disc Discharger.

The obvious advantage of the method, as compared with the quenched spark arrangements already described, is the possibility of constructing the discs to handle large power outputs, since considerable experience has already been obtained in the design and operation of single studded disc spark-gaps, to handle, if need be 200 kw. or more, so that apart from the difficulties of exact speed regulation, there should be little trouble in using this method for similar outputs. It may be noted in passing that the speed question is not such a serious matter as might at first sight be supposed, since the conditions are simplified by having a constant load (air friction, etc.), upon the motor driving the discs ; whereas in the case, say, of the high-frequency alternators (Chapter XIV. p. 193), where the speed must also be maintained extremely constant, the load may be very variable. These difficulties have, however, been overcome in practice by suitable governing arrangements.

It may here be mentioned that it is evidently possible, at least in small installations, to employ only *one* studded disc, but with a number of fixed electrodes properly arranged round its periphery, so that sparks take place successively to these

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[1] Such a wave would have appreciable damping if the log. decrement were to be calculated per *half period* ; but obviously has none when the decrement is reckoned per *complete period.* See also footnote on p. 44.

electrodes, thus discharging the condensers connected to them in turn, just as when a number of discs are employed.

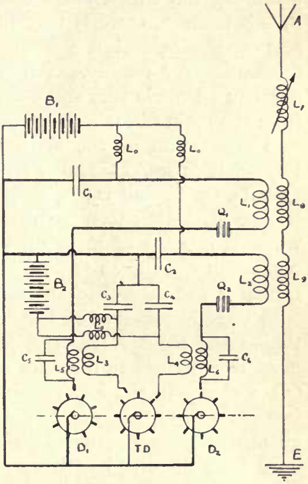

FIG. 65.—Multi-Disc Discharger for Continuous Oscillations, with Trigger Disc for timing the Main Discharges.

As an improvement upon this method, to further sustain the regularity of the rate of discharge which is essential to its successful operation, it is customary to control the rate of sparking at the main discharge gaps by means of some form of trigger arrangement that will allow the main discharges to pass only at the correct instant, thus eliminating any chance of irregular sparking such as sometimes occurs when disc gaps are handling large powers.[1] To this end quenching arrangements are inserted in series with each disc of such a nature that the normal supply voltage is insufficient to cause a discharge. These may conveniently take the form of ordinary quenched spark-gaps of any of the types that have already been described. They are indicated at Q_1, Q_2 in Fig. 65, and also at Q_1, Q_2, Q_3, Q_4 in Fig. 63. Their function serves to cut off the "tails" of the discharge in each case, and to limit the primary oscillations to but four or five half-waves, as shown in Fig. 64. An auxiliary or "trigger" disc having the same number of teeth as the main gap is mounted upon the same shaft, so that it revolves synchronously with the main discs. Fixed electrodes are arranged so that a spark occurs on the trigger disc (TD, Fig. 65) at the same instant that a discharge should pass on the main disc. The oscillation circuits C_3, L_3 and C_4, L_4 which are connected to this disc are made to have a much higher frequency than the main oscillation and aerial circuits. They are coupled respectively to coils L_5 and L_6, which are in series with the main oscillation

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[1] Reference No. 191.

circuits, and are tuned to the higher frequency by condensers C_5 and C_6. The maximum possible potential is thereby obtained across these coils. Hence, when a spark occurs on the trigger disc, a high voltage is momentarily induced into one of the main oscillation circuits so as to precipitate the main discharge in that circuit at the correct instant. By arranging the trigger disc circuits to have a higher frequency in this manner, there is very little reaction between the two sets of circuits, and as a result the trigger disc is enabled to discharge very readily. The power handled by the trigger disc can be made very small compared with the whole output from the main discs.

The diagram of the arrangement here given shows but two main discs, D_1 and D_2, with two separate oscillation circuits, C_1, L_1 and C_2, L_2 connected to them; but a similar trigger arrangement may obviously be applied to cases in which a number of main discs are employed, each with its oscillation circuit (as in Fig. 63) so as to ensure the correct timing of the main discharges.

A large installation on these lines, with the trigger disc for timing the main discharges, is shown in Fig. 66, and the most recent form suitable for an output of 300 kw. in Figs. 66A and B. In the latter installation three discs are used—two main discs, and one trigger or timing disc. The special quenching gaps mentioned in the above general description have been dispensed with by arranging that each main discharge shall take place across *four* gaps in series. These gaps are each about $\frac{1}{10}''$ long, so that the normal condenser voltage (the condensers are charged from a 5000-volt D.C. generator) is insufficient alone to jump the gaps.

Each main disc is provided with twenty-four studs, and four revolving plain discs—two each side—to form the sparking electrodes. The side discs are set so that a main discharge can pass through four gaps in series, two on each disc, on one side of the discs; and then at $\frac{1}{48}$th of a revolution later through the four gaps on the opposite side of the discs.

The side disc electrodes (small horizontal discs) can be seen clearly in Fig. 66B, with the strip connection between the adjacent side electrodes belonging to the two main discs, for connecting the four gaps in series. The connections to the second set of electrodes can just be seen at the back of the main discs.

The trigger disc is mounted on the same shaft as the main

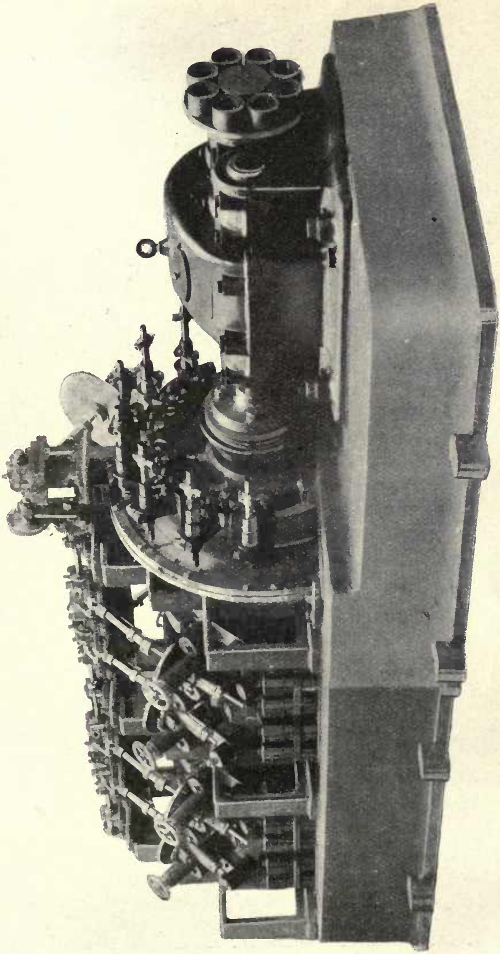

Fig. 66.—Timed Spark Disc Discharger, for Continuous Wave Production for High Power Stations.

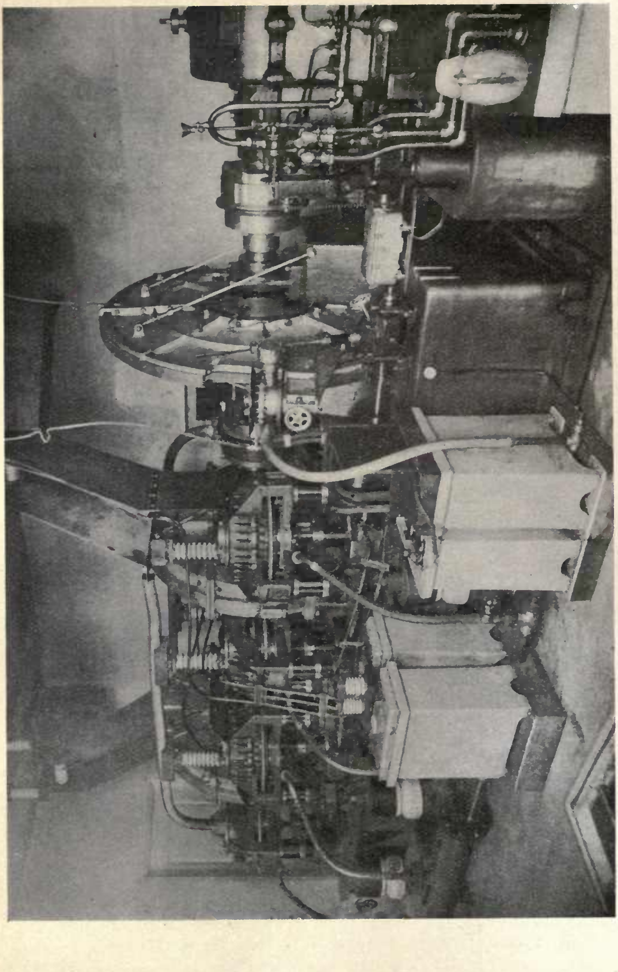

FIG. 66A.—300 kw. Marconi Timed Disc Continuous-Wave Generator (View from the Trigger Disc end).

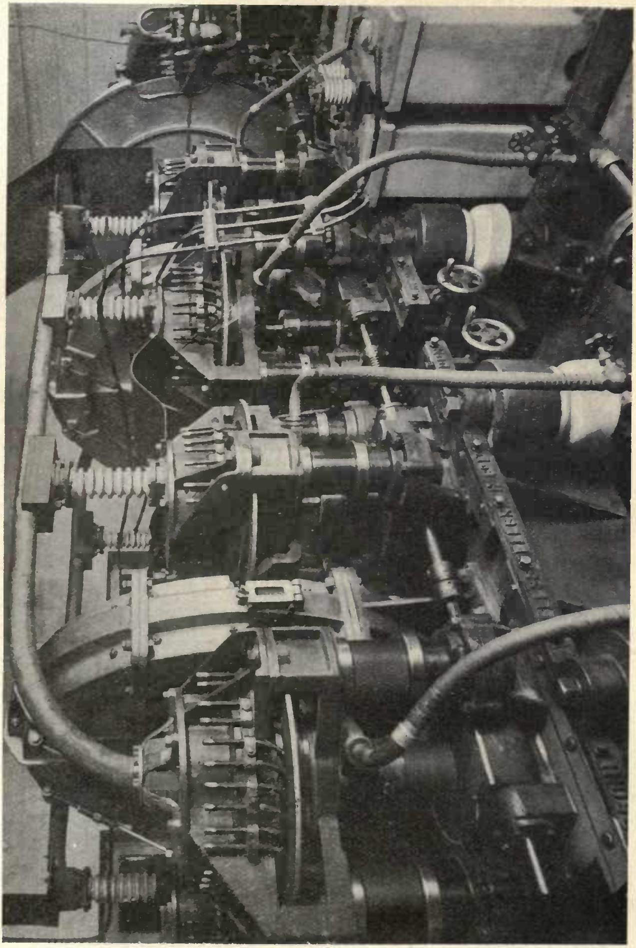

FIG. 66B.—300 kw. Marconi Timed Disc Continuous-Wave Generator (View showing the two Main Discs).

discs, as can be seen in Fig. 66A, but it is provided with twice the number of studs as the main discs have, in order that the high-voltage (high-frequency) impulses derived from the discharges occurring between its studs and its side electrode may be able to start off in turn the successive main discharges on both sides of the main discs.

The high-voltage impulses from the trigger disc are led to the main gaps through small auxiliary condensers. The oscillation frequency of these timing discharges is much higher than that of the main oscillations, so that the impulsing voltage may be passed on to the main disc gaps through much smaller condensers than are used in the main circuits. The main high-power oscillations are thus largely prevented from passing back on to the trigger disc circuits. Strong air blasts are used at each of the gaps in order to promote rapid quenching of the discharges and to prevent the primary discharge being drawn over between studs. The primary wave is thus quenched down to only a few alternations.

An aerial having a low decrement is necessary for the successful operation of these generators, in order that the oscillations in the aerial circuit may not die down too much between successive primary discharges.

In the case of the 300 kw. set illustrated, the discs run at close on 2000 r.m.p., giving 793 discharges per second on each side of the main discs, or an effective sparking rate of 1586 per second.

The aerial circuit is tuned to a frequency of 21,400, corresponding to a wave-length of 14,000 metres. There are thus 13½ oscillations in the aerial circuit between successive primary discharges; but it is found in practice that even with this comparatively large number of free oscillations a continuous wave is still obtained, with very little effective fluctuation in amplitude.

MARCONI TOOTHED WHEEL SPARK-GAP FOR CONTINUOUS OSCILLATIONS

An earlier method than the above, that was patented by Marconi for the generation of continuous oscillations by spark discharges, involves the use of two insulated discs or wheels provided with a large number of teeth round their periphery.[1] The wheels are so placed that the teeth of one alternate with

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[1] Reference No. 192.

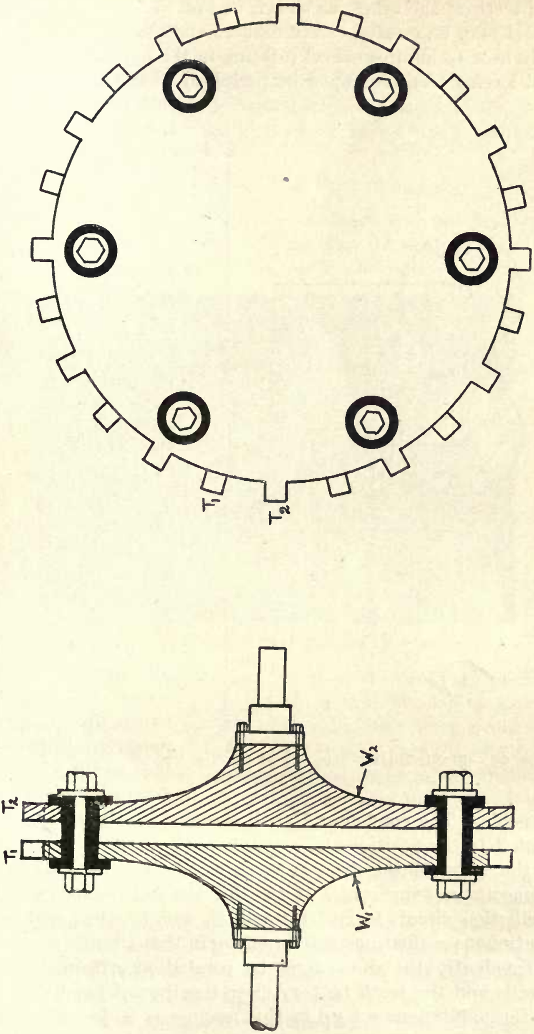

Fig. 67.—Double-Toothed Wheel Spark-Gap for Continuous Oscillations (Marconi).

the teeth of the other, as shown in Fig. 67. This compound wheel may be rotated either past a fixed electrode, or preferably near to another wheel rotating in the opposite direction, and having teeth cut upon its periphery of the same pitch as those upon either of the other wheels. W_1 and W_2 in Figs. 67 and 68 represent the two discs, insulated from each other and running in insulated bearings. A connection is made to each wheel by a rubbing brush contact. The interspacing teeth of the two wheels are shown at T_1, T_2. . . . Two condensers, C, C′ (Fig. 68), are connected in series between these two discs, and are kept charged from a high-tension D.C. dynamo G. The voltage applied from this dynamo must be sufficient to spark across the gap between the oppositely revolving discs when the teeth approach as close together as possible. The condenser C_1 will thereby be alternately connected to the positive and negative poles of the dynamo, and if the speed of the discs is so adjusted that these alternate connections synchronise with the natural period of the oscillation circuit formed through C_1 and L_1, then sustained continuous oscillations will be set up in that circuit.

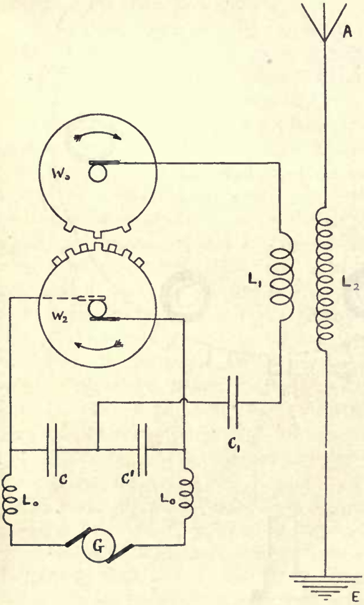

Fig. 68.—Double-Toothed Wheel Spark-Gap for Continuous Oscillations (Marconi).

Evidently the discs must be rotated at extremely high speeds and the teeth be very close together, if the frequency of the oscillations set up in this manner is to be sufficiently high for wireless telephone purposes. The nearness of the adjacent teeth seriously limits the voltage which can be applied to the discs, and consequently also the available power will be limited, otherwise sparking may take place to several teeth at the same time, and the regularity of operation will be lost.

An early form of toothed wheel spark-gap is shown in Fig. 69.

THE MARCONI SMOOTH DISC SPARK-GAP

A simpler method, from the constructional point of view, of achieving the same result is that known as Marconi's Smooth Disc Discharger. The use of a smooth revolving disc spark-gap has already been mentioned (p. 63). Such an arrangement may be employed in a very similar manner to the toothed wheel gap just described, and thus avoid any difficulties of securing exact synchronism between the speed of rotation and the oscillation frequency. The available energy output is, however, limited. The diagram of connections is given in Fig. 70.

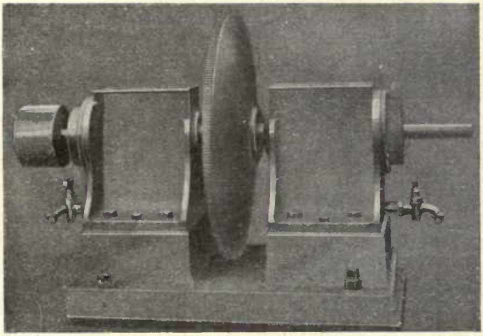

FIG. 69.—Toothed Wheel Spark-Gap (Marconi).

In this diagram, C_1 and C_2 are the two condensers which are charged by the high voltage direct current supply from the dynamo (or battery) V, through the usual choking inductances L_0 and resistances R_0. The main oscillation condenser C is connected in series with the jigger primary L between the central " smooth " disc D and central connection of the condensers C_1 and C_2, as shown.

The mode of operation is somewhat as follows. The two condensers C_1 and C_2 are charged up from the dynamo V until the air-gap breaks down between one side disc, say B_1, and the central disc D. The energy that has been stored in the condenser C_1 will then rush round the circuit L_1,B_1,D, L, C, C_1 to charge up the condenser C. Owing to the cooling and quenching action of the rapidly revolving disc, this discharge will be quickly quenched out at the completion of the first half wave, leaving the condenser C in a condition to help the discharge of C_2 across the gap D,B_2. As soon as this discharge is completed, it can discharge again in the reverse direction across the gap B_1,D. In this manner a continuous succession of rapid discharges takes place alternately across the two gaps, just as if the toothed discs were employed, and a steady continuous oscillation is set up through the condenser C and inductance L. For telephonic purposes the controlling microphone would generally be inserted in the earth lead between L_3 and E, though other methods of control are also available (see Chapter XVI., p. 238, on "Modulation of the Transmitted Energy").

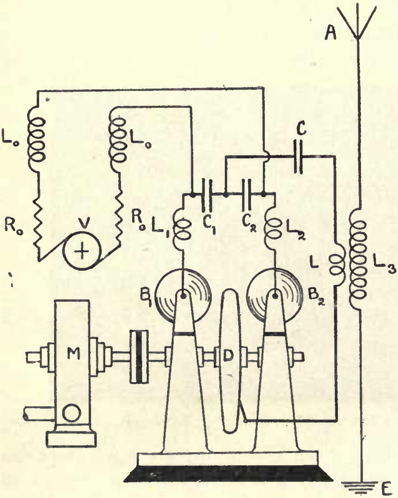

Fig. 70.—Connections of Smooth Disc Spark-Gap for Continuous Oscillations (Marconi).

The discharges and oscillations obtained by this method are apt to become irregular when any considerable power is handled by the gap, largely through the persistence of the ionisation at each discharge when large currents are passing, causing the discharges to overlap one another and the regularity to be lost.

CHAPTER IX

MULTIPHASE SPARK TRANSMITTERS FOR WIRELESS TELEPHONY

Quenched Spark-Gaps—Multiphase

The power and frequency limitations of the quenched spark discharge gaps, when used on direct current for the generation of continuous oscillations, have already been pointed out. Still another method for their use presents itself, however, as an extension of the early arrangements employing " partial discharges " with a low-frequency alternating current supply.[1]

The idea really originated in an attempt to fill up the gaps in the series of partial discharges which occur at each instant when the E.M.F. wave passes through its zero value, by utilising a three-phase alternating current supply circuit with three spark-gaps. Each spark-gap has its associated oscillation circuit shunted across it, and arranged to influence a common secondary circuit including the aerial, very much on the same general lines as the Marconi Multi-Disc method already described.[2]

The origin of the idea appears to be traceable back to Eisenstein's patents taken out in 1905 and 1906,[3] in which he proposed using three transformers connected one in each phase of a three-phase alternating current supply, and each provided with a discharge spark-gap with its associated oscillation circuit. These three circuits were coupled with a common aerial circuit by reason of their each having a common inductance in series with the aerial, as indicated in Fig. 71. J_1, J_2, J_3 are the three transformers connected in " star " across the three-phase lines, 1, 2, 3, with the common neutral connection, or " star point " O. S_1, S_2, S_3 are the three spark-gaps

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[1] See pp. 42 *et seq.*

[2] See p. 89.

[3] Reference No. 193, also No. 195.

and C_1, C_2, C_3 the three condensers associated with their respective transformers. L_1 is the common inductance forming part of the three oscillation circuits, and connected in the aerial circuit A-E.

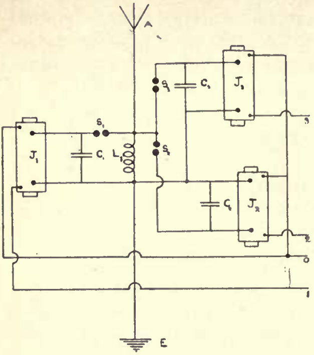

Fig. 71.—Arrangement of Early Three-Phase Spark Transmitter (Eisenstein).

The mode of operation is indicated in Fig. 72. A, B, C represent the E.M.F. waves of the three phases taken separately. Each of these will give rise to multiple discharges after the manner of the early arrangements with single phase current.[1] These "partials" are represented by the vertical lines S, S. These, it is seen, overlap one another and give rise to an almost continuous and uniform succession of spark discharges, so that a continuous stream of waves should be radiated from the aerial and would be suitable for speech transmission. Unfortunately the early hopes in this direction were not realised, through the irregularity of the discharges that were obtained from the open spark-gaps. Little progress was made with these

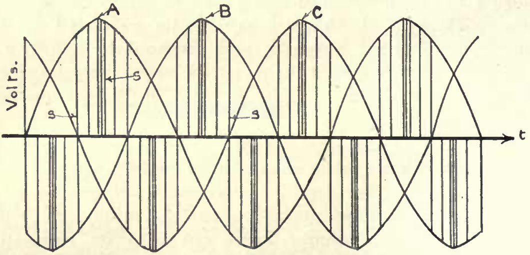

Fig. 72.—Diagram illustrating Mode of Operation of Three-Phase Spark Transmitter utilising Multiple Discharges.

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[1] Figs. 28, 29, 30, pp. 42 and 43.

arrangements until the quenched spark-gaps were substituted for the older ones.

In these circumstances it becomes possible to use the quenched spark-gaps under conditions best suited to their satisfactory and regular operation, viz. with alternating current, and giving *one* discharge every half-cycle of the E.M.F. wave of the supply. Much larger capacities can be used in the oscillation circuits than are possible when high spark rates on direct current are desired, and higher sparking voltages are much easier and cheaper to obtain. A greater output of high-frequency energy can thereby be obtained provided that the spark-gaps are properly designed for this purpose.

To render this method available for telephony it is necessary to employ alternating current of such a frequency that the *resultant* spark or group frequency is above the acoustic limit. If, for instance, a three-phase supply at 5000 ∾ is employed, the resultant group frequency of 30,000 per second[1] should be high enough for telephonic purposes under certain conditions.

On the other hand, we are not necessarily limited to using a three-phase supply—a greater number of phases can be used if so desired, enabling an alternator designed for lower frequencies to be used. The above figure of 5000 ∿ is, however, quite within the practical limits of frequency for the ordinary types of alternator—that is to say, without going into the complications consequent upon extremely high frequency.[2]

It is possible, too, to secure the advantages of such a multiphase arrangement by "splitting up" the phases of, say, a two- or three-phase supply from a low-frequency alternator, and so to obtain a very high sparking rate. This cannot be carried too far, however, since owing to the consequent multiplication of apparatus the result would be too cumbersome and too costly.

It is preferable to adopt an *odd* number of phases, otherwise full advantage will not be obtained in increasing the sparking rate, since two or more sparks would be occurring simultaneously in different phases since there are two sparks per period in each phase.

One simple method of transforming a three-phase low-

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[1] Each phase gives two sparks per period (one at each E.M.F. maximum, positive and negative), that is, in this case 10,000 per second per phase.

[2] Compare Chapter XIV. on "H.F. Alternators," p. 193.

frequency supply into one of a larger number of phases is indicated in Fig. 73. This diagram represents a ring-shaped transformer core, T, wound with a three-phase primary, and a number of separate secondary coils disposed at equidistant points round the ring. The three primary terminals, P_1, P_2, P_3, are connected to three equidistant points round the continuous ring winding forming the complete primary P.

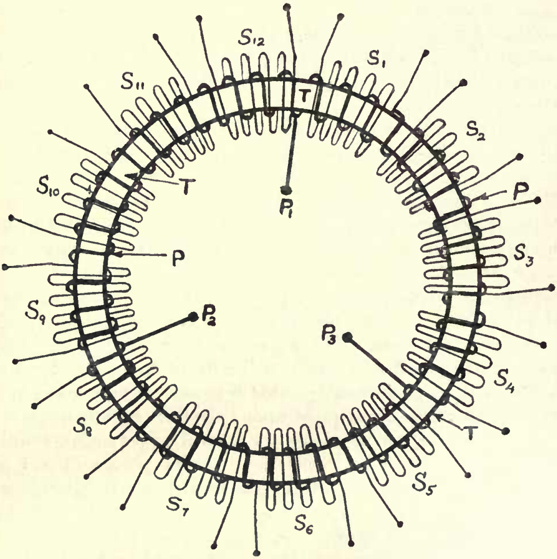

FIG. 73.—Arrangement for increasing the Number of Phases from a Three-Phase Supply.

When these terminals are connected to a three-phase supply, the resultant magnetic field will rotate once round the ring during each complete cycle of the alternating supply. The E.M.F.'s generated in the secondary windings, S_1, S_2, S_3, etc., will therefore successively reach their maximum values in the coils distributed round the ring. If each secondary coil supplies a quenched spark transmitting set, the total number of spark discharges obtained per cycle of the supply will be twice the number of separate secondary windings. Hence the resultant effective sparking rate will be $=2nN$, where $n=$ frequency of the low-frequency supply, and $N=$ number of secondary phases.

Even with this arrangement the fundamental frequency of the supply cannot well be below about 1000 ∾.

Some practical work has been done by E. G. Gage with a three-phase transmitter using an alternating current at about 4000 ∾ from a special alternator designed to give a three-phase supply at that frequency.[1] The circuit arrangements are shown in Fig. 74. 1, 2 and 3 are the terminals of the three-phase supply. These are connected through three low-frequency tuning inductances L′, L″, L‴, to the primaries of three single-phase transformers T_1, T_2, T_3. In the diagram these are shown in "star" connection, one terminal of each being joined to the common neutral connection N. The secondaries of these transformers are joined through the inductances L_0', L_0'', L_0''' to the condensers C_1, C_2, C_3, forming the capacities in the three separate oscillation circuits.

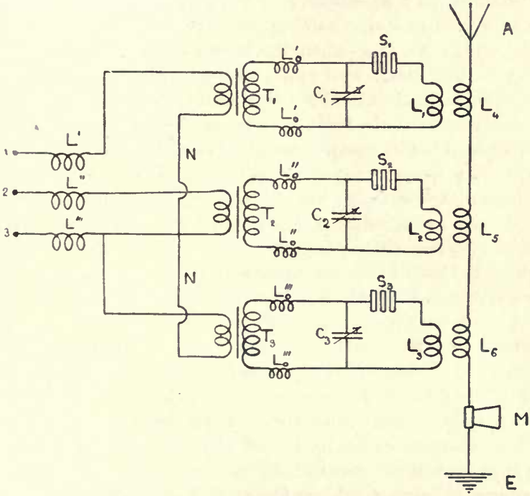

Fig. 74.—Three-Phase Quenched Spark Transmitter (E. G. Gage).

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[1] Reference No. 194.

S_1, S_2, S_3 are the three quenched spark-gaps, and L_1, L_2, L_3 the three jigger primaries coupling the separate oscillation circuits on to the common aerial circuit A, L_4, L_5, L_6, E.

In order to secure satisfactory regular operation of all three quenched spark-gaps, it is advantageous to carefully tune the primaries and secondaries of the three step-up transformers T_1,T_2,T_3 to the frequency of the supply current from the alternator. The inductances L_0' and L', L_0'' and L'', L_0''' and L''' are useful for this purpose, though if necessary condensers may be inserted in the supply leads to the three transformers in order to obtain better tuning. This can, of course, only be done when the initial frequency of the alternator is, say, 2000 ∿ or more, as the condensers required for lower frequencies would be too costly and bulky for use in most cases.[1] It is further very necessary that the three oscillation circuits should each be tuned to exactly the same oscillation frequency, and that their respective constants (inductance, capacity, log.-decrement, etc.) should also be as nearly as possible the same, or the regularity of the emitted waves will be partially lost. In the above diagram the microphone is shown connected in the earth lead. Other arrangements are discussed in a later chapter, XVI. (p. 238).

A very important point in connection with the successful operation of transmitters of this type has been brought to light by E. J. Simon and L. Israel, in a paper read before the Institute of Radio-Engineers (New York), describing experiments with similar apparatus.[2] Their tests were made with 500 ∿ current so as to be suitable for musical note telegraphy, but their conclusions are applicable to the higher frequencies as well. They found that after the transmitters in each phase had been separately adjusted to equality of wave-length, power consumption, etc., and each was giving a good note (corresponding in this instance to 1000 sparks per second), that when the three phases were simultaneously switched into circuit, the aerial current and power output did not increase by anything approaching the correct amount; that the over-all efficiency of the apparatus fell to nearly half

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[1] The current I passed by a condenser of C microfarads, when subjected to a sinoidal voltage of V volts at a frequency of n cycles per second is $I = \frac{2\pi n C V}{10^6}$ amperes. Hence to pass a given current, the necessary capacity varies inversely as the frequency of the supply.

[2] Reference No. 197.

its initial value obtained when using one phase only ; and that the signals emitted did *not* give the expected note due to 3000 sparks per second, but merely an irregular hissing sound.

A series of calculations and experiments showed that this was entirely due to the overlapping of the successive wave trains in the aerial circuit. They showed that the oscillations in the aerial circuit due to each spark still had a considerable amplitude when a fresh discharge occurred, with the result that this might either hinder or help the setting up of a steady stream of oscillations. This will depend upon whether the oscillation frequency is, or is not, an exact multiple of the group frequency of the waves.

An effective remedy, in this case, was found by increasing the damping of the aerial circuit (by adding a resistance in series with it) to such a point that the train of oscillations in the aerial circuit, due to each spark, had to all intents and purposes died out before the next discharge occurred.

Under these conditions the efficiency rose to about the same value as it initially had when using one phase only, while, further, the signals had a good tone corresponding to the spark frequency of 3000 per second.[1] It is possible that a small spark-gap inserted in the aerial circuit might have brought about the same result in a more efficient manner, and prevented the overlapping of the successive wave trains.

Effects of this kind will be relatively more important as the spark frequency approaches the oscillation frequency of the aerial circuit ; but at the same time the reaction between the secondary and primary circuits becomes more helpful in enabling the circuits to be so tuned that the best effects are secured, with a proper fitting together of successive impulses.

Although the most desirable condition to secure, whenever possible, is that of supplying the secondary with a fresh impulse once in every cycle of the oscillation (since under these conditions the oscillations would be undamped), yet it is easily seen that it cannot be realised in practice by this method, without the employment of inconveniently high frequency alternators, or a great number of phases. Thus, suppose that it is desired to transmit a wave of 1000 metres wave-length ; this means an oscillation frequency of

$$n = \frac{3 \times 10^8}{1000} = 300{,}000 \sim .$$

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[1] See also p. 293 (Fig. 205).

Hence, with *one* fresh impulse per cycle, the same total number of impulses will be required per second. Using a three-phase supply, giving six sparks per cycle of the supply current, the necessary alternator frequency becomes

$$N = \frac{300,000}{6} = 50,000 \sim,$$

which is quite impracticable with the usual constructions for such machines. Further, in order to limit the alternator frequency to 10,000 ∿, which is about the highest value that can be constructed with any degree of ease, it would require the use of

$$P = \frac{300,000}{2 \times 10,000} = 15 \text{ phases.}$$

This again is too many. The nearest practical case would probably be to employ, say, nine phases, with an alternator designed for 8333 ∿. This would yield 150,000 impulses per second, that is to say the secondary would receive a fresh impulse every other cycle of the oscillation. The resulting current would be sufficiently undamped for all practical purposes ; while good results would probably still be obtained if the alternator frequency were cut down to 5555 ∿, yielding an impulse every three complete cycles.

Evidently with such arrangements a very constant frequency must be maintained by the supply alternator, and practically as much care must be taken over the governing arrangements for the prime mover (driving the alternator) as is necessary with the high-frequency alternators supplying radio-frequency currents (Chapter XIV.).

Another possibility is, however, open for adoption for telephonic purposes, viz. the production of a " continuous " wave in the aerial circuit from a comparatively low discharge frequency, as was indicated in Simon and Israel's experiments referred to above.[1] In that case only a 500 ∿ supply was employed, yet it was found that with the minimum aerial damping the signals possessed no " tone " whatever beyond a hissing sound. This was brought about by the overlapping of the successive wave trains, as has been already described. Speech transmission should be possible with such an arrangement, and has, in fact, been suggested by L. de Forest for other arrangements giving like results.[2]

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[1] Reference No. 197.

[2] Reference No. 196.

Rotary Spark-Gaps—Multiphase

Three-phase synchronous studded disc spark-gaps have been used in a similar manner to the three-phase quenched spark apparatus just described, on alternating current supplies up

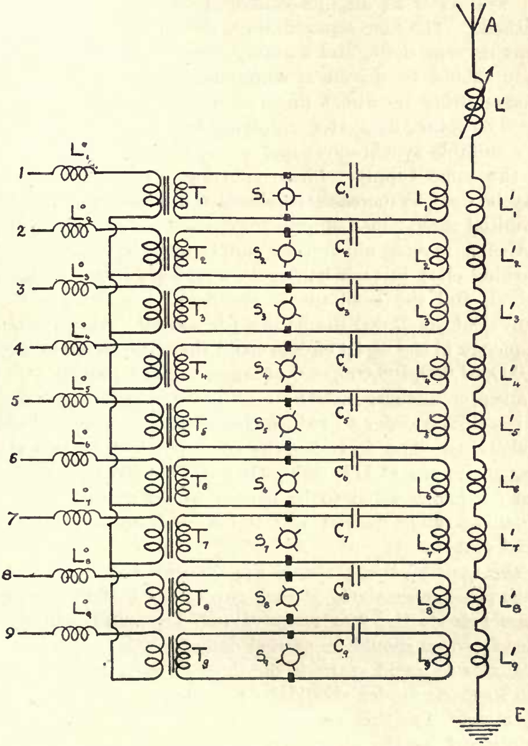

Fig. 75.—Nine-Phase Rotary Spark Transmitter.

to about 120 ∿. They are, of course, not limited to this range of frequencies, although they cannot well be used for very high initial frequencies with a small number of phases. An increase in the number of phases renders the arrangement very similar to the Marconi Multi-Disc method already described (p. 86), but with the important advantage that the use of the alternating current supply enables the necessary high voltage to be very much more easily obtained than with direct current.

The diagram of a nine-phase apparatus on these lines (Fig. 75) will serve as an illustration of the possibilities of the method.[1] The nine separate discs should be mounted on the same driving shaft, and suitably insulated from each other. They should be driven synchronously with the supply frequency either by direct (insulated) coupling with the alternator or rotary converter supplying the current, or by means of a suitable synchronous motor run from, say, three phases of the same supply. Phase-splitting transformers (p. 104) may be used to increase the effective number of phases from an initial three-phase supply.

Using, say, a nine-phase supply at 1500 ∿, each disc sparking once in each half-cycle would give 3000 sparks per second, and the resultant in the aerial would therefore be equivalent to 27,000 discharges per second. The oscillation frequency in the aerial circuit could therefore be made 27,000, 54,000, 81,000, 108,000, etc.—that is, any exact multiple of the number of discharges. The multiple should be kept as low as possible in order to reduce the effective decrement of the oscillations. The wave-lengths corresponding to the above frequencies are 11,111, 5666, 3703, 2777 metres respectively. The particular value to be chosen would depend upon the signalling range desired and the corresponding size of the aerial system.

The gaps S_1, S_2 . . . S_9 in Fig. 75 are set so that sparking takes place successively at each gap as the E.M.F. in its own phase reaches the maximum value. The exact adjustment of each phase should be carried out when the set is running until a pure-toned spark is obtained on each phase in turn. The fixed electrodes should be provided with small angular adjustment for this purpose. A constant speed must be maintained by the alternator and discs to ensure that the successive discharges properly reinforce the aerial circuit oscillations.

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[1] Reference Nos. 198, 199.

CHAPTER X

ARC OSCILLATION GENERATORS—I. GENERAL REMARKS ON THE PRODUCTION OF OSCILLATIONS BY ARCS

WHEN we take an ordinary continuous current arc between carbon rods, and, while maintaining the arc length constant, vary the current passing through it, at the same time measuring the P.D. between its terminals, we obtain what is called the " characteristic " of the arc.

A convenient means of securing the constancy of the arc length during such an experiment is to project an image of the arc on to a suitable graduated screen by means of an ordinary convex lens. If a graduated scale is placed on this screen the adjustments can very easily be carried out to maintain the arc of a constant length (Fig. 76). By determining the magnification produced by the lens, the actual arc length can be very readily ascertained from readings taken of the distance between the images of the two electrodes upon the screen. The arc itself usually provides ample illumination for the purposes of the projection in this manner.

When the readings of voltage and current obtained from such an experiment are plotted upon squared paper, it is seen that the resulting characteristic curve is a " falling " or " negative " one—that is to say, when the current increases, the potential difference between the electrodes falls, and *vice versa*. Fig. 77 shows some typical curves obtained with solid carbon rod electrodes for different arc lengths. It shows the general form of all such curves, although the actual scale will in every case depend upon the nature of the particular electrodes in use, and on the gas or medium in which the arc is burning.

Suppose now that we connect across an arc running off a constant voltage supply, with a suitable steadying resistance R_0 in series, a shunt circuit containing an inductance L_1 and a condenser C_1, as shown in Fig. 78. There will then be a sudden rush of current into the uncharged condenser to charge it up to the P.D. across the arc. With the arc connected to the supply circuit merely through the resistance R_0 (as is usual with arc lamps for lighting purposes), this rush of current will be drawn mainly from the supply without producing a very great change in the value of the current flowing through the arc itself. This is especially the case if the supply is taken from a network possessing considerable power capacity, or from storage batteries. If, however, we connect in series with the arc an inductance L_0 (Fig. 78) of considerable value, it will tend to prevent any rapid changes in the value of the current passing through it, by reason of the back E.M.F. that is induced in its windings by any small change in the current. This back E.M.F. tends to oppose the current change.

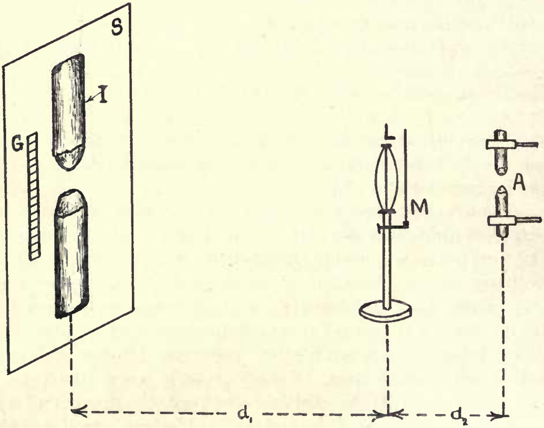

Fig. 76.—Measurement of Arc Length for Characteristic Curves.
S = screen with graduated scale G; I = image of arc A; L = convex lens; M = thin sheet of mica to avoid possible damage to the lens by heat from the arc; Magnification $= \frac{d_1}{d_2}$.

Hence in this case the rush of current required to charge the condenser C_1 will be drawn from the arc circuit itself.

The current through the arc is therefore diminished, while the supply current remains sensibly constant.

Referring again to the arc characteristics (Fig. 77), we see at once that this diminution of the current flowing through the arc must be accompanied by a simultaneous *increase* in the potential difference between the arc electrodes, which will therefore assist the charging of the condenser to a higher voltage than the normal P.D. across the arc. As the condenser charges up, the arc current will gradually increase again to its original value, accompanied by a decrease of the P.D. across its terminals. The state of affairs at this point is, therefore, that the condenser is charged to a higher voltage than that across the arc terminals. Consequently it commences to discharge back again through the arc, augmenting the current flowing through the latter, and giving rise to a *decreased* P.D. between the arc terminals. The inductance in the supply leads again prevents any considerable change in the supply current, and the condenser continues to discharge until its voltage is less than the normal arc voltage. As a

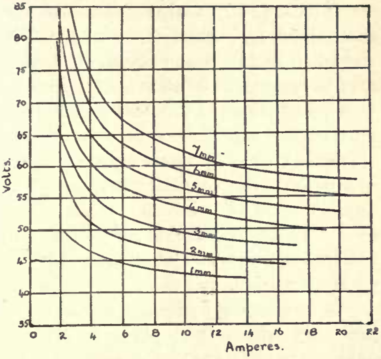

FIG. 77.—Characteristics of Carbon Arcs in Air (H. Ayrton).

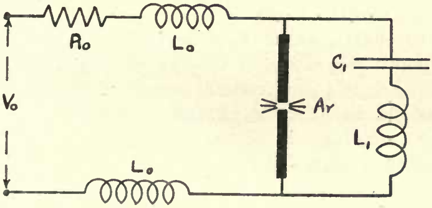

FIG. 78.—Arrangement of Oscillating Arc.

result, the arc current gradually falls to normal value again, with a resultant rise in the P.D. between its terminals. The whole cycle is then repeated, and continues indefinitely, without alteration, as long as the supply current is maintained and the arc length kept constant.

The condenser will therefore be continuously charged and discharged at regular intervals, which depend upon the inductance in the shunt circuit, the capacity of the condenser, and the length and other conditions of the arc.[1] The production of continuous oscillations in this manner from a direct current arc was first shown by W. Duddell in 1900.[2] The original experiments were chiefly concerned with low-frequency oscillations of acoustic frequency—hence the commonly applied term of "singing arc." The various factors which determine the oscillation frequency, and the limitations of the oscillation frequency obtainable with this and other arrangements, are discussed more fully later (Chapter XII., p. 153).[3]

An interesting hydraulic model, illustrating to the eye the processes which take place in an oscillating arc, has been devised by W. Duddell.[4] Briefly, it consists of a suitably loaded and controlled valve to take the place of the arc, and to imitate its negative characteristic. The flow of water through the valve from a constant pressure source (head of water, corresponding to supply voltage) takes the place of the electric current flow through the arc. The pressure relations may be shown up by suitable stand-pipes.

It may be mentioned in passing that the generation of continuous electric oscillations in the above manner is not limited to electric arcs. Any conductor having a negative or "falling" characteristic may be employed for the same purpose. For instance, certain metallic oxides have such a characteristic and can be caused to set up oscillations in associated circuits. A Nernst lamp-glower will show this effect.[5] Other examples are mentioned on pp. 164 and 165. The frequency of the oscillations that are obtained may be limited by other considerations (such, for example, as "hysteresis"[6]), but given suitable circuits, oscillations of certain frequencies can be set up.

Experiment shows that when an arc is functioning in the

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[1] See also Reference No. 206.

[2] Reference Nos. 43, 202; see also Nos. 203, 204.

[3] Also Reference Nos. 200, 201.

[4] Reference No. 210.

[5] Reference No. 209.

[6] See below.

manner set out above, its characteristic curve no longer retains precisely the shape indicated in Fig. 77, but that there is a certain so-called " hysteresis " effect, as a result of which the characteristic does not follow the same curve for decreasing currents as it does for increasing ones.[1] Fig. 79 illustrates diagrammatically one form taken by the curve under these conditions, between current limits I_1 and I_2, the arrows indicating the parts of the curve for increasing and decreasing currents respectively. From the form of the curve it is evident that the effect is due to the changes in temperature of the arc electrodes and of the ionised conducting vapour between them with changes of current through the arc.[2] (Compare also p. 16 above.)

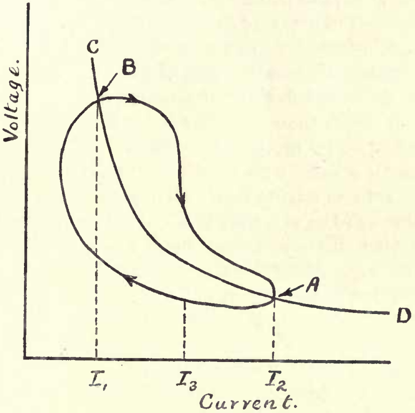

FIG. 79.—Dynamic Characteristic of Arc.
CD=Static Characteristic for the same Arc.

Commencing, for instance, at the point A, with a large current through the arc, the electrodes will be at a high temperature, and consequently there will be a copious supply of ions to maintain the arc. If now the current is suddenly diminished from its value I_2 at this point towards some other lower value, say I_3, the temperature of the electrodes, and therefore also the supply of ions, will *not immediately* decrease

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[1] This was first pointed out by H. T. Simon in 1905; see Reference Nos. 212, 213, 214.

[2] Reference No. 215.

to the values they would normally have for the current in question, since the electrodes will require a certain time interval for cooling down. The arc gap will therefore be in a more conducting state than usual, for the current I_3, and therefore the P.D. between its terminals, will be lower. The part of the curve traced out under these conditions for decreasing currents will therefore be, as shown in Fig. 75, *below* the "static" curve, or the curve obtained with very slowly varying currents. In the same way for the upper part of the curve, the arc commences at B with a small current I_1 and an impoverished supply of ions. When the current is increased the electrode temperatures do not immediately respond to the change, so that consequent upon this the gap is less ionised than usual, and exhibits therefore a *higher* apparent resistance—or what is the same thing, the P.D. between its terminals is *higher* than the usual value for the same current.

The exact shape of these curves, or "dynamic characteristics" as they are usually called, will depend considerably upon the rate of change of the increasing and decreasing current through the arc, that is to say, upon the frequency of the oscillating current in the shunt circuit, since the effect is consequent upon the heating and cooling of the electrodes. The delineation of the curves at various frequencies and under various conditions is most conveniently carried out by means of a cathode-ray oscillograph (see Chapter XX.).

The shape of the dynamic characteristic becomes of special importance when high-frequency oscillations are required, and often puts a limit to the upper value of the frequency of the oscillations that can be generated by the arc.

It should also be carefully noted that the usual so-called "static" characteristic obtained with slowly varying currents is not a perfectly definite curve unless the current variations that are necessarily made to determine the curve are carried out with extreme slowness, and a considerable time interval is allowed, after adjusting the current to a particular value, before the actual voltage readings are taken—the current and arc length being maintained constant during this period. These precautions are necessary in order to secure that the actual arc crater and the surrounding electrode material shall attain their final steady temperatures. For instance, Mrs. Ayrton, in her extended experiments on the phenomena of the carbon arc, found it sometimes necessary to wait for periods of several hours before taking the readings in order to secure consistent results.[1] The actual time interval that should be allowed depends upon the material of the electrodes and its physical properties, such as thermal conductivity, emissivity, etc., and also upon the properties of the medium surrounding the arc. With a nickel arc it has been shown that a period of about one hour is usually necessary.[2] The changes that take place before the steady state is reached are also dependent upon the length of the arc.

From a study of the dynamic characteristics of arcs under various conditions, it may be deduced that the wave shape of the oscillatory current set up in the shunt circuit across the arc depends to a considerable extent upon the relative magnitudes of the shunt and arc currents.[3] In practice, three general types may usually be distinguished:[4]

(1) In which the oscillatory shunt current is much smaller than the normal direct current drawn from the supply and passing through the arc. In this case the oscillations, although of feeble intensity, have very nearly a sine wave form. This type has of necessity very little application in practice for the generation of transmitting oscillations for wireless telephony, mainly on account of the very small energy outputs that are possible. It has, however, a small field of utility in the generation of feeble continuous oscillations for certain forms of receiver (see Chapter XXI. p. 324).

(2) In which the oscillation current through the shunt circuit has such an intensity that its maximum instantaneous value in each cycle is just about equal to the value of the normal direct current supply to the arc. The arc is therefore extinguished and restruck again once in each cycle of the oscillations. In this case the wave form of the oscillations is no longer a pure sine curve, and becomes still more deformed as the oscillatory current is further increased with respect to the supply current.

(3) In which the oscillations may be so strong relatively to the arc supply current that not only is the arc extinguished as in Case 2 above, but it is also restruck again in the reverse direction once in each cycle of the oscillations.

All practical forms of arc oscillation generator may be

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[1] Reference No. 211.

[2] Reference No. 216.

[3] Reference No. 217.

[4] See also Reference No. 242.

placed in one or other of these classes, and those suitable for useful wireless telephone work are usually to be found in Class 2. The methods employed for "forcing" the arc in such a manner that powerful oscillatory currents are generated (Classes 2 or 3) are considered more in detail in the following pages.

The existence of the above three types of oscillations has been proved for all cases of low-frequency oscillations using one or other of the usual forms of oscillograph; but with very high frequency oscillations the third type does not usually appear.[1] The reason is probably to be found in the lagging that takes place in the heating and cooling of the electrodes with the rapid current changes, as shown up by the dynamic characteristic.

The strength of the oscillations set up in the shunt circuit across the arc depends to a considerable extent upon the "steepness" of the characteristic curve of the arc, since if it is steep a given change in the current through the arc will give rise to a greater variation of the voltage across the electrodes, and therefore more energy will be imparted to the condenser in each cycle, and the oscillations consequently more vigorous than they would be under similar conditions with a flatter characteristic.

It is therefore easiest to set up oscillations (especially when of high frequency) with an arc having a steep characteristic curve. The hysteresis of the arc must also be small, that is to say, both parts of the dynamic characteristic must also be as steep as possible.

By inspection of the characteristics that have already been given, we see that they become much steeper for small arc currents, and for long arcs at high voltages. It is therefore generally the case that low current arcs oscillate better than heavy current ones. In practice the arc length must usually be kept as short as possible when high-frequency oscillations are required in order to reduce its resistance, and also its hysteresis. There are certain well-defined limits within which the current must be maintained, if stable oscillations are to be set up at all. The exact values of these current limits depend entirely upon the type of arc in use; upon the nature and composition of the carbons, or other materials used for the electrodes; the length of the arc and the conditions under

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[1] Reference No. 221.

which it is used—such, for example, as the presence or otherwise of magnetic fields ; upon the nature and pressure of the surrounding medium (usually gas), and also upon the values of the capacity and inductance in the shunt circuits.[1]

[1] See also Reference No. 208.

CHAPTER XI

ARC OSCILLATION GENERATORS—II. ARCS IN AIR, AND OTHER GASES

THE simplest cases of oscillating arcs consist of arcs in air at atmospheric pressure, between electrodes of ordinary solid arc lamp carbon rods. The oscillations obtainable from these arcs are practically always of the *first class* (p. 117), that is to say, the shunt oscillation current is *less* than the normal supply current to the arc. Very high frequency oscillations cannot be obtained from them.[1] They have therefore very little practical utility beyond for experimental work requiring feeble continuous oscillations. It is usually found necessary to limit the supply current to values of not more than about 2 or 3 amperes, by the use of the proper series resistance between the arc and the supply mains, depending upon the voltage employed. The supply voltage should not be less than about 200 volts; and frequently much higher voltages, from 400 to 1000 volts, are utilised for arc oscillation generators used in practical work.[2] It has already been pointed out that suitable choking coils must be inserted in one or both of the supply leads to the arc to maintain the value of the supply current as constant as possible, and thereby to promote vigorous oscillations. They further serve to localise the high-frequency currents in the oscillation circuit, and to prevent their passing back to the supply mains and becoming dissipated by the resistance, etc., of the latter, and by their capacity to earth. The supply current to the arc must be smaller the higher the frequency of the oscillations. This enables a steeper part of the characteristic to be utilised. The arc length must be kept short to diminish the resistance in the oscillation circuit. Very careful regula-

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[1] Reference No. 222.

[2] Compare with Reference No. 219.

tion of the arc length is usually required to secure steady oscillations of constant intensity. Further regulation beyond the initial "striking" of the arc is also required to compensate for the wear of the electrodes.[1] This regulation is best performed by hand while watching a hot wire ammeter in one of the oscillation circuits supplied from the arc. With large installations foot-pedal controls have been fitted to give the operator greater freedom.[2] Automatic electromagnetic regulation has often been attempted, but it is seldom as successful as hand regulation.[3]

The material and shape of the electrodes is very important as affecting the strength of the oscillations in the shunt circuit.[4] The electrodes should not too readily yield ions, or the gap will retain a nearly constant conductivity and the arc voltage will fluctuate but little with the varying currents. A good thermal conductivity for the electrodes should enable the "steady" temperatures to be reached rapidly with each current change. Some grades of graphite rods are very suitable, especially for generating very high frequency oscillations. Best results are, however, usually obtained with metallic or semi-metallic electrodes. These constructions are dealt with more fully under the details of the various practical forms of apparatus.[5] Water circulation or other artificial cooling may be used with electrodes of good thermal conductivity.[6] Water cooling usually promotes an increase in the P.D. between the electrodes, and therefore a greater transference of energy to the shunt circuit.[7]

An increase in the pressure of the air round the arc is usually beneficial, especially for high frequencies. It causes an increase in the intensity of the oscillations.[8]

The ratio of capacity to inductance in the oscillation circuit is important not only for arcs in air, but for practically every other form as well. A rough guide for experimental work is ratio—(Inductance in microhenrys) to (Capacity in microfarads) = about 50,000 to 100,000. This figure is, however, liable to very considerable variation to obtain the most satisfactory results with different types of arcs. It should therefore be used with caution, and merely as a starting-point

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[1] See also description of Colin-Jeance arc, p. 142.

[2] Reference No. 246.

[3] Reference Nos. 299, 300, 301, and 302.

[4] Reference No. 225.

[5] Chapter XII. p. 132.

[6] Reference No. 240.

[7] Reference No. 227.

[8] Reference No. 223.

in any particular experiment. With many types larger capacities can be employed than given by the above figures. An increase in the capacity in the shunt circuit usually increases the value of the oscillatory current. Too great a capacity gives unsteadiness. A compromise must therefore be effected depending on each particular set of circumstances. For telephonic purposes steadiness is all-essential to successful operation. An unsteady arc causes disturbing noises in the receiving telephones and variations in the quality of the speech transmission. The best ratio of inductance to capacity depends upon the supply voltage and current in use, and especially upon the nature and properties of the gas surrounding the arc. F. Mercer, in a paper before the Physical Society of London [1] describing experiments upon oscillatory arcs, summarised his conclusions as follows :

(1) " There is a definite value of inductance for any given capacity which gives a maximum current in the shunt circuit."

(2) " The effect of increasing the gas pressure becomes more marked as the electric pressure [voltage] is increased ; but as the gas pressure rises the steadiness of the arc diminishes. The effect is somewhat similar to that obtained by increasing the arc length."

These conclusions, especially the last part, refer particularly to copper-carbon electrode arcs in air. They do not apply to every type of arc oscillation generator.

MULTIPLE ARCS

(i.) *Arcs in Series.*—When high voltages are employed to increase the output of oscillatory energy from the arcs, a number of similar arcs may be connected in series across the supply mains, care being taken that sufficient resistance (and inductance) is retained in the circuit to permit of the steady running of the arcs. A common oscillation circuit is usually connected across all the arcs in series. Fig. 80 shows such an arrangement with six arcs in series, such as might be utilised on a 400 to 600 volt circuit, depending on the type of arc.[2] The energy of the oscillations in the shunt circuit across the arcs is most usually transferred to the aerial circuit by an ordinary magnetic coupling as shown in Fig. 81, in which

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[1] Reference No. 226.

[2] In some special cases with metallic electrodes, higher voltages than this have on occasion been obtained on but one or two arcs in series.

R_0, L_0 are the usual series resistance and inductances, Arc represents the arc in use (or several in series[1]); C_1, L_1 the shunt oscillation circuit. The coil L_1 is magnetically coupled with the coil L_2 included in the aerial circuit A, L_3, L_2, E. L_3 is an extra inductance in the aerial circuit for tuning purposes. M in the diagram is a microphone shown as connected in the aerial circuit for the purpose of modulating the radiated energy in accordance with the speech or sound waves that it is desired to transmit. Other microphonic control arrange-

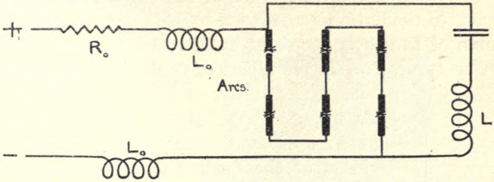

FIG. 80.—Arcs in Series with Common Shunt Oscillation Circuit.

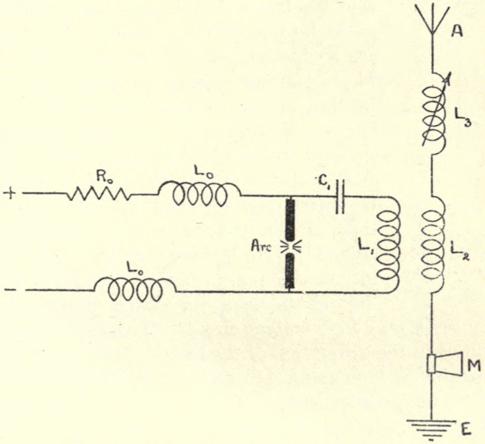

FIG. 81.—Scheme of Oscillatory Arc Transmitter.

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[1] In this and other diagrams showing oscillatory arcs the single arc symbol is employed to represent one or a number of arcs. The actual number used in series is often a matter of convenience, depending upon the available supply voltage.

ments are discussed in a later Chapter,[1] as well as the various forms of microphone that may be employed for this purpose. For the present purposes, however, this mode of modulation may be taken as typical for use in the explanatory diagrams referring to oscillation generators.

Some of the early forms of Telefunken apparatus may be taken as typical of simple forms of multiple arc apparatus.[2] The type of arc used by the Telefunken Company in 1906[3] is shown diagrammatically in Fig. 82. A represents a copper tube, closed at the bottom with a concave copper plug B. The second electrode C is of carbon, and the arc is struck at D between the carbon and the copper. The upper copper tube electrode is filled with water for cooling purposes. A number of such arcs may be conveniently mounted side by side in a suitable insulating stand, and connected up in series by joining the carbon electrode of one arc to the copper of the next, and so on. The mounting should be arranged so that all the carbon or copper electrodes may be moved simultaneously by one handle for striking and regulating the arcs, but provision should also be made to enable each arc to be separately adjusted in order to ensure that all the arcs are of the same length (Fig. 83). As the arcs are arranged to burn in air the power output available is very limited unless a very large number can be used in series on a high voltage circuit. This again introduces difficulties in the generation of the high voltage direct current. The maximum input on a 440 volt circuit is limited to about 2 kw. The peculiar shape of the upper carbon electrode serves to a certain extent to exclude the free access of air to the arc and improves the operation.

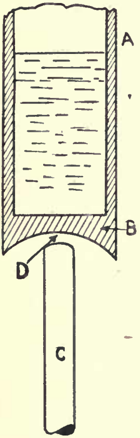

FIG. 82.—Section of Early Telefunken Copper-Carbon Arc, used in Air.

(ii.) *Arcs in Parallel.*—It should be noted that a number of arcs cannot be directly connected in parallel in order to increase the available energy on a supply circuit of given voltage, so as to avoid the difficulties connected with the generation of high voltage direct current.

[1] Chapter XVI. p. 238. [2] Reference No. 224. [3] Reference No. 228.

Such an arrangement would be unstable since all the current would be diverted to one arc, and the others would be extinguished.

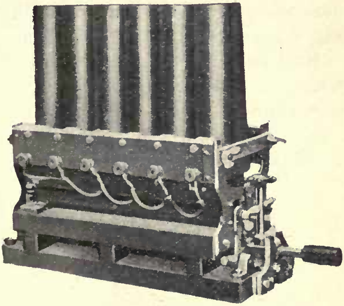

FIG. 83.—Multiple Copper-Carbon Arcs in Air (Telefunken Co., 1906).

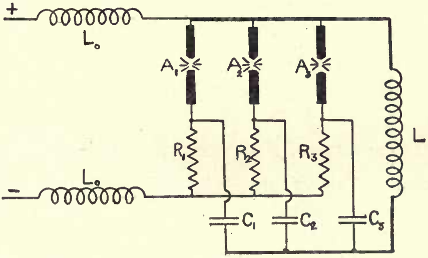

FIG. 84.—Scheme for working Oscillatory Arcs in Parallel (V. Poulsen).

By providing each arc with its own resistance and inductance, however, a number of them may be connected in parallel on a constant voltage supply circuit. Each arc must then be provided with its own independent oscillation circuit, and all such circuits coupled together to assist one another. It is possible to combine these separate oscillation circuits to include but one inductance (which may form the primary of the jigger by which all the circuits are coupled with the common aerial circuit), while retaining a separate condenser for each arc. The arrangement of three such arcs shown in Fig. 84 is due to V. Poulsen.[1] The common inductance (which would be coupled with the aerial circuit) is shown at L, while each arc, A_1, A_2, A_3, has its own independent condenser C_1, C_2, C_3, and is supplied through its own individual resistance R_1, R_2, R_3

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[1] Reference No. 249.

respectively. Common choking inductances L_0 are used in the supply leads.

A slightly different method has been used by W. Duddell,[1] G. W. Nasmyth,[2] and others when using two arcs. They are connected in parallel on the supply mains to feed a common oscillation circuit across the two arcs in series, as shown in Fig. 85.

The two arcs A_1 and A_2 are connected each with their resistances and inductances R_1, L_0' and R_2, L_0'' in parallel across the supply mains. The common oscillation circuit CL is connected across the two arcs in series as shown. This oscillation circuit would be coupled to the aerial in the usual manner. More stable oscillations are produced by this arrangement than when one arc alone is employed.

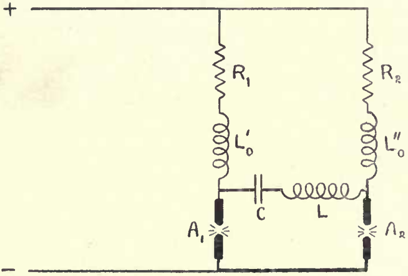

FIG. 85.—Arrangement of two Parallel Arcs to feed a Common Oscillation Circuit (W. Duddell ; G. W. Nasmyth).

ARRANGEMENTS FOR VERY HIGH FREQUENCIES

A means by which powerful high-frequency currents may be obtained—as distinct from merely increasing the output as just described—consists in the employment of a *double* oscillation circuit shunted across the arc terminals, one circuit being tuned to a harmonic of the other. In this way steadier and more powerful oscillations may often be obtained than when but one circuit is employed. The presence of the lower frequency circuit serves to maintain the oscillatory condition of the arc (or arcs), since low-frequency oscillations

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[1] Reference No. 43.

[2] Reference No. 232.

are usually set up with greater facility than high-frequency ones, and thus augments the oscillations of higher frequency in the second circuit. The frequency of the latter must be arranged to be an exact multiple of the lower frequency oscillations in the first circuit.[1] The most useful ratio is 2 : 1, since the double frequency harmonic is often present in the wave form of an oscillating arc.[2] This is especially the case when a large capacity and small inductance are used in the shunt circuit.[3]

Fig. 86 shows such an arrangement. C_1, L_1 is the lower

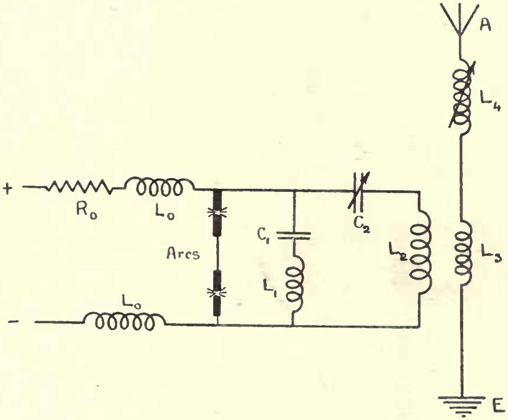

FIG. 86.—Arcs with Double Oscillation Circuits for High Frequencies.

frequency shunt circuit across the arcs (two arcs only are shown, but this arrangement does not depend upon any particular number), and C_2, L_2 the higher frequency circuit, tuned (by varying C_2 or L_2) to twice the frequency of C_1, L_1. This second circuit is coupled to L_3 in the aerial circuit, in the usual manner, or in any other special way (see pp. 156-160). There should be no appreciable direct magnetic coupling between the coils L_1 and L_2 in the two oscillation circuits.

Another method, due to V. Poulsen,[4] is really a combination of an arc generating moderate frequency oscillations with

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[1] Reference No 231. See also No. 624.

[2] Reference No. 230.

[3] Reference No. 233.

[4] Reference No. 249.

an "arc-frequency-raiser,"[1] to increase the frequency of the currents obtained from the first arc to the value required for transmission. The arrangement is indicated in Fig. 87. The first arc A_1 (or arcs in series) is fed from a D.C. source through the usual resistances and inductances, R_0 and L_0. It supplies moderate frequency alternating current (say of the order of 100,000 ∿) to the second arc A_2, where its frequency is further raised by the oscillation circuit C_2, L_2 shunted across this arc. These high-frequency oscillations may be transferred to the aerial circuit as shown. The most useful ratio of frequencies of C_2, L_2 and C_1, L_1 is 3 : 1, since the most prominent harmonic in the voltage wave of an alternating current arc is the one of triple the fundamental frequency.[2]

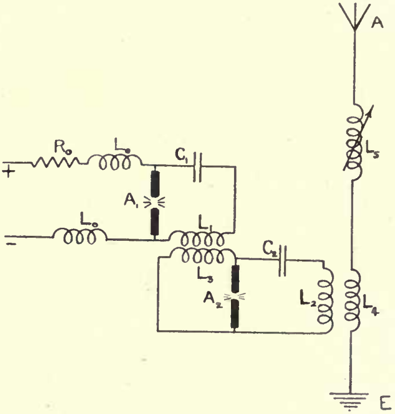

FIG. 87.—Arrangement of Double Arcs to obtain Powerful High-Frequency Oscillations (V. Poulsen).

EFFECT OF ELECTRODE MATERIAL AND OF THE ATMOSPHERE ROUND THE ARC

It has already been pointed out that steepness of the arc characteristic is desirable from the point of view of generating vigorous oscillations. Further, if the dynamic characteristic

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[1] See also p. 235 below, and Reference No. 625.

[2] Compare also p. 235.

of the arc shows very excessive "hysteresis" in the sense in which this term has previously been employed, some of the effects of this steepness will be lost. Excessive arc hysteresis is therefore to be avoided.

The steepness of the characteristic depends very considerably upon the material used for the electrodes, and also upon the medium in which the arc burns. Considering the former of these first, Fig. 88 shows a number of arc characteristics

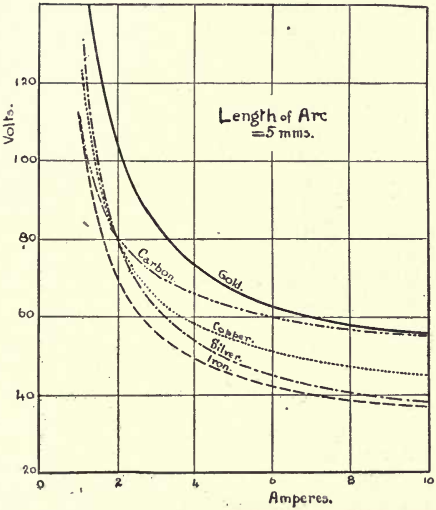

Fig. 88.—Characteristics of Arcs with various Electrode Materials.

obtained with various metallic electrodes.[1] The characteristic of an arc of the same length between solid carbon rods is also shown for comparison. It is noted that the silver arc has the steepest characteristic of those shown.

The employment of gases other than air round the arc also modifies the characteristic curve, some gases flattening it, and some making it steeper. On the whole, hydrogen or coal gas usually yield the steepest curves.[2]

An explanation of the effect of different gases upon the

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[1] Reference No. 244.

[2] Reference Nos. 234, 236, 238.

characteristic curve of the arc has been given by J. A. Fleming in the light of the electron theory.[1] In the electric arc we have two electrodes separated by gaseous material. When the two electrodes are first brought together to start the arc, the contact resistance causes their tips to become incandescent. From the hot negative electrode an emission of electrons immediately takes place. These electrons move across the air-space between the electrodes under the influence of the electrostatic attraction of the positive pole. During this passage between the poles collisions take place with the gas molecules. Ionisation is thus set up, rendering the air-space conductive, and enabling the current to traverse the space between the electrodes in the usual manner. Molecules of carbon or other vapour from the electrodes are also present, and likewise become ionised by the flying electrons. The bulk of the current between the electrodes is carried by the positive and negative ions thus formed which migrate in opposite directions between the electrodes under the influence of the applied potential difference. These ions are not absorbed at the electrodes instantly, so that if the current is increased there arises an accumulation of ions near the electrode surfaces. These ions are of opposite polarity to the electrode surfaces to which they are adjacent. They therefore reduce the effective potential difference between the electrodes. Hence an increase of current is accompanied by a decrease of potential. The arc characteristic is therefore a falling one.

If the arc is formed in air there is also an oxidation of the incandescent electrode. Consider for the moment a carbon arc. The hot positive carbon ions have a strong affinity for the negative oxygen ions in the air. Combination occurs and neutral carbon dioxide is formed. In this manner many of the positive carbon ions which would otherwise collect on the negative electrode are prevented from reaching this electrode, being oxidised on the way. The characteristic curve is therefore not very steep, and an increase in the current does not result in a great decrease in the potential difference of the electrodes.

If, however, the arc is formed in an atmosphere of hydrogen or hydrocarbon gas, which excludes oxygen from reaching the arc, then this removal or recombination of the positive carbon ions does not take place, and the characteristic curve

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[1] Reference No. 243.

has a steeper downward slope. We have here the reason for the superiority of some electrode materials over others. For arcs in air materials having the least affinity for oxygen will yield the steepest curves. Hence the steepness of the silver curve in Fig. 88. As a general rule we may therefore say that those gases that have least chemical action on the electrodes give the steepest characteristics, while the occurrence of chemical action between the gas and the hot electrodes usually lowers the characteristic by reason of the increased ionisation resulting from the reaction.

Various liquids have also been used to supply the "atmosphere" in which the arc burns. Alcohol is frequently employed to produce a hydrocarbon vapour by dropping it into the arc enclosure.[1] Water and water vapour have also been employed, for instance by Morretti[2] and by De Forest. Other liquids have also been experimented with, but do not as a rule yield very good results from the point of view of steadiness and single-waveness of the oscillations.[3]

The practical forms of arc oscillation generator usually employ a gaseous atmosphere with one or both electrodes of a metallic nature. The choice of electrode material and gas is governed very largely by the considerations set out above.

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[1] See, for example, p. 146.
[2] See p. 147.
[3] Reference Nos. 235, 237.

CHAPTER XII

PRACTICAL FORMS OF ARC OSCILLATION GENERATOR

General Features—Poulsen Arcs

It has already been pointed out that the simple direct current arcs in air between carbon or metallic electrodes are not suitable for the generation of powerful oscillations and therefore find very little practical application. A great advance in these arc methods of generating oscillations was made in 1902 when V. Poulsen discovered that if an arc is set up in an atmosphere of hydrogen or coal gas it is capable of generating more powerful oscillations than when burning in air.[1] This action is not limited to carbon electrodes, but is also shown when metallic electrodes are used. He advocated the use of an arc between a copper anode (positive electrode) and a carbon cathode (negative electrode) as being the most suitable for the production of continuous high-frequency oscillations for wireless purposes. When metallic electrodes are employed they should be made hollow and water-cooled in order to secure steady and reliable generation of oscillations. Some

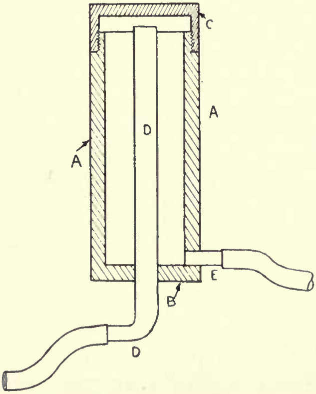

Fig. 89.—Water-cooled Electrode for Oscillatory Arcs.

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[1] Reference Nos. 245, 248, 249, 250.

designers have adopted special forms of air cooling instead of a water circulation for low power apparatus. A convenient construction of water-cooled electrode is shown in Fig. 89, and consists of a copper tube A, closed at its ends by metal caps B, C, the latter, forming the active end, being made easily replaceable when it becomes worn by the arc. Water circulation is provided inside the electrodes through the tubes D, E.

It is now customary in most modern apparatus to employ some form of hydrogen or hydrocarbon atmosphere round the arcs. Fig. 90 illustrates the difference between the characteristics of such arcs and of ordinary carbon arcs in air.[1] It shows that the copper-carbon arc in hydrogen should be much better suited for the generation of powerful high-frequency oscillations than the carbon arc. The reason for the difference in the two characteristics in this Fig. has already been given (p. 130).

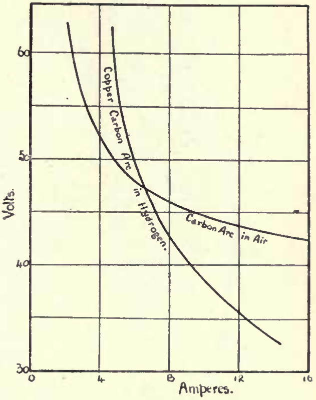

Fig. 90.—Arc Characteristics (W. L. Upson).

Poulsen also claimed in his patents[2] the use of a magnetic field in the vicinity of the arc for the purpose of steadying the position and length of the arc, and thereby rendering the oscillations more stable and of more constant intensity. The magnetic field is usually placed transversely to the arc length. Fig. 91 shows the arrangement. Ar represents the arc with a hollow copper positive electrode through which a water circulation may be passed for cooling purposes by means of the tubes P_1, P_2. The usual series resistance is shown at R_0; while the two magnets M_1, M_2, arranged to produce a transverse magnetic field across the arc as shown, serve to take the place of the usual choking inductances in the supply leads to the arc. The oscillation circuit C_1, L_1 is connected across

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[1] Reference No. 259.

[2] Reference No. 249.

the arc and serves to transfer into the aerial circuit the oscillatory energy set up by the arc. The complete arc apparatus is mounted in some suitable form of enclosure as indicated in this diagram, in order to enable a coal-gas or hydrogen atmosphere to be maintained round the arc. The gas should be continually passed through this enclosure while the arc is in use, and is preferably burnt at a small jet at the outlet. The heat of the arc discharge decomposes the gas and usually gives rise to rather evil-smelling products which are most conveniently removed by combustion. Means must also be provided for cooling the arc enclosure. In the small sets, as illustrated in Fig. 92, air cooling from radiating flanges is quite effective,

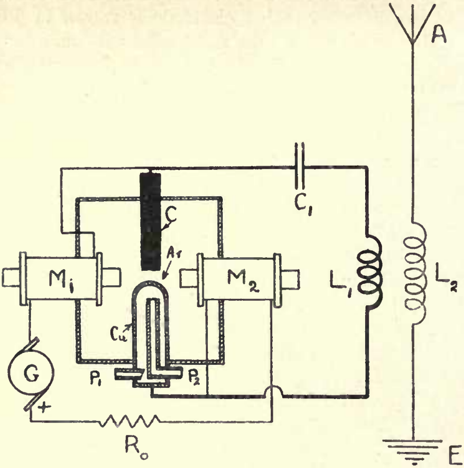

FIG. 91.—Arrangement of Poulsen's Arc with Water-cooled Copper Anode.

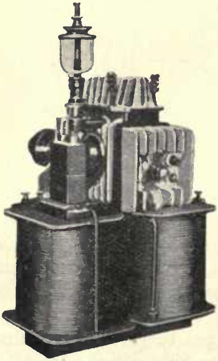

FIG. 92.—Poulsen Arc Oscillation Generator (air-cooled).

but water cooling has generally to be resorted to for larger outputs.

As a general rule it is found necessary to rotate slowly by clockwork, or by gearing from a small electromotor, the carbon negative electrode. This secures in conjunction with the magnetic field that a fresh surface of carbon shall be continually presented to the arc. Fig. 93 illustrates a simple apparatus of this type. Such a device considerably improves the steadiness of the oscillations. Fig. 94 shows the approximate position of the arc with respect to the electrodes when under the action of the magnetic field. E_1 is the hollow copper positive electrode, and E_2 the solid carbon negative one. If the magnetic field is arranged perpendicular to the paper in this diagram, and the lines of force are imagined as proceeding *into* the paper, the arc, being a flexible conductor, will be blown out in the direction shown, by reason of the ordinary electromagnetic reactions that take place

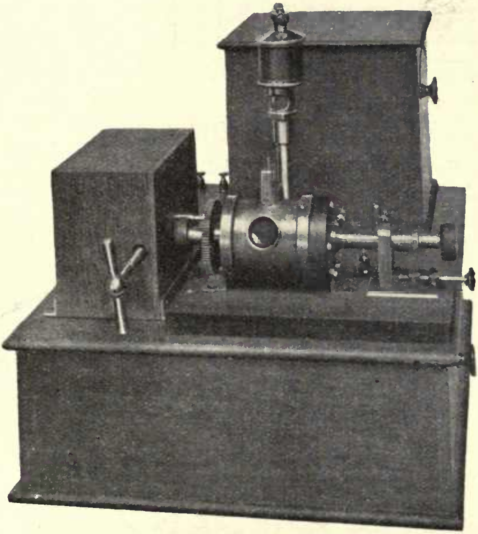

Fig. 93.—An Arc Generator used for Wireless Telephone Transmission, with Clockwork Attachment for Rotation of Electrode.

between a current-carrying conductor and a magnetic field (Fig. 95).

It should be evident that under these conditions rotation of the carbon will provide a fresh surface for the arc to start from. The actual spot from which the arc jumps is therefore prevented from rising in temperature to so great an extent as would otherwise be the case; while, what is still more important, the arc length is maintained much more constant for a longer period than if the wear came always in one place. A scraper has sometimes been employed to true up the edge of the carbon during its rotation.

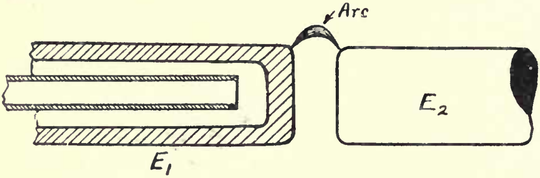

FIG. 94.—Position of Arc with respect to Electrodes.

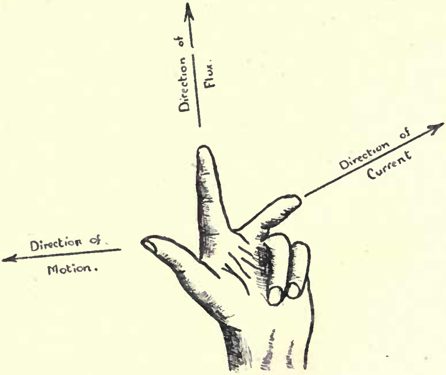

FIG. 95.—"Left-Hand Rule"—illustrating the Direction of the Force on a Conductor carrying a Current when placed in a Magnetic Field.

It is often found advantageous to provide an extension on the end of the copper electrode for the purpose of more definitely localising the arcing point, as indicated at A in Fig. 96. This extension tip may very conveniently be made removable, as shown, so that it may be replaced from time to time as may be necessary. Owing to convection currents in the gaseous atmosphere surrounding the arc, arising through the heat of the discharge, the arc will of itself naturally tend to rise upwards. This copper projection should therefore be placed at the top, as shown in Fig. 96, and the direction of the magnetic field arranged in accordance therewith. This applies, of course, to horizontal arc electrodes, which is the most usual arrangement.

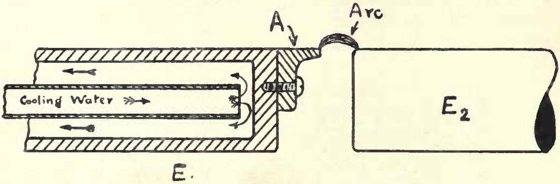

Fig. 96.—Copper Tip for Arc Electrode.

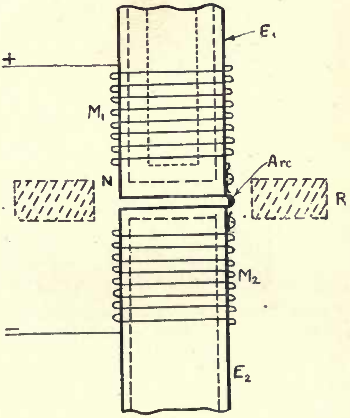

Fig. 97.—Radial Magnetic Field for Arc.

As an alternative construction the arc may be arranged in a radial magnetic field, thus causing it to *rotate* round the periphery of the electrodes and so avoid the necessity of their mechanical rotation. This form is not, however, so satisfactory in operation as the usual types, and is therefore seldom used in practice, except perhaps for small experimental apparatus.[1] It is preferable that the electrodes be arranged

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[1] Reference No. 256.

vertically in this case, as otherwise but very imperfect or irregular rotation of the arc would be obtained on account of the disturbing action of convection currents. Fig. 97 shows such an arrangement in diagrammatic form. Coils M_1 and M_2 are arranged round the two electrodes E_1 and E_2, and are so connected that their fields oppose one another, thus giving rise to a diverging radial field through the arc gap (Fig. 98).

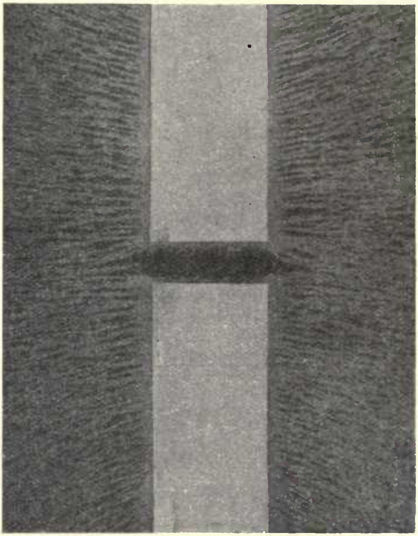

FIG. 98.—Iron Filings Diagram showing Production of the Radial Magnetic Field in the Arrangement of Fig. 97.

It is of advantage if some form of iron core can be obtained inside the coils M_1, M_2 (Fig. 97), such, for instance, as by constructing the upper part of electrode E_1 of iron and using a copper end-plug for the arcing surface. Similarly the electrode E_2 may be sheathed in iron, leaving the carbon projecting from the end. A circular ring R may be added to further concentrate the field.

In modern forms of the Poulsen arc apparatus it has become the practice to employ very much larger and more powerful magnets (arranged to give a transverse field across the arc) than was formerly the custom[1] (Fig. 99). Such arrangements are found especially necessary when large powers have to be dealt with, and it is probable that in these cases the magnets do more than merely steady the arc and maintain it of constant length, but *force* it to generate powerful oscillations after the manner of "arc interrupters,"[2] in which the arc is actually blown out by the magnetic field, and immediately restruck again automatically by the supply voltage sparking across the small space between the electrodes. By careful adjustments it is possible to cause an arc to set up powerful oscillations (even without a shunt oscillation circuit) by subjecting it to a powerful magnetic field. A loud whistling noise is often obtained with such an arrangement, and with care the frequency can be made very high. By tuning the shunt oscillation circuit to synchronise with these interruptions very powerful oscillations may be generated in the former.[3]

In the actual arc apparatus the intensity of the shunt circuit oscillations is very considerably augmented by the presence of the magnetic field; and what is more, the maximum permissible direct current input to the arc is at the same time greatly increased, so that much greater power can be handled by a given plant with the field than without it. This increase may be as much as 300 to 400 per cent.[4]

With low power sets, however, the increase of output by the use of the magnetic field is frequently detrimental to the steadiness of the oscillations, and causes them to be broken up into groups following one another rapidly, but at somewhat irregular intervals. The same effect has been pointed out by F. Mercer in the Paper referred to above. He states: "Any attempt made to increase the output by the use of a magnetic field, or by altering the arc length, or the resistance in series with the arc, is detrimental to the steadiness of operation."[5] This conclusion, although arrived at from experiments with a copper-carbon arc *in air*, is yet applicable in general to the same type of arc when burning in a coal-gas or hydrogen atmosphere.

It should of course be noted that the "arc interrupter"

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[1] Reference No. 252.
[2] Reference No. 257.
[3] Reference Nos. 258, 260.
[4] Reference Nos. 261, 262, 263.
[5] Reference No. 226.

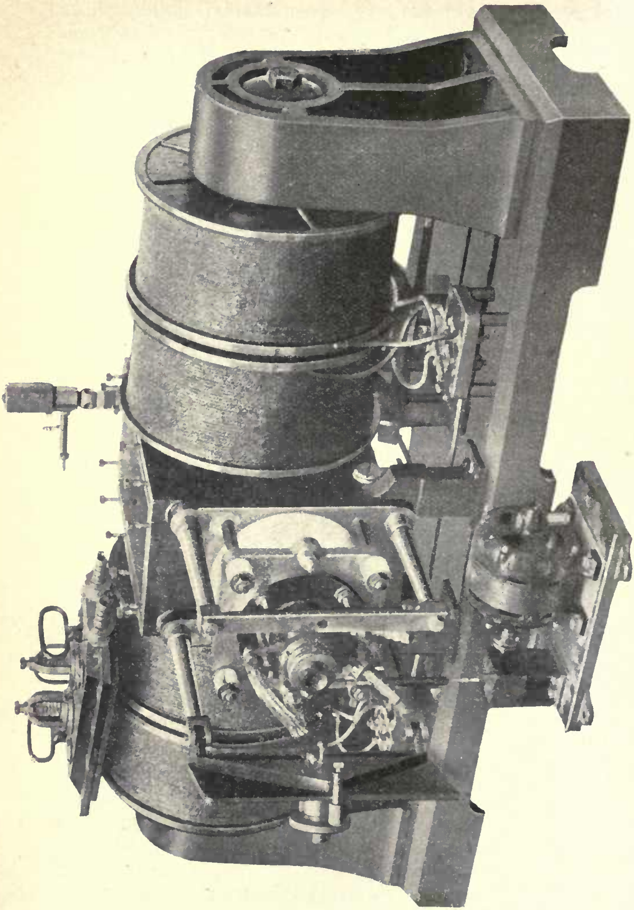

FIG. 99.—200 kw. Poulsen Arc.

action referred to above cannot take place when the magnets are fed from a separate source of current, as is sometimes the case.

A recently published paper by P. O. Pedersen deserves special mention here.[1] It contains an account of an extensive experimental research upon the Poulsen arc, with a view to testing existing hypotheses and of deducting a working theory of the operation of the Poulsen arc. Such a theory should be capable of furnishing particulars to aid in the *design* of arc apparatus to suit any given conditions.

A few of the points mentioned in the above Paper as to the most advantageous adjustment of the arc may be reproduced here :

> For the normal Poulsen arc—*i.e.* an arc working with at least 10 to 15 amps direct current, with an oscillatory wave-length of 1000 metres or more, the ratio of the high-frequency current to the supply current $= 1/\sqrt{2} = 0{\cdot}707$. This relation holds when the ratio of inductance to capacity in the shunt circuit is not less than 2500 (L in microhenrys ; C in microfarads). Near the above limits, and after passing them, the current ratio assumes *higher* values.
>
> The arc gives maximum efficiency when the supply voltage is a minimum, and with a constant supply circuit resistance when the supply current is a maximum.
>
> To obtain the maximum high-frequency current under given circumstances, a certain distance between the electrodes, and a certain value of the magnetic field is required. These values are greatly dependent upon the constants of the circuits.
>
> The arc is not active in producing oscillations until it is pulled out to a certain critical length, but having reached this length, and the oscillations started, it can be shortened a little without losing its activity.
>
> The arc works most efficiently with a magnetic field just strong enough to keep it steady.

From the above it is evident that either an arc generator is active and supplies an oscillatory current $\geqq 0{\cdot}707 \times$ supply current, or it is quite inactive and gives no oscillations at all. It is therefore easily understood that comparatively small changes in the condition of the arc can be deciding factors as to its ability to operate as a radio frequency generator, since such small changes may just carry it past the critical point.

The Poulsen apparatus may be taken as a typical example of practically all modern forms of arc oscillation generator,

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[1] Reference No. 244A.

the various other apparatus differing mainly in details as to the production of the hydrocarbon atmosphere for the arcs, or in the nature of that atmosphere, or else in the construction and form of the electrodes.[1]

A few of the most prominent types are described briefly, in order to indicate the directions in which experimental work has been carried out, and any particularly noteworthy features.

THE COLIN-JEANCE ARC GENERATOR

This apparatus was first brought out about 1909,[2] and represents an attempt to overcome some of the difficulties experienced in the operation of arc generators of the Poulsen type (particularly in the early forms), chiefly the great difficulty of maintaining a constant arc length and intensity of oscillations through the wearing away of the carbon electrodes when the arc is in use. The frequency of the oscillations is, moreover, a function of the arc length,[3] so that difficulties in tuning are experienced when the arc length is continually varying.

When the arc is run in an atmosphere of air, or one containing oxygen, the carbon electrode is burnt away, while the arc is in use. If, however, the atmosphere surrounding the arc is a hydrocarbon gas very rich in carbon, the decomposition of the gas by the heat of the discharge causes carbon to be deposited from the gas on to the electrodes. In such gases, therefore, the carbon electrode will "grow" instead of wearing away. It should, therefore, be possible to obtain a gas, or so to choose a mixture of gases, that the natural burning away of the carbon is as nearly as possible compensated for by the deposition of carbon from the gas surrounding the arc. The electrode will thus remain of nearly constant length for much longer periods, and consequently less attention should be required to maintain the arc of the correct length to obtain good oscillations. Further, the oscillations should be steadier and of more constant frequency.

A mixture of gases suitable to obtain these results is one of acetylene and hydrogen in suitable proportions, which are best found by experiment. A mixture of these gases is employed in the Colin-Jeance arc apparatus. It may be

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[1] For further descriptions of Poulsen type arc apparatus, see Reference Nos. 246, 247, 251, 252, 253, 254, 255.

[2] Reference No. 264.

[3] See also p. 153.

most conveniently obtained by adding water to a mixture of calcium carbide [CaC_2] and calcium hydride [CaH_2], contained in a gas generator very similar to that used for the generation of acetylene for ordinary purposes.[1]

Another suitable mixture is one of hydrogen and acetone in proper proportions. This is claimed to yield very good results and to maintain the carbons of very nearly constant length.[2]

In the usual Colin-Jeance apparatus several copper-carbon arcs of the form shown in Fig. 100 are used in series. They may be connected to a direct current supply at from 500 to 750 volts. Three of such arcs are shown in the diagram as mounted in one containing vessel. The special features of this apparatus are the use of positive electrodes, in the form of large copper cylinders closed at their ends with copper plates and maintained cool by an internal circulation of water or other insulating liquid; and of negative electrodes, in the form of very thin carbon rods fastened to holders of large surface area for cooling purposes. In Fig. 100 the copper electrodes (anodes) are shown at E, E, E, and the thin carbon negative electrodes at C, C, C, in massive metallic holders F, F, F. These holders are all arranged on a common framework, so that they are insulated from one another, but at the same time mechanically connected so that they may all be raised

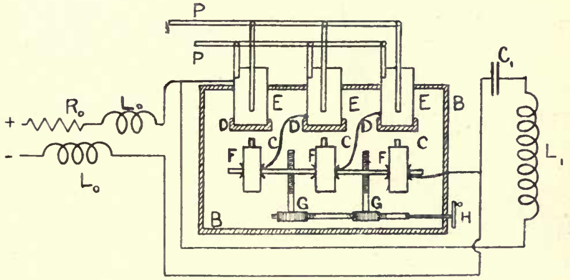

FIG. 100.—Colin-Jeance Arc Apparatus.

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[1] The reaction that takes place may be represented as follows:

$$CaC_2 + nCaH_2 + 2(n+1)H_2O = (n+1)Ca(OH)_2 + C_2H_2 + 2nH_2.$$

The symbol n is introduced as the ratio of the two substances employed.

[2] Reference No. 265.

and lowered simultaneously by the handle, H, and screws, G, G. The arcs are struck between these carbon electrodes and the copper caps, D, D, D, on the ends of the tubular electrodes, E. Water circulation pipes, P, P, are arranged for these electrodes.

The three (or more) arcs may be enclosed in a gas-tight chamber, B, and connected in series as shown. They are fed from the supply circuit through the usual choking inductances L_0 and resistances R_0. The common oscillation circuit across the arcs is shown at C_1, L_1, and is coupled with the transmitting aerial either directly or through a tuned intermediate circuit. The latter is a special feature claimed in the Colin-Jeance patents, as being advantageous for producing steady and sharply tuned oscillations of constant frequency in the aerial circuit, and is of some advantage in facilitating the microphonic control of the radiated energy, since the aerial circuit is then more free from reaction with the main oscillation circuits.[1] It is not, however, customarily employed with the majority of arc oscillation generators.

RUHMER'S ALUMINIUM ARC

A form of arc was devised by E. Ruhmer about 1906, with the intent of avoiding the difficulties and irregularities consequent upon the changing of the arc length in the ordinary forms of arc apparatus.[2] It consists of two moving wires W_1, W_2 (usually of aluminium), between which the arc is struck. In one form these wires are placed at right angles to one another, and the arc passes at the point where they are nearest together. The wires are wound off from reels of fresh wire, and after passing the arcing point are wound up again on other reels by clockwork or a small electric motor. By this continual (slow) movement of the wires, a fresh cool surface is always being brought into position for the arc to play upon, and thus

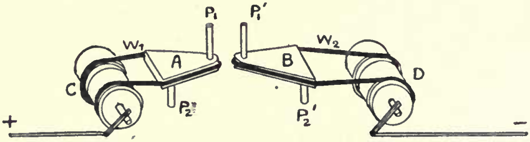

FIG. 101.—Ruhmer's Aluminium Wire Arc.

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[1] See also p. 279.

[2] Reference No. 266.

the arc length is maintained very constant, since the wire is removed from the gap as soon as it becomes worn by the arc.

In another pattern, shown in Fig. 101, the two wires are passed round two insulated supports, A, B, shaped somewhat as shown in the diagram, and are kept in continual movement.[1]

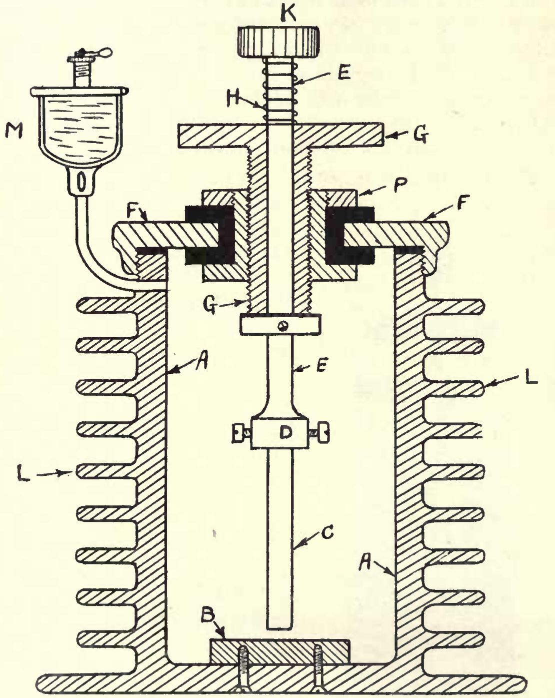

FIG. 102.—Dubilier Arc in Section.

The arc is struck at the point where they approach nearest to one another. The wires should move in opposite directions across the gap to prevent the arc from being drawn out to one side with a consequent increase in length. The wires are wound up on reels C, D, which are kept in rotation by a clock-

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[1] Reference No. 267.

work or other motor. One of the electrode supports is arranged to be movable nearer or further from the other, so that the arc length between the wires may be readily varied as desired. The electrode supports, A, B, may be either of some refractory insulating material, such as slate or marble, or better be in the form of hollow metal boxes which can be water-cooled. They are provided with a groove round the outer edge to guide the wires.

This type of arc, though possessing several interesting features, has never been brought into any extensive practical operation.

THE DUBILIER ARC

This arc oscillation generator, as does the Poulsen, makes use of carbon and copper (or bronze) electrodes, in an atmosphere of hydrocarbon gas.[1] The containing case is in the form of a hollow metal cylinder, A (Fig. 102), containing a copper block, B, which forms one of the arc electrodes. The cylinder, A, is provided with flanges, L, for cooling purposes. The second arc electrode is a solid carbon rod, C, clamped in a suitable holder, D, on the rod, E. This rod passes through a well-fitting metallic bushing, G, which screws into the plug, P, insulated by mica from the cover, F. The rod, E, is held up in the bushing, G, by the spring, H, bearing against the knob. The screwed bushing, G, therefore, serves for adjustment of the arc length, while the arc may be "struck" by depressing the knob, K, on the top of the rod, E. A drip feed, M, for alcohol or methylated spirit is fastened in the cover, F, while a small safety-valve is provided to maintain the gas pressure inside approximately constant. A view of the complete arc is shown in Fig. 103.

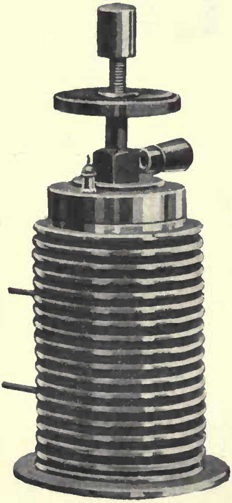

FIG. 103.—Dubilier Arc Oscillation Generator.

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[1] Reference No. 268.

It will be noticed that in this apparatus provision is made for the introduction of alcohol into the arc chamber, so that by its vaporisation by the heat of the arc, a hydrocarbon vapour will be obtained in the enclosure. Alcohol is now very largely used for this purpose, as it has proved to be very effective in maintaining constant oscillations; while it is more convenient in manipulation in many cases than coal gas, which, in fact, may not be available in all circumstances. It has the additional advantage of being useable, if so required, in portable apparatus. Further, there is not so much wearing away of the carbon electrode as when hydrogen alone is used, so that the arc is more stable and the oscillations of more constant intensity.

MORETTI'S ARC

In this apparatus the atmosphere round the arc between the copper and carbon electrodes is provided by the vaporisation of water.[1] A hollow copper electrode, A (Fig. 104), is placed vertically and closed with a copper plug, B, at its upper end. This plug is pierced with a small hole H. The arc is struck between the plug B and a carbon rod C placed coaxially over it. The copper electrode A is placed in connection with a reservoir, G, by the pipe D, E, and is thus maintained full of water. The heat of the arc causes rapid evaporation of the water through the hole H, and thus maintains an atmosphere of water vapour (and of decomposed water vapour) round the arc. The supply is taken from a direct current source at about 500 volts, and the arc is shunted with an oscillation circuit in the usual manner. Both electrodes for this arc are often made of copper instead of one of carbon and one of copper.

The electrode through which the water vapour is admitted is best connected to the positive pole of the supply circuit for most satisfactory results. The best arc length to obtain high-frequency oscillations is, as is usual with most arcs, very short—of the order of 0·1 millimetre.

DWYER'S ARC

A very similar construction to the preceding has been used by H. P. Dwyer, except that a stream of alcohol is forced through the hollow electrode into the arc space instead of

[1] Reference Nos. 269, 270.

water, and the complete apparatus is also immersed in alcohol, kept at a low temperature, for cooling purposes.[1]

A copper positive and an aluminium negative electrode are preferred, and both should be cooled by liquid circulation at a low temperature. It is stated that this arrangement yields much steadier and more powerful oscillations than when water is employed as in the Moretti Arc.

It appears almost probable that this arrangement, and to a certain extent the preceding one due to Moretti, resembles more closely the spark oscillation generators of Chaffee and Yagi[2] than the pure arc apparatus of Duddell, Poulsen, etc., in that the discharge is most likely more in the nature of a rapid succession of sparks than of a continuous arc.

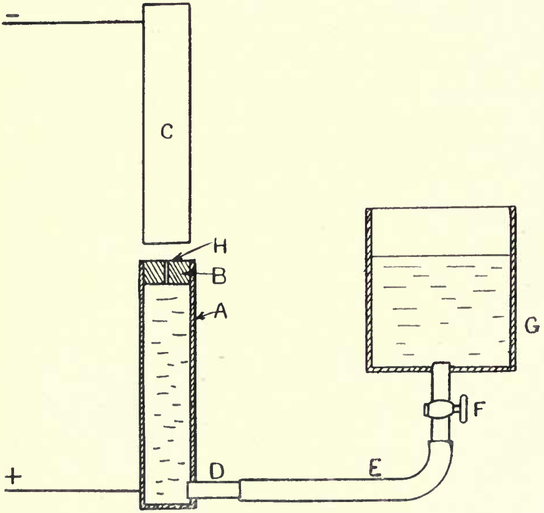

FIG. 104.—Scheme of Moretti's Arc in Water Vapour.

FLEMING'S "OIL-ARC"

This again is a copper-carbon arc in an atmosphere of hydrocarbon gas.[3] The novelty of the apparatus lies mainly

[1] Reference No. 271.

[2] See pp. 67 and 78.

[3] Reference No. 272 (also No 243, and "Discussion" in No. 226).

in the particular construction employed and in the means for obtaining and maintaining the desired atmosphere round the arc. The material used is a heavy lubricating oil, close over the surface of which the arcs are struck, and which is evaporated by the heat of the discharge. Fig. 105 shows the arrangement. C is the solid carbon electrode carried by the insulated holder E, so that its upper end just projects over the surface of the oil, F, F. The flat copper electrode, B, B, is held over the carbon by the rod D, and carries the copper tube, A, A, projecting downwards round the carbon rod, and thus enclosing a small space G over the surface of the oil, and round the arc, which is struck between B and C. The copper electrode B is perforated with two or three small holes, H, near its periphery, which serve as vents for the gas generated by the vaporisation of the oil.

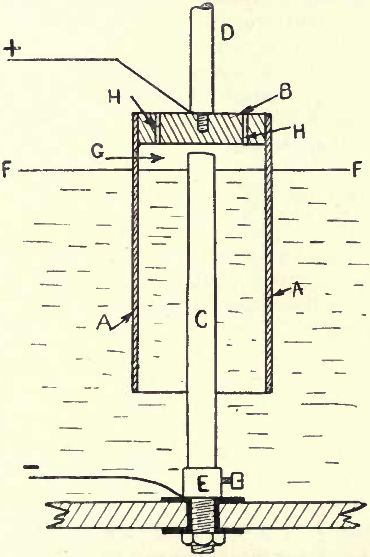

Fig. 105.—Fleming's "Oil-Arc."

By a proper choice of oils, or mixture of oils, the wear of the carbon can be compensated for by that deposited through the decomposition of the vapour, and the arc length consequently maintained fairly constant without much adjustment of the electrodes.

A number of these arcs may be mounted together in one tank of oil, and connected in series on a high-voltage direct-current circuit so that more energy may be obtained in the form of oscillations in the shunt circuit, which is connected across all the arcs in series in the usual manner. The large mass of oil contained in the tank usually affords sufficient cooling for the arcs, since the heat is very rapidly conducted down into the oil by the copper tubes, A, A. A further cooling by a spiral of pipe through which water is circulated may be provided if necessary to limit the temperature rise when operated over long periods.

THE EFFECT OF ELECTRODE POLARITY WITH COPPER-CARBON ARCS

It has already been pointed out that it is usual to operate copper-carbon arcs in an atmosphere of hydrogen or hydrocarbon gas, with the copper as the positive electrode and the carbon as negative. This is the custom with the Poulsen and most of the other forms described above.[1] It may, however, be worth mentioning here that each particular case should always be tried on its own merits, since advantages are occasionally obtained with the reverse connection. The normal direction, however, will generally be found in the majority of cases to yield the steadiest oscillations.

OSCILLATING ARCS WITH ALTERNATING CURRENT SUPPLY

It should be noted that it has been shown on more than one occasion to be possible to successfully operate oscillatory arcs on alternating current supplies of comparatively low frequency instead of on direct current as is usual, and yet to obtain high-frequency oscillations of sufficient constancy for wireless telephone purposes. The advantages of alternating current over direct current for this purpose lie in the ease of obtaining the high voltages that are usually considered necessary to increase the output by operating a greater number of units in series. The idea has further been employed in connection with frequency-raisers, since the arc under these conditions

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[1] Reference No. 273.

serves to increase the frequency of the initial supply to that of the shunt oscillation circuit. This arrangement has already been touched upon and is dealt with more fully in Chapter XV.[1]

In any case the most important point to be remembered is that the shunt oscillation frequency should be *an exact multiple* of the initial supply frequency to the arc. Under these conditions the effect of the low-frequency supply in causing a superposed "tone" upon the steady oscillations is least noticeable.

THE T.Y.K. ARC

An interesting development of the arc oscillation generator that does not belong to the "copper-carbon" type has been made by three Japanese inventors—W. Torikata, E. Yokoyama, and M. Kitamura.[2] Its chief novelty lies in the materials used for the arc electrodes. These are made up of a selected pair of such substances as: Silicon, Ferro-Silicon, Carborundum, Boron, Magnetite, Iron pyrites, Molybdenite, and some metals such as Brass and Copper. The best results are usually obtained with magnetite for the negative electrode, and brass for the positive one. A continuous current supply at about 500 volts is employed; and the arc may be enclosed in a hydrogen or hydrocarbon atmosphere.

A noteworthy point in connection with these oscillation generators is that the materials used for the electrodes are capable of acting as rectifiers of alternating currents of low voltage, when they are placed in contact with one another. Nearly all the substances enumerated in the above table have been employed at one time or another as "crystal" detectors for wireless reception. It has also been shown by W. H. Eccles[3] that many of these crystal detectors or crystal contacts, when shunted by a suitable oscillation circuit, are capable of setting up feeble continuous electric oscillations in that circuit. The most notable instance of this action takes place in the Galena-Plumbago, and Galena-Galena detectors.

It would therefore almost seem as if the utility of these materials as arc electrodes might be connected in some way with their ability to set up oscillations at low voltages. It is somewhat difficult, however, to say what the precise mechanism of the action may be. On the other hand it is

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[1] P. 235.

[2] Reference Nos. 274, 275.

[3] Reference No. 276.

possible that the explanation of their utility may lie in a different direction—more as in the case of Chaffee's and Yagi's spark-gaps,[1] and in the Dwyer Arc.[2] This view is perhaps supported by the results of Yagi's experiments with his gap, in which he showed that a thin coating of oxide or oil on the surface of the aluminium electrode was often advantageous. The reason for this is probably to be found in the additional quenching thereby obtained—just as in the case of the aluminium electrolytic rectifier the film on the aluminium electrode quenches out the current flow in one direction.

The T.Y.K. sets have only, up to the present time, been made up in small units. They are compact and, if necessary, portable. Dry cells may be employed as source of power. Ranges up to 30 or 40 miles have been secured.

MERCURY VAPOUR ARCS

These have not been employed to any very great extent for the generation of high-frequency oscillations, as the ordinary mercury arc does not readily lend itself to the passage through it of oscillatory currents.[3] Where mercury vapour apparatus has been employed for the production of oscillations it is generally arranged to function either as a spark-gap,[4] or in a similar manner to the oscillions described below.[5] Vreeland's arc apparatus may be classed as a special case of the latter with magnetic control instead of electrostatic.[6] The former of these groups, which has already been dealt with,[5] might perhaps also be looked upon as an arc oscillation which is confined to type 2 in which the arc is completely extinguished once during each cycle.[7]

P. Cooper-Hewitt is said to have devised an efficient form of mercury-arc oscillation generator,[8] but the majority of the experiments made in this direction have not led to results of much practical value.

B. Liebowitz has shown[9] that by a special construction of the mercury vapour tube it is possible to establish steady oscillations, and to overcome the difficulties otherwise experienced in passing alternating currents through mercury vapour arcs. The special feature of the tube is the use of *two* mercury cathodes (or negative electrodes) in conjunction with

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[1] Pp. 67 and 78.
[2] P. 147.
[3] Reference Nos. 278, 282.
[4] See pp. 83 *et seq.*
[5] Chapter XIII. p. 161.
[6] P. 153.
[7] See p. 117.
[8] Reference Nos. 283, 284.
[9] Reference No. 278.

one iron or graphite anode. The oscillation circuit is arranged between the two cathodes. The supply is taken to the common anode and to the two cathodes arranged in parallel with a separate choking inductance and resistance in series with each of them. The circuit connections are thus very similar to those of Fig. 85,[1] where A_1 and A_2 may be taken to represent the two arcs inside the tube, working to the common anode.

A supply voltage of the order of 4000 v. was employed, with small capacities (0·002 mfd. or less) in the oscillation circuit.

The small units of these "converters" (from D.C. to oscillations) are constructed with glass envelopes, but these arrangements of mercury arc are eminently suited for use in metal containers, after the manner of the recent developments of the mercury-arc rectifiers.[2]

VREELAND'S ARC OSCILLATOR

In 1908 F. Vreeland[3] described an interesting method of generating practically undamped oscillations from a direct current supply. Use is made of a special mercury vapour tube —in this case having one mercury cathode, and two carbon anodes on opposite sides of the bulb. The anodes are arranged in parallel through choking inductances and resistances, in a similar manner to Liebowitz's apparatus described above. An oscillation circuit is connected between the two anodes. The special feature of this apparatus is the arrangement of the coils forming the inductance in the oscillation circuit in such a manner that the magnetic fields set up in them cause a direct deflection of the stream of arc vapour towards one anode or the other. Oscillations when first set up are thus maintained in a perfectly steady state by the discharges of the condenser through the deflecting coils. These coils may be seen round the bulb in Fig. 106, which shows one form of the complete apparatus.

THE FREQUENCY OF THE OSCILLATIONS OBTAINED FROM ARCS

It has already been mentioned that the frequency of the oscillations set up in the shunt circuit across the arc is a

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[1] P. 126.

[2] See, for example, Reference Nos. 288, 626.

[3] Reference Nos. 285, 286 (also Nos. 281 and 287 for similar method).

function of the arc length, and other factors besides merely the capacity and inductance of the circuit.[1] In the case of a closed oscillation circuit containing capacity = C microfarads, inductance = L centimetres, and negligible resistance, it is well known that the natural frequency of the free oscillations in this circuit is given by the expression

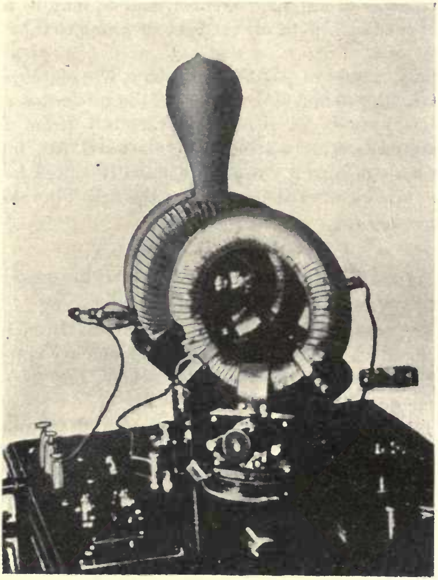

FIG. 106.—Vreeland's Mercury Vapour Arc Oscillator.

$$n = \frac{5{\cdot}033 \times 10^6}{\sqrt{CL}}.$$

This is also approximately true in the case of ordinary spark transmitters, where the oscillation circuit includes a spark-gap, since the resistance of the latter is usually not sufficient to seriously disturb the natural frequency of the

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[1] See p. 114.

circuit, though J. Stone-Stone has shown that it may have considerable effect upon the decrement of the oscillations.[1]

With an oscillation circuit shunted across an arc, however, the case is usually very different, since the resistance of the arc is not by any means a constant quantity, while at the same time it is not small enough to have a negligible effect on the frequency. Characteristic curves for various arcs have already been given.[2] From them it may be seen that the arc resistance $\left(=\frac{\text{voltage}}{\text{current}}\right)$ increases rapidly as the current is decreased. The arc resistance therefore not only depends upon the direct current flowing through the arc, but also varies during the cycle of the oscillations. When the oscillatory current is very small compared with the direct current[3] the resistance remains sensibly constant, the wave form of the oscillations is approximately a sine curve, and the frequency is very nearly that given by the simple formula above.[4] With larger oscillatory currents the shape of the characteristic curve must be considered. Taking first the " static " characteristic, it has been shown by Mrs. Ayrton[5] that the voltage and current may be connected by an expression of the form :

$$\mathrm{V}=a+bl+\frac{c+dl}{\mathrm{I}},$$

where a, b, c, and d are constants depending upon the material of the electrodes,[6] and also upon the atmosphere surrounding the arc ; l = length of arc ; and I = current through the arc.

By combining this expression with the formula giving the natural oscillation frequency of a circuit containing capacity, inductance, and resistance, it has been shown by G. W. Nasmyth[7] that an expression of the following form may be obtained for the oscillation frequency :

$$n=\frac{1}{2\pi}\sqrt{\frac{1}{\mathrm{CL}}-\frac{\left(\mathrm{R}-\frac{c+dl}{\mathrm{I}}\right)^2}{4\mathrm{L}^2}}.$$

It is therefore evident that any change in the arc length or

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[1] J. Stone-Stone, *Proceedings Inst. Radio-Engineers,* 2, p. 307 (1914), and 4, p. 463 (1916).

[2] Figs. 77 (p. 113), 88 (p. 129), and 90 (p. 133).

[3] Type 1, Oscillations, see p. 117.

[4] Reference No. 290.

[5] Reference No. 211.

[6] Some values of these constants are tabulated in Eccles's *Handbook of Wireless Telegraphy and Telephony* (Electrician Publishing Co.), p. 39 (1st edition).

[7] Reference No. 289.

supply current will cause changes in the frequency of the oscillations. The formula given is, however, a very rough one, for the reason that when the arc is oscillating its characteristic, as has already been pointed out, no longer follows the " static " curve, from which this expression is derived. For this reason the formula should be looked upon mainly as an *indication* of the fact that the oscillation frequency is some function of the supply current and arc length, rather than as a strictly quantitative expression that may be employed for calculations in any specific instance.[1]

VARIOUS CONNECTION ARRANGEMENTS AVAILABLE WITH ARC OSCILLATION GENERATORS

The most usual mode of transference of the oscillatory energy from the arc shunt circuit to the aerial circuit is by an inductive coupling of the same type as is used in most spark transmitters (Fig. 107). The shunt circuit C_1, L_1 is coupled magnetically to the aerial circuit through the coils L_1, L_2, while L_3 is used when required for tuning purposes. A_1 may represent one or several arcs in series.

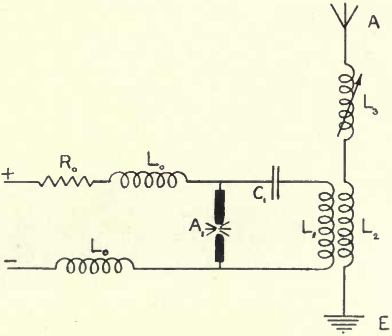

Fig. 107.—Inductive Coupling of Arc to Aerial Circuit.

Other possibilities are, however, open for consideration in special cases. For instance, a tuned intermediate circuit

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[1] Reference may here be made to Reference Nos. 291 to 295. A similar expression to Nasmyth's has also been arrived at by K. Vollmer. See Reference No. 298.

may be introduced between the main (arc) oscillation circuit and the aerial, as indicated in Fig. 108, in which the closed circuit C_2, L_2, L_3 represents the intermediate circuit, and is coupled to the main arc circuit by the coils L_1, L_2, and to the aerial circuit by the coils L_3, L_4, both of which couplings may of course be varied as desired. The intermediate circuit is tuned by the variable condenser C_2. This arrangement was first advocated for use with arc oscillation generators by V. Colin and M. Jeance in their patents, to which reference has already been made.[1] It has the advantage of giving greater flexibility to the tuning and greater ease of microphonic control of the aerial oscillations. At the same time, however, it renders it very imperative that the arc oscillations shall be extremely steady and of constant frequency. These conditions are not always very well attained in small power arc apparatus, but they are ones that are being realised to a much greater extent with the large arc generators now in use. A convenience, when adopting this arrangement, is to arrange for a part of the condenser C_1 (Fig. 108) in the main oscillation circuit to be very readily variable by the operator, so that by watching the hot-wire ammeters in the various circuits he is enabled to very largely eliminate the effects of any variations in the frequency of the arc oscillations should they occur.

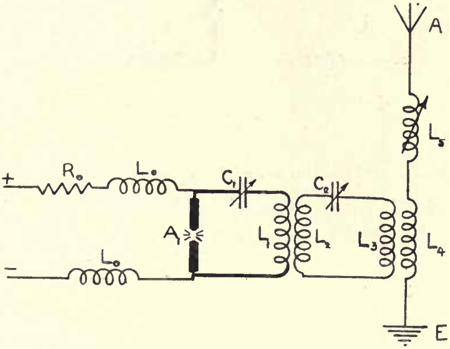

Fig. 108.—Intermediate Circuit for coupling Arc to Aerial Circuit.

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[1] See pp. 142 *et seq.*

Another mode of connection sometimes adopted is shown in Fig. 109. In this instance a direct connection is made between the aerial circuit and the main oscillation circuit C_1, L_1. It is often desirable in this case to insert a condenser

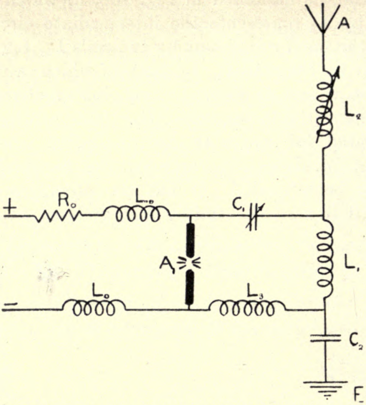

Fig. 109.—Direct Connection of Aerial and Shunt Oscillation Circuits of Arc.

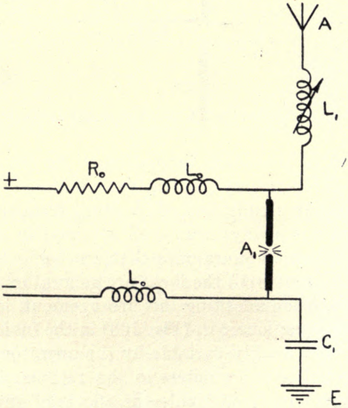

Fig. 110.—Arc Oscillation Generator direct in Aerial Circuit.

C_2 in the ground connection in cases where it may be advisable to avoid a direct earth connection to the supply circuit.

The development just outlined may be carried a stage further by the entire suppression of the closed oscillation circuit across the arc, and the utilisation of the aerial circuit itself as the shunt oscillation circuit (Fig. 110). This method has been employed with considerable success—notably in America—when the arcs yield oscillations that are sufficiently steady and of constant frequency.[1] An advantage is secured by the elimination of some of the bulky high-frequency apparatus by this method. A disadvantage is the addition of the resistance of the arc to the natural resistances of the aerial circuit. This effect may be largely eliminated by an arrangement due to L. F. Fuller, shown in Fig. 111.[2] An additional condenser C_2 is shunted across the combination of arc A_1 and condenser C_1, and serves to shunt a considerable portion of the aerial current to earth without passing through the arc itself. A substantial increase in the aerial current is thereby usually secured. As a further improvement a damping circuit (shown at R, L) may be placed in parallel with the condenser C_1 to confine the aerial oscillations as much as possible to the path through C_2. The condenser C_2 may have a capacity of about twice that of C_1, which latter should be of the same order of magnitude as the effective capacity of the aerial.

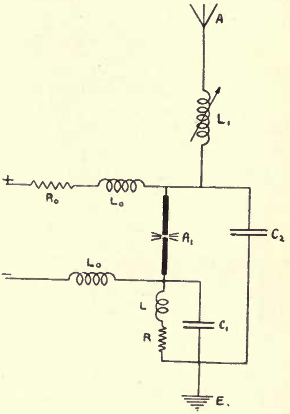

FIG. 111.—Arrangement of Arc with Shunt Condenser to increase Aerial Current (L. F. Fuller).

In the case of a 50 kw. arc, an increase of about 75 per cent in the aerial current by the addition of the condenser C_2 has been cited,[3] and a further increase of about 11 per cent by the addition of the damping shunt L, R. The proper values of

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[1] Reference No. 296.
[2] Reference No. 303.
[3] Reference No. 304.

C_1, C_2, L and R must be found by experiment to secure the maximum aerial current in any given case. The improvement is most marked with low-power arcs, because the arc resistance is larger than in the case of high-power arcs drawing a large direct supply current.

CHAPTER XIII

VACUUM OSCILLATION GENERATORS

The Edison Effect in Glow Lamps

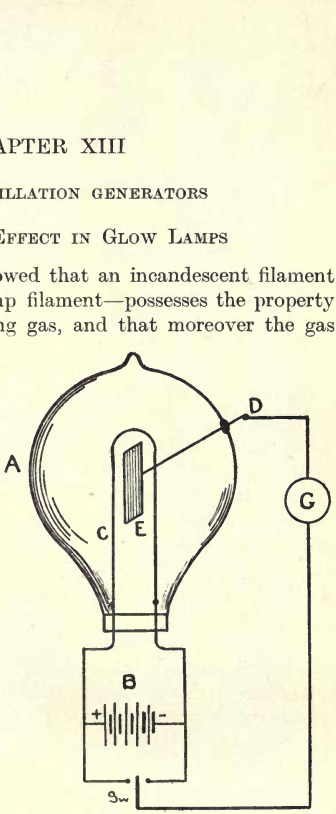

Fig. 112.—The "Edison Effect."

In 1884 T. A. Edison showed that an incandescent filament of carbon—such as a lamp filament—possesses the property of ionising the surrounding gas, and that moreover the gas so ionised is capable of carrying a current in one direction only—at least when small voltages only are impressed upon it.[1] The experiment by means of which this phenomenon was demonstrated may be carried out as indicated by the diagram, Fig. 112. A glass electric-lamp bulb, A, containing a single loop carbon filament, C (such as was commonly employed in the early days of electric incandescent lamps), has sealed into its interior before exhaustion a small platinum plate, E, carried by a platinum wire support, D. This is sealed through the glass, and serves at the same time as a terminal connection to the platinum plate. The plate is thus supported midway between the two legs of the filament loop, as indicated in the diagram. The filament

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[1] Reference No. 305.

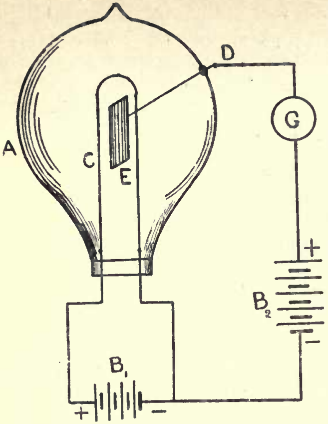

FIG. 113.—The "Edison Effect"—Flow of Current to Positively Charged Electrode.

is raised to incandescence by current from the battery, B; and a galvanometer, G, is connected between the platinum plate and either the positive or negative leg of the filament by the switch, Sw. It is found that the galvanometer gives a strong deflection when it is connected to the positive leg, but none or very little when connected to the negative.

By inserting another battery in series with the galvanometer it may readily be shown that a current will pass between the negative leg of the filament and the plate E when the positive pole of the second battery is connected to E, but that none passes when the battery is reversed (Figs. 113 and 114). This therefore indicates that the intervening space between the hot filament and the plate becomes capable of passing a current from the plate to the filament, but not in the reverse direction, *i.e.* taking the usual convention as to direction of current flow, viz. from positive to negative. When the filament is cold no current will flow in either direction under the same voltages.

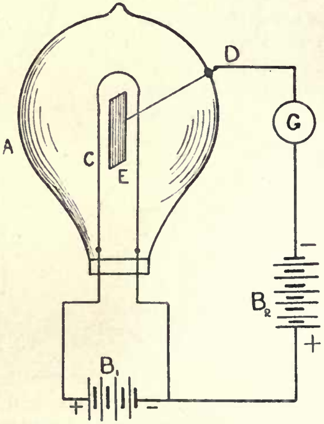

FIG. 114.—The "Edison Effect"—No Current Flow to Negatively Charged Electrode.

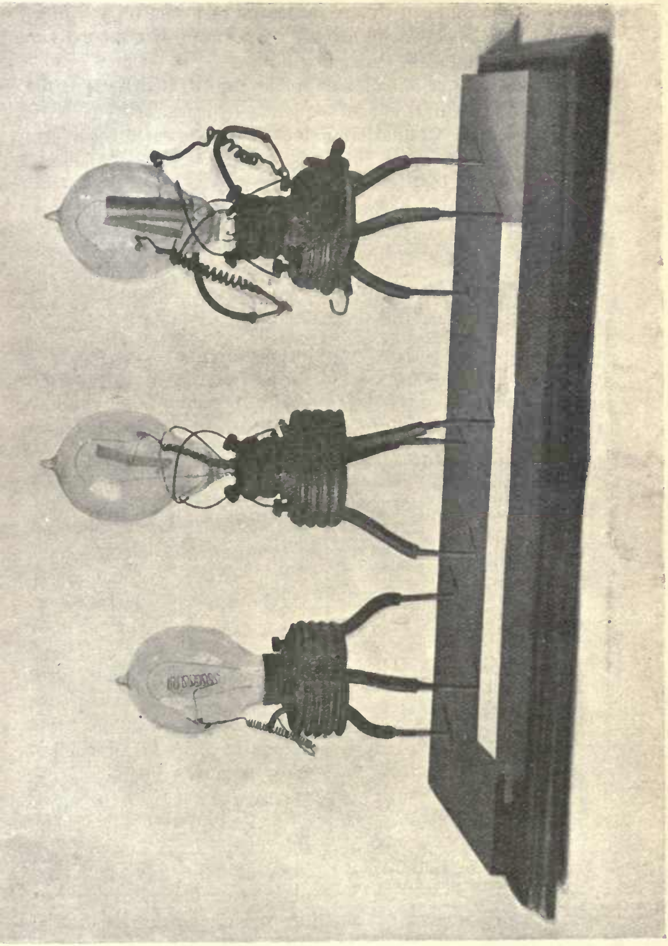

Fig. 115.—Fleming Valves.

Photograph of the original Oscillation Valves used by Dr. J. A. Fleming, F.R.S., in October 1904, as Rectifiers and Detectors of the High-Frequency Oscillations employed in Wireless Telegraphy.

This phenomenon—the "Edison Effect" it is usually called—is not confined to any particular gas at any particular pressure, but is shown by all gases, and even at atmospheric pressures, as well as in exhausted bulbs.

This property of hot filaments has been turned to account by Dr. J. A. Fleming, and subsequently by others, and evolved into the Fleming Oscillation Valves, well known as receiving detectors.[1] It is upon this same effect that the vacuum oscillation generators are based.

In the centre valve shown in Fig. 115 the loop filament and central plate can be clearly seen.

VALVE CHARACTERISTICS, AND THE DIRECT PRODUCTION OF OSCILLATIONS

The characteristic curve of these vacuum valves may be drawn out in exactly the same way as for the arc generators already discussed, that is to say by plotting the voltage applied between the plate and filament against the current passing through the space between them. A typical curve obtained in this manner with a carbon filament is shown in Fig. 116. It sometimes happens that these valves — more particularly when they have metal filaments instead of carbon ones, and when the filaments are run at a high temperature—do not have a regular characteristic as in Fig. 116, but show points of instability at one or more critical voltages, as at A in Fig. 117. When this is the case a telephone inserted in the circuit between plate and filament can be made to emit a piercing whistling noise, showing that the current passing through it is very rapidly changing. By a suitable capacity-inductance shunt circuit across the valve,

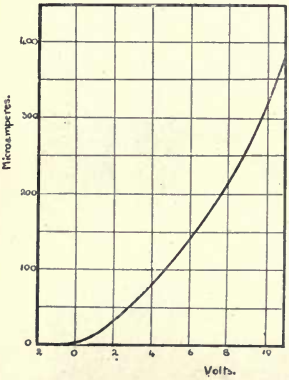

FIG. 116.—Characteristic Curve of Carbon Filament Valve.

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[1] Reference No. 307.

oscillations of fairly definite frequency may usually be set up in this manner, just as in the case of the oscillating arcs.[1]

The occurrence of this negative characteristic in vacuum valves is usually most evident with very high vacua.[2]

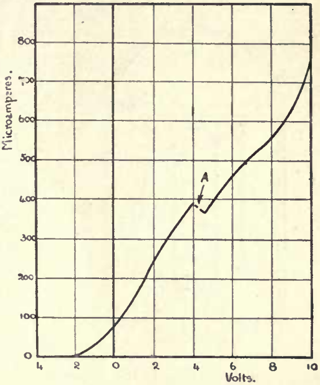

FIG. 117.—Characteristic Curve of Oscillation Valve showing Discontinuity.

In practice it is frequently the custom to surround the filament loop with a metallic cylinder instead of using merely a small plate between the legs. Such arrangements lower the resistance of the valve and allow larger currents to be passed through it. At the same time the cylinder serves to shield the glass bulb from static charges. This factor is often of considerable importance, as will be evident later. Fig 118 is a diagram of this type of construction. Very many forms and types of valves have been brought out at various times. Some of these are dealt with in the following pages.

A piece of apparatus in which a discharge in rarefied gas shows a negative characteristic is the tungsten arc in an inert gas. The commercial form of this is usually known as the "Pointolite" lamp.[3] The characteristic curve of these lamps is very steep for small currents and high voltages, but becomes very much flatter at the normal current for which the lamps are rated.

Oscillations may be obtained by the use of one of these arcs in hydrogen, shunted by a usual oscillation circuit.[4]

MODE OF OPERATION OF VACUUM VALVES AND OSCILLATION GENERATORS

The construction of a Fleming vacuum oscillation valve is indicated in the diagram of Fig. 118. G is the sealed glass

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[1] Reference No. 309.

[2] Reference No. 308.

[3] Reference No. 310.

[4] Reference No. 351.

envelope containing an ordinary lamp filament F, of carbon, tungsten, tantalum, or other suitable material. This is surrounded by the metal cylinder C, supported in place by wires W, W from the glass bulb G and stem S. The wires H serve as a means of connection to this cylinder, or "plate" electrode. Connection to the filament may be made by an ordinary "bayonet" pattern lamp cap B. In connection with the choice of filament material, carbon was often used in the earlier forms. Tungsten is now very largely employed, though tantalum sometimes shows advantages in the form of allowing larger currents to be passed through the vacuous space.

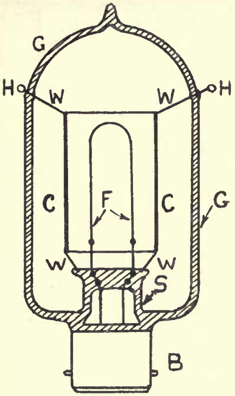

FIG. 118.—Vacuum Valve with Cylinder surrounding Filaments.

B = Lamp Cap; C = Metal Cylinder; F = Lamp Filament; G = Glass Envelope; H = Wire Connections; S = Stem for Filament; W = Wire Supports for Cylinder.

The origin of the unilateral conductivity in these valves lies in the emission of a stream of negatively charged electrons from the hot filament. These moving electrons, since they carry an electric charge, constitute an electric current between the filament and the plate. It must be remembered that the direction of motion of the electron stream constituting an electric current is *opposite* to the direction in which the electric "current" is usually supposed to flow between two points at different potentials. The electrons, being charges of negative electricity, move under the action of an applied potential difference, from the negative to the positive pole. Bearing this in mind the action of the battery B_2 in Fig. 113 is at once explainable, since its positive pole is connected to the plate electrode of the valve, thus attracting the negatively charged electrons from the filament on to the plate, and assisting the passage of the current round the circuit, through the galvanometer. When the battery is reversed (Fig. 114) the plate E becomes negatively charged, and the electrons are therefore repelled from it and the current flow consequently stopped.

The stream of electrons between the filament and the plate constitutes a flexible conductor, which may therefore be deflected by a magnet, just as we have seen that an arc may be so deflected.[1] By bringing up a magnet to a vacuum valve it is easily shown that this is the case. The current passing through the vacuous space and indicated on the galvanometer G (Fig. 113) can be caused to undergo large fluctuations as the magnet is moved about.[2]

Further, since this electron stream is made up of minute *charged* particles, it is able to be affected by an electric field as well as by a magnetic field. The current flowing through the galvanometer G (Fig. 113) can be caused to fluctuate by bringing a charged rod [3] into the neighbourhood of the valve. When the electric field of the charged rod is so disposed that the electrons are attracted towards the plate, the current will be increased, while if they are caused to move in any other direction the current will fall from its normal value when no charged rod is near.

By inserting into the bulb another electrode, besides the plate already referred to, and setting up electric charges upon this, the intensity of the electron stream passing to the plate can be very readily modulated by quite small electric charges upon the third electrode. A still greater effect can be secured with the minimum electric charges upon this additional electrode, if it is constructed in the form of a perforated plate or wire grid placed right in the path of the electron stream between the filament and the plate. The construction of Fig. 118 then becomes Fig. 119, in which G represents the additional perforated or " grid " electrode. Such arrangements are the basis of practically all successful " vacuum " oscillation generators employing the above properties of a vacuous space. Their first construction in this form—as distinct from the simple oscillation valve of Fleming—is largely due to L. de Forest, but they have latterly been developed in very many forms by a large number of workers in the radio field.[4]

The importance of avoiding the production of an electrostatic charge on the glass bulb of a valve (see p. 165 above) should now be evident, for if the electrons shot off from the

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[1] Pp. 135 and 153. See also Reference No. 311.

[2] Applications of this are mentioned on pp. 153 and 236.

[3] Such as a piece of ebonite that has been rubbed with flannel.

[4] See p. 177, etc.

hot filament are allowed to bombard the glass bulb to any great extent, there is considerable likelihood of the accumulation of a negative electric charge upon the inside surface of the glass. This charge will therefore repel the electrons issuing from the filament, and in extreme cases frequently causes an *almost complete cessation of the current passing from the filament to the plate.* These actions should therefore be avoided both by screening the glass as much as possible from such bombardment, either by means of the "plate" electrode or by an auxiliary metallic screen from which the charges can be led away to earth (or rather, back to the filament battery),[1] and also by removing the glass as far as possible from the

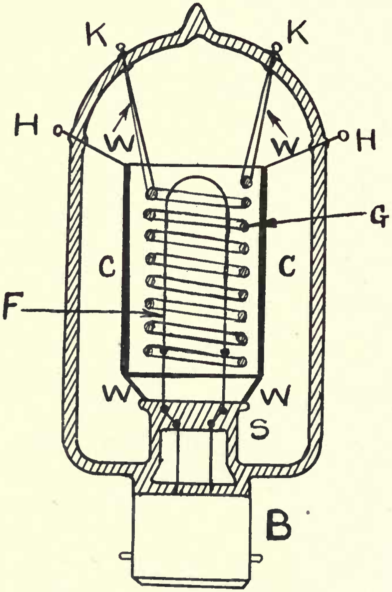

FIG. 119.—Three-Electrode Vacuum Valve.
C=Cylinder, or "Plate" Electrode; G=Wire Spiral, or "Grid" Electrode; F=Lamp Filament.

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[1] See, for example, Reference No. 319.

filament, that is to say, by employing a large bulb. This last factor is of special importance in securing reliable operation of the valves, particularly when they are required for passing large currents for generating high-frequency oscillations and for other purposes.

H. J. Round has shown that it is possible to operate these vacuum oscillation generators with the third or grid electrode placed on the *outside* of the glass bulb instead of inside.[1] This somewhat simplifies the construction of the apparatus. The exterior " grid " may take the form of a metallic coating of wire or foil round the vacuum tube in the region between the filament and the plate. The glass tube is conveniently constricted at this point to enable the grid to exert greater control upon the electron stream. This constriction of the glass near the electron stream might conceivably introduce troubles through the accumulation of a static charge upon it. In general this construction is not nearly so effective as when the grid is mounted inside the valve bulb and in the direct path of the electron stream, and is not adopted in usual practice.

ARRANGEMENT OF THREE-ELECTRODE VALVE OR AUDION, AS AN AMPLIFIER AND OSCILLATION GENERATOR

The three-electrode valves of the type just outlined have been developed by many experimenters, both in this country and abroad, but especially in America and Germany. Various names have been given to such apparatus, such as vacuum relays, or gas relays or amplifiers, "pliotrons," etc.; but perhaps the most commonly used designations are those of "oscillating valve," "audion," "oscillating audion," or "oscillion." The general principles of all are, however, the same. The term "thermionic valve" is now frequently employed as a general name covering *all* forms of this apparatus.

If we choose such a three-electrode valve that shows considerable sensitiveness to electrical deflection of the electron stream, we can arrange it to *amplify* a feeble current in the following manner (Fig. 120). The valve is shown at V, containing the lamp filament F, a " grid " electrode G, and a " plate " anode P. The filament is heated by the battery B_1, with an adjustable resistance R_1 in series. From the negative pole of the filament battery B_1, a lead is taken to the grid

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[1] Reference No. 322.

electrode G through the secondary coil L_2 of a step-up transformer L_1, L_2. In circuit with the plate electrode (anode) P is connected another battery B_2, the effective voltage of which can be varied by means of the potentiometer resistance R_2, or by means of a multiple contact switch to cut in or out the cells of the battery one at a time. If finer adjustment than this is desired a single cell shunted with a potentiometer resistance may be inserted in the circuit as well (Fig. 121), thus saving the waste of energy in the large potentiometer resistance R_2 in Fig. 120. Such fine adjustment is, however, usually unnecessary, and the multiple contact switch provides all the necessary adjustment. One coil of another transformer L_3, L_4 is also inserted in this circuit.

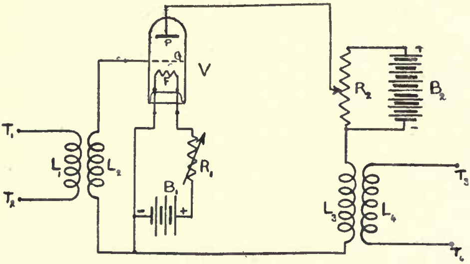

FIG. 120.—Amplification of Current by Valve.

By passing the current to be amplified through the coil L_1, corresponding voltage variations will be impressed upon the grid G. It is usually advantageous to arrange the transformer L_1, L_2 to be a step-up one, in order that the potential variations of the grid may be as large as possible. Variations of the grid electrode potential will, as we have seen, produce large fluctuations in the strength of the electron current flowing from the hot filament to the plate. Hence from the terminals T_3, T_4 it is possible to draw a current that is considerably amplified as compared with the variations impressed upon T_1, T_2. The voltage B_2 must be adjusted to obtain the best operating conditions for the particular valve in use. Further, it is obviously necessary that the valve or audion that is used must be capable of carrying currents that are at least as large as those to be passed through the coil L_1, or amplification will not be obtained, but merely a feebler copy of the original current variations.

The amplified currents obtained by such methods are very faithful copies of the impressed currents, as is evidenced by the fact that speech may be very clearly transmitted through these valves. This shows that the amplification is not confined to one frequency alone, but that the device is capable of amplifying successfully the currents of very various frequencies and irregular wave-forms that occur in telephone circuits. In all cases it is essential that the transformers L_1, L_2 and L_3, L_4 should be properly designed to suit the other circuits connected to the amplifier, and also the average frequency of the currents to be amplified. For telephonic frequencies they may contain iron cores, but for high-frequency currents they must be ordinary air core jiggers, such as are usually employed in wireless work.[1]

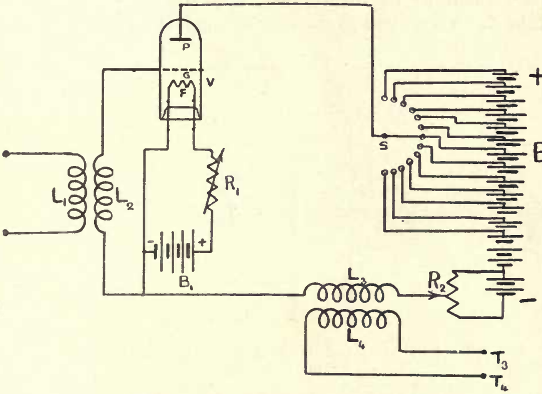

FIG. 121.—Current Amplification by Valve.
(Plate circuit voltage adjustment by multi-contact switch.)

Let us now consider the amplification of a simple harmonic current by such an arrangement. It is at once evident that a considerably augmented voltage variation in the "grid-circuit" will be obtained if the secondary circuit of the transformer L_1, L_2 is tuned to the frequency of the impressed current.

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[1] Reference No. 320.

Similarly, the "plate-circuit,"[1] by which the energy is handed on to the indicating instrument or other apparatus, may be tuned and the amplified current variations thus further augmented. The arrangement is indicated in Fig. 122. The condenser C_2 is used to tune the secondary L_2 to the impressed frequency; and the condenser C_3 the coil L_3 in similar manner. In this way the maximum amplification may be obtained, provided that the applied E.M.F. is a simple harmonic one.

Suppose, now, we so arrange the circuits that the amplified currents obtained with the above arrangement are led back again into the "grid-circuit" side of the amplifier. We should expect them to be reamplified, and still stronger currents obtained. These will again pass through the amplifier by the same connection and be further strengthened. Such a process will continue until the limit of amplification is reached for the particular valve in use.

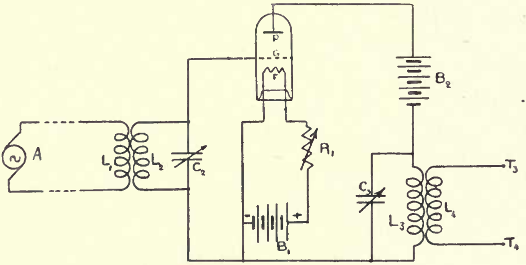

FIG. 122.—Amplification of Simple Harmonic Current by Valve using Tuned Circuits.

It should be borne in mind that amplifiers of this type produce relatively greater amplification for feeble initial impulses than for stronger ones, for the reason that their output is limited by the maximum current that can be passed through the vacuous space. Therefore, provided that the applied impulse is sufficient to adequately modulate this current, good amplification of the initial feeble impulse is

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[1] The circuit connected to the grid G, or the circuit by which energy is applied to the valve, is generally called the "*grid-circuit*"; while that connected to the plate P is called the "*plate-circuit*" or "*anode-circuit.*" Some American writers often refer to this latter as the "*wing-circuit,*" and the battery B_2 in that circuit as the "*wing-battery.*"

obtained, while as the initial impulse becomes strengthened by the successive amplifications outlined above, it cannot under any circumstances do more than produce 100 per cent variation of the steady electron or plate-circuit current. Hence the ratio of amplification—*i.e.* the ratio of the strength of the outgoing modulated current, to the input current, falls off as the latter increases, until finally in the case considered above a steady state is reached when the maximum possible modulation of the plate-circuit current is obtained.[1]

The applied alternating potential to the grid may be removed without causing a cessation of the currents flowing in the various circuits—a part of the amplified current being led back and taking the place of the original supply. The arrangement thereby becomes self-exciting and constitutes the elements of the "oscillating-valve," or "oscillion," as it is often termed in America. It may be questioned, how such an arrangement is possible without the energy of the oscillations rapidly dying down after the original excitation has been removed. The reason is that the energy of the amplified currents is drawn from the direct current source B_2 and not from the initial supply. The amplification is an energy amplification, so that a small part of the outgoing energy may evidently be taken back again to the input side,[2] just as the field current of a shunt dynamo may be drawn from the armature of the same machine, since the energy is provided by the prime mover.[3]

The frequency of the oscillations that are set up depends upon the electrical constants of the circuits connected to the valve—on the natural frequency of the oscillation circuits so formed—so that the frequency of the currents generated may be very readily varied over wide limits. Currents having frequencies ranging from 0·5 per second to 10×10^6 per second have been set up in this manner.[4] When high-frequency currents are to be generated a condenser should be shunted across the battery B_2 to provide a path for the oscillations without their passing through the cells. A diagram of this arrangement is given in Fig. 123. In this instance the

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[1] The amplification ratio for feeble impulses, using a single audion bulb, is usually of the order of about ten times.

[2] Reference No. 321.

[3] A theoretical discussion of the conditions necessary for setting up oscillations is given in Reference No. 631.

[4] Reference No. 325.

frequency of the oscillations is determined by the constants of the circuit L_3, C, L_4. For this reason this circuit is often termed the "flywheel-circuit."[1] The coupling L_1, L_3 serves to connect the flywheel-circuit with the grid; and L_2, L_4 the plate and flywheel circuits. K is the condenser shunt to the battery B_2. The mode of operation is precisely as described above.

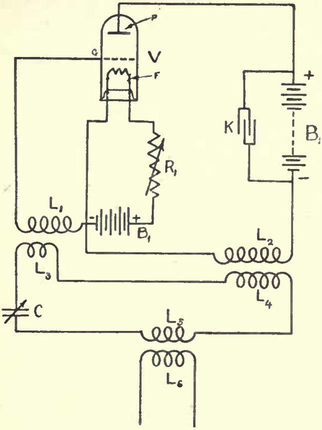

FIG. 123.—The Self-excited Valve Generator or "Oscillion" (A. Meissner).

As an alternative to the use of the flywheel-circuit, the grid and plate circuits may be directly coupled together, while one or both of them is provided with means of tuning to the desired oscillation frequency (Fig. 124). In this diagram the grid-circuit includes the coil L_1 across which is shunted the variable condenser C_1. The plate-circuit includes L_2 shunted by the condenser C_2, and coupled with L_1. The condenser C_1 is sometimes omitted, but the most commonly adopted arrangements are usually of this or similar type.[2]

It is often desirable to arrange the circuits so that a small variable voltage may be applied to the grid electrode as well as to the plate. For this purpose one or two cells shunted by a potentiometer resistance may be inserted in the grid-circuit with the positive terminal connected to the grid, and the negative to the negative pole of the filament battery B_1. A more convenient arrangement that dispenses with the use of extra cells is to shunt the filament battery itself, or part of it at the negative end, by a potentiometer resistance of which the slider is joined to the grid-circuit. A slight improvement in the results may often be secured by this arrangement.[3]

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[1] Reference Nos. 315, 316.

[2] Reference Nos. 314, 317, 318.

[3] This arrangement is indicated in Fig. 200 and other diagrams.

The output of oscillatory energy from these valves is necessarily limited to the current passing through the vacuous space, and the value of the boosting voltage B_2 in the plate-circuit. By constructing larger valves with the filament and electrodes adapted for carrying larger currents, the limit of available output may be increased. The oscillations obtained from one valve may also be amplified by a second and larger valve, so as to increase their energy. To further increase the output a number of these amplifiers may be connected in parallel, thus adding together their plate-circuit currents. This process may be carried on to any desired extent, and in actual fact several hundred such amplifiers have been used in parallel for wireless telephone purposes.[1] A strict proportionality may be observed in the output current as the number of valves in parallel is increased. The limit to these arrangements is generally imposed from an economic and financial standpoint rather than from an electrical one. When a number of these oscillions or amplifiers are operated in parallel

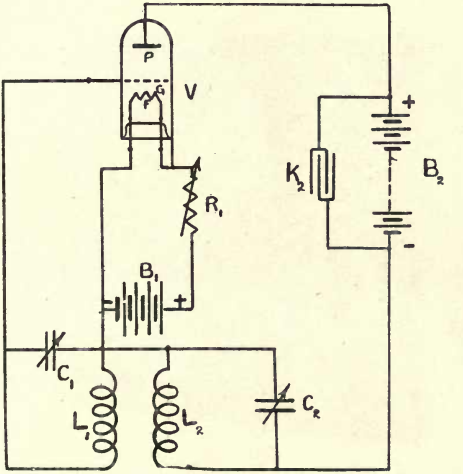

FIG. 124.—Oscillating Valve with Direct Coupling between Plate and Grid Circuits.

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[1] Reference Nos. 609, 610.

with a common battery or generator to supply the high voltage for the plate-circuits of all of them, it is desirable to insert a resistance in series with the plate of each valve in order to limit the possible current that may be passed by any particular valve to prevent the possibility of the formation of an arc inside the bulb. The stability of the complete arrangement is thereby increased. These resistances should each be shunted by a small condenser to provide a by-path for the oscillations and to prevent the wastage of their energy in the resistances.[1]

Fig. 125.—Audion Amplifier (L. de Forest).

A view of an Audion amplifier complete with battery-regulating switches and other accessories is given in Fig. 125,[2] and of complete oscillation generator outfits as fitted up for transmission purposes by the Marconi Company in Figs. 126, 127.

The possible number of circuit arrangements for generating oscillations with valves is very large. Some attempt at classification has recently been made by L. Hazeltine[3] in a paper read before the Institute of Radio Engineers.

[1] Reference No. 317.
[2] Reference No. 663.
[3] Reference Nos. 651, 652.

VARIOUS FORMS OF VACUUM OSCILLATION GENERATOR

From the preceding paragraphs it is evident that the limit of practical utility of these vacuum oscillation generators, as just described, arises through the relatively small currents that it is possible to pass through the vacuous space between the filament and the plate. These currents cannot be increased to any very great extent with the type of construction just outlined, without rapid disintegration of the filament taking place followed by complete destruction of the valve. When the current is increased to any great extent by raising the applied voltage, the plate and grid electrodes are subjected to an intense ionic bombardment, by which they soon become excessively heated. Water cooling of these electrodes is sometimes adopted to minimise the effects of excessive heating, or the whole valve may be immersed in a cooling oil bath.

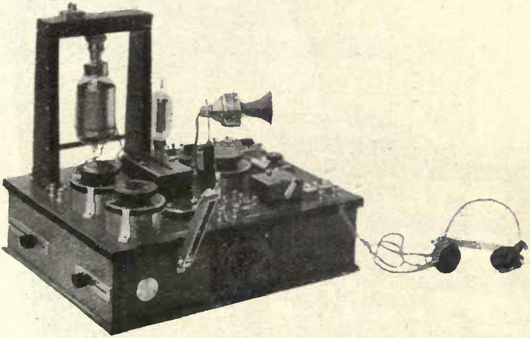

FIG. 126.—Valve Oscillation Generator (Marconi Co.).

As the potential of the plate circuit battery B_2 (see previous diagrams, Figs. 120 to 124) is steadily increased from zero upwards, the plate circuit current at first increases rapidly as at C in Fig. 128; but after a time reaches a practically constant value B which is not passed as the voltage is further raised. This value is known as the "saturation current."

The value of the saturation current depends amongst other things upon the temperature of the filament. It increases with increase of filament temperature as indicated in Fig. 129,

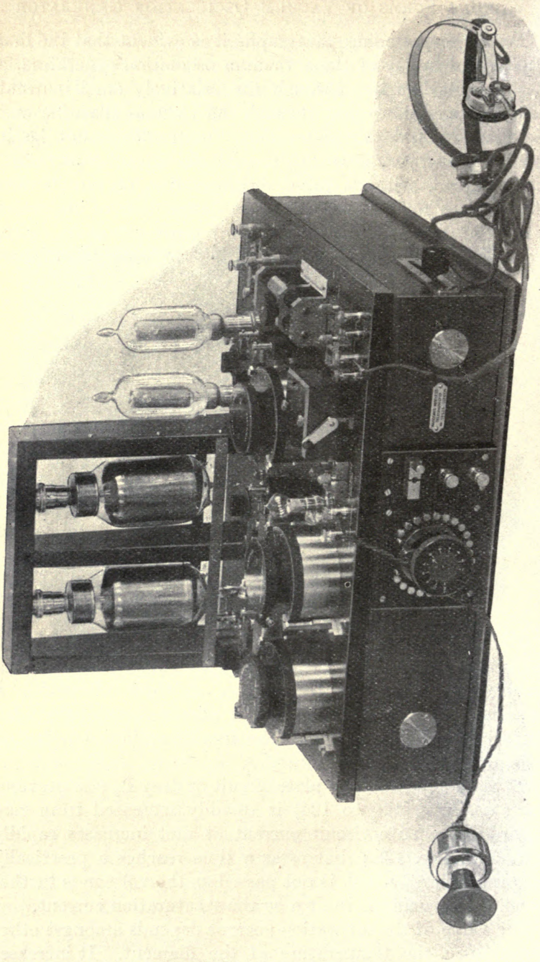

FIG. 127.—Valve Oscillation Generator (Marconi Co.).

which is replotted from curves given by I. Langmuir[1] The method of increasing the maximum current by increase of filament temperature evidently cannot be carried very far without destroying the filament. Metallic filaments are better than carbon ones in this respect, since they may be run at much higher temperatures. Tungsten is customarily employed for filaments for these valves on account of its very high melting-point.

If the applied voltage is further increased, however, it is usually found that a further large increase of current takes place beyond the saturation value. This occurs when great ionisation of the residual gases takes place, and finally an arc is established across the space between the electrodes. The intense ionic bombardment of the electrodes under these conditions may cause their fusion, unless constructed of materials of high melting-point, or cooled by artificial means. This stage is represented by part A of the curve in Fig. 128.

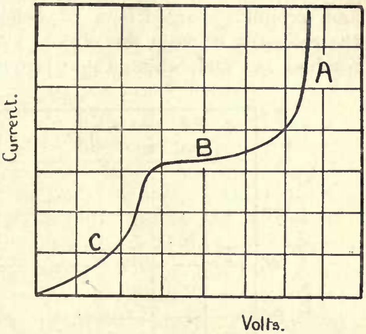

FIG. 128.—Saturation Curve for Electron Discharge in Rarefied Gas.

A device patented by H. J. Round[2] may be mentioned here as a method for increasing the life of the filament, and avoiding such rapid disintegration as occurs with large currents through the bulb. It consists in providing platinum tubes inside the bulb, and arranging for them to be heated not by passing the heating current directly through them, but by means of carbon filaments mounted inside the tubes. This arrangement has not, however, proved to be of any great practical utility. G. S. Meikle has also shown that the nature of the residual gas in the bulb exercises a considerable influence upon the rate of disintegration of the filament and other electrodes. By using extremely pure

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[1] Reference No. 331. See also No. 306.

[2] Reference No. 339.

Argon it is claimed that the disintegration can be practically eliminated.[1]

We may therefore say that the conduction of electricity across the space between the filament and the plate electrode is effected by two agencies—viz. a stream of electrons shot off from the filament and passing directly between it and the plate; and secondly, charged ions (of molecular size) produced by the collisions between the rapidly moving electrons and the residual gas molecules. These latter are set in motion by the electrostatic field between the electrodes.[2] These moving ions having a very much greater mass than the electrons are the chief cause of the heating set up by their bombardment of the electrodes in the bulb. Their presence also sets a limit to the maximum voltage that can be applied to the plate circuit without the formation of an arc inside the bulb.

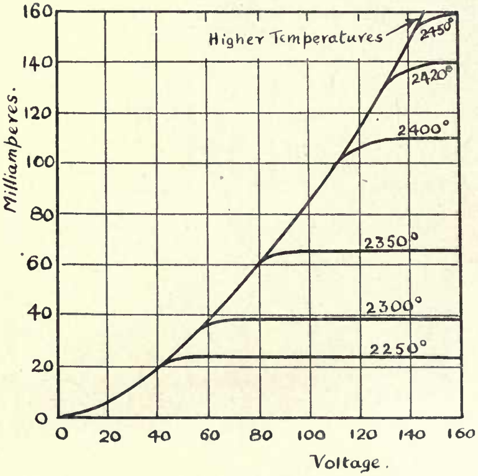

FIG. 129.—Saturation Curves of Electron Discharge at various Cathode Temperatures (I. Langmuir).

The number of these ions can be greatly reduced by reducing the gas pressure inside the bulb. Higher voltages may then be used. This condition is desirable as leading to a greater

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[1] Reference Nos. 343 and 654; also 332 and 638.

[2] See also p. 322.

energy output from these valves. By pushing the exhaustion to the highest possible limits the electrons become practically the only current carriers in the bulb, and very high voltages may be employed.[1] Further, very much larger currents can also be passed through the tubes without reaching the saturation limit or setting up an arc discharge. The presence of minute traces of residual gas appears at first to hinder the thermionic emission of electrons from the hot filament itself, although at the same time providing a larger number of current carriers between the electrodes [2]

Considerable work on very high vacuum valves has been carried out, particularly by the Marconi Company, and by the Government establishments in England; and by I. Langmuir and S. Dushman,[3] and others in America. These forms of amplifiers and oscillation generators are, in America, customarily called "Pliotrons."[4] Extremely high vacua are necessary for this type of apparatus, and very great care must be taken to free the electrodes, glass walls and all component parts of the bulb from all traces of occluded gases. The electrodes and all parts must be heated to a very high temperature in vacuo for this purpose, and the exhaustion carried out with the bulb as hot as possible.[5] Subjection of the electrodes to intense cathode-ray bombardment during the exhaustion has been found to be very advantageous in eliminating occluded gases from the metals. Such treatment is essential if the extreme vacua are to be maintained in these bulbs during operation.[6] It is for this reason that tungsten is now so largely used in the construction of these instruments, since its very high melting-point enables the parts to be raised to a very high temperature during the exhaustion. An important fact has lately been discovered influencing the construction of these oscillation generators. It is that once the electrodes have been carefully freed from occluded gases, they may be exposed to the air without reabsorption of gas. It thus becomes possible to treat the electrodes, and all metal parts, in a

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[1] Reference Nos. 329, 330, 331, 333.

[2] Reference Nos. 332, 334, 366.

[3] Reference Nos. 334, 335, 325.

[4] From the Greek πλεῖον = "more"; see also Reference Nos. 334, 336, 326.

[5] At about 500° to 600° in a vacuum furnace

[6] Special vacuum pumps are also necessary—such, for example, as the Gaede molecular pump, or one of the forms of Langmuir's condensation pump. See Reference Nos. 408 and 409; also 640, 641, 665.

specially constructed vacuum furnace to remove the occluded gases before they are finally mounted in position in the bulbs. They may in this manner be heated to a much higher temperature than is possible when they are enclosed by the glass bulb. During exhaustion the filament is heated by current through it—also the grid wires if both ends are available for this purpose—and a voltage is applied between the filament and plate to subject the latter, and the grid, to electronic (cathode-ray) bombardment. This voltage is gradually raised as the exhaustion proceeds and the gases are driven out, until the full working voltage, or a somewhat higher one, is applied.[1]

A great many different designs of these high-vacuum valves have been utilised at one time or another, and many of them have been patented. A diagram of a Pliotron oscillation generator is given in Fig. 130, and may be taken as a typical construction. The genera features in all cases are a tungsten filament, usually in the form of a single loop, or a zigzag in one plane; a grid of fine tungsten wire on each side of and very close to the plane of the filament; and a "plate" of sheet tungsten on each side of the filament, on the outside of the grid electrodes. The spacing between the filament and grid should be less than that between grid and plate. For general purposes the former may conveniently be about 2 to 3 mms., and the latter about 3 to 5 mms. or more. The fine grid wires [2] should be supported by being wound round a suitable frame, of glass or metal. They may thus be spread out over the entire area covered by the filament, without presenting a very large surface area to the electron stream. The current drawn off by the grid is thus kept as small as possible—a very desirable factor in securing good amplification and generation of oscillations. Very much more regular and consistent results may be obtained from these high-vacuum valves than from audions in which there

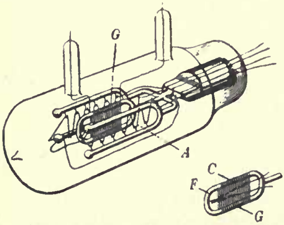

FIG. 130.—Pliotron Oscillation Generator (General Electric Co., U.S.A.).

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[1] Special constructions to facilitate exhaustion are described in Reference No. 568.

[2] About 0·01 mm. diameter.

is appreciable gas ionisation. With the latter variable and unknown amounts of gas or vapour are liable to be liberated from the electrodes during the use of the tube. The amount of this gas that is thus liberated may be reduced by maintaining the whole bulb at as low a temperature as possible, as by means of an oil bath in which a good circulation of cool oil is maintained.

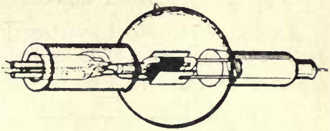

FIG. 131.—Pliotron Oscillation Generator (another form).

With apparatus of this kind difficulties are sometimes encountered through the large electrostatic forces set up between the filament and the anode. Special care has to be taken to adequately support all the parts in order that no damage may be done by these forces when the plate circuit voltage is high.[1] Symmetrical arrangements of anodes and grid electrodes on opposite sides of the filament are also useful in diminishing the tendency of these forces to cause damage to the thin filaments. This feature is illustrated in Figs. 130 and 131.

The characteristic curve of a high voltage valve is given in Fig. 132. It is noticeable that over a range of at least ± 10 volts impressed upon the grid, there is a linear relation between the current in the plate circuit and the voltage between the grid and filament.

This feature is of great importance in connection with the use of these instruments as amplifiers, and therefore also as oscillation generators. It implies that when a variable voltage is impressed upon the grid circuit, the resultant variations of the current in the plate circuit will be a faithful copy of the impressed voltage wave.[2]

It may perhaps also be noted from Fig. 132, what a relatively small grid potential is required to bring about a large modulation of the plate circuit current. This can only occur when the grid electrode is as close as practicable to the filament, as there the potential gradient is small. A very few volts are thus able to control the current flow in the plate circuit which is

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[1] Apparatus of this type has been constructed for working voltages as high as 50,000 volts to 100,000 volts.

[2] A theoretical discussion of the operation of audions and pliotrons is given in Reference Nos. 320 and 321; also 630.

supplied from a source of several hundred or even a thousand or more volts.

High Current Valves

A number of special constructions have been patented at various times with a view to increasing the current-carrying capacity of valves. The oscillatory energy generated by them may thereby be increased without having recourse to very high voltages. The chief features lie in reducing the spacing between the grid and filament and grid and plate as much as possible, and in removing as far as possible the blocking effect of the grid electrode upon the electron stream between filament and plate. The surface areas of the plate and filament should also be as large as possible. In one particularly novel construction a film of oxide formed upon one of the electrodes is relied upon to provide the necessary

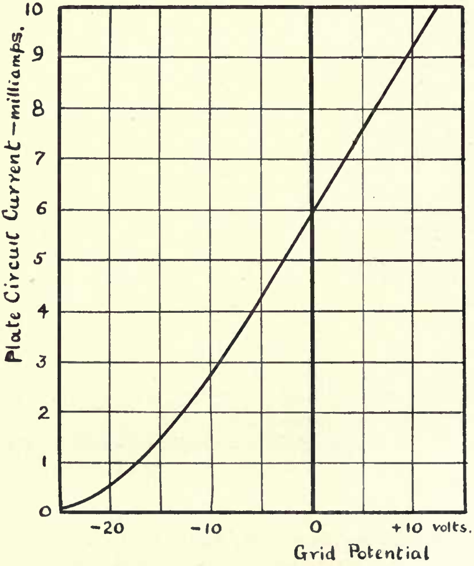

Fig. 132.—Characteristic Curve of a Pliotron (I. Langmuir).

insulation between them, and the filament wires are wound upon a central electrode—forming the " grid "—while the plate is mounted very close to it on the outside. The filament is thus between the " grid " and the plate, so that there is no obstruction between them.[1]

The current-carrying capacity of audions may be increased by augmenting the emission of electrons from the filament. One method of effecting this is to utilise the property possessed by certain metallic oxides—such as lime, CaO—of emitting electrons when they are heated. The lime or other oxide is usually arranged upon a platinum strip that takes the place of the customary filament, and through which a current may be passed to raise the oxide to incandescence.[2, 3] The discovery of these properties was first made by A. Wehnelt, who showed that a very copious stream of electrons was obtainable by their use in an exhausted bulb.[4] The voltage required in the plate circuit is quite small compared with that used in the very high vacuum bulbs just referred to.[5]

The conductivity of the valve may be further augmented by the use of other substances besides metal plates for the anode.[6] In this instance substances that emit positive ions when heated are necessary.[7] One such material is Aluminium Phosphate.[8] This substance, like the lime or oxide cathodes, must be heated by a platinum strip through which a current can be passed. R. S. Willows and S. E. Hill have shown that the conductivity of a valve containing such substances on the anode and cathode is increased some five- or six-fold. The anode should not be heated to so high a temperature as the cathode.[9]

A serious disadvantage of these additions to the simple valve oscillation generators is that in almost every case these substances emit gases more or less rapidly when they are heated, and as a result it is difficult to maintain a constant vacuum in the bulb unless it is maintained constantly in communication with the pump.[10] Such a procedure, although

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[1] Reference Nos. 340, 341.

[2] Several patents have been taken out concerned with the best construction for this type of hot cathode; as examples see Reference Nos. 344, 345.

[3] Reference No. 355.

[4] Reference No. 346.

[5] These electrodes are generally referred to as *Wehnelt Cathodes*.

[6] Reference No. 348.

[7] Reference No. 642.

[6] Reference No. 349.

[9] Reference No. 350.

[10] See also p. 189.

practicable for experimental purposes and investigations in a laboratory, is scarcely suitable for commercial use where one essential requirement should be the minimum possible amount of attention for the apparatus to maintain it in efficient working order. Any emission of gas from the materials upon the electrodes would considerably modify the properties of the valve, while the resulting gaseous ionisation would limit the output of oscillatory energy.[1] The seriousness of this defect may be very considerably lessened by keeping the filament temperature extremely low.

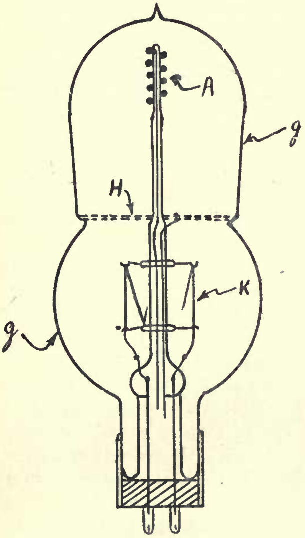

Fig. 133A.—The "Lieben-Reisz" Valve.

The best-known instance of the use of the hot lime cathode is in the Lieben-Reisz Amplifier. In general constructional features it is very similar to the Audion type amplifiers already described.[2] A perforated plate dividing the bulb into two compartments, one for the hot cathode and the other for the "plate" electrode (usually a spiral of wire in this instrument), forms the grid electrode. The bulb contains a small quantity of mercury which is vaporised when the apparatus is in use by the heat from the cathode. The mercury vapour provides a plentiful supply of ions for carrying the current. For this reason this amplifier is often known as a "Gas Relay." Voltages up to about 200 are customarily employed in the plate circuit. A diagram of the bulb is given in Fig. 133A—*g* is the glass envelope, A the anode, H the grid, and K the filament. The anode A is formed of a helix of 2 mm. diameter aluminium wire. The grid H is a sheet of aluminium perfor-

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[1] Reference Nos. 353, 357. See also Nos. 347, 354, 356, 643.

[2] Reference Nos. 358, 359, 360

ated uniformly over its surface with holes $3\frac{1}{2}$ mm. diameter. The filament (cathode) K is a platinum strip about 1 metre long, 1 mm. wide, and 0·02 mm. thick, coated with a thin layer of calcium and barium oxides. It is rendered incandescent by a 30-volt battery. The tube shown in Figs. 133A and B is about 1 foot long, and contains either mercury vapour, or vapour of a mercury amalgam. The average amplification obtained when used as a simple amplifier is about 10 to 12.

The operation of these tubes differs slightly from the high-vacuum valves on account of the presence of gaseous ionisation. These differences have been shown up by various theoretical and experimental investigations.[1]

In connection with the treatment of the valve filaments, or coating them with various substances, as above, with a view to increasing the electronic emission, and therefore the current-carrying capacity of the tube, mention must be made of an important discovery recently published by Langmuir.[2]

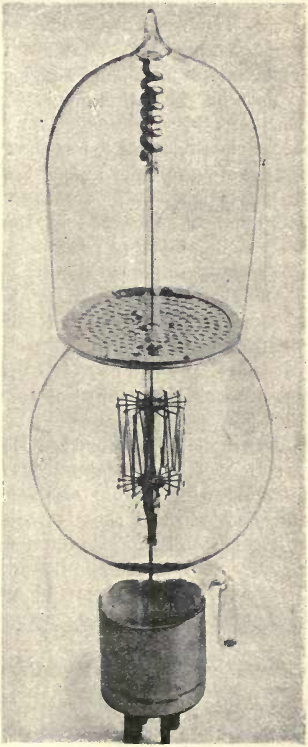

FIG. 133B.—The "Lieben-Reisz" Valve.

He claims that by treating the tungstic oxide used for constructing the tungsten filaments, with certain compounds of thorium—such as thorium nitrate—before reduction to metallic tungsten, a species of alloy or compound is formed when the filament is finally completed. The filament becomes

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[1] Reference No. 645.

[2] Reference No. 664.

one of "thoriated tungsten." Various heat treatments are necessary, and all traces of oxygen must be excluded. With these precautions the electron emission is claimed to be several thousand times that from pure tungsten at the same temperatures. These filaments may consequently be run at low temperatures—1700° to 1800°. As a result their effective life is longer than usual, and a higher current capacity is obtained.

Vacuum oscillation generators possess many advantages over the other methods of generating continuous oscillations for wireless telephony, but they at the same time have many disadvantages—chief amongst which are: the limited power output of each unit, and the high cost of construction and maintenance occasioned by the large number of units that must be employed in practical work.[1]

The most important line of development with these valves should therefore be in the direction of increasing the output from each unit in order to diminish the number of units requiring to be used in parallel. It is probable also that the glass envelopes will have to be replaced by some material of a more robust nature—just as metal containers are now used for high power mercury vapour rectifiers in place of the glass bulbs originally employed.[2] De Forest has outlined the construction of Audion apparatus having steel containers, and provided with cooling arrangements for dealing with large outputs.[3] Special care is required in maintaining vacuum tight joints for the leading-in wires, etc., with such arrangements. Some form of liquid mercury seal is usually necessary. The metal container may be arranged to form the "plate" electrode to simplify the construction.

THE VALVE AS A NEGATIVE RESISTANCE—THE "DYNATRON"

Another method of generating oscillations by means of vacuum valves having three electrodes is to so connect them that they behave as a resistance having a negative or falling characteristic. The utility of such resistances for this purpose has already been mentioned (see p. 164). It has been shown by A. W. Hull that these conditions are fulfilled if the grid electrode of a 3-electrode audion is maintained at a higher potential than the main anode.[4] A valve arranged in this way

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[1] Reference Nos. 337, 338.

[2] Reference Nos. 279, 288.

[3] Reference No. 342; also Nos. 626 and 658.

[4] Reference No. 312.

he has called a "Dynatron." The action depends upon the liberation of secondary electrons from the metal of the anode when under the bombardment of the main electron stream. If a strong electric field is maintained in the neighbourhood of the anode by means of the high potential impressed upon the grid, these electrons will be drawn away from the anode and collected by the grid. The number of electrons entering the anode (and therefore the current flow) is thereby decreased by an increase in the potential gradient near the electrode. Alternating currents of any frequency may be obtained from such a device by connecting in the "plate" circuit an oscillation circuit comprising a condenser and an inductance in parallel.[1] The advantage of this arrangement over the "negative resistance" of an arc is that there is no appreciable hysteresis or lag — since no temperature changes of the electrodes are involved in the action. In order that stable oscillations may be set up, the product of the resistance of the tube and the resistance in the plate circuit must be less than the ratio of inductance to capacity in the oscillation circuit forming the plate circuit, all being measured in the same system of units, such as ohms, henrys, and farads.[2]

CONTROL OF THE VACUUM IN OSCILLATION GENERATORS

With high voltage valves, as has already been mentioned, it is essential that the vacuum shall be maintained at the highest possible value. This can only be achieved when every care has been taken to eliminate all occluded gases from the electrodes and bulb. When this has been done the vacuum will tend to rise rather than fall with prolonged operation. This is in the right direction for good results.

With the Audion type, which may be taken as exemplifying those valves in which the gas pressure is not absolutely negligible, the exact pressure of the residual gas is of some importance to secure the desired results with a given voltage in the plate circuit. The effective regulation of the gas pressure in vacuum tubes (without opening and re-exhausting the tube) has been studied extensively in connection especially with X-ray bulbs, for which constancy of vacuum is of considerable importance. The application of some of the

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[1] Reference No. 634.

[2] Reference No. 368A.

devices there employed to vacuum oscillation generators should be of some advantage.

One of the most commonly adopted methods of controlling the vacuum in X-ray bulbs involves the use of the property possessed by platinum, palladium, and similar metals of absorbing or occluding large quantities of hydrogen. By sealing a piece of platinum wire through the glass of a high vacuum tube, and heating the exterior end of the wire, hydrogen can be caused to diffuse through the metal from a region of high pressure to one of low. Hence if the exterior end of the wire is surrounded by hydrogen, the gas will gradually diffuse through the wire into the inside of the tube. The mere heating

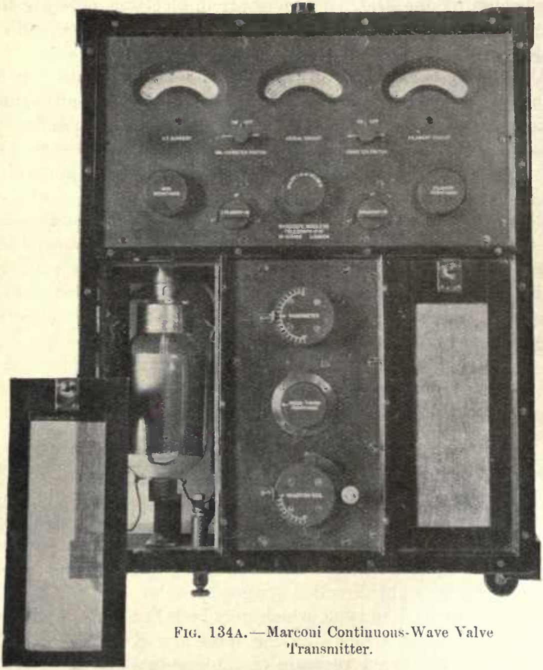

FIG. 134A.—Marconi Continuous-Wave Valve Transmitter.

of the outside end of the wire by a Bunsen burner is usually sufficient to cause this interchange of gas from the flame to the interior of the tube. Conversely, if the vacuum tube contains some hydrogen at low pressure, and the wire is heated (electrically, so as to avoid contact with flame gases) while its exterior surface is exposed to the atmosphere, hydrogen gas will diffuse through the wire from the tube to the air. Such a platinum, or palladium, wire therefore forms a convenient means of either raising or lowering the vacuum in the bulb.[1]

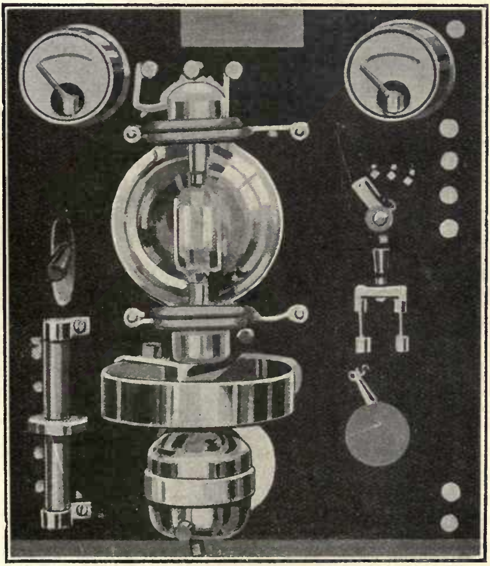

FIG. 134B.—De Forest Oscillion Type Transmitter.
Output=15 watts.

In cases where it might be desired not to employ hydrogen inside the bulb, recourse must be had to some other than the above method. One arrangement available for any gas, but one that is not quite so convenient as the above, consists in including in a side-tube attached to the main bulb a small

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[1] Reference Nos. 362, 659, and 660.

quantity of some material that readily absorbs gases, such, for example, as asbestos, charcoal, mica, etc. By cooling the side-tube containing this substance gas may be absorbed, or by warming it some may be liberated. The vacuum may thus be controlled within certain limits.[1]

In order to maintain continuously the high vacuum required for those valves employing the "pure electron discharge," without the necessity of cooling the side-tube as in the above arrangement, a small quantity of metallic thorium or zirconium may be included in the bulb. These metals combine with all such gases as hydrogen, oxygen, nitrogen, etc., with the formation of compounds of very low vapour pressure.[2] Some heat is required to bring about this combination, but generally this may be obtained from the hot filament.

[1] Reference No. 363.

[2] Reference No. 648.

CHAPTER XIV

ALTERNATORS AND FREQUENCY RAISERS

I. High-Frequency Alternators

Owing to the extreme difficulty of designing and constructing an alternator of any of the usual types for generating an alternating current of any considerable power at the frequencies required for wireless work, attempts have been made from time to time to construct apparatus which shall be capable of raising the frequency of a low-frequency alternator, or other source of alternating current, to such a value as will bring it within the wireless range. Frequency-raising apparatus may therefore be included in the same class as alternators, since the latter machines serve to raise the frequency of the direct current used for excitation (zero frequency) to one of higher frequency ($=n$, say).

The various types of rotary generators for high-frequency alternating currents may be broadly classified as follows :[1]

(1) Machines resembling the ordinary types of synchronous alternator.

(2) Machines arranged so that the rotation of the rotor periodically varies the inductance or capacity in a circuit. (This includes the electrostatic and similar types of alternator.)

(3) Machines in which the harmonics in the flux and E.M.F. wave are utilised.

(4) Machines involving the cascade principle. (This includes machines on the lines of the Goldschmidt reflection alternator, which combine the functions of an A.C. generator and a frequency raiser into one machine.)

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[1] See also Reference Nos. 368 and 372.

SYNCHRONOUS ALTERNATORS

Let us in the first place briefly consider the problem of the direct generation of high-frequency currents by a machine resembling the usual type of ordinary alternator.

In the case of a simple coil of wire revolving in a two-pole field N times per minute, the frequency of the induced currents is, as is well known, given by $n=\frac{N}{60}$ cycles per second. With a multipole field, each alternate pole being North and South, the frequency of the induced currents is

$$n=\frac{N}{60}\times\frac{p}{2}=\frac{Np}{120}, \quad . \quad . \quad . \quad . \quad (1)$$

where p = the number of poles.

If D = the diameter of the rotor in feet and P = its peripheral speed in feet per minute, then $P=\pi DN$ . . . . (2)

If we put τ = the distance in inches between adjacent poles on the stator, then, neglecting the air-gap clearance between stator and rotor, we have

$$\pi D=\frac{\tau p}{12},$$

$$\text{or } p=\frac{12\pi D}{\tau} \quad . \quad . \quad . \quad . \quad (3)$$

Substituting (2) and (3) in (1), we get

$$n=\frac{P}{\pi D}\times\frac{12\pi D}{\tau}\times\frac{1}{120}$$

$$=\frac{P}{10\tau} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

If we fix upon a maximum value of the peripheral speed P that may be employed consistent with mechanical safety, we can at once determine what value of the "pole-pitch," or distance between adjacent poles ($=\tau$) must be used for any given frequency for the currents to be generated. For ordinary alternators the maximum value of P is usually taken at about 10,000 feet per minute. Hence to generate a current of 50,000 ∾ only, the poles must be only $\frac{10,000}{10\times 50,000}=\frac{1}{50}$ inch apart.

This frequency corresponds to a wave-length of $\frac{3\times 10^8}{5\times 10^4}=$ 6000 metres, which is far too long for any but the largest stations. By very special care in construction it has been shown to be possible to increase the peripheral speed of a rotor constructed of steel laminations to about 40,000 feet per minute,[1] but even this increase still means a pole-pitch of $\frac{2}{25}''$, which is still rather unpractical for any but very small outputs.

The most useful application of high-frequency alternators is evidently to design them for the generation of only moderately-high frequency currents—say 10,000 to 15,000 ∿—and to employ them to feed quenched spark-gap transmitters operating at sparking rates above the upper acoustic limit, or to work with one of the many forms of frequency raisers, by means of which their frequency can be increased sufficiently to be suitable for direct transmission purposes

Inductor Alternators

The inductor type of alternator possesses some advantages for high-frequency purposes as compared with the ordinary revolving field type, since the rotor carries no windings. Higher speeds are possible with these machines by using solid steel rotors than with the ordinary laminated type. Many attempts have been made to build inductor alternators that shall give sufficient output at a sufficiently high frequency to be of use for wireless telephone transmission. A certain measure of success has been secured, but the outputs obtained have not been very great.[2]

The credit for much of the pioneer work with these alternators is due to R. A. Fessenden,[3] although the application of inductor type machines to high-frequency work was pointed out some twenty-seven years ago by Cail-Helmer,[4] and again much more recently by G. Guy.[5] E. F. Alexanderson has carried out extensive research work with these machines, and has developed designs yielding a few kilowatts at frequencies of 100,000 to 200,000 ∿.[6]

One of the most important features in the design of high-frequency alternators is to ensure that the main, or exciting, flux shall remain as constant as possible. The losses in the machine are thereby lessened. Special devices have been adopted in most designs with this end in view. For this

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[1] See p. 213.

[2] Reference No. 372.

[3] Reference Nos. 371, 373.

[4] Reference No. 373A.

[5] Reference No. 373B.

[6] Reference No. 374.

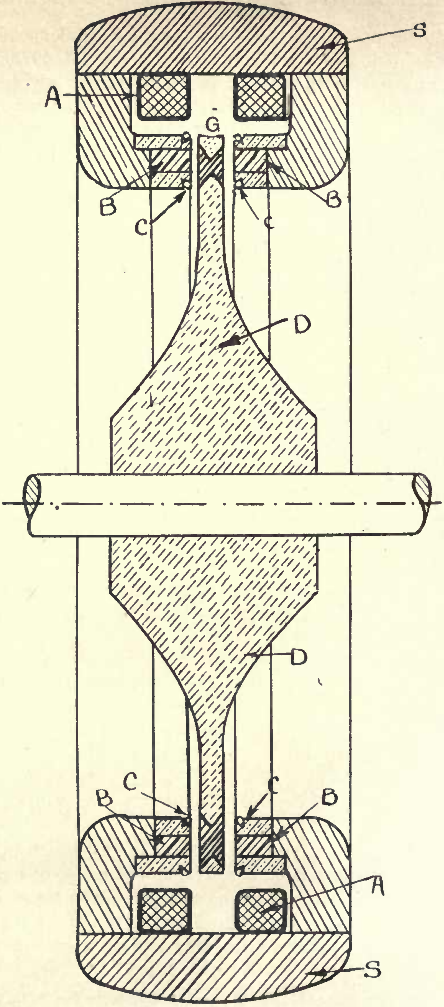

FIG. 135.—Alexanderson H.F. Alternator (Section).

reason greater outputs can be obtained from inductor alternators by constructing them with a double rotor. The teeth on the two rotors should be interspaced, so that with the combined stator energised from a common magnetising winding the total flux through the latter remains sensibly constant.[1] With single rotor machines this condition is approximated to by using different tooth pitches on the stator and rotor.[2] The working conditions are usually a compromise between equal pitches, and a pitch ratio of 1 : 2.

The chief features of Alexanderson's alternator are shown diagrammatically in Fig. 135. The outer steel stator framework, S, is magnetised by the fixed field coils A. These produce a steady flux through the laminated iron "pole-pieces," B, past the windings C, across the air-gaps and through the rotor D. The rotor is a carefully constructed and balanced nickel-steel disc, which is driven at about 20,000 revolutions per minute. The peripheral speed of this disc is about 63,000 feet per minute. Three hundred slots, G, are cut through this disc near its edge, about $\frac{1}{8}''$ apart. They are filled up with non-magnetic metal plugs—such as phosphor-bronze—securely fastened in position, to reduce the air friction on the disc. The laminated iron facing, B, on the stator frame is cut radially with 600 slots on each side of the rotor. These serve to accommodate the "armature" windings C in the form of a simple zig-zag winding (Fig. 136). It is evident that during the rotation of the rotor the tufts of flux emerging from the rotor teeth (D, Fig. 136) will successively cut through the winding in opposite directions, and thereby induce an alternating E.M.F. in it. There will therefore be 300 complete alternations in the induced E.M.F. for each revolution of the rotor. The frequency is therefore

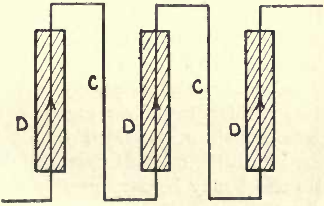

FIG. 136.—"Zig-zag" Winding for Alexanderson H.F. Alternator.

$$= \frac{300 \times 20{,}000}{60} = 100{,}000 \sim \text{ for this machine.}$$

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[1] Reference No. 369. See also Reference No. 370 for effect of polar shape upon the output of H.F. alternators. [2] Reference No. 669A.

In the later forms of these machines a pitch ratio of 1 : $1\frac{1}{2}$ has been adopted.

The air-gap between the stator and the rotor must be kept extremely small in order that magnetic leakage may be reduced as much as possible. The usual air-gap for these machines is about 0·015 inch. Special care must be taken to secure accurate balancing of the rotor for such high speeds. The shaft and bearings must be designed to prevent damage through the small air-gap clearances when running the machine up through the critical vibration speeds. Chain or gear drive from an electric motor is convenient to secure accurate speed regulation. Small units can be direct coupled to a steam turbine of the high-speed de-Laval type. The special shape given to the rotor, as shown in Fig. 135, is with the object of securing the maximum strength of section.

C. S. Franklin has patented the construction of a special form of alternator in which the rotor slots are cut at a small angle to the axis of rotation. High frequencies can be obtained in this manner without excessive speeds.[1]

SPECIAL APPLICATIONS TO INCREASE THE FREQUENCY OR OUTPUT

It is possible to so design the poles and teeth of the stator and rotor of a high-frequency alternator that a pronounced harmonic of higher frequency is generated in the E.M.F. wave of the machine. Currents having the frequency of this harmonic may be filtered out by appropriate tuned circuits. The fundamental frequency may be eliminated by connecting two similar machines together with 180° phase difference between them, provided that the harmonic required is an *even* multiple of the fundamental frequency.[2] Alternatively, its effect may be very greatly reduced by providing a tuned short-circuit path for currents of that frequency, as indicated by C_1, L_1 in Fig. 137. The desired higher-frequency harmonic is filtered out by the circuit C_3, L_3 tuned to its frequency. Circuit C_2, L_2 may be used, if required, for diminishing the effect of any other undesired harmonic that may exist in the original E.M.F. wave of the machine.

J. Bethenod and E. Girardeau have shown that a harmonic having a frequency = n times the fundamental may be fostered

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[1] Reference No. 378.

[2] Reference No. 379.

in inductor type alternators, by designing the machine so that the ratio of width of the teeth on the stator and rotor to the pitch of the teeth on the stator is approximately 1 to 2 n.

This is evidently an extension of the above-mentioned case of a pitch ratio of 1 : 2, since by putting $n=1$ we get the best condition for the fundamental frequency.

Ripples having a frequency of several times the fundamental of the machine may be fostered in ordinary types of alternator by particular arrangements of the relative number of poles and teeth and of the winding pitch on the "armature."[1] An oscillogram illustrating this effect is given in Fig. 138. The high-frequency ripple may be tuned out by an appropriate circuit and utilised in the manner outlined in Fig. 137 if its frequency is sufficiently high. The lower curve in Fig. 138 shows the current obtained in a simple tuned circuit connected across the machine.

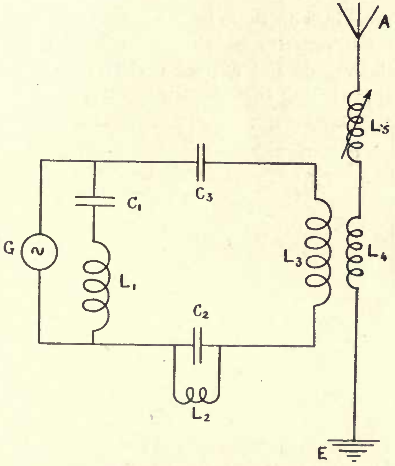

Fig. 137.—Filter Circuits for utilising Harmonic in E.M.F. Wave of Alternator.

L. Bouthillon has described a high-frequency alternator

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[1] This has been investigated especially by S. P. Smith and R. S. H. Boulding. See Reference Nos. 381 and 382.

based somewhat upon this principle.[1] The high-frequency harmonic is augmented by connecting the windings of a multiphase machine in series. If a machine has $2p$ poles, and it is driven at N revolutions per minute, the fundamental frequency will be $=\frac{pN}{60} \backsim$. If there are n separate phase windings which are all connected in series, it should be possible to obtain from the machine currents having a frequency $=np\frac{N}{60}$ cycles per second.[2] It is claimed to be possible to construct machines on these lines for frequencies up to about 100,000 ∾ for outputs of the order of 100 kw. Up to the present they do not appear to have been developed to anything approaching these figures.

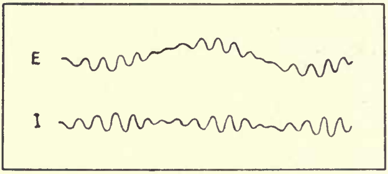

Fig. 138.—E.M.F. Wave of Alternator showing Pronounced Ripple, also Current Curve with Shunt Circuit tuned to Frequency of Ripple (R. S. H. Boulding).

A somewhat analogous method, using static transformers only, has recently been patented by I. Schoenberg (see p. 230).

In order to increase the output of high-frequency alternators it is possible to provide them with two-phase windings and to so arrange the connections that both phases may be employed to excite the transmitting aerial.[3] One possible arrangement for this purpose is shown in Fig. 139. In this diagram 1, 1′ and 2, 2′ represent the two pairs of slip-rings of the two-phase alternator G. One phase, 2, 2′, is connected directly in series with the aerial in the usual manner, with the inductance L_2' for tuning purposes (and also, if necessary, the condenser C_2). The other phase is connected to a closed circuit C_1, L_1, L_3, and is also tuned to the fundamental frequency of the machine. The current flowing in this circuit will be in phase with the E.M.F. generated in phase 1 (the

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[1] Reference Nos. 380, 383.

[2] Compare also p. 227.

[3] Reference Nos. 384, 385.

condition of resonance). Similarly the current in the aerial will be in phase with the E.M.F. of phase 2. The magnetic flux traversing the coil L_1 will be in phase with the current in that coil, and therefore also in phase with the generated E.M.F. in phase 1. Coils L_1 and L_2 are coupled together. The E.M.F. induced in L_2 by the current flowing in L_1 is proportional to $\frac{db_1}{dt}$ where b_1 is the instantaneous flux traversing its windings at time t. This E.M.F. will therefore be 90° out of phase with the flux in L_1, and therefore 90° out of phase with the E.M.F. in phase 1. By coupling the coils in the correct direction this E.M.F. induced in L_2 can therefore be made to help the currents already flowing in the aerial circuit from phase 2, since there is a difference of 90° between the E.M.F.'s in the two phases of a two-phase alternator. By suitably adjusting the coupling between L_1 and L_2, both phases can take their share in supplying the energy to the aerial and the loading of the two phases can be made equal.[1]

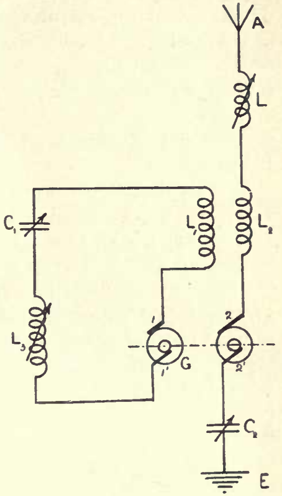

FIG. 139.—Arrangement of Two-Phase H.F. Alternator to excite a Single Aerial (J. Bethenod and E. Girardeau).

ELECTROSTATIC AND OTHER HIGH-FREQUENCY MACHINES

A number of other modes for directly obtaining a high-frequency current may be mentioned here as resembling the alternator machines in that high-speed rotating parts are necessary. Many of them are very limited in their output, but may perhaps be of some interest for experimental purposes.

In the first place, we have a method by which the desired

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[1] A similar method is applicable to the Goldschmidt and other reflection alternators; see p. 215.

currents are produced electrostatically instead of magnetically as in ordinary alternators.[1] The required results may be obtained by periodically varying the capacity included in a circuit in much the same way as the reluctance of the magnetic circuit is varied in the inductor alternators. The variable capacity may, for instance, be formed between two revolving metal discs with teeth cut in their edges. A suitable direct current-supply voltage is connected across the terminals of the machine. A pulsating charging current is consequently drawn from the supply. By a sufficiently high rate of revolution of the discs a high-frequency current may thereby be obtained.

Machines of this type have been put forward by W. Petersen.[1]

If two discs such as may be used in an electrostatic alternator are mounted to run in an electrolyte, we arrive at a machine, such as has been proposed by A. F. Sykes, for generating high-frequency currents by reason of the varying currents drawn from the supply circuit by the periodically varying resistance between the discs.

This method is really an extension of the "commutator-converter" and "mercury-break" oscillation generators that have been proposed by the author and others.[2] In the above instance the speed of interruption, or variation of resistance, has been much increased over these earlier methods, until it has become either equal to, or an exact small submultiple of, the frequency of the oscillatory circuit. A similar extension has also been worked out by the author and independently by W. Dubilier. It consists of a metal disc having a large number of teeth cut in its periphery and driven round at a high speed. The product of number of teeth and revolutions per second should equal or be a small exact submultiple of the desired oscillation frequency. A fine metal wire brush is used for making contact with the edge of the disc. For large currents a number of similar brushes may be employed, all making and breaking contact simultaneously (Fig. 140). The circuit C_1, L_1 is tuned to the desired frequency. The condenser C_1 is charged by the direct current supply, and when contact is made between the disc W and the contact brushes, it discharges through L_1. This discharge is oscillatory. If the disc is running synchronously with the oscilla-

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[1] Reference No. 386; see also 445.

[2] Reference Nos. 387, 388.

tions the discharge current will be passing through the zero value at the instant of interruption. A sharp clean break is thereby obtained without sparking.

Somewhat analogous arrangements have been patented by S. Cabot.[1]

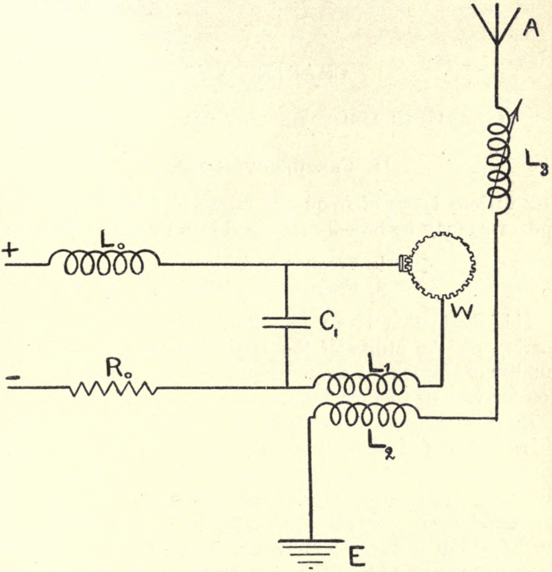

FIG. 140.—Toothed Wheel Oscillation Generator.

Other applications of a toothed wheel to generate oscillations have been described by W. Book.[2] The chief novelty lies in producing the necessary high speed of rotation by means of the effect of a magnetic field upon a movable conductor (such as an arc discharge) instead of by direct mechanical means.

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[1] Reference No. 406.

[2] Reference No. 391.

CHAPTER XV

ALTERNATORS AND FREQUENCY RAISERS (*continued*)

II. Frequency Raisers

The various types of frequency raisers and frequency-raising apparatus may be broadly classified into two main classes :

1. Frequency Adders.
2. Frequency Multipliers.

This distinction is an important one, and has a direct bearing on the utility of the apparatus by determining the number of stages that are necessary and the range of application for various frequencies.

Each of these groups may be subdivided into a number of different types of apparatus. The first includes most of the " machine " frequency raisers—that is to say, those of the alternator type involving moving machinery. To it belongs the well-known Goldschmidt " reflection " alternator. The second group includes mainly the " static " or transformer frequency raisers which utilise the peculiar magnetic properties of iron.

Frequency-Adding Machines

Cohen's Frequency Raiser

An ordinary single-phase alternator has its field-magnet windings excited by means of direct current. By the rotation of the " armature " windings relative to the field magnets an alternating E.M.F. is induced in them. Let us for simplicity assume a 2-pole machine, and that the field-magnet system is fixed and that the armature windings are upon the revolving rotor. Let the rotor be driven round at an angular velocity $p = 2\pi n$. The armature windings will then have induced in them an E.M.F. of frequency $= n$. We have therefore *added* the frequency n to the initial zero frequency (direct) current used to excite the field magnets.

Suppose now that instead of using direct current to excite the field windings of such a machine in a normal manner, we utilise an alternating current of frequency $= n$. The magnetic field of this machine is then no longer fixed in space, but is periodically reversing its direction n times per second.

Now, any simple-harmonic vector quantity may be resolved into two equal vectors of constant magnitude, but rotating with equal speed in opposite directions (see Fig. 141).

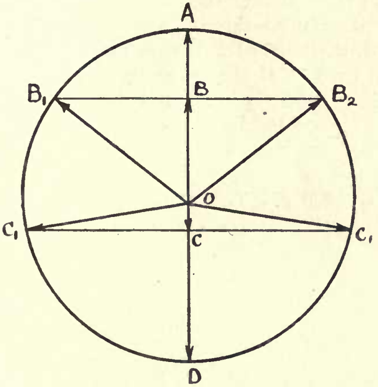

FIG. 141.—Resolution of Simple Harmonic Vector into two Equal Vectors revolving in Opposite Directions.

O A, O B, O C, O D = successive positions of S.H. Vector, having maximum value = O A.
O B may be resolved into O B_1 and O B_2.
O C ,, ,, ,, O C_1 and O C_2, etc.

Hence vector O A may be resolved into two vectors revolving with equal speed in opposite directions. Size of revolving vectors is $\frac{1}{2} \times$ maximum amplitude of simple harmonic vector.

We may therefore so resolve the periodically varying flux set up in the field magnets of the above machine. We therefore arrive at two *revolving* magnetic fields of constant strength, rotating in opposite directions with angular velocity $= 2\pi/T$ where $T =$ the periodic time of the alternating field $= 1/n$. Hence with respect to the rotor windings, which are themselves revolving with an angular velocity $= 2\pi n$, one of these component fields will be stationary, while the other will have a relative angular velocity $= 2\pi n + 2\pi/T = 4\pi n$. This value is double the absolute angular velocity of the rotor in space. The E.M.F. induced in the rotor windings will therefore have a frequency of $4\pi n/2\pi = 2n$. This is therefore double the frequency of the initial current used to excite the machine.

We have in this machine a simple form of frequency adder, since the angular velocity of the rotor is added to the angular velocity of the rotating field.

The case may be put in more general terms as follows: The E.M.F. (instantaneous value) induced in a coil which is revolving in a uniform magnetic field of strength b is proportional to the cosine of the angle between the axes of the field and coil. Calling this angle θ and the angular velocity of the coil ω, the induced E.M.F. is proportional to $b \cos \theta = b \,.\, \cos \omega t$ at time t. If the magnetic field is not of constant strength, but is varying in a simple-harmonic manner (as in the case above considered), we may put $b = B \sin pt$ where $B =$ the maximum value of the flux; $p = 2\pi n$ where $n =$ the frequency.

Hence we have

$$\begin{aligned} E = \text{E.M.F.} &\propto b \cos \omega t. \\ &\propto B \sin pt \,.\, \cos \omega t. \\ &\propto \frac{B}{2} \sin (p + \omega)\, t. \end{aligned}$$

The frequency of the induced E.M.F. is therefore $\frac{p+\omega}{2\pi} = n + \text{N}$ where $\text{N} =$ revolutions per second made by the rotor, $= \frac{\omega}{2\pi}$. The frequency of revolution of the rotor is therefore added to the frequency of the current supplied to the machine.

The case considered is precisely similar to that of an ordinary single-phase induction motor with the stator excited by currents of frequency n and the rotor driven round mechanically at synchronous speed. A current of double the fundamental frequency n will under these conditions be found to be flowing in the rotor windings. Fig. 142 is a reproduction of an oscillogram showing this effect. The curve V_s is the wave form of the voltage applied to the stator windings, and I_R that of the current flowing in the rotor circuit when it is revolving at synchronous speed.

We may in like manner employ the current of frequency $= 2n$ obtained in the above way, to excite the field windings of another and similar machine. The rotor windings of this machine will therefore have induced in them currents of frequencies $2n+n$ and $2n-n$, *i.e.* $3n$ and n respectively. For our purposes we require the use of the higher frequency only. It is therefore advantageous to tune the rotor circuit to a frequency of $3n$, and thus to augment this current at the expense of the other.

Such a process may evidently be continued for any desired number of stages provided that each machine is properly designed for operation at the frequency of the current with which it will be supplied. Both rotors and stators must be very finely laminated for high-frequency work to reduce the eddy current losses as much as possible. Laminations having low hysteresis loss are essential. The overall efficiency of the complete set will fall off as the number of machines is increased. A fairly high initial frequency is thus necessary both for this reason and to reduce the capital cost of the whole. As a general rule, three or four addition stages represent the economic limit of this apparatus (Fig. 143). It is understood, of course, that multipole machines may (and must) be employed, not merely di-pole ones as in the above explanation. This method with a number of machines on a common shaft was first proposed by Cohen,[1] and has also been advocated by Bethenod.[2]

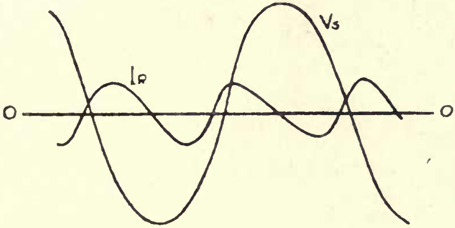

FIG. 142.—Double Frequency Current in Rotor of Induction Motor at Synchronous Speed (Coursey).

Korda's Frequency Raiser

A means of frequency raising in which the initial frequency is increased three times in the same machine has been proposed by Korda.[3] It is really a method by which *two* of the frequency-adding stages of the arrangement just described may

[1] Reference No. 394. [2] Reference No. 439. [3] Reference No. 435.

be combined into one machine. It may therefore justly be classed among the frequency *adders*.

One form of the arrangement is indicated diagrammatically in Fig. 144. A_1 and A_2 represent two similar rotors (shown as Gramme-rings) mounted together upon the same shaft and each furnished with a stator winding, L_1 and L_2. Both stators and rotors must be finely laminated for high-frequency work. The first field (stator) system is supplied with alternating current at frequency $= n$, say, from any ordinary single-phase alternator. If the rotor A_1 is driven round in the proper direction, it becomes the seat of an E.M.F. having a

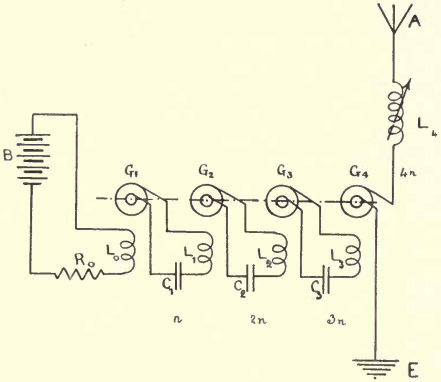

FIG. 143.—Cohen's Cascade Frequency Adder.

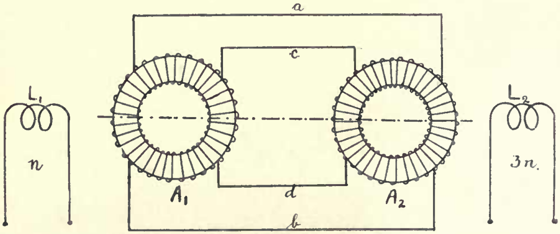

FIG. 144.—Korda's Frequency Raiser.

frequency of $2n$, just as in the case already considered. Double-frequency, two-phase current could therefore be drawn off from the wires a, b, c, d if these were joined to four slip-rings. By connecting these leads to four points on the second rotor A_2, it becomes possible to establish in the latter a rotating magnetic field, revolving with a speed corresponding to the frequency $2n$ in one direction or the other relative to the rotor itself according to the relative order in which a, b and c, d are connected. Since, however, this rotor A_2 is already revolving with a speed corresponding to the initial frequency n, by arranging the revolving magnetic field to rotate in this same direction it will have a speed of rotation in space (or relative to the fixed windings $L_2) = n + 2n = 3n$. Currents of triple frequency are thereby induced in the windings L_2. These may be directly utilised, or else further raised in frequency by another similar, or even by the same, apparatus, by leading these currents of increased (triple) frequency back again to the first stator L_1. The arrangement then closely resembles a modification of the Goldschmidt alternator (see next section).

This machine possesses the important feature of not requiring any slip-rings or other moving contacts either to collect the current or to lead in the initial supply. Tuning condensers may be inserted with advantage in the leads between the two rotors to tune these circuits to the double frequency, $2n$. The triple-frequency circuit connected to the second stator windings should also be tuned for best results.

Goldschmidt's Reflection Alternator

The most successful frequency-adding machine that has so far been employed in commercial work is that known as the Goldschmidt alternator, the invention of Dr. Rudolf Goldschmidt.[1] The mode of operation of this apparatus is in reality very similar to that already described in the case of the series of machines used in Cohen's apparatus, but possesses the valuable distinction that *all* the frequency-raising stages take place in *one* machine. The efficiency of operation is thereby increased.[2]

We have already seen[3] that a simple (harmonic) periodic magnetic field may be looked upon as composed of, or the

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[1] Reference Nos. 395, 397.

[2] Reference No. 396.

[3] P. 204.

resultant of, two equal magnetic fields of constant strength rotating with equal velocity in opposite directions. Let us apply this to the rotor of a single-phase alternator of which the stator is supplied with direct current excitation in the usual manner. This rotor has induced in it an E.M.F. of frequency $=n$ by reason of its rotation in the fixed magnetic field of the stator. This E.M.F. may be allowed to send a current through an appropriate circuit tuned to this frequency n. These alternating currents of fundamental frequency may, by the above theorem, be resolved into two equal magnetic fields rotating in opposite directions with respect to the *rotor itself*. Their speed of rotation relative to the rotor is necessarily the same as that of the rotor relative to the stator. One of these components will therefore be stationary, relative to the stator, and the other revolving forwards (in the same direction as the rotor), with an angular velocity *twice* that of the mechanical rotation of the rotor. This field component will therefore give rise to an alternating E.M.F. in the stator windings having a frequency $=2n$—*i.e.* double the fundamental frequency of the machine.

This is quite a well-known phenomenon with single-phase alternators. It may be demonstrated by taking an oscillogram of the armature voltage and of the field exciting current of the machine. The double-frequency E.M.F. shows its presence by a double-frequency ripple upon the otherwise steady direct current (Fig. 145). The dotted line I_0 shows

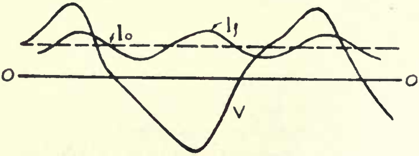

FIG. 145.—Oscillogram showing Double-Frequency Ripple on Field Current (Coursey).

the normal direct exciting current ; V the rotor voltage ; and I_f the actual field current. The greater the load that is put upon the rotor circuit the stronger does the reaction become and the more pronounced the ripple.

These double-frequency currents in the stator circuit of such a machine have, in the above arrangement, necessarily to flow through the battery or exciting generator, unless some special circuit is provided for them. Such a circuit is formed by connecting across the stator terminals one containing capacity and inductance to tune it to the frequency $2n$, and at the same time inserting large choking coils in the battery leads to prevent the double-frequency current from flowing in that path.

The process, however, does not finish here, since the magnetic field set up by this double-frequency current in the stator windings may be resolved into two revolving components in like manner to the rotor current. One of these components rotates in the same direction as the rotor, but at twice its speed (giving a velocity *relative to the rotor windings* equal to the velocity of mechanical rotation of the machine). The other component must therefore be revolving in the opposite direction to the rotor at twice its speed—giving a relative velocity to the rotor windings equal to *three times* the rotor velocity. The former of these therefore gives rise to an E.M.F. of the fundamental frequency (n) in the rotor windings, and the latter one of three times the fundamental frequency—that is of frequency $= 3n$. This E.M.F. may be caused to set up a current of triple frequency in an appropriate tuned circuit.

By a similar reasoning it may easily be seen that this triple-frequency current can be reflected back again to the stator and produce an E.M.F. of frequency $= 4n$ in those windings. This process may be continued for any desired number of stages until the desired frequency is reached. The tuned circuit for the final stage of the highest frequency may be the transmitting aerial circuit, as indicated diagrammatically in Fig. 146. The stator is primarily excited by direct current from the generator G, through the choking coils L_0, L_0. The circuit L_1, C_1, C_1', R is tuned to the fundamental frequency n; the circuit L_2, C_2, S to the frequency $2n$. The condenser C_3 is chosen so that C_3, C_1', R resonates to the frequency $3n$, while the aerial circuit is tuned by the inductance L_4 to the frequency $4n$.

In practice it is found that it is desirable to limit the number of stages to four or five by designing the machine to have a sufficiently high initial frequency n.

When tuning up these machines ammeters are placed in each of the oscillation circuits, while, commencing at the lowest frequency, these are gradually brought into resonance, as shown by maximum reading on the ammeter. It is found that tuning up one of the higher frequency circuits then causes a gradual diminution of the current of next lowest frequency. This demonstrates that the pairs of magnetic fields of the same frequency that are induced in the stator and rotor are in opposition to one another—much as the secondary current of a transformer produces a diminution in the primary flux. When finally tuned up, the machine therefore becomes almost completely a converter from direct current to current of the highest frequency for which a circuit is provided. The intermediate lower frequency currents remain only in sufficient magnitude to supply the losses at those frequencies.

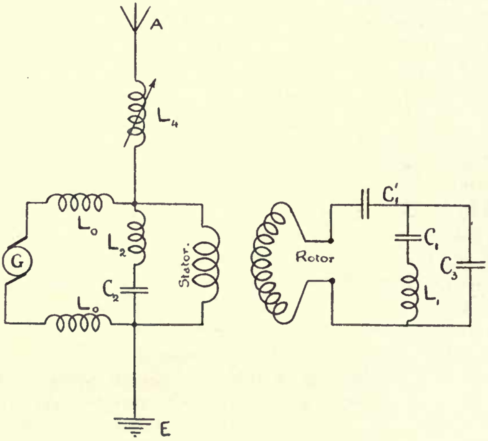

Fig. 146.—The Goldschmidt H. F. Alternator (Frequency Adder).

The eddy-current hysteresis and copper losses in the machine are therefore mainly those due to the currents of the highest frequency. The efficiency of the machine is consequently greater than that it would otherwise be.[1]

It is essential that only the best quality of iron having the lowest possible losses be employed. The iron must further be very finely laminated, and the laminations care-

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[1] Reference Nos. 398, 400, 401, 402.

fully insulated from one another. Very thin paper is usually employed for this purpose. Machines of this type have been constructed up to outputs of about 150 kw.,[1] and have been successfully employed for Transatlantic signalling (telegraph). The principal features of one of these large machines are as follows :[2]

Output = 160 kw.
Fundamental generated frequency = 10,000 ∾.
Speed of rotor = 3000 r.p.m.
Diameter of rotor = 1·25 metres = 4′ $1\frac{1}{4}''$.
Peripheral speed of rotor = 200 metres per second = 39,400 feet per minute.
Number of poles = 400.
Pole pitch = width of 1 tooth + 1 slot = 1 cm.
Material of rotor and stator laminations = steel.
Thickness of laminations = 0·002 inch.
Thickness of paper between each steel lamination = 0·0012 inch.
Length of air-gap between stator and rotor approximately $\frac{1}{32}$ inch.
Energy used for excitation = approximately 8 kw.

The air-gap must be reduced to the smallest practicable limit to reduce the magnetic leakage. With such high peripheral speeds extreme care is required in manufacture to secure exact balancing, especially when such a large percentage of the material in the rotor is of such an "unmechanical" nature as paper.

The manufacture of these machines thus becomes a very costly matter. It was found necessary to devise special automatic machinery for handling the very thin paper and steel laminations, and for attaching them to one another. Owing to the small pole pitch a serious loss of output occurs if all the slots are not perfectly parallel to the axis of rotation. These slots have therefore to be milled out after the complete rotor is assembled, and the burrs so raised carefully removed, in order not to impair the insulation between the laminations. It therefore yet remains to be seen whether machines of this kind can compete commercially with the other methods of generating undamped oscillations. Their use up to the present time has been mainly of an experimental nature. Fig. 147 is a view of a 100 kw. machine.

[1] The station at Brussels which was equipped with this type of transmitter (for telegraphic work) had a machine designed for an output of 250 kw. The entire station and apparatus was destroyed in the early stages of the war. (Reference No. 405.)

[2] Reference Nos. 399, 404, 440.

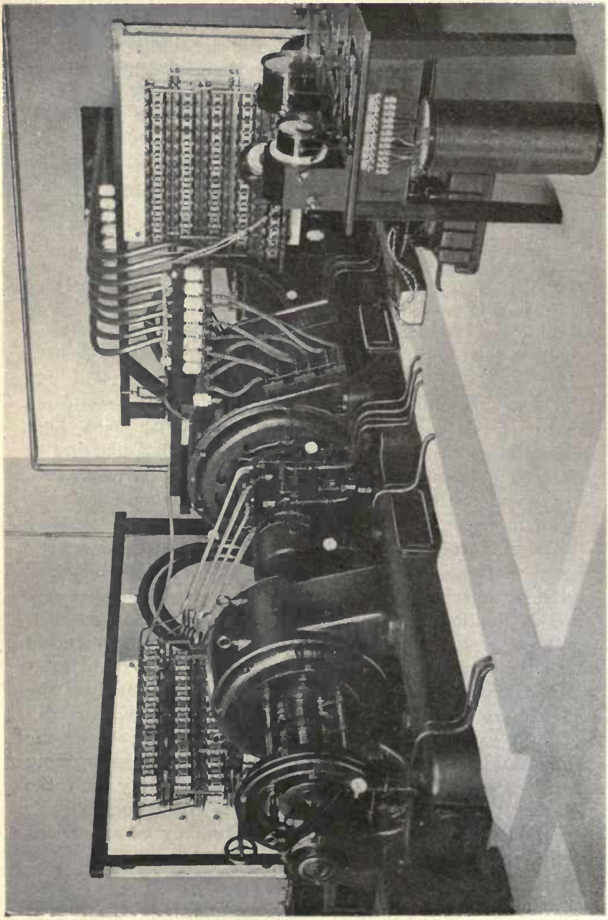

Fig. 147.—100 kw. Goldschmidt Alternator.

An increased output may be obtained from these machines by arranging a two-phase winding upon *either* the stator *or* the rotor (the former for preference in order to avoid additional slip-rings, since the collection of H.F. current from slip-rings is not such a simple matter as with low frequencies).

The resulting two-phase high-frequency current can be utilised to excite a common aerial circuit by employing some such circuit arrangement as has already been described.[1] A similar result may be achieved by connecting one phase in parallel with a condenser and the other in parallel with an inductance, both condenser and inductance being directly in series with the aerial-earth circuit. The condenser and inductance must be so proportioned that the current drawn from one phase is caused to lead by 45°, and the other to lag by 45° relative to the phase voltage.[2]

Petersen's Frequency Raiser

We have just seen that the ordinary type of electromagnetic alternator can, when properly designed, perform the functions of a frequency adder. The electrostatic alternator can also be employed in a very similar manner. P_1 and P_2 (Fig. 148) represent diagrammatically two fixed electrodes of such a machine, and R_1, R_2 two revolving ones. When the plates P_1, P_2 are charged positively and negatively from a suitable direct current source, and R_1, R_2 are driven round at a speed of n revolutions per second, an alternating E.M.F. of frequency n is set up between these revolving plates. Suppose now that instead of a direct current voltage we apply the alternating voltage of frequency n to the plates P_3, P_4. These plates will thereby become charged alternately positively and

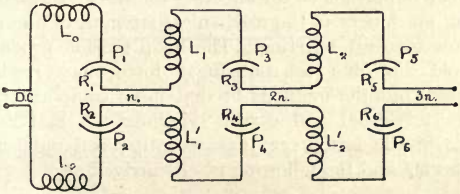

FIG. 148.—Electrostatic Frequency Raiser (W. Petersen).

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[1] P. 201.

[2] Reference No. 384.

negatively and a simple-harmonic (alternating) electric field is established between them. By the help of the theorem discussed on p. 205 above, this field may be resolved into two equal fields rotating in opposite directions. One of these is therefore rotating oppositely to the plates R_3, R_4, so that the relative velocity between the plates and this field component is $2n$ revolutions per second. An alternating E.M.F. of frequency $2n$ is therefore set up between them, and may be utilised to produce a current of this frequency in an appropriate tuned circuit. By a second application of a similar machine the frequency may be raised to $3n$, and so on, just as in Cohen's frequency raiser.

The successive frequency-raising stages may be combined into one machine, as in the case of the Goldschmidt alternator, by the use of a number of tuned circuits connected across both the stationary and the moving plates.[1] The output obtainable is, however, rather limited owing to difficulties in the design of the apparatus for high voltages and for high speeds of rotation.

The Strength of High Speed Rotors

A very important factor affecting the design of high speed rotating machinery is the mechanical strength of the revolving rotor to resist bursting. The hoop tension produced in a simple disc due to centrifugal force may readily be calculated, but the methods become more complicated when the disc is slotted and carries windings. A mathematical analysis of the latter case has recently been published by R. Roberts,[2] and the following results arrived at:

Let D_1 = outside diameter of rotor (inches).
D_2 = inside diameter
N = number of slots.
V = peripheral speed in feet per second.
w = width of tooth at root (inches).
P_1 = stress at root of tooth due to centrifugal force on tooth and windings attached thereto (lbs. per square inch).
P = average radial stress due to P_1.
K and C = constants (see Fig. 149).
d = depth of slot (inches).

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[1] Reference No. 386.

[2] Reference No. 441.

Then $$P = P_1 \frac{wN}{\left(\frac{D_1}{2} - d\right)2\pi} = P_1 \frac{wN}{\pi(D_1 - 2d)} \quad . \quad . \quad . \quad (1)$$

The tensile stress in the material of the disc may be divided into two parts—the first due to the material of the solid disc itself, and the second due to the centrifugal force on the teeth and windings. This hoop tensile stress is not uniform over the entire section of the disc. The maximum values only are considered here since these decide the stability or failure of the material.

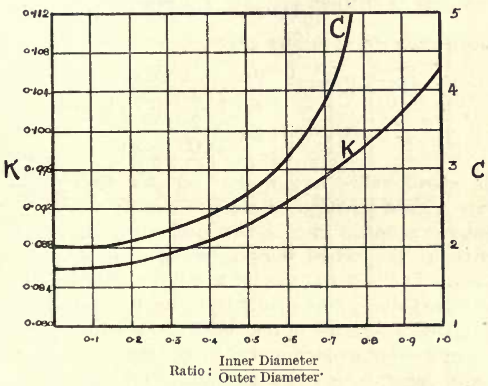

Fig. 149.—Curves for calculating Stresses in Revolving Discs.

The first part, due to the material of the solid part of the disc, is

$$P_y' = K \, . \, V^2 \quad . \quad . \quad . \quad . \quad (2)$$

Values of K are given in Fig. 149.

The second part, due to the teeth, etc., is

$$P_y'' = C \, . \, P \quad . \quad . \quad . \quad . \quad (3)$$

Values of C are given in Fig. 149.

The *total* maximum tensile stress in the material

$$= P_y' + P_y'' \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$= KV^2 + \frac{CP_1 wN}{\pi(D_1 - 2d)} \quad . \quad . \quad . \quad (5)$$

The stress P_1 at the roots of the teeth must be calculated from the known weight of each tooth *plus* its associated windings; the centrifugal force upon a weight of W lb. revolving in a circle of diameter D_1 inches with a peripheral velocity of V feet per second.

$$= \frac{24WV^2}{gD_1} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

$$= 0{\cdot}746\,\frac{WV^2}{D_1}\text{ lb} \quad . \quad . \quad . \quad (7)$$

If t = the axial thickness of the revolving disc, the stress P_1 at the roots of the teeth will therefore be

$$P_1 = 0{\cdot}746\,\frac{WV^2}{D_1tw}\text{ lbs. per square inch} \quad . \quad (8)$$

Substituting (8) in (5), we get:

$$P_y' + P_y'' = KV^2 + \frac{0{\cdot}746}{\pi} \cdot \frac{CwNWV^2}{D_1tw(D_1 - 2d)}$$

$$= KV^2 + 0{\cdot}238C\,\frac{NWV^2}{D_1(D_1 - 2d)t} \quad . \quad . \quad (9)$$

The above values are worked out for steel discs. The ultimate tensile strength of steel is usually taken as about 30 tons per square inch. A factor of safety must be allowed to arrive at the actual working stress that should not be exceeded. The material that is to be employed for the rotors of high speed alternators should be tested to determine its safe working load before use in the construction of the machine.

In many cases the stress due to the mass of the windings may be as large as, or larger than, the stress due to the rotor itself. Solid steel rotors, as used, for example, in the Alexanderson alternator, are thus much safer than wound rotors such as are necessarily employed in the Goldschmidt machine.

STATIC FREQUENCY RAISERS

These frequency raisers are so called because they involve the use of no moving parts such as are necessary for the machines that have already been described.

Fundamentally all the apparatus or instruments in this class are FREQUENCY MULTIPLIERS, since there is no addition of any velocity of rotation to the angular velocity of the given supply current. The best known and most successful types involve an application of the peculiar magnetic properties of iron, and especially of the shape of its magnetisation and hysteresis curve. Fig. 150 is a typical magnetisation curve for a specimen of soft iron, such as may be delineated by any of the well-known magnetometric methods. Consider some point on this curve, such as P near the upper bend or " knee " of the curve. The induction density, B, at this point is given by the ordinate OK, and the magnetisation force by the abscissa OE. Imagine a cyclical change to be made in the applied magnetising force, commencing at the point E and increasing the force to the value OC, and then reducing it again through the value OE to some smaller value OD, such that DE = CE. Then by projection from the magnetisation curve we see that the corresponding values of the flux density in the iron do not go through a similar change of values, but that when the magnetising force is increased by the amount EC the flux density only increases by the amount KG, whereas when the magnetising force decreases to the value OD there is a much larger decrease in the flux density to the point L.

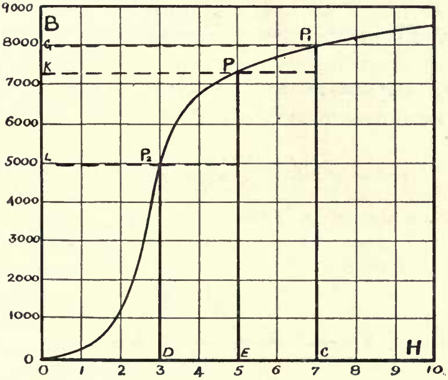

FIG. 150.—Magnetisation Curve for Soft Iron.

Therefore, if a simple harmonic change be created in the magnetising force H, the curve expressing the corresponding changes in the flux density B will not be by any means a sine curve. Such a curve contains higher harmonics, as may be shown by a Fourier analysis of the curve. Hence if we pass a sine wave current through the magnetising coil surrounding the iron specimen, while the iron is subjected to a steady magnetising force to bring the magnetic state of the iron to the point A in Fig. 150, then the potential difference between the terminals of the coil will be far from sinoidal.

When the changes brought about in the magnetic state of the iron do not occur extremely slowly, the hysteresis of the specimen has to be taken into account, instead of merely the magnetisation curve. This introduces a further exaggeration of the irregularities in the wave-form.

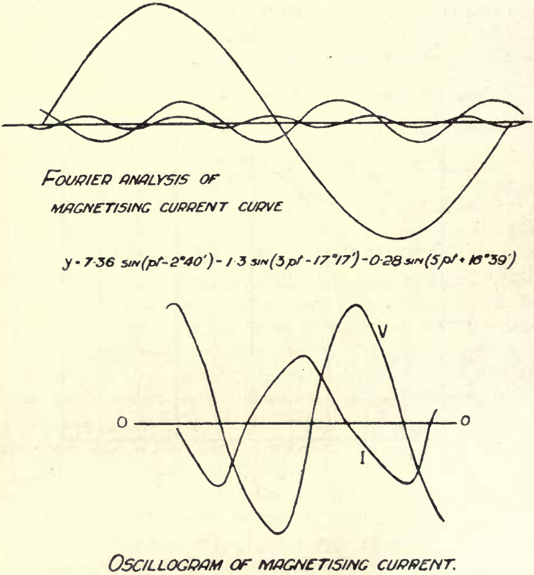

FIG. 151.

Another way in which this phenomenon is brought out is in the non-sinoidal shape of the curve of magnetising current when a sine wave E.M.F. is applied to a transformer or choking coil. A Fourier analysis of such a curve of magnetising current shows several harmonic components, among which the *third* is usually specially prominent. Fig. 151 shows a typical magnetising current curve for a transformer, and the analysis of the same curve into the components of the Fourier series. The amplitudes of the harmonics depend upon the flux density in the iron, and are usually increased at higher densities.[1]

By connecting an oscillation circuit in parallel with the coil, and tuning it to three times the fundamental frequency, the amplitude of this harmonic may be considerably augmented.

The triple-frequency current obtained in this manner could be applied to another frequency-raising stage, and the frequency again tripled—giving a ninefold increase with but two stages.

Such a method as the above is scarcely workable in practice, on account of the extremely limited power output that would be obtainable, since the magnetising current curve becomes more and more sinoidal as the loading is increased. The arrangement serves, however, to indicate the essential principles upon which this type of apparatus depends.

The Frequency Doubler

The principle of the method of frequency doubling by static transformers is the one in which an alternating magnetising force is superimposed upon a steady one. The steady or " direct current " magnetisation is arranged to bring the iron just to the " knee " of the magnetisation curve, after the manner outlined in connection with Fig. 150.[2] The idea of the method originated with Epstein about 1902,[3] and was developed by Joly some years later. As has already been explained, the effect of the steady magnetisation is to render the current wave non-sinoidal, while in addition the positive and negative periods become unequal as a result of the lag due to hysteresis. Prominent double-frequency harmonics are thereby introduced.

In the practical arrangement as indicated diagrammatically in Fig. 152 two transformers are utilised. Both of these operate under the above conditions, but they have their secondary circuits connected in opposition, and by this means the components of the E.M.F. that are of fundamental frequency are cancelled out. The resultant E.M.F. in the secondary circuit is therefore of double frequency.[4] A represents the supply alternator of frequency $=n$. The

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[1] Reference Nos. 410, 411, 413, 414.

[2] Reference No. 415.

[3] Reference No. 419.

[4] Reference Nos. 412, 419.

frequency-raising unit comprises the transformers T_1 and T_2. Each of these is provided with three windings—a primary P, a secondary S, and a direct current magnetising winding M. The two primaries are connected in series as shown. The windings M_1 and M_2 are supplied in series from the battery (or other D.C. source) B, through a choking coil L. The double-frequency circuit comprises the two secondaries S_1 and S_2 (in opposition), and the tuning condenser C_1, together with the necessary means of handing on the double-frequency energy to any desired circuit or apparatus. This double-frequency energy may further be utilised to feed a second frequency-raising unit by means of which the frequency may again be doubled, and so on.

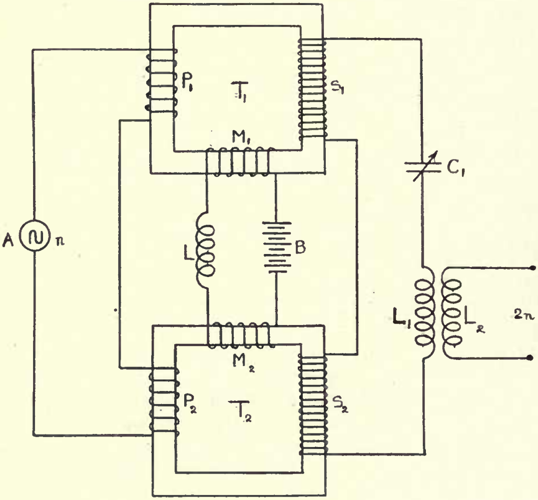

FIG. 152.—The "Polarised" Frequency Doubler.

The mode of operation of a frequency-doubling unit of this kind is indicated in Fig. 153. Curve (1) shows the applied current (sinoidal) passing through the two primaries in series; curves (2) and (3) the resulting flux curves in the two transformers—these differ by 180° in phase by proper arrangement of the direction of magnetisation in the two transformers. B_0' and B_0'' indicate the values of the D.C. magnetisation in the two transformer cores. Curves (4) and (5) are the resulting E.M.F.'s induced in the secondary windings S_1 and S_2; and curve (6) is the difference between curves (4) and (5), and gives the *resultant* E.M.F. in the complete secondary circuit. This is evidently of double frequency. It may be noted that the back E.M.F.'s of the primary windings will be of the same wave-form as for the secondary coils, hence curve (7) is of interest as indicating the resultant E.M.F. applied to the *primary* circuit. Curve (7) is the *sum* of curves (4) and (5), and is approximately a flattened sine curve. This is of importance as showing that the complete unit may be operated from quite a normal alternator giving an approximately sine wave E.M.F.

The successful operation of the device is essentially dependent upon the correct adjustment of the strength of the current in the magnetising windings M_1, M_2, as well as upon the suitable design of the magnetic circuits. This dependence of the output of higher frequency energy upon the direct current magnetising ampere-turns is of special importance in radiotelephony, as it furnishes an additional means of control for the radiated energy other than by a microphone in the aerial circuits.[1]

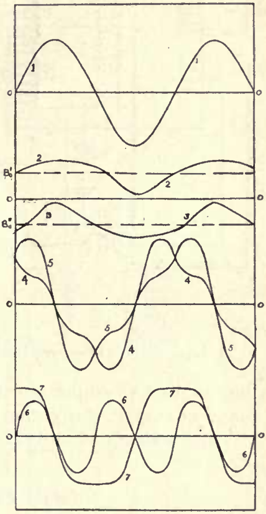

FIG. 153.—Curves for Polarised Frequency Doubler.

Vallauri's Frequency Doubler

G. Vallauri has shown that it is possible to simplify the above method by combining the two transformers into one magnetic circuit, and thus reducing the number of separate

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[1] See also Chapter XVIII. p. 287.

windings from six to five.[1] The arrangement is indicated in Fig. 154. A “ three-leg ” transformer T_1 has two primary and two secondary windings upon each of the outer limbs, and a common magnetising winding M upon the central one. The mode of operation is the same as for Joly's apparatus. An addition in the form of a “neutralising” transformer T_2 is made to swamp out a small double-frequency E.M.F. that is also set up in the direct current circuit. This addition improves the “ regulation ” of the apparatus—that is to say, it helps the double frequency terminal voltage to be maintained when the apparatus is on load.

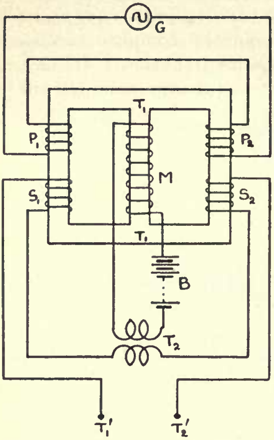

FIG. 154.—Vallauri's Frequency Doubler.

M. Osnos has indicated that to obtain the most efficient results from an arrangement of this type the maximum A.C. ampere-turns of the windings must be approximately equal to *twice* the direct current ampere-turns upon the magnetising winding.[2]

Joly's Frequency Tripler

M. Joly has devised a method by which the frequency may be increased threefold in a single stage.[3] The arrangement does not employ any additional direct current magnetisation, but depends simply upon the deformed magnetising current taken by a transformer, but is an improvement over the simple arrangement indicated in the first section. The scheme is shown diagrammatically in Fig. 155. It involves the use of two transformer cores, one designed to be rather highly saturated (magnetically), while the other is relatively unsaturated. The function of the unsaturated transformer (T_1, Fig. 155) is to pass over an E.M.F. of fundamental fre-

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[1] Reference No. 416. [2] Reference No. 678. Reference No. 418.

quency and approximately sine wave-form to the secondary circuit, and thus by arranging the two secondaries in opposition the fundamental component of the secondary E.M.F. can be largely neutralised.

The secondary circuit should be tuned to the triple frequency, and the energy may be handed on to the "work" circuit by appropriate coupling with the coil L_1 as indicated.

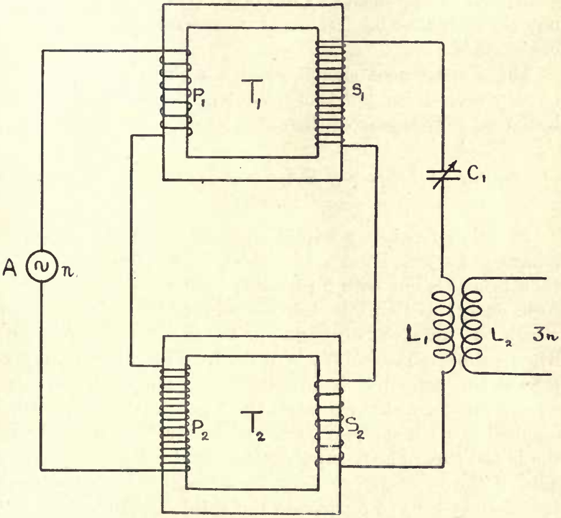

FIG. 155.—Joly's Frequency Tripler.

Joly has also shown that a similar result may be obtained from the frequency-doubling arrangement of Fig. 152 (p. 222) by using the direct current magnetisation upon *one* transformer core only of the pair used in the unit. The core of this transformer is thereby saturated while the other remains unsaturated. The two secondary windings should be connected in opposition as for the double-frequency arrangement, and the condenser in this circuit adjusted to tune up to the triple frequency.

Kujirai's Frequency Tripler

T. Kujirai has patented[1] a method of tripling the frequency of a given alternating supply, which is essentially a combination of the two arrangements proposed by Joly. Three transformers are used, two of which are provided with direct current magnetisation to saturate the iron cores, while the third or unpolarised transformer has its secondary winding connected in opposition to the other two in order to balance out the fundamental frequency component of the secondary circuit E.M.F.'s.

The arrangement should yield a slightly purer triple frequency wave-form, but this advantage is rather set off by the increased capital cost of the extra transformer unit.[2]

Spinelli's Frequency Tripler and Taylor's Frequency Raisers

In Joly's frequency tripler just described the principle is adopted of aggravating a desired harmonic (the " third ") and then tuning it out with a resonant circuit. It is evident that fresh energy can only be introduced into the triple-frequency circuit *once* in each half-period of the fundamental frequency, when a single-phase supply is utilised. In Spinelli's frequency tripler the principle is introduced of supplying the fresh energy impulses at three times the fundamental frequency by employing a three-phase source of power. In each phase of the initial three-phase supply is arranged a frequency-tripling unit of the type due to Joly, comprising a highly saturated transformer core to aggravate the third harmonic. Three of these are connected in " star " on the three-phase supply of fundamental frequency, and their secondaries are joined up in series. The three secondary windings thus form an " open-delta " connection arranged in series with the load, but having one coil reversed as compared with the normal " delta " connections.[3]

A triple-frequency impulse is obtained from each unit in turn, once in the half-period of the fundamental frequency, so that when the three are combined in series, a steady triple-frequency E.M.F. is secured.

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[1] Reference No. 442.

[2] For oscillograms showing the mode of operation of this frequency raiser, see Reference No. 623.

[3] Reference No. 443.

As an alternative construction the three units may be combined into one compound four-core transformer in a similar way to the combination of two-frequency doubling units into the three-core transformer arrangement of Vallauri.[1] The three outer cores carry one winding of the fundamental three-phase supply, and the common central core winding yields the triple-frequency (single-phase) E.M.F.

Taylor has set out a further extension of this idea using an initial source of N phases to multiply the frequency N times,[2] obtaining one impulse per cycle from each phase as in Spinelli's arrangement. Hence if the frequency of the initial polyphase supply is n cycles per second, the frequency of the resultant single-phase current will be $= N \times n$.

These arrangements have found practical application in transforming low-frequency three-phase "power" and "traction" supplies at, say, 15 or 20 ∾ to single-phase current of triple frequency—*i.e.* 45 to 60 ∾—which is more suitable for lighting purposes.

It is thus evident that by the use of a suitable polyphase alternator to furnish the initial supply, a very great multiplication of frequency may very simply be obtained. For example, a 27-phase alternator having a fundamental frequency of 5000 ∾ would yield an E.M.F. having a frequency of 135,000 ∾, which is plenty high enough for a good deal of wireless work.

It should be noted that the method is merely one mode of carrying out in practice the principle established by L. Bouthillon, and made use of in his high-frequency alternator.[3] It has long been demonstrated theoretically that the sum of N E.M.F.'s in N phases is an alternating current whose frequency is N times that of the original polyphase current.[4] The generalisation of the above that was established by Bouthillon may be stated as follows: "If in a conductor there are superimposed N periodic E.M.F.'s of frequency n, identical except that each one is out of phase in regard to the preceding one by an angle $2\pi\frac{x}{N}$ (x being a whole number), the frequency of the resulting E.M.F. is equal to the product of the frequency n of the elementary E.M.F.'s, and $\frac{N}{d}$ where

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[1] See p. 223.

[2] Reference Nos. 420, 421.

[3] See p. 199; also Reference No. 383.

[4] See, for example, Reference No. 444.

d is the greatest common divisor of x and N. The amplitude of the fundamental term of the resulting E.M.F. is equal to the product of N and the amplitude of the harmonic of the order of N/d in the Fourier development of the elementary E.M.F.'s."

The case treated by Spinelli is that in which $x = 1$, and N, the number of phases, is usually $= 3$, though other arrangements with $N = 9, 27$, etc., are quite possible, as shown by Taylor.

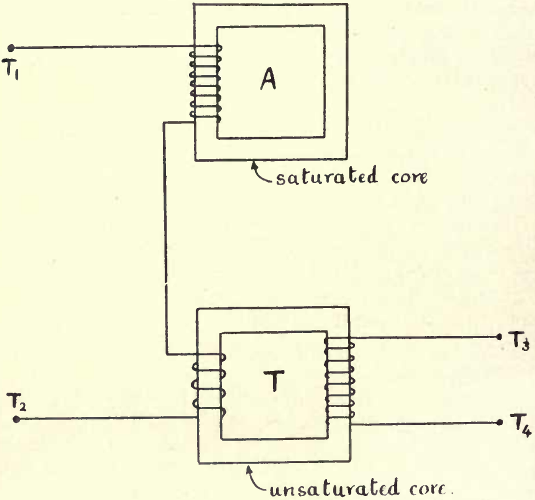

FIG. 156.—Scheme of Taylor's Frequency Raiser.

The alternator supplies the required number of phases at the initial frequency n, and they are combined by the transformer units instead of in the alternator itself as in Bouthillon's machine.[1]

The specially important feature of Taylor's method is the fact that the production of the increased frequency is not dependent upon the existence of no-load or light-load conditions in the secondary to so great an extent as in many other arrangements. For instance, with Joly's frequency tripler

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[1] See also Reference Nos. 436, 437.

the production of the triple-frequency E.M.F. is so largely dependent upon critical relationships between the relative degree of saturation of the two transformers that the secondary E.M.F. tends to fall off very rapidly when the arrangement is loaded up. A large output cannot therefore be obtained. The success (or otherwise) of this and similar methods is therefore very largely dependent upon careful design of all the parts.

Taylor's arrangement may be briefly outlined as follows :

An unsaturated transformer T (Fig. 156) has its primary winding supplied from an alternator or A.C. mains, through a highly saturated choking coil A. Assuming an approximately sine wave E.M.F. to be applied to this arrangement, the saturated state of the core of the choking coil A causes a rush of current to be drawn from the mains at the instant that the magnetic flux in its core attains its maximum value—that is to say, at the instant when the E.M.F. wave is passing through the zero value. The wave-form of a typical case is shown at I in Fig. 157, while E is the wave of applied voltage. These current peaks of course flow through the primary of T as well. The core of T is arranged to be unsaturated at all loads within the capacity of the arrangement. The transformer T therefore exerts very little modifying action upon the wave-form of this current. The flux wave in this transformer is therefore able to adequately follow the general form of the current wave. We may therefore arrive at the approximate wave-form of the secondary E.M.F. by plotting the first-derivative curve of the current curve I. This curve is shown at E_3 in the same diagram, and is evidently, in the case shown, of triple the fundamental frequency, although parts of the usual symmetrical sine wave are missing. By the use of three

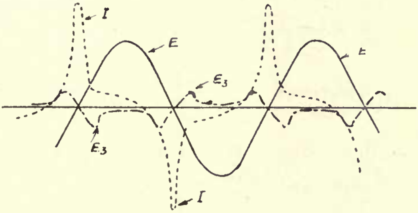

FIG. 157.—Voltage and Current Curves for Taylor's Frequency Raiser.

sets of apparatus fed from a three-phase supply these missing parts can be filled in, and a symmetrical triple-frequency wave obtained. The three secondary windings of the three transformers may be connected either in series or parallel to obtain this result. The parallel connection is preferable, and yields better voltage regulation.

In a slightly modified arrangement a certain saving of material is achieved by combining the three transformers into one which is provided with three primaries and one secondary winding (T, Fig. 158) Three separate saturated-core choking coils L_1, L_2, and L_3 are retained.

The fraction of the fundamental period that is occupied by a half-wave of the secondary E.M.F. evidently depends upon the duration of the current peak drawn from the supply circuit. By proper design of the transformers, accompanied if necessary by a slight modification of the E.M.F. wave of the supply alternator, the duration of this current peak can be considerably shortened over that shown in the diagram. As before, regular waves of the higher frequency are secured by filling up the blank spaces by parts drawn from the other phases.

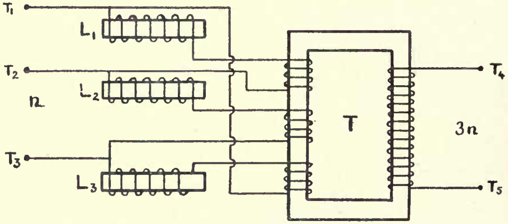

Fig. 158.—Taylor's Frequency Tripler using one Common Transformer.

A ninefold, and even a twenty-seven-fold increase thus becomes possible in a single stage

Schoenberg's Frequency Multiplier

A patent recently granted to I. Schoenberg and the Marconi Company[1] sets out another method of putting into practice Bouthillon's theory on the addition of several E.M.F.'s out of

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[1] Reference No. 438. Compare also Reference Nos. 436, 437.

phase with one another.[1] The method is practically the same as Bouthillon's H.F. alternator, except that no moving parts are employed, and the phase splitting and combining is performed entirely by static transformers. The initial supply may conveniently be three-phase and feeds a transformer, having a number of separate secondary windings as in Fig. 73 (p. 104). These secondary windings (S_1, . . . S_{12} in Fig. 73) are the seat of E.M.F.'s differing in phase from one another. By connecting them all in parallel the harmonic of the initial E.M.F. of the order of N times the fundamental frequency is strengthened N times—where N is the number of secondary windings. The transformer may with advantage be designed so that this harmonic is fostered in the E.M.F. of each secondary winding by appropriately adjusting the degree of magnetic saturation of the transformer core. This may be aided if necessary by the use of additional highly saturated transformers or choking coils.[2]

VALVE, MERCURY-VAPOUR, AND SIMILAR FREQUENCY RAISERS

The utility of this type of apparatus for frequency raising (*i.e.* frequency multiplying) depends upon its being able to function as a rectifier for an alternating current. They all serve to limit the current flow from an alternating supply to one direction only, and to suppress all (or practically all) of one set of half-waves.

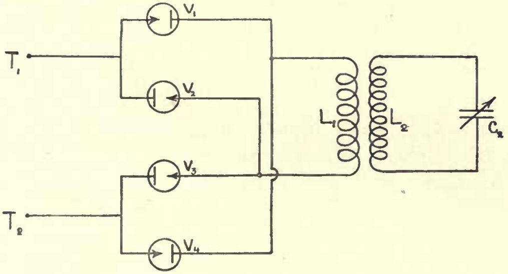

FIG. 159.—Rectifying Valve Frequency Doubler.

Fig. 159 represents an arrangement of four such rectifiers

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[1] See p. 227.

[2] Reference No. 670.

(electrolytic valves or any convenient type) to achieve the desired result. The direction of current flow through each valve is intended to be represented by the arrow-shaped electrode. Hence, when T_1 is positive, current will flow from T_1 through V_1, L_1, and V_3 back to T_2. When T_2 is positive, current will flow through V_4, L_1, and V_2 back to T_1. Both half-waves of the alternating E.M.F. therefore send current in the same direction through the transformer primary winding, as indicated roughly in Fig. 160. Curve (2) represents the current flow through L_1, and curve (3) the resulting E.M.F. in the secondary winding L_2. This E.M.F. is evidently of double frequency as compared with the applied voltage shown in curve (1). The secondary circuit should be tuned to the double frequency.

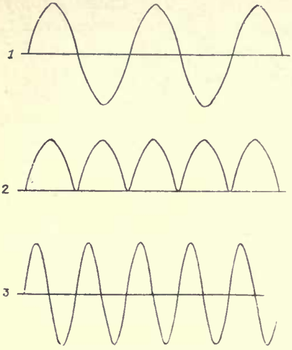

FIG. 160.—Current and Voltage Curves for rectifying Valve Frequency Doubler.

Any convenient form of rectifier may be utilised for the above arrangement, provided that it is suitable for the frequencies to be employed and for the currents to be passed through it. Aluminium plate and similar electrolytic valves,[1] and mercury-vapour arcs, have been utilised in these arrangements.[2]

A somewhat better connection is indicated in Fig. 161. Two valves only are employed. Two transformers L_1, L_3 and L_2, L_4 are used, and connected so that all the positive half-waves flow through one primary, and all the negative half-waves through the other. The mode of operation is very similar to that already indicated in Fig. 160.

A method involving the use of a special form of mercury-arc rectifier having a single mercury cathode and two in-

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[1] For example, aluminium electrodes in sodium-molybdate solution, or aluminium and lead electrodes in ammonium-phosphate solution (strength = about 5 per cent).

[2] Reference Nos. 423, 425.

dependent anodes has been devised by O. O. Kruh.[1] The rectifier is connected through choking inductances to a special transformer so that double-frequency impulses are obtained.

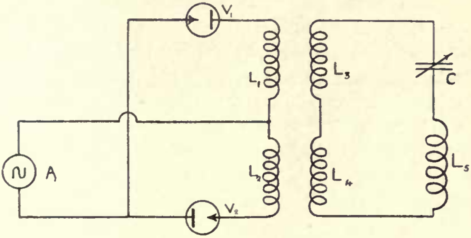

FIG. 161.—Rectifying Valve Frequency Doubler (Zenneck).

Another manner in which rectifiers may be employed for doubling the frequency of a given supply has been described and patented by C. S. Franklin.[2] A single valve or rectifier is arranged as shown in Fig. 162. It is connected in series with a battery (or D.C. generator) B, and the primary winding L_1, of the transformer T, to the terminals of the alternator G supplying the energy to the circuit. The secondary circuit, L_2, C_2, L_3, of the transformer T is tuned to double the frequency yielded by G.

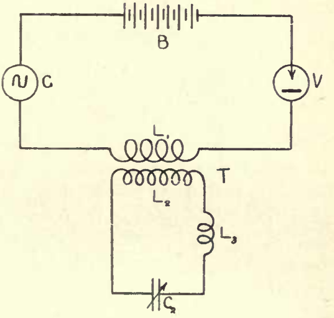

FIG. 162.—Arrangement of Rectifying Valve with Polarising Voltage as Frequency Raiser (C. S. Franklin).

By adjusting the voltage of B, relative to the voltage of the alternator G, the period during which current passes through the rectifier may be controlled at will, from zero upwards. If the voltage of B is chosen about equal to half the maximum voltage of the alternator wave, this period of passage of the current becomes practically equal to the semi-periodic time of a wave of double the fundamental frequency, as shown in Fig. 163.

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[1] Reference Nos. 426, 427; see also 428 and 280.

[2] Reference No. 422.

The energy-consuming circuit (coupled to L_3) may, if a further increase of frequency is desired, include another and similar rectifying and frequency-doubling arrangement. It is possible, however, to arrange that several frequency-doubling stages take place in the *same* rectifier, and using the same polarising voltage B for each stage. This is effected by leading the doubled-frequency current back to the rectifier again—just as was done in some of the earlier forms of Goldschmidt and similar alternators. Fig. 164 shows a connection scheme for this purpose. The common rectifier and polarising

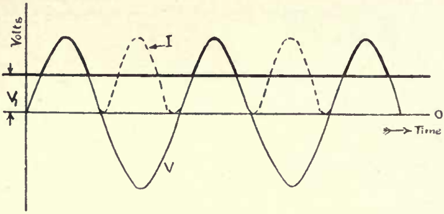

FIG. 163.—Current and Voltage Waves for Polarised Valve Frequency Doubler (C. S. Franklin).

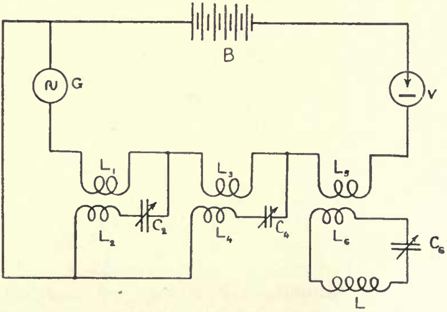

FIG. 164.—Multi-stage Polarised Valve Frequency Raiser (C. S. Franklin).

voltage are shown at V and B respectively, and the initial source of fundamental frequency (n) at G. By adjusting the relative voltages of G and B, a double-frequency ($=2n$) E.M.F. is produced in the secondary L_2. This secondary circuit includes L_2, C_2, L_3, L_5, V, B, and is tuned to the frequency $2n$. The alternator G forms a shunt to this circuit, but since it is not tuned to the double frequency, the current flow through it will not be large. The number of turns on L_2, and its coupling with L_1, should be adjusted until the correct value is obtained for combining with the voltage of B to yield a second doubling of the frequency. The circuit L_4, C_4, L_5, V, B is tuned to this frequency $4n$, and likewise the circuit L_6, C_6, L_7 to the frequency $8n$.

The dimensions and properties of the rectifier must be so chosen that currents of the highest frequency can be successfully worked with. The mercury-arc rectifier is specially suitable.

Arc Frequency Raisers

In Chapter XI. (p. 128), dealing with arc apparatus, a brief mention has already been made of an interesting form of frequency raiser. The most satisfactory arrangements have been studied in particular by H. Rukop and J. Zenneck.[1] Fig. 165 shows the connection scheme. An arc Ar is supplied through choking inductances L_0 from an alternator A, giving an E.M.F. of frequency $= n$. The oscillation circuit C_1, L_1 is connected across the arc, and is tuned to an *exact multiple* of the frequency n. Best results are obtained when C_1, L_1 is tuned to the frequency $3n$.

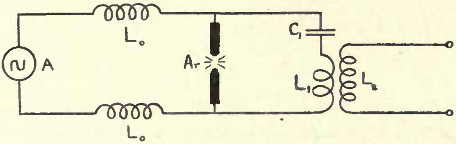

FIG. 165.—Arc Frequency Raiser (H. Rukop and J. Zenneck).

The employment of a hydrocarbon or hydrogenous atmosphere round the arc (as is usual for most oscillatory arcs) is advantageous.[2] Alternatively it has been suggested that the arc might be established in a closed vessel containing air in the first place, but from which the oxygen would rapidly become exhausted when the arc is in operation.

The especial effectiveness of this arrangement for a 3-fold increase in frequency is well brought out by the specially

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[1] Reference Nos. 433, 434.

[2] Reference No. 432.

prominent harmonic of that frequency, which occurs in the voltage wave of any alternating current arc[1] (Figs. 166 and 167).

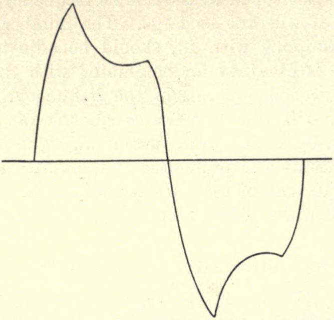
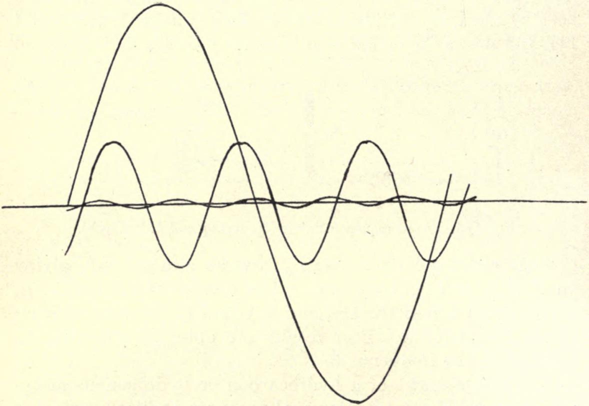


FIG. 166.—Voltage Wave of Alternating Current Arc.



$$y = 18{\cdot}82 \sin(pt + 5^\circ) + 5{\cdot}83 \sin(3\,pt - 26\tfrac{1}{2}^\circ) + 0{\cdot}428 \sin(5\,pt - 48^\circ).$$

FIG. 167.—Fourier Analysis of Voltage Wave of A.C. Arc in Fig. 166.
Amplitude of third harmonic is nearly one-third of the fundamental term.

Vacuum Valve Frequency Raisers

Vacuum valves may be employed as frequency raisers in a number of ways. They may be utilised as rectifiers, and

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[1] Reference No. 431.

arranged according to Figs. 159, 161, 162, or 164. The absence of lag in rectification renders them specially suitable for service in this connection, especially for high-frequency currents.

The influence of a magnetic field upon the electron flow, in a simple (2-electrode) vacuum oscillation valve,[1] may also be employed. By arranging a magnetic field—supplied with the initial current of frequency n—coaxial with the normal direction of the electron stream in the valve, that stream becomes deflected away from its normal course, for both positive and negative half-waves of the current through the magnetising coil. The pulses of current that flow in the plate circuit of the valve therefore occur twice in each period. A circuit coupled with the plate circuit (and tuned to double the initial frequency) will, therefore, become the seat of a double-frequency E.M.F.

The valve used in this manner is therefore also a frequency doubler, and is available for currents of any frequency.

The Use of Frequency Raisers

The chief functions of frequency raisers are, as already mentioned, for use in conjunction with moderate frequency alternators, so as to step up the frequency for direct wireless work. Many different arrangements have been outlined in detail by different workers.[2] The frequency raisers of greatest utility are those which yield the greatest frequency multiplication with good efficiency and regulation. The last feature is of special importance, since with some of the arrangements the voltage of the higher frequency current suffers great diminution when attempts are made to draw much energy from the apparatus. The various forms of static frequency raiser are in general the most useful—especially the ones employing auxiliary direct current magnetisation for the transformer cores. Control of the direct current magnetisation enables an effective control of the output of higher frequency energy to be obtained.

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[1] See p. 167.

[2] Reference Nos. 417, 429.

CHAPTER XVI

MODULATION OF THE TRANSMITTED ENERGY

So far we have been merely considering the various methods by which we may produce the high-frequency oscillatory energy that is necessary for the transmission of speech by aether waves. We have therefore yet to consider that most important section of the subject, comprising the ways and means by which this high-frequency energy may be modulated in accordance with the speech waves, as well as the various methods available for receiving the speech at the other station. We will therefore devote our attention in the first place to the methods of modulating the high-frequency energy. This is a matter that still presents one of the greatest difficulties in the development of the commercial wireless transmission of speech. Many attempts have been made towards its solution from time to time, but although many of these have proved to be fairly successful, the problem has become increasingly difficult of solution with the development of the modern high-power oscillation generators which are necessary (at least as far as we know at present) for communication over great distances. The problem has, however, at the same time been simplified to a certain extent by the development of these modern high-power oscillation generators, for not only are some of them much more susceptible to microphonic control of their output by the voice, but their very development has at the same time enabled fresh discoveries to be made, and opened up other methods of solving the problem. Some of these would appear to show considerable prospects of success. At the same time it is evident that the development of commercial wireless telephony is dependent upon the provision and use of a suitable microphone transmitter that will not require any skilled attention, or as little as possible.

A further desideratum is that the microphone must be capable of being controlled by an ordinary commercial land line telephone instrument if the use of radiotelephony for long distance and trans-ocean communications is to progress to the extent it should. It should be possible for a person using a simple and robust type of microphone transmitter to have his circuit relayed directly on to the high-power wireless telephone transmitting station, without the necessity of his having to attend in person at the station itself. Still more preferable is it that this microphone transmitter should be in the form of the ordinary subscribers' telephone instrument, so that any telephone subscriber connected to a public telephone system could ring up the exchange and ask for " radio " just as he now asks for " trunks," and thus be connected to an appropriate high-power transmitting station in communication with the country or district to which he desires to speak.

The high-frequency energy radiated from a wireless telephone transmitting station may be modulated in accordance with the speaker's voice in a variety of different ways. There may either be direct modulation of the whole of the actual energy output from the station, or the modulation may be effected by indirect means.[1]

1. SERIES CONNECTION

The simplest example of the direct modulation of the radiated energy is afforded when a microphone of the variable resistance type is connected directly in the aerial circuit of the transmitter. Fig. 168 shows the arrangement, M being the microphone, and L_3 the usual aerial tuning inductance. L_1, C_1 is shown merely to represent the primary circuit including the source of oscillations, coupled on to the aerial circuit by the coils L_1, L_2, and may stand for any of the forms of high-frequency oscillation generator that have already been described in these pages.

The variation of the resistance of the microphone causes a varying proportion of the aerial energy to be absorbed as heat. Thus the actual radiated energy, being the difference between the energy supplied from the generator and that absorbed by the microphones, is caused to vary in like manner.[2]

With this arrangement the microphone or microphones

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[1] Reference No. 446.

[2] Reference No. 449.

M employed must evidently be suitably designed for carrying without overheating the maximum aerial current that may be employed, and must at the same time possess a sufficient range of resistance variation (when spoken to) to give rise to a reasonably large modulation of the aerial current and radiated energy. This means that the microphones must be capable of dissipating (as heat) a considerable fraction of the total energy output of the station. This method, although very effective, may therefore be very wasteful of energy, especially in high-power stations, although as yet no simple variable resistance microphone has been constructed that is capable of such work with large powers, and the method is limited to at most a very few kilowatts. The value of the resistance of the microphone M, for most satisfactory results, is evidently to a certain extent a compromise between conflicting conditions—viz. firstly, if the microphone is to effect large variations in the radiated energy its resistance variations, and therefore its average resistance, must be large; and secondly, to diminish the wastage of power and the heating of the microphone, its resistance should be low. The first condition will lead to an efficient modulation of the energy, but the overall efficiency of the station will be low and the radiation small—a condition unsuitable for long distance, and commercial working under all conditions.

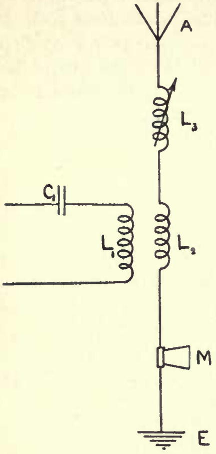

FIG. 168.—Series Connection of Microphone in Aerial Circuit.

The mathematical theory as to the best value of the average microphone resistance in practical cases, in which the radiation must be as large as practicable, and the radiation changes also large, has been worked out by Eccles,[1] who has reached the conclusion that the *average* microphone resistance *m* should be chosen equal to the *mean* of the radiation, and ohmic resistances of the aerial, the latter being measured *before* the insertion of the microphone. That is to say, if R_a

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[1] Eccles, *Handbook of Wireless*. Reference No. 453; see also No. 449.

is the radiation resistance of the aerial (ohms), and R_w the actual ohmic resistance of the wires, coils, earth connection, etc., in the aerial circuit, then the average microphone resistance m should be

$$m = \frac{1}{2}(R_a + R_w)$$

for the greatest absolute change in radiation to be secured.

2. Shunt Connection

Another simple mode of connection of a variable resistance microphone is afforded by arranging it in shunt to all or a portion of the inductance in the aerial or the primary oscillation circuit, as indicated in Fig. 169. As before (Fig. 168), C_1, L_1 may represent the primary oscillation circuit of any of the forms of high-frequency oscillation generator that have been already described, coupled on to the aerial circuit by the coil L_2. L_3 represents the usual aerial tuning inductance. The microphone M, connected in series with a resistance R, is arranged in parallel with a variable number of turns of the jigger secondary L_2. The number of turns so shunted may be controlled by the sliding or switch contact shown, until the maximum effects are secured. In any case the number of these turns, and the value of the resistance R, in series with the microphones, must be adjusted until the current A_1, through the microphones, does not exceed the maximum safe current to prevent overheating of the instruments. It is important to note that the turns of L_2 so shunted should be on the *earthed* side of the coil, so as to avoid the production of high potentials on the microphones, and so to limit the

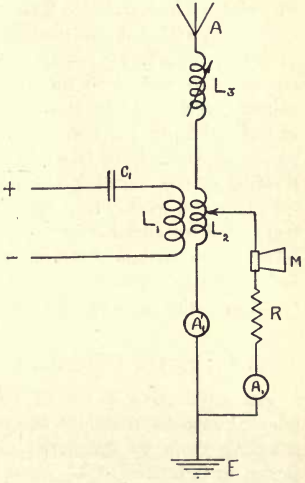

Fig. 169.—Shunt Connection of Microphone in Aerial Circuit.

capacity currents that will flow through them to earth, and to the operator speaking into them. These capacity currents will not be much affected by the variations of the microphone resistance. This arrangement of circuit with shunt microphones is of advantage as compared with the direct series arrangement, shown in Fig. 168, since the microphones are not called upon to carry the whole of the transmitting aerial current, but merely a small portion of it. The modulation of the whole radiated energy is not so direct as in the series case, but it is nevertheless effective, provided that the microphones have a sufficiently high resistance, and a correspondingly large resistance variation under speech action. When several microphones are used, they should all be connected in series. The resistance R should be kept as small as possible, consistent with not overloading the microphones. The action of the microphones is partly to shunt off energy from the aerial circuit, and partly to modify the tuning of the aerial, by causing variations in the effective inductance of the turns of the coil L_2 that are shunted.

As an example of the relative magnitudes of the currents flowing in the aerial circuit, and through the microphones for successful working, V. Colin and M. Jeance in some of their tests used an aerial current of 3·2 amperes and an average microphone current of 0·5 ampere. The normal aerial current before the microphones were connected up was 4·6 amperes. Good articulation was obtained.[1]

3. INDUCTIVE COUPLING ON TO THE AERIAL CIRCUIT

An alternative mode of causing the variable resistance microphones to modulate the aerial energy is by inductively coupling them to the aerial circuit by a suitably arranged jigger, as indicated at L_3, L_4 in Fig. 170. A regulating resistance R is shown as connected in series with the microphones M. This may or may not be required in any particular instance, and should be dispensed with if possible, while not exceeding the safe current through the microphones. It may also sometimes be found advisable to provide an earth connection, *e*, to one terminal of the microphones to reduce capacity currents to the speaker.

One advantage of this method of control is found in the

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[1] Reference No. 264.

facility with which the effect of the microphones upon the aerial circuit may be controlled at will, by varying the coupling, L_3, L_4, until the best results are obtained. The current through the microphones can be varied in the same manner, and also by changing the number of turns on the coil L_4.

The variable reaction of the coil L_4 upon L_3, caused by the variations of the microphone resistance when spoken to, serves to modify the tuning of the aerial circuit relative to that of the oscillation generator, and also to absorb a variable amount of power from the aerial The coupling L_3, L_4 should not be too tight.[1]

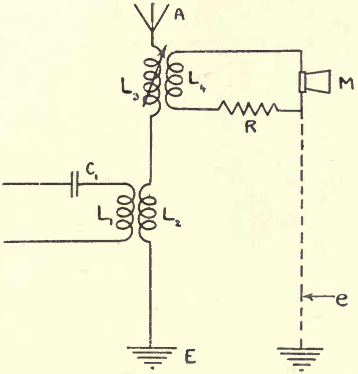

FIG. 170.—Variable Resistance Microphone inductively coupled to Aerial Circuit.

4. INTERMEDIATE CIRCUIT CONTROL

When an intermediate circuit is employed between the source of energy and the aerial circuit, it is possible to arrange the microphones in this circuit to control the rate at which energy is handed over from the oscillation generator to the aerial. The microphone M is connected directly in series with the intermediate circuit L_2, L_3, C_2, in Fig. 171. By suitably proportioning the turns on the coils L_2 and L_3 the current in this intermediate circuit may be adjusted to be the most suitable for the microphone, so as to avoid overheating. The inductance of L_2 should not be made too large

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[1] Reference No. 448.

compared with the resistance of the microphones, or they will be unable to effectively modulate the current in this circuit.

One terminal of the microphones should preferably be earthed for the reasons already mentioned. The condenser C_2 may be omitted, converting the circuit to an untuned one.

Other control arrangements of the intermediate circuit (tuned or untuned) are possible, and although in some cases one particular arrangement may prove the most satisfactory, yet if properly arranged there is usually very little to choose between the results obtainable. Two other examples are given in Figs. 172 and 173.

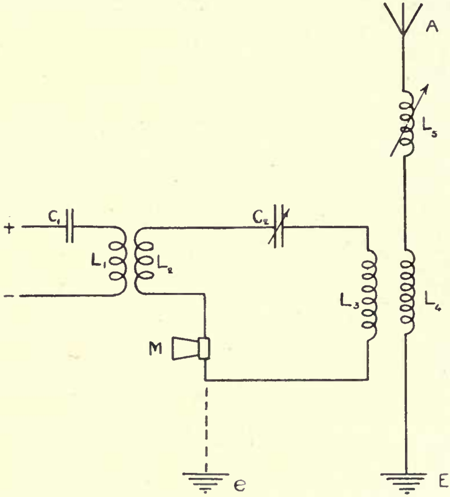

FIG. 171.—Variable Resistance Microphone in Intermediate Circuit.

5. DIRECT CONTROL OF GENERATOR OUTPUT

In many cases it is found practicable to directly control the high-frequency output of the oscillation generator by some suitable form of variable resistance microphone. As examples, may be mentioned the control of the output of an arc generator by microphonic control of the direct current

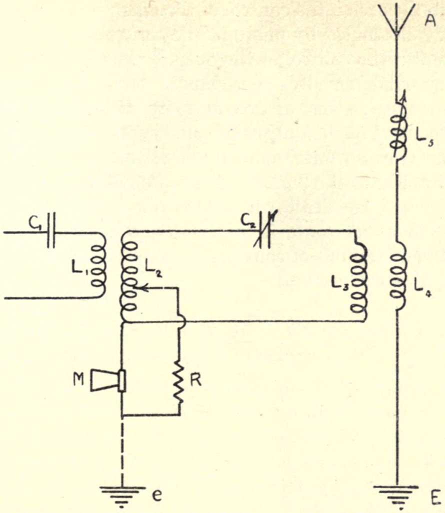

FIG. 172.—Variable Resistance Microphone in Shunt to Inductance of Intermediate Circuit.

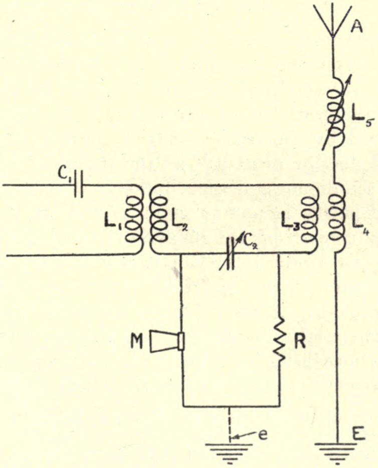

FIG. 173.—Variable Resistance Microphone in Shunt to Capacity in Intermediate Circuit.

supply to the arcs; the control of the energy output of a high-frequency alternator by microphonic control of its field exciting current; the control of the output of some forms of static frequency changers by microphonic control of the direct current magnetisation of one or more of the transformers; and the control of the output of some types of vacuum oscillation generator by microphonic control of the direct current voltage applied to the " grid " electrode. These and a number of other cases are dealt with more fully in Chapter XVIII. p. 278. In many cases it is advantageous to adopt one of these special methods of control, as compared with the general methods already outlined.

6. INDIRECT CONTROL OF THE RADIATED ENERGY: CONDENSER MICROPHONES

The methods of modulation just described have involved, at least in part, a direct control of the radiated energy by variable resistance microphones. At the same time, however, there is in some cases a certain amount of indirect control brought about by the microphone affecting the tuning of the aerial circuit relatively to the oscillation generator. Another method of control which depends entirely upon alterations of tuning has been experimented with—notably by R. A. Fessenden.

For this purpose a *condenser microphone* is employed, that is to say, a microphone consisting of a small condenser of which the capacity is varied and controlled by the speaker's voice. In its simplest form this may consist of a parallel plate condenser, formed by the transmitting diaphragm as one plate, and a fixed disc or armature as the other. Owing to the bending of the diaphragm when influenced by air waves the change in capacity is not as great as can be obtained by mechanically connecting the diaphragm to a movable plate, forming one electrode of such a condenser, and so causing bodily movement of this electrode towards and away from the fixed electrode. A magnifying lever attachment may be inserted between the diaphragm and the movable plate to magnify the amplitude of motion of the latter as much as possible for a given amplitude of movement of the diaphragm.[1]

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[1] The motions of the condenser armature may be controlled magnetically through the medium of an electromagnet and a local circuit containing an ordinary variable resistance microphone. Reference No. 452.

Such a variable condenser microphone may be inserted in the aerial circuit of the transmitter to vary its natural oscillation frequency, and so to cause a modulation of the radiated energy, by throwing the aerial more or less in or out of tune with the oscillation generator (Fig. 174).

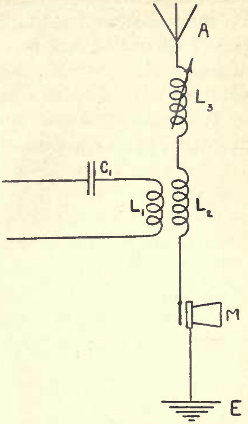

Fig. 174.—Condenser Microphone in Aerial Circuit (R. A. Fessenden).

For the maximum effects the aerial circuit should normally be not quite in tune with the oscillation generator, so that the condenser operates upon the steep part of the resonance curve (Fig 175). At the peak of the curve where the maximum current occurs in the aerial circuit, the rate of change of current with capacity, or $\frac{dI}{dC}$, is zero. The best conditions are obtained when $\frac{dI}{dC}$ has its maximum value (*i.e.* the point on the curve where the slope is greatest, that is, at C_1), for then a small change in

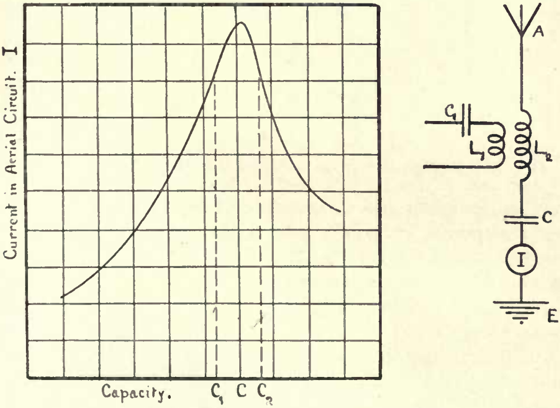

Fig. 175.—Operation of Condenser Microphone.

capacity will give rise to the greatest possible change in the aerial current. The point C_2 is not quite so favourable as C_1, since the curve is not so steep at this point. The aerial circuit should therefore be detuned to a slight extent in the direction of higher frequencies. From 3 per cent to 5 per cent detuning should be sufficient.

These microphones have not been employed to any great extent in practical working, and some difficulties are experienced in designing and constructing them to handle a large amount of power, and at the same time effectually to modulate it, on account of the very limited changes in capacity that are available when the diaphragms are sufficiently separated for the dielectric to withstand the applied voltage without breakdown.

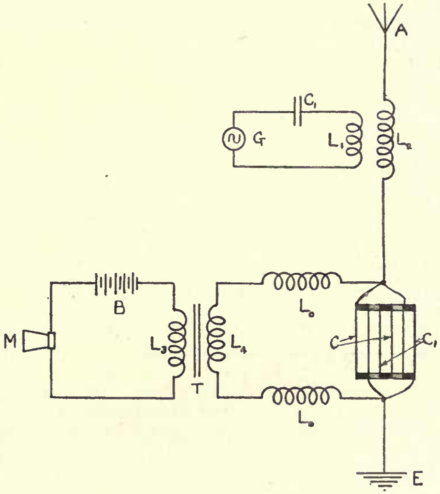

FIG. 176.—Multiple Diaphragm Condenser Microphone (W. Burstyn).

An attempt has been made to overcome this difficulty, by constructing multiple diaphragm condenser microphones with a number of pairs of parallel diaphragms, connected alternately together like an ordinary condenser. The movements of the diaphragms are brought about by applying to the terminals of the instrument a varying voltage produced by the local microphone under the influence of the speaker's voice.[1] In Fig. 176, C C′ are the pairs of flexible diaphragms, connected up in the aerial circuit in the manner shown. The local microphone transmitter M is joined up in series with a battery B, and the primary L_3 of the "telephone-transformer" T. The secondary L_4 of this transformer should be designed to yield a high voltage. It is connected, through the choking coils L_0, L_0, to the terminals of the condenser microphone. The voltage thus impressed upon the condenser terminals causes movements of the diaphragms towards and away from one another, thus varying its capacity. The diaphragms are unable to vibrate to the high-frequency voltage impressed upon them from the oscillation generator G. The resulting capacity variations modulate the aerial current in the manner already explained. The normal capacity of the microphone may conveniently be of the same order as the effective capacity of the aerial itself.

A rather better connection scheme for condenser microphones is shown in Fig. 177. In this case the potential difference applied to the microphones is much higher, so that smaller capacity variations are more effective.

Just as the variable resistance microphones may, as we have already seen, be applied in a number of different ways for the modulation of the aerial current, so the condenser microphone may also be applied at any point, where a change in capacity can be caused to vary the amount of energy available in the aerial circuit for radiation. Another good arrangement, besides connecting the microphone in the aerial circuit, is to insert it in an intermediate circuit coupling the aerial

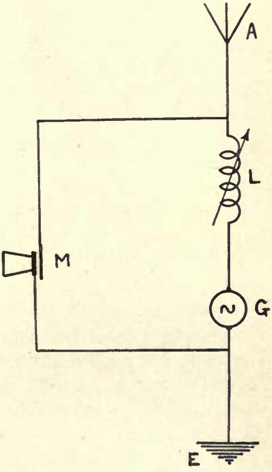

FIG. 177.—Condenser Microphone in Shunt to Aerial Circuit (R. A. Fessenden).

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[1] Reference No. 451.

on to the oscillation generator, as indicated at M, in Fig. 178. One electrode of the microphone may with advantage be connected to earth.

Another form of microphone that operates by variation of tuning of the aerial circuit is dealt with in the next Chapter (Alexanderson's Magnetic Microphone, p. 272). The changes are effected not by a varying capacity but by a varying inductance under the control of the speaker's voice.

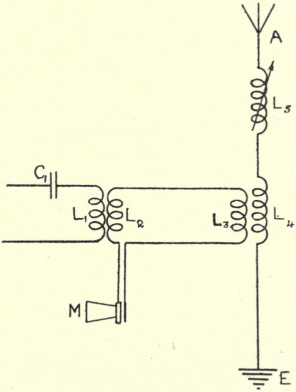

Fig. 178.—Modulation of Transmitter by Condenser Microphone in Intermediate Circuit.

CHAPTER XVII

MODULATION OF THE TRANSMITTED ENERGY—II. TYPES OF VARIABLE RESISTANCE AND OTHER MICROPHONES

THE most important types of variable-resistance microphones include a number of very diverse instruments, ranging from the ordinary commercial carbon microphone to special instruments, designed for carrying large transmitting currents. The ordinary commercial carbon microphone that is employed as the transmitter on all the multitudinous land line telephone circuits of the world, is never, in such work, called upon to modulate more than at the most a very few watts, or to pass currents of more than a fraction of an ampere. It is therefore evident that they cannot be employed directly for wireless work, except for the smallest of stations working over very short ranges—since in ordinary long-range wireless work it is customary to employ transmitting energies running up to more than a hundred kilowatts. Experiments show that the ordinary "solid-back" type of carbon microphone transmitter (Fig. 179) is usually capable of carrying currents up to, or a little over, 1 ampere without serious overheating of the carbon granules. If larger currents are passed through such a transmitter the heating and burning of the granules that takes place as a consequence soon destroys the sensitiveness of the instrument, and prevents a proper transmission of the speech. When larger currents have to be dealt with several such transmitters may be connected in parallel, and mounted in such a manner that they may all be influenced simultaneously by the voice of the speaker. Here, however, we have two difficulties introduced, viz. the difficulty of ensuring that all the microphones shall be acted upon to the same extent by the voice of the speaker; and secondly, distortion of the transmitted speech by reason of local currents circulating between the microphones caused through their resistance changes not being identical.[1] Both these, and especially the latter,[2] place a very decided limit upon the number of microphones, that it is possible to operate in parallel with any degree of success. Ordinarily it will be found that the maximum possible number is about six, while it is usually advisable to limit them to three or four in parallel. A commonly adopted construction for mounting the microphones for this purpose is shown in Fig. 180.

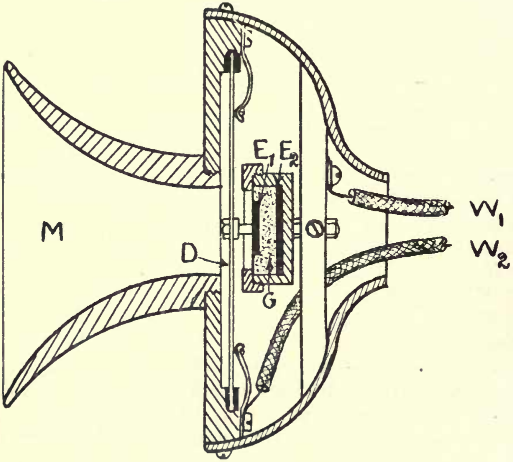

FIG. 179.—"Solid-Back" Microphone Transmitter.

M = Mouthpiece; D = Diaphragm; G = Carbon Granules in Metal Box closed with Mica Disc, carrying E_1; E_1 E_2 = Carbon Electrodes; W_1 W_2 = Terminal Connections.

Each microphone is mounted on the end of a metal tube which terminates with the other tubes in a spherical cavity, to which a mouthpiece is attached.

Many other constructions will doubtless be evident to the experimenter, but in all cases it must be borne in mind that the microphones must all, as far as possible, be equally

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[1] Reference Nos. 455, 459.

[2] See also p. 254.

influenced by the speaker's voice, otherwise not only will the clearness of the speech be diminished, but a considerable loss of efficiency will also take place.[1]

The Differential Microphone is another form in which a multiple microphone may be employed.[2]

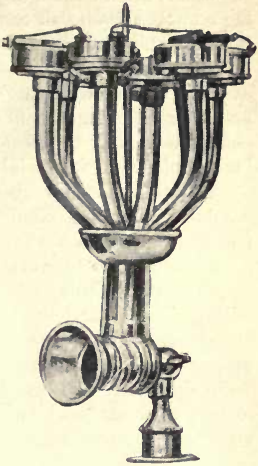

FIG. 180.—Multiple Microphone with Single Mouthpiece (W. Dubilier).

A point that arises in connection with the use of multiple microphones is the advisability—or otherwise—of connecting them all in parallel. It is often advantageous to connect some or all of them in series with one another. This arises from the fact that although a microphone may be able to carry a certain current without overheating, it does not follow that it will necessarily be able to efficiently modulate that current in the particular circumstances in which it may be employed, for the reason that its resistance variations may be too small to adequately influence or modulate the current passing through it. Under these conditions an improvement will usually be effected by connecting two or more of the microphones in series, although at the same time the effective current-carrying capacity of the complete unit may be diminished, assuming as is usually the case that the total number of microphones that can be successfully spoken to simultaneously is limited by the conditions set out above. It is therefore convenient to arrange that the several microphones in a complete group or unit may be rapidly and easily changed over by a suitable switch from all in parallel to all in series, with one or more intermediate series-parallel arrangements depending on the number of microphones in use. In this way the most satisfactory arrangement in any particular circumstances may be very quickly determined, and the effective average microphone resistance adjusted in this manner to satisfy as nearly as

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[1] Reference No. 461.

[2] Reference No. 460.

possible the conditions required for maximum effect as brought out by Eccles' theory (see p. 240).

In an arrangement of multiple microphones due to Ditcham only two microphones are employed in series at a time, while the others are mounted in pairs and so arranged that by turning a knob, a fresh pair can be instantly brought into speaking position, and into circuit in place of the pair previously in use. In this manner excessive heating of the microphones can be avoided by quickly changing over from one pair to another, and thus allowing the first ones to cool down again. This change over may be effected easily, and without causing any inconvenience or appreciable interruption of a conversation.[1]

A trouble that is frequently met with, especially in experimental work using commercial microphone transmitters in metal boxes, arises through "capacity-currents" flowing from terminal to terminal of the microphone, and also from one microphone to another when several are used simultaneously, via the capacity between the various parts and the metal framework. These current paths form a shunt to the proper one through the microphone granules, and as such seriously reduce the efficiency of the instrument, since they remain constant, and of course are quite unaffected by the voice and the consequent variations in the resistance of the carbon granules. The trouble may be removed to a great extent by mounting all the parts of the microphones on a suitable insulating material, and by avoiding as much metal work as possible in the constructional parts of the microphones. An example of this construction is afforded by the Colin-Jeance microphones, in which four or five are mounted on a marble slab and spoken to simultaneously. This particular arrangement is said to be very successful.

The operation of several microphones in parallel may usually be improved by some special circuit arrangements that will limit or prevent any circulating currents between the microphones themselves. An arrangement devised for this purpose by R. Goldschmidt[2] is shown diagrammatically in Fig. 181. Inductances L_1, L_2 are arranged in series with the microphones M_1, M_2 as shown. They are coupled together, so that as a result current variations in the same direction in all the microphones—*i.e.* variations of the same kind produced by the speech—flow through the coupled coils in such a

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[1] Reference No. 149.

[2] Reference No. 462.

direction that their fields oppose one another, and their effective inductance becomes very small. On the other hand, circulating currents between the separate microphones flow through the coils in such a manner that the fields assist one another, and a high impedance is therefore presented to the circulating currents.

When more than two microphones are to be operated in parallel, two inductance coils should be inserted in series with each so as to couple the circuit from each microphone on to two other circuits through adjacent microphones such as is illustrated diagrammatically in Fig. 182. M_1, M_2, M_3 are three microphones each connected in series with two inductance coils L_1 L'_1, L_2 L'_2, etc., between the terminals T_1, T_2, of the complete microphone unit. The coils are cross-connected in the manner shown so that the magnetic fields in each core due to currents flowing in the same direction from the proper equal operation of the microphones cancel each other. Thus the coils offer little choking action to the current variations due to the normal operation of the microphones. If, however, the resistance of one microphone alters more than that of another there will be a resultant circulating current between them. The magnetic fields in the coupled coils will not then cancel out, and as a consequence a considerable impedance will be offered to the flow of this circulating current and its value limited.

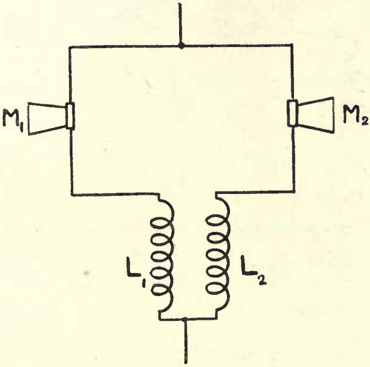

FIG. 181.—Microphones in Parallel to avoid Circulating Currents.

An alternative arrangement that has been suggested where

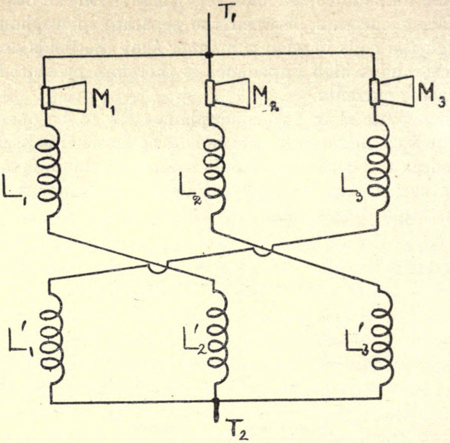

FIG. 182.—Arrangement of Microphones in Parallel (R. Goldschmidt).

several microphones have to be operated in parallel, is shown in Fig. 183.

In order to increase the current-carrying power of micro-

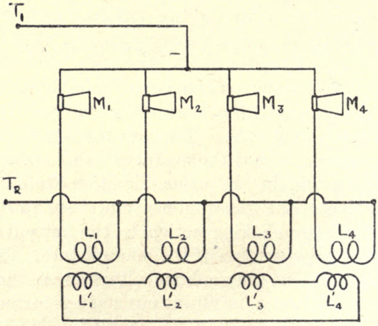

FIG. 183.—Arrangement of several Microphones in Parallel (R. Goldschmidt).

phones of the ordinary type attempts have been made to utilise other materials than carbon for the microphonic granules.[1] One such arrangement is S. G. Brown's microphone employing an osmium-iridium alloy.[2] Carborundum and similar refractory conducting materials have also been used.[3] These are not so likely to be influenced by overheating through excessive currents as a readily oxidisable material like carbon.

An improvement in the operation of carbon microphones may often be effected by placing them in an enclosure filled with hydrogen or hydrocarbon gases. The utility of so doing in preventing oxidation of the granules will be evident if the microphones run at all warm, but in any case it should serve to maintain the granules in a cleaner condition, and to improve the articulation.

Alcohol may also be used in the microphone enclosure with similar results. The liquid further serves to maintain the granules as cool as possible, since it is in contact with the actual points where the heat is generated.[4]

Marzi's Carbon Powder Microphone

In order to overcome the difficulties and limitations encountered in the use of the ordinary carbon microphone through excessive heating due to the current, Marzi has employed a special form in which the microphonic material is continually being removed and replaced by fresh, cool material. Carbon powder is employed for this purpose, and it is caused to fall between the two electrodes of the microphone, so that any given set of particles is only in the current path for a very short time before it is replaced by a fresh one.[5] Various constructional arrangements have been adopted—one of these is shown diagrammatically in Fig. 184.

The container C for the carbon powder forms one electrode of the microphone. Contact with the carbon powder is made by the electrode E_1 round the exit tube. The carbon powder streams out between E_1 and the second electrode E_2, which is carried by the plate P on the arm L. Modulated currents from a local transmitter are passed through the magnet windings M_1, M_2, and serve to control the distance between the two electrodes E_1, E_2. The effective resistance of

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[1] Reference Nos. 456, 457, 458.

[2] Reference No. 565.

[3] Reference No. 464.

[4] Reference No. 463.

[5] Reference No. 464.

the carbon powder stream between these points is thus varied in accordance with the speech currents.

DUBILIER'S WATER-COOLED RELAY MICROPHONE

This microphone is capable of acting as a repeater for relaying an ordinary land line telephone circuit on to a wireless telephone transmitter.[1] The chief novel feature lies in the provision of two diaphragms which are arranged to move simultaneously in opposite directions, thus increasing the resistance changes on the granules placed between them. Fig. 185 illustrates the arrangement in diagrammatic form. C, C are the two diaphragms mounted on opposite sides of the ebonite ring D. This ring also carries supports E, E for the containing cups for the granules and cooling water circulation. The granules are in the circular space G, and are surrounded on both sides by compartments F and H for the circulating water, which is led in and out by the pipes I, I. The granules are retained in position by the mica discs, and the current is led in and out by the platinum rings J, J attached to the

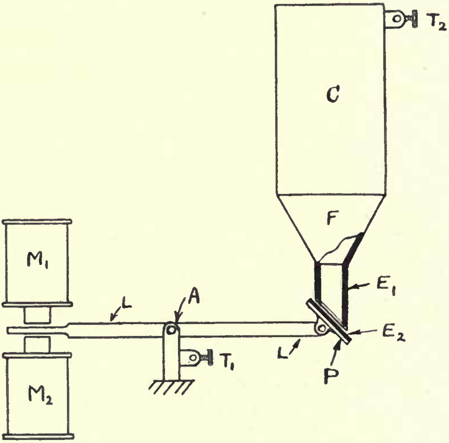

FIG. 184.—Marzi's Carbon Powder Microphone.

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[1] Reference No. 482.

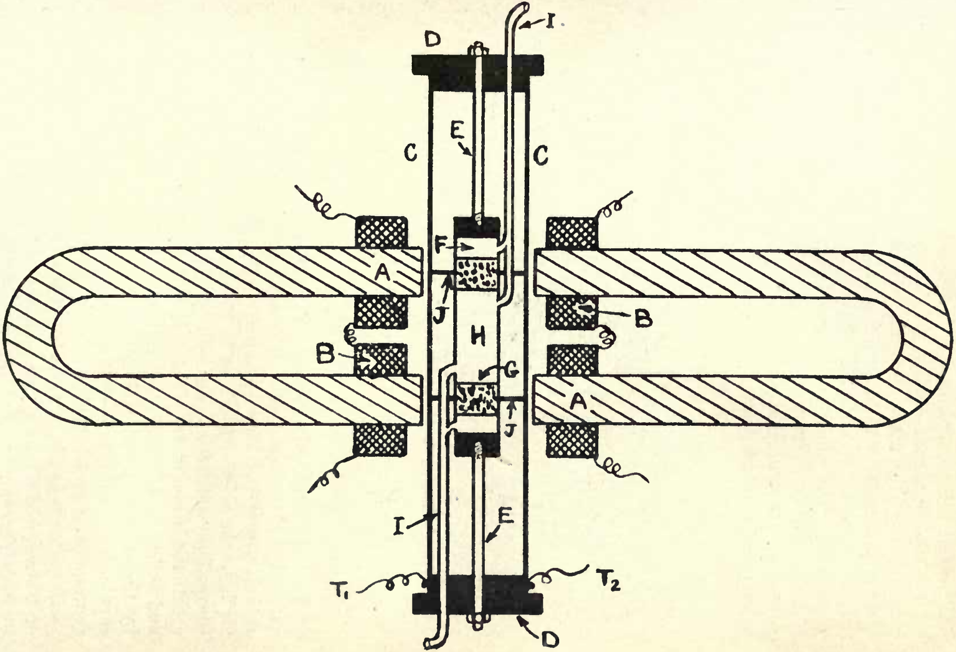

FIG. 185.—Water-cooled Relay Microphone (W. Dubilier).

A, A = Permanent Magnets; B, B = Relay Windings; C, C = Diaphragms; D, D = Ebonite Ring; E, E = Supports for Granule Box; F, H = Water-cooling Spaces; G, G = Granule Compartment; I, I = Cooling Water Pipes; J, J = Platinum Contact Rings, from Diaphragms to Granules; T_1, T_2 = Microphone Terminals.

centres of the diaphragms C, C, to which the terminals of the instrument are connected.

The motion of the diaphragms is controlled by the speaker's voice through the medium of the windings B, B (round the permanent magnets A, A), which are connected in series with an ordinary microphone transmitter and a few cells in the usual way. The whole instrument, in fact, is very similar to a large edition of two ordinary electromagnetic telephones placed with their diaphragms adjacent to one another with the microphonic carbon granules between them.

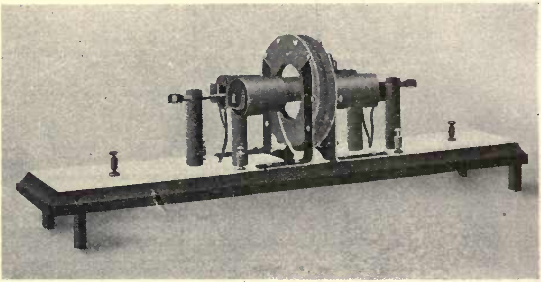

FIG. 186.—Dubilier's Water-cooled Relay Microphone.

LIQUID OR HYDRAULIC MICROPHONES

The liquid or hydraulic microphones are among the most successful that have been developed so far for the direct modulation of the high-frequency energy at the transmitting station. In most of them, as in Marzi's microphone (p. 257), the medium which forms the "microphonic contact," or whose resistance is modulated by the voice, is continually replaced and replenished by fresh cool material, to prevent overheating by the current passing through the instrument. They are capable of being operated electromagnetically from a circuit containing an ordinary type of small current microphone.

In the earliest forms use was made of a direct modulation of a stream of liquid by a needle, or other valve connected to a diaphragm, so that the cross-section of the current-carrying liquid is varied by the vibrations of the diaphragm caused by the sound waves. Fig. 187 illustrates the essential idea of this arrangement. A metallic container C is kept supplied with conducting electrolyte through the pipe A, and is provided with a glass jet tube J, terminating in a fine orifice V, fitted with a needle valve N. This valve is supported from a lever L, pivoted at P, and attached to the centre of the diaphragm D. Thus in speaking in at the trumpet M the diaphragm will be set in vibration, and a variable quantity of liquid allowed to flow out from the valve V, on to the electrode E. The resistance of this stream will be dependent upon the cross-sectional area of the valve V, and of the resulting stream of liquid that is allowed to flow on to the plate E, and will therefore depend upon the character of the sound waves impinging on the diaphragm D.

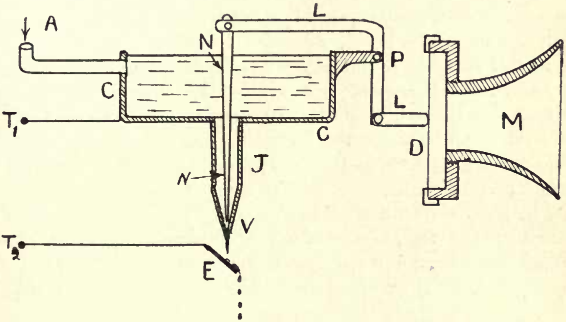

FIG. 187.—Variable Resistance Liquid Microphone, early type.

As liquid for this and other patterns of liquid microphones, any conducting electrolyte may be employed. Preference should of course be given to a liquid that does not readily attack the electrodes and other parts in contact with it. The most commonly employed liquids are dilute acids, or salt (NaCl), or soda solutions (Na_2CO_3; or NaOH or KOH).

It should be noted that all liquid microphones should be used to modulate an alternating rather than a direct current, on account of the greater diminution of the electrolysis of the electrolyte in the former case. This limits their use to connection either directly in the aerial circuit, or in a circuit coupled with it. They should not be used to modulate a direct supply or control current in such types of transmitter as the direct current supply to an oscillating arc generator, or the D.C. field current of a Goldschmidt or other high-frequency alternator, or the D.C. magnetising current of certain types of static-frequency raisers.[1]

Any convenient metal may be employed for the electrodes of liquid microphones, but the choice should fall on a material that is acted upon as little as possible by the liquids used. In general, therefore, platinum is good from this point of view.

As has already been indicated a magnifying lever arrangement may often with advantage be inserted between the diaphragm and the valve or other moving parts of the microphone. Care must be taken in designing the magnifying lever, when one is employed, in order to maintain the mass of material that has to be moved by the diaphragm as small as possible. If the mass is too great its inertia will largely damp out the vibrations of the diaphragm itself. The aim should be so to shape the lever that the centre of gravity of the moving parts is as nearly as possible coincident with the fixed pivots.[2]

In the construction of such levers to magnify the minute amplitude of vibration of a telephone diaphragm, very great mechanical accuracy must be secured. A small " shake " or misfit in a joint or pivot may absorb all or at least a major portion of the original movement, without producing any useful results.

In order to increase the energy available to set the diaphragm in motion, electromagnetic control may be utilised in place of direct action by the speaker's voice. The electromagnet should be connected in series with a small battery and local microphone transmitter to take the place of the ordinary receiver in a simple telephone circuit.

JERVIS-SMITH MICROPHONE

In an early pattern of liquid microphone due to F. Jervis-Smith,[3] the diaphragm is arranged to control the movements of an inclined plate electrode placed in the path of a thin stream of conducting liquid issuing from a small jet. The movements of the electrode are such as to vary the effective length of the current path through the jet. Fig. 188 illustrates

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[1] See Chapter XV. [2] Reference No. 465. [3] Reference No. 466.

the principle involved. A stream of conducting liquid J falls from the tube T on to the electrode E.' This electrode is inclined at an acute angle to the liquid flow, so that a slight movement of E in a horizontal direction produces a very much larger change in the length of the liquid path. The second connection is made to the mass of liquid in the tube T. It is advisable to keep the normal length of the liquid stream as short as possible, so that the changes in length produced

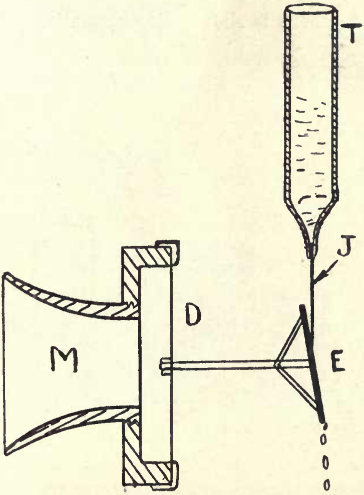

FIG. 188.—Simple Form of Variable Resistance Liquid Microphone (F. Jervis-Smith).

by the movements of E may be as large a percentage of the whole as possible.

The above illustration should be taken merely as diagrammatically illustrating the principle involved, rather than the actual construction of the apparatus.

VANNI'S LIQUID MICROPHONE

In this instrument a jet of acidulated water, or other convenient electrolyte, is allowed to fall on to a slanting metal plate which forms one terminal of the microphone. Another, and smaller, plate electrode is arranged on a suitable lever system in such a manner that one of its edges just dips into the thin stream of liquid which spreads out over the first (and fixed) plate electrode. The lever mechanism is controlled by a diaphragm, so that it is caused to vibrate into or out of the thin liquid stream. Large variations of the resistance between the two plate electrodes are thereby produced by reason of the varying thickness of the electrolyte between them.[1]

The arrangement is shown diagrammatically in Fig. 189.

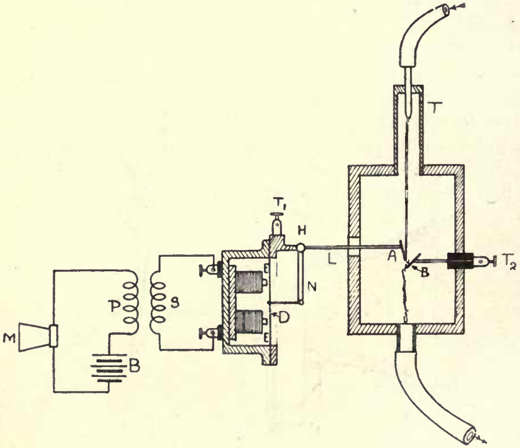

FIG. 189.—Vanni's Liquid Microphone.

B is the fixed inclined plate electrode. A is the moving electrode controlled by the vibrations of the diaphragm D, to which it is attached by the lever L, N. The jet of conducting electrolyte issues from an ebonite nozzle attached to the tube T, and falls between the plates A and B, as indicated by the dotted lines. E, E are the electromagnets for controlling the diaphragm D. They are connected to the ordinary carbon-microphone transmitter M, through the battery B and telephone transformer P, S.

Microphones of this type have been successfully used for

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[1] Reference Nos. 467, 468.

the direct control of aerial currents up to about 15 amperes. With careful adjustments quite good articulation may be secured.

The pressure of water at the jet is critical and must be carefully adjusted to secure the best results. A head of between 4 and 5 metres is usually satisfactory.

Chambers' Liquid Microphone

This instrument is somewhat similar to Vanni's in that the thickness of a stream of electrolyte, and consequently its resistance, is varied under the action of the voice.[1] In this instance, however, the diaphragm is arranged to form one of the electrodes, while the jet is the other. The jet is placed immediately under the centre of the (horizontal) diaphragm, and very close to it, so that the liquid issuing from the jet impinges directly on the under surface of the diaphragm, and then spreads out in a thin stream and falls back into a container (Fig. 190). The vibration of the diaphragm D due to the speaker's voice causes variations in the thickness of the film of liquid between the fixed jet and the diaphragm, and therefore corresponding variations in the resistance of the liquid between these two points.

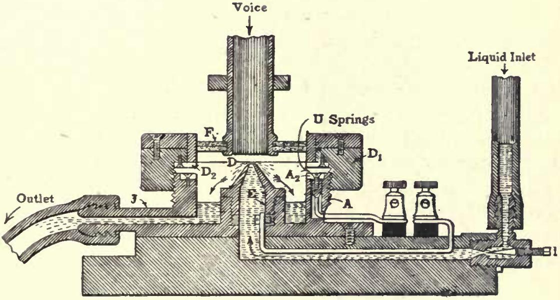

Fig. 190.—Chambers' Liquid Microphone.

In this diagram, D is a thin metallic diaphragm rigidly attached to the ebonite ring D_1. It is provided with a metal contact ring, D_2, by means of which the current is led to it from the left-hand terminal T_1 through flat metal springs

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[1] Reference No. 469.

between the metal rings D_2 and A_2. A_2 is connected to T_1 by the wire A. The ebonite ring D_1 carrying the diaphragm is screwed on to the framework of the instrument as shown. Thus the spacing between the diaphragm D and the metal nozzle electrode E may be easily varied till the best results are obtained. This may be effected without disturbing the position and mounting of the mouthpiece M, since the junction with the diaphragm chamber and the ring D_1 is effected through the soft felt ring F attached to the mouthpiece tube and fitting just inside the ring D_1. The connection from T_2 is led to the metal nozzle E, through which the electrolyte issues from the inlet tube P. The rate of flow is controlled by the inlet valve I until the liquid issuing from the outlet pipe J shows a temperature not in excess of about 80° C.

One feature of this type of instrument is the clearness of articulation and the freedom from resonance effects due to the natural vibration period of the diaphragm. The damping of the diaphragm's motion by the inertia of the liquid in contact with it effectually limits its amplitude of free vibration. Thus it can only execute the movements forced upon it by the variations of air pressure in the sound waves. The objectional resonance magnification of certain tones in the speech—usually noticed to a greater or less extent in most transmitters—is therefore prevented.

MAJORANA'S LIQUID MICROPHONE

This instrument depends on a discovery made by Bell in 1886. He found that a jet of liquid issuing from a small orifice is extremely sensitive to any disturbance of its circular form near the nozzle from which it flows. A small disturbance at this point, even such as may be caused by sound waves, increases in effect as the jet of liquid gets farther from the orifice, until it causes an actual break up of the liquid column into isolated beads, a few inches down the stream. Q. Majorana has made use of this phenomenon to form a liquid microphone, by allowing such a jet of electrolyte to fall between two fixed electrodes and bridge the gap between them with the conducting liquid stream.[1] The jet is placed in contact with the diaphragm of an enlarged telephone receiver, so that the motions of the diaphragm are communicated to

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[1] Reference Nos. 471, 472, 473.

the jet. This causes the jet to break up into beads and globules, to a greater or less extent depending on the quality of the sound affecting the diaphragm. The electromagnets controlling the diaphragm are connected in circuit with a local microphone and battery in the usual manner (Fig. 191). A length of land telephone line may be interposed so as to enable a distant speaker to control the microphone in the wireless transmitting station. M represents the local transmitting microphone with battery B in series with the magnets of the receiver R. The diaphragm D is connected to the jet J by the lever A, so that the vibrations are communicated to the jet and cause variations in the liquid stream L, as set out above. P_1, P_2 are the two electrodes which are bridged by the liquid stream. They are held in position by insulating supports F, G, and are inserted in the transmitting circuit through the terminals T_1, T_2. The vibrations of the jet modify the flow of liquid between the electrodes, and so control the resistance in the circuit between T_1 and T_2.

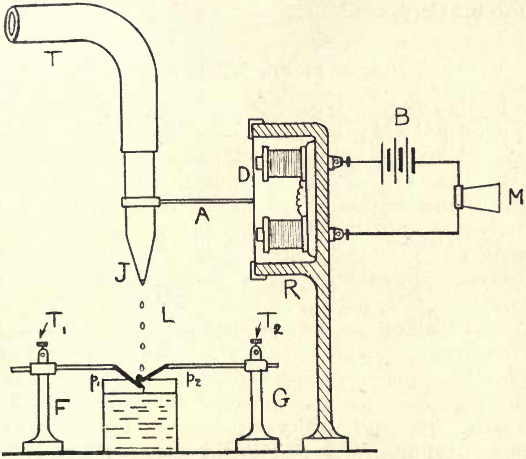

FIG. 191.—Majorana's Liquid Microphone.

The control of the flow of electrolyte in this and similar forms of liquid microphone may also be brought about in a very effective manner by utilising a modified form of Einthoven galvanometer. A powerful electromagnet has a fine wire stretched between its poles and connected in series with a local battery and microphone transmitter. The movements of this wire in the magnetic field brought about by the varying currents flowing through it are caused to control the movements of a valve to regulate the flow of electrolyte between the electrodes of the microphone. As a very simple arrangement the wire may be made to partially flatten a soft rubber tube through which passes the stream of electrolyte on its way to the electrodes.[1]

Sykes' Liquid Microphone

A highly ingenious type of liquid microphone has recently been developed and patented by A. F. Sykes, employing quite a different mode of operation from that already described.[2] The variation of resistance is effected, not by varying the length or cross-section of the current-carrying path in the electrolyte between the electrodes, but by varying the concentration of the salt or other conducting material in the electrolyte. Thus the resistance offered by a stream of the electrolyte flowing past two fixed electrodes is also varied. This variation of conductivity is effected by causing the diaphragm to control the volume of a stream of a concentrated solution of the electrolyte, admitted into a stream of non-conducting liquid (such as water) flowing past two fixed electrodes. The conductivity of the electrolyte between them is thus varied in accordance with the sound waves falling on the diaphragm.

One might perhaps imagine that rapid diffusion of the concentrated salt solution into the water or non-conducting liquid stream would considerably modify the original distribution between the admission valve and the electrodes. Tests have shown, however, that the instrument yields remarkably good articulation, so that diffusion of this nature cannot be a serious item in the moving stream of liquid. Owing to the continual circulation of liquid, any particular portion of it is only carrying current for a very short space of time, and therefore overheating does not take place. For this reason quite a small instrument can be constructed to

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[1] Reference No. 470.

[2] Reference No. 474.

carry and to modulate quite a considerable amount of high-frequency energy.

The particular construction of the jet orifice, and arrangements for ensuring that a high velocity solid jet of liquid is obtained, form the subject of a special patent application.[1] A solid jet that does not splash when it meets a solid object is necessary in order to secure reliable and consistent operation of the instrument.

SENSITIVE FLAME MICROPHONES

A type of variable resistance microphone altogether distinct from the preceding, in which every effort is made to cool the active microphone material, is afforded by the sensitive flame microphone transmitters. Of these several forms and types have been experimented with from time to time.[2]

The simplest form consists of a manometric flame controlled by a diaphragm for receiving the sound waves. The flame is arranged to form a path of variable resistance between two fixed electrodes. Fig. 192 will serve to illustrate the principle

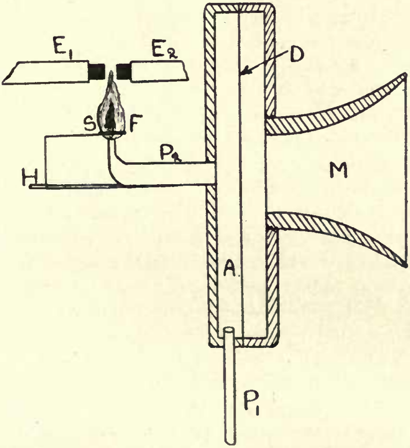

FIG. 192.—Manometric Flame Microphone.

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[1] Reference No. 483.

[2] Reference No. 481 for one example.

involved. M is the mouthpiece and D the diaphragm for controlling the sensitive flame F. E_1 and E_2 are two fixed electrodes placed a short distance apart in the path of the flame. The ionised gases in the flame form a bridge across these electrodes having a resistance depending on the height and size of the flame, and therefore on the character of the sound falling on the diaphragm D. It will be found advisable to increase the conductivity of the flame by the addition of extra ions, as for instance from a small receptacle containing a volatile salt S, held in the base of the flame by a light wire holder H. It is possible to obtain a rough transmission of sound by these devices—of which a number have been invented from time to time—but they are not nearly so reliable as many of the other forms of microphones.

MERCURY VAPOUR MICROPHONE TRANSMITTER

A type of microphone that possesses some possibilities from the point of view of the modulation of considerable amounts of energy is one involving the use of a mercury vapour arc, and the control of the position and movements of the same by a magnetic field under the action of an ordinary microphone transmitter.

The principle of the arrangement is set out in diagrammatic form in Fig. 193. A glass containing vessel has sealed through it an anode A, and two auxiliary electrodes B and C. It is provided with a connection to a pool of mercury H, which serves as a cathode, and is contained in the lower parts of the tube. The electrodes A and H are connected to a battery B of, say, about 100 volts through suitable series resistances and inductances R_0, L_0. An ordinary mercury vapour arc is set up between them in the usual manner. The arc may be started by the provision of an auxiliary starting anode, with which the mercury H may be brought momentarily into contact by tipping the tube; by the provision of a momentary high voltage glow discharge inside the tube; or by any other of the usual methods employed in starting mercury vapour arc lamps. The whole tube is, of course, hermetically sealed and exhausted at a low pressure—somewhere in the neighbourhood of 0·01 mm. of mercury. It is placed between the poles of an electromagnet or solenoid F, the polarity of which is arranged to deflect the arc stream in the direction of the electrodes B and C. These electrodes are connected to the terminals T_1 and T_2 in the aerial or other suitable circuit of the transmitter, so that the resistance between T_1 and T_2 may depend on the position of the arc stream in the bulb, and on the amount it is deflected into the neighbourhood of these auxiliary electrodes. By controlling the field of F by a microphone M and battery B_1 these variations become dependent upon the speech or other sound waves affecting the microphone M, and the complete apparatus may serve as a microphone transmitter capable of carrying quite large currents if suitably designed.

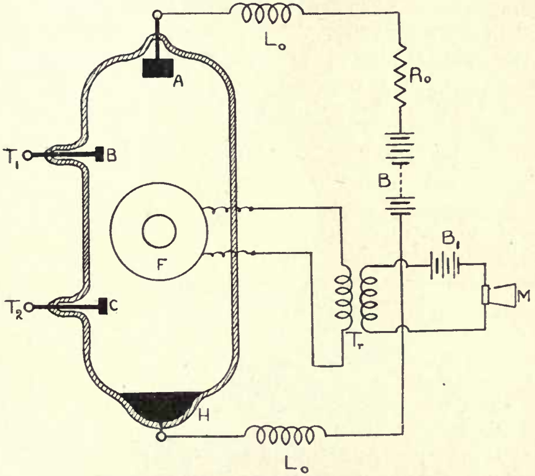

FIG. 193.—Mercury Vapour Microphone Transmitter (Coursey).

The difficulty of this and other similar methods involving the use of vacuum apparatus lies in the difficulty of sealing heavy current conductors through the glass containing vessel. Several special modes of effecting this have been used from time to time, but for very large currents it is usually most satisfactory to adopt some other material than glass for the containers so as to avoid risk of fracture.

A somewhat analogous arrangement is due to J. Schiessler.[1]

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[1] Reference No. 475.

It consists of a vacuum tube connected in shunt to the oscillation generator. The resistance of the gas path in the tube is controlled by a transverse or longitudinal magnetic field.

ALEXANDERSON'S MAGNETIC MICROPHONE

Quite recently a new type of microphone transmitter has been developed by E. F. W. Alexanderson and the General Electric Company of America.[1] The modulation is mainly effected by variations in the tuning of the aerial circuit. It gives promise of being easily adaptable to the modulation of large amounts of energy.

The essential principle of the instrument depends on the well-known fact that the permeability of iron is not a constant quantity, but is a function of the applied magnetising force. The inductance of a coil containing an iron core is therefore dependent upon the magnetising force applied to the core—that is, upon its state of magnetic "saturation." If an iron core has wound upon it two independent coils, it thus becomes possible to vary the effective inductance of one of them by changes in the magnitude of the current sent through the other. Hence one coil may form part of a high-frequency circuit, either included in or affecting the aerial circuit, while the second is traversed by a direct control current under the influence (for example) of a local transmitting microphone.

For successful operation in this manner, it is necessary that the direct current windings provided for varying the magnetic state of the iron core should be so disposed that there is no appreciable direct induction of high-frequency energy into the direct current circuit. One mode of achieving this result is shown in Fig. 194. A laminated iron shell C is provided with a double winding leg, D, E, in the centre. Three coils are wound upon this core: two, F and G, each embracing one half only of the double limb; and one, H, embracing the two limbs together. This last coil is connected in series with the battery B and control microphone M. It provides the direct current control magnetisation for the iron core. The windings F and G, connected in series or parallel as desired, carry the high-frequency currents that are to be modulated. It is evident that the magnetic flux produced by the currents in these windings (when connected up as in-

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[1] Reference Nos. 476, 477, 478. Compare also No. 479.

dicated) has a closed path round the two centre limbs as indicated by the small arrows in the diagram, while at the same time both these flux paths pass through the coil H *in opposite directions*, and therefore practically neutralise one another. No appreciable high-frequency E.M.F. is thereby induced in the direct current circuit. Similarly there is practically no direct magnetic induction from currents in coil H on to coils F and G.

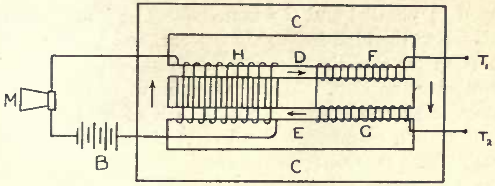

FIG. 194.—Alexanderson's Magnetic Microphone Winding Scheme.

In actual practice the coils F and G and the coil H are not arranged at opposite ends of the core, as shown for simplicity in the diagram, but are each wound in sections and sandwiched together after the style of ordinary transformer construction. This may be seen from Fig. 195, which illustrates

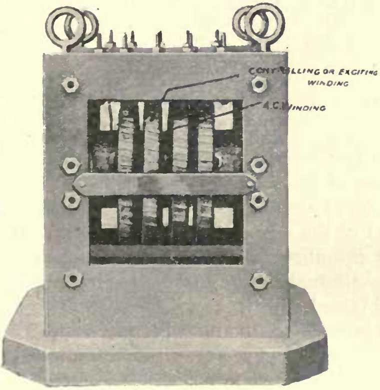

FIG. 195.—Alexanderson's Magnetic Microphone, for Modulation of 75 kw.

an instrument capable of modulating high-frequency energy up to about 75 kw.

The coils F and G are shown in the above diagram as connected in series, but it is evident that they may also be arranged in parallel and the same effects obtained. A lower impedance to the high-frequency current, and a more effective modulation by the direct control current, are advantages of the parallel connection. At the same time it becomes necessary to insert small condensers in series with each of the parallel paths F and G, to prevent the flow of circulating currents of "speech" frequency between them. These condensers must not be too small, however, or the flow of high-frequency current will also be impeded. This arrangement is indicated diagrammatically in Fig. 196. A condenser C^1 connected in series with the complete microphone is found to increase the sensitiveness of the whole arrangement.

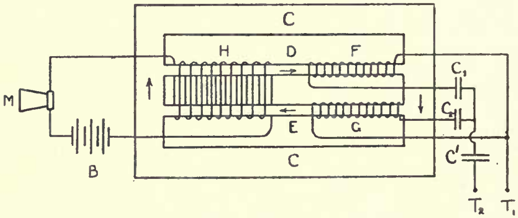

FIG. 196.—Alexanderson's Magnetic Microphone Winding Scheme—Parallel Connection.

This type of amplifier has been successfully employed for the control of the energy output of a 75 kw. high-frequency alternator (at about 40,000 ∾), by connecting it in shunt across the alternator terminals. As great a modulation is thereby obtained as if the whole field exciting current of the alternator were acted upon, with the further advantage of being also available for use with alternators not having a laminated field magnet system. Direct telephonic modulation of the field current of this class of machine is impracticable. The uses of this microphone are not, however, restricted to this type of H.F. alternator. The instrument should prove equally available for modulating the aerial circuit energy of any form of undamped oscillation generator.

Oscillograph records taken with the apparatus in operation have indicated an amplification of about 350 : 1 between the voltamperes used in the microphone control circuit, and the actual H.F. energy that is modulated.

By proper adjustment of the values of the shunt and series condensers used with the instrument, the relation between the direct current through the controlling winding and the energy output from the alternator can be made almost a linear one. This is a valuable feature from the point of view of " distortionless " telephony.

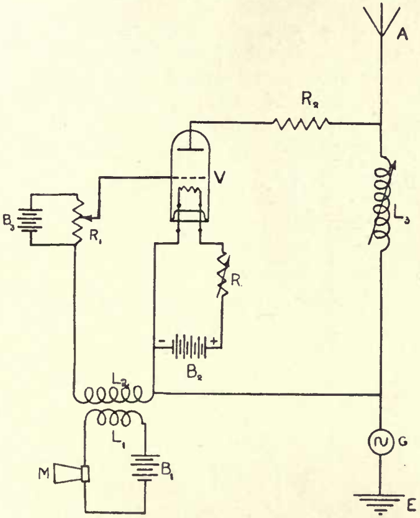

FIG. 197.—General Scheme of "Shunt Valve" Microphonic Control of Oscillation Generator.

When large outputs of H.F. energy have to be dealt with, it is desirable to amplify the initial microphone modulations before utilising them to control the magnetic microphone. This is in order to obtain sufficient variation in the ampere-turns on the control winding to effectively control the high-frequency currents. This preliminary amplification may, if necessary, be effected by one of the forms of audion or pliotron amplifiers (see also p. 302).

Shunt Valve Microphonic Control

The General Electric Company (U.S.A.) have developed a mode of utilising a vacuum valve to control the radiation from an aerial in a similar manner to the Alexanderson Magnetic Microphone.[1] The valve is arranged in shunt to the aerial circuit or to the oscillation generator (alternator, arc, valves, etc.), so that a variable portion of the energy that would normally be radiated is diverted from the aerial circuit. One arrangement is shown in Fig. 197. The source of H.F. oscillations is represented by G, and may be of any of the suitable forms. The plate circuit of the control valve V is connected across the aerial-tuning inductance L_3, and its

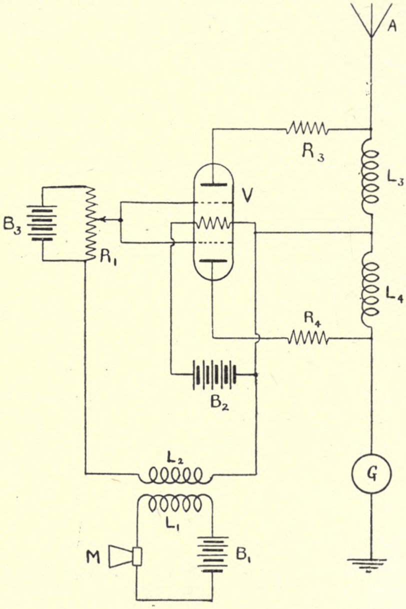

FIG. 198.—Shunt Valve Microphonic Control with Double Anode Valve.

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[1] Reference No. 480.

grid circuit is controlled by the microphone M in the usual manner.[1] An alternating E.M.F. is impressed in the plate circuit of V from the coil L_3, but owing to the unilateral conductivity of the valve, current only flows during the half-waves when the plate is positive with respect to the filament. The magnitude of this current, and therefore of the energy abstracted from the aerial, is entirely dependent upon the grid potential of the valve. It is therefore directly under the control of the microphone M. The valve V should by preference be of the very high vacuum type in order that it may be suitable for connection to the coil L_3 where high voltages may arise. The resistance R_2 serves to limit (if necessary) the current passing through V, in order to prevent any excessive heating. A small battery B_3 of a few cells, shunted by a potentiometer resistance R_1, is inserted in the grid circuit to enable the best working conditions to be secured.

A modified form using a special valve with double grid and plate electrodes is indicated in Fig. 198. This arrangement enables energy to be drawn from the aerial circuit during *both* half-waves of the oscillation instead of during one only. Its mode of operation is otherwise precisely similar to the arrangement previously described. This special valve could obviously be replaced, if preferred, by two ordinary valves, arranged so that one passes the current during one half-wave of the impressed voltage, and the other when the voltage is reversed.

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[1] See p. 281 for microphonic control of valves.

CHAPTER XVIII

MODULATION OF THE TRANSMITTED ENERGY—III. SPECIAL MICROPHONIC CONTROLS FOR DIFFERENT TYPES OF OSCILLATION GENERATOR

It has already been mentioned in the discussion of the various forms of microphone, that in certain circumstances it may be advantageous to employ special methods of control for particular types of oscillation generator. It may, therefore, be of some value to collect together and summarise the various controls available for use with the leading types of oscillation generator that have already been described.

Quenched- and Rotary-Spark Generators

These types of oscillation generators do not as a rule admit of successful control other than by a microphone transmitter (liquid microphone, etc.), either directly in the aerial circuit or inductively or conductively connected therewith.[1]

A novel method of the control of the output of rotary-spark transmitters of the continuous wave type has been described by the Marconi Company and S. O. Trost.[2] It consists in setting up two sources of oscillations of the same frequency and intensity, and connecting them in opposite phase so that their effects neutralise one another in the aerial circuit and no radiation takes place. If now the intensity or phase of one of the oscillations is modified by some suitable microphonic control, a resultant wave will be radiated from the aerial which depends entirely upon the speech impressed upon the microphone. With the trigger control of the main discharges of the multi-disc arrangement,[3] the microphone may very conveniently be caused to control merely the small

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[1] Pp. 238-250.

[2] Reference No. 489.

[3] P. 86.

quantity of energy handled by the trigger circuits. In this manner the phase of one set of the main discharges may be readily controlled, and the resulting radiation thus made to depend upon the speech to be transmitted.

Under certain circumstances it is possible to obtain a control of the energy output from the aerial, by direct variations of the spark-gap itself. Especially when the gap is very short is this method a possible one. F. Majorana has employed a spark-gap between one electrode fixed, and the other a stream of mercury, which can be set in vibration by the diaphragm.[1] The method is scarcely one to be recommended as the variations are too irregular, and the relation between change of output and change of spark-gap length too uncertain to obtain satisfactory speech transmission, as compared with what may be accomplished by the other methods.

ARC OSCILLATION GENERATORS

These as a rule admit of greater flexibility of control than the spark methods. There is generally but little choice to be made between the results obtainable in the several cases, provided that the most suitable arrangements are secured in each instance.

The direct methods of control already described,[2] using microphones in the aerial circuit or coupled to it, or else in an intermediate circuit, are the ones most commonly adopted. When the microphonic control is arranged to directly influence the aerial circuit, it is generally advisable to operate the arc with a fairly loose coupling to the aerial circuit, so that there may not be too great a reaction to hinder efficient modulation. It is further possible to modulate the output from the arc by control of the direct current supply to the arcs.[3] To this end, any of the electrical methods of control of the *luminous* output from the arc may be adopted.[4] The inductive method, with the microphone magnetically coupled to the direct current supply leads, is, as a rule, the most convenient of these arrangements.[5]

It is further possible to control the output by arranging

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[1] Reference No. 447.

[2] P. 238 *et seq.*

[3] This method of control operates very largely by causing the arc to pass backwards and forwards from the active to the inactive state. Compare Reference Nos. 484, 485.

[4] Pp. 16-19.

[5] Reference No, 485.

one or more microphones in series (if more than one is desirable) with a suitable resistance across the arc terminals (Fig. 199). The shunt valve or magnetic microphone methods (pp. 272, 276) should be particularly suitable for this style of control. The microphones might evidently also be arranged in shunt to the condenser C_1, or inductance L_1, in the main oscillation circuit of the arcs, on the lines of the arrangements occasionally used when intermediate coupling circuits are employed (p. 244). When the arcs are arranged directly in the aerial circuit (compare p. 158) these shunt controls become essentially the same as those already mentioned, viz. with the microphones either directly in series with the aerial circuit, or in shunt to, or coupled with all or part of the inductance in that circuit; or in shunt to the arc generator itself.

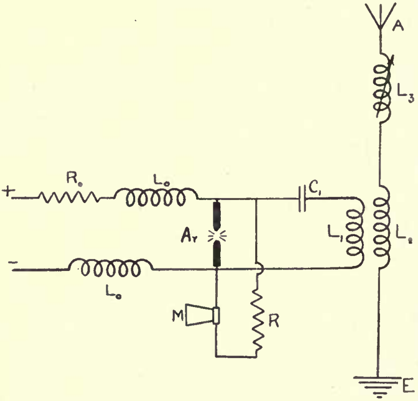

Fig. 199.—Shunt Microphone Control for Arc.

In some cases, with low power apparatus, it may prove feasible to modulate the output from the arcs by control of the arc length from the transmitting diaphragm under the influence of the speaker's voice. This arrangement has been used for experimental work,[1] but has little to recommend it, as the changes are usually far too irregular.

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[1] Reference No. 683.

VACUUM OSCILLATION GENERATORS

These on the whole may fairly be said to be the easiest types of oscillation generator to control microphonically, for the reason that the whole plate circuit current is completely under the control of the potential applied to the "grid" electrode of the valve. If, therefore, this potential is controlled microphonically in any convenient manner, the output of oscillatory energy is likewise controlled. As a second alternative, the potential applied to the plate circuit of the valve may be varied microphonically; while as a third possibility the microphone may control the filament current of the valve.

These generators are therefore eminently adapted for an extremely simple and efficient microphone control from an ordinary land-line telephone circuit and subscriber's instrument.

One mode of procedure is to inject into the grid circuit of the oscillating valve a control voltage obtained from a microphone transmitter as indicated in Fig. 200.[1] A "telephone-transformer" L_1, L_2 has the microphone M and battery B connected in one winding, while the other, L_2, is inserted in the "grid" circuit of the oscillating valve V. It is usually necessary to shunt the winding L_2 by a condenser C_1, large enough to allow a free path for the rapid high-frequency current variations in the grid circuit, but at the same time not sufficiently large to form too great a shunt across L_2 for the currents of "speech" frequency. Should it prove necessary, a resistance could be inserted between L_2 and C_1, to damp out the effects of any undesired low-frequency resonance to harmonics of the speech wave. This control arrangement can, of course, be applied equally readily to any of the various connection schemes of the oscillatory valve that may be employed.[2]

In an indirect method of energy control of this type care must always be taken in suitably proportioning the constants of the various circuits, or distorted or "broken" speech will be obtained. If the control of the grid voltage is carried too far the oscillations will cease entirely and then recommence, giving very poor speech. A similar trouble may also be experienced if too great a variation is impressed upon either the plate or filament currents, as after a certain point is reached

[1] Reference No. 486.

[2] Chapter XIII.

the energy output is no longer linearly related to the controlling voltage from the microphone transmitter.

Any of the other methods of modulating the radiated energy (such as by a microphone in the aerial circuit) could be employed with vacuum oscillation generators; but as a general rule it may safely be said that none of these methods will be as effective or so convenient as the direct control of the grid potential of a modulating or amplifying valve, which is then used to control the output of the main valve oscillator, by direct action on to the aerial circuit.

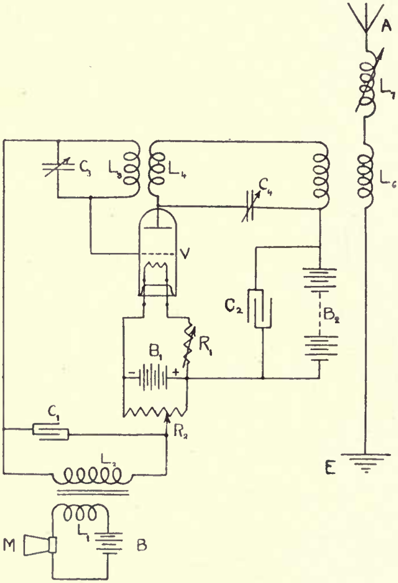

FIG. 200.—Microphonic Control of Vacuum Valve Oscillation Generator.

A good method of controlling the output from a valve oscillation generator, when connected up on the lines of the de Forest "Oscillion" and "Ultraudion" (Fig. 232)—*i.e.* with the main oscillation circuit joined between the Grid and

Plate—is to arrange the microphone as a variable resistance leak between the grid and the filament.[1]

With large oscillating valve units (using a number of valves in parallel) it becomes necessary to amplify up the current obtained from the initial transmitting microphone before applying it to vary the potential of the grid electrodes of the generating valves.[2] Potential variations of the grid electrode bring about a certain flow of current to and from that electrode.

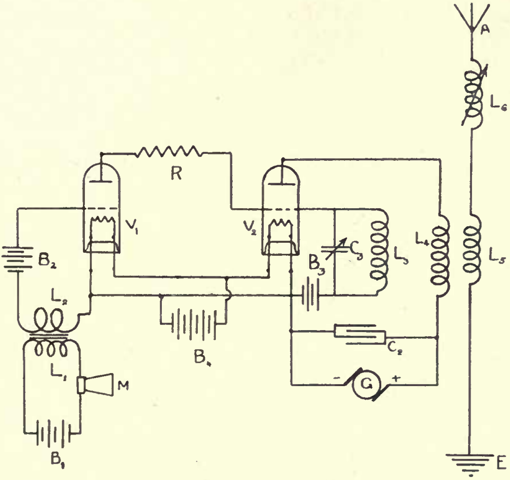

FIG. 201.—Microphonic Control of Oscillion with Amplifying Valve (G.E. Co., U.S.A.).

Hence a certain volt-ampere capacity is required in the microphone in order to bring about these potential changes. This volt-ampere capacity evidently increases with the number of valves used in parallel. Hence the need for amplification of the initial microphone variations when large numbers of valves are used. Efforts are made in the construction of the valves to reduce this grid current to as small a quantity as possible, but limits are always imposed by mechanical considerations.

This amplification may be secured by the use of the same

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[1] Reference No. 681.

[2] Reference No. 490.

type of vacuum apparatus arranged as a simple amplifier. The initial microphone transmitter may be caused to control the grid potential of one or more of these amplifiers in parallel, and the amplified currents (of " speech " frequency) from the plate circuits of these, arranged to operate upon the grids of the main oscillation generators. Fig. 201 represents one possible arrangement in which the microphone M (and battery B_1) controls the potential of the grid electrode of the amplifying valve V_1. The plate circuit of this amplifier is directly connected to the grid of the oscillating valve V_2, thence *via* L_3 and the adjustable battery B_3, back to the common filament battery B_4. The energy of the high-frequency oscillations is supplied from the direct current generator G in the usual manner. This arrangement is due to the General Electric Company (U.S.A.). When distinct filament heating circuits and batteries are used for the two valves, it becomes necessary to form a separate closed circuit for the plate electrode of the amplifier, and to couple this inductively or conductively with the second grid circuit. The common heating battery arrangement is, however, much more convenient in practice, especially when a large number of valve units are in use.

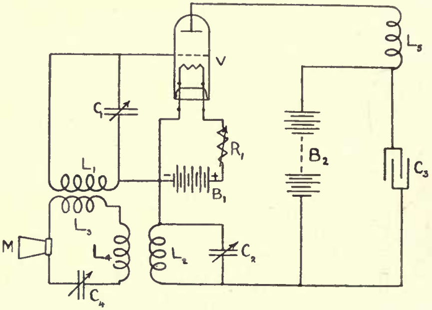

FIG. 202.—Microphonic Control of " Return-Coupling " of Vacuum Oscillation Generator (H. J. Round).

In place of the direct control of the grid potential of the vacuum oscillation generators, it is possible to arrange the modulation to take effect upon the energy that is handed back from the plate circuit to the grid to maintain the oscillations. For this purpose the microphone may be placed in an intermediate circuit forming part of the " return-coupling " of the valve.[1] This control arrangement is indicated in Fig. 202. The return-coupling between L_2 (in the plate circuit) and L_1 (in the grid circuit) is provided by the circuit L_3, L_4, C_4, which includes the microphone M. This circuit may with advantage be tuned to the oscillation frequency of the valve, by means of the condenser C_4. Many other modifications of

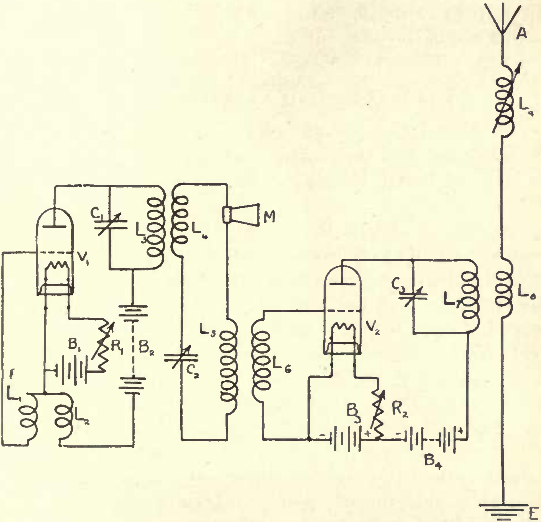

FIG. 203.—Microphonic Control of Coupling between Valve Oscillator and Amplifier (H. J. Round).

this general idea are possible, especially when there is one or more amplifying stages as well as the main oscillation generator. For instance, Fig. 203 shows an intermediate circuit including the control microphone arranged to couple the oscillating valve V_1, on to an amplifier unit V_2, by which the energy of the oscillations are amplified before being handed over to the aerial circuit.

Another useful method, patented by the General Electric

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[1] Reference No. 317.

Company (U.S.A.), involves the use of an additional grid electrode to the oscillation valve.[1] One grid electrode is then employed in conjunction with the plate circuit to generate the oscillations in the usual manner, while the other is connected solely to the microphone circuit. Potential variations of this grid electrode influence the strength of the electron stream passing through it to the main grid and plate, and so bring about corresponding variations in the intensity of the main oscillations. Some reduction in the necessary volt-ampere capacity of the control circuit may be effected by this arrangement.

ALTERNATORS AND FREQUENCY RAISERS

These oscillation generators are, of course, susceptible to effective control of their energy output by any of the general methods of aerial circuit control that have been already dealt with.

The output of any alternator is also as much dependent upon the strength of its field as the output of an oscillating valve is upon its grid electrode potential. Modulation of the exciting current of the alternator is therefore an additional method of control that is available when the magnetic circuit is suitable for the purpose.[2] The entire magnetic circuit must be well laminated, and the inductance of the windings reduced as much as possible. Field control is impossible in all machines having a solid steel rotor. A difficulty that arises when the field current or the output of the alternator are modulated in any way is the large variations in speed that are liable to take place as a consequence of the load variations. An exceedingly sensitive and rapidly acting governor mechanism is therefore necessary to control the speed of the driving motor. In the use of the Goldschmidt alternator for telegraphic work, it is found desirable to arrange the sending key by which the load on the machine is varied during signalling, to also control the field circuit of the (electric) motor used to drive the alternator. It is thus possible to weaken the motor field by the proper amount when the load is on the alternator to maintain it running at the same speed as with the load off.

Should any such arrangement prove necessary in telephonic work (apart from the use of sensitive speed governors), it

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[1] Reference No. 682.

[2] Reference No. 488.

should be possible to arrange some form of differential microphone transmitter to control the field current of the driving motor as well as the field of the H.F. alternator. By careful adjustments the speed could then be maintained constant. Amplifiers would, of course, be necessary in both circuits to enable an ordinary hand microphone transmitter to be employed. Alternatively liquid or similar heavy current microphones could be arranged in each circuit, and placed under the direct control of a small local transmitter.

In cases where other prime movers than an electric motor are employed for driving the high-frequency alternator, different arrangements must be adopted to maintain a constant speed. For example, a second machine may be rigidly coupled to the same driving shaft, and arranged with suitable loading to be able to absorb as much power as is involved in the necessary microphonic variations in the output of the high-frequency machine. The field windings of the two machines may then be interlinked with some form of differential microphone, so that when under the action of the speech the sum of the outputs of the two machines remains constant—as much load being removed from the auxiliary machine as is put upon the H.F. alternator, and *vice versa*.[1]

A constant running speed is thus made possible in a fairly easy manner, but at the expense of increased capital cost and considerably reduced efficiency, owing to the large wastage of power by the auxiliary machine. The second machine may be a direct current dynamo or a low-frequency alternator as most convenient.

With most forms of frequency raiser that have been described, there is some direct current control which can be adapted to microphonic control. Taylor's and Joly's static frequency raisers may be mentioned as being specially suitable for this purpose. A medium-frequency alternator combined with a frequency-raising unit is therefore both a convenient means of generating high-frequency currents and susceptible to comparative ease of microphonic control.

In many instances the d.c. control current would be too large to be handled directly by an ordinary carbon microphone transmitter unless an amplifier unit is inserted as well. A number of audion amplifiers in parallel could be used.

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[1] Reference No. 487.

Summary of Controls

In summarising the methods of voice control of the energy radiated from the wireless telephone transmitting station, it is abundantly evident that a great variety of methods exists, some of which, directly controlling the intensity of the oscillations in the aerial circuit, are equally applicable to any form of high-frequency oscillation generator. Some of the best forms of electromagnetically controlled liquid microphone are useful for direct insertion in the circuit or for shunting off the energy from the aerial, as desired. The shunt method of control appears to be the most useful, as it is adaptable to deal with almost any desired energy output.

Until the construction of large output, robust, and cheap valves has been successfully achieved on a commercial scale, the beautiful ease of control that they furnish must necessarily remain practically unused, except for low power and experimental work, and the shunt valve microphone arrangement.

The whole subject of the microphonic control of large amounts of high-frequency energy has, up to the present, been dealt with in a rather haphazard manner, with very few really quantitative determinations of the utility, efficiency, or other factors connected with the instruments, and their field of usefulness and limitations. The result is the miscellaneous collection of diverse ways and methods that has been briefly set out in the preceding pages, where some attempt has been made at their systematic classification.

It is true that the aim of experimenters and inventors has always been directed towards devising some apparatus that will enable the voice to control as large an amount of power as possible, but except in a few instances the problem does not appear to have been attacked in any very systematic manner.

An essential to further real progress will probably lie in exhaustive quantitative testing of different microphone constructions, and of different methods of control, somewhat after the manner in which the commercial testing of telephone transmitters is now carried out by the British Post Office and other administrations.[1] Such testing has, in fact, been reduced quite to a standard of engineering precision. It is no longer sufficient merely to state that "Mr. —— telephoned

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[1] See, for example, Reference Nos. 491, 492.

wirelessly to his friend ——, x miles away, using an aerial y feet high, by means of his new microphone transmitter." Exact measurements must become the order of the future.

The mode of operation of the microphones requires minute study and all details of construction need to be improved as much as possible, just as the carbon microphone has been similarly treated.[1]

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[1] Reference No. 493, etc.

CHAPTER XIX

THE EFFICIENCY OF WIRELESS TELEPHONE TRANSMITTERS

An important question that arises when considering the commercial value of various methods of wireless telephony is the efficiency of generation of the required high-frequency oscillations, as affecting the running costs of the apparatus. The efficiency varies very considerably with the type of oscillation generator employed. It is usually lowest for the open type spark-gap, and highest for the alternator and vacuum types of generator.

The actual efficiency of an oscillation generator is rather a difficult matter to determine correctly, since one is ordinarily concerned with the amount of energy actually *radiated* as compared with that supplied to the apparatus. The measurement of the energy radiated from an aerial is not, however, an easy one to perform. It is generally a quantity that is either rather vaguely guessed at, or else estimated by difference after deducting all the known losses. Some of these losses—notably the losses in the aerial by brushing, etc., and in the more or less unknown resistance and absorption in the earth connections—are, however, rather difficult even to estimate. The final figures obtained for the actual radiation can therefore only be rough approximations.

When comparing the various methods available for wireless telephony with one another, the types of current oscillations set up in the aerial with each arrangement are so nearly alike that these " aerial " losses will be very much the same fraction of the whole input to the aerial in all cases. A very fair idea of the usefulness of any particular oscillation generator may therefore be obtained from a consideration of its total output of high-frequency energy as compared with the corresponding mechanical or electrical energy input.

The actual figure for this efficiency of generation of H.F. energy is liable to be considerably modified by the particular constructions and circuit arrangements that are adopted. No more than a very brief outline of the general figures to be expected can therefore be given.

In connection with this efficiency too much stress cannot be laid on the necessity for attention to small and apparently insignificant details in the construction and installation of the apparatus. Such details may have greater effect upon the overall efficiency and high-frequency output than would at first be thought possible. For instance, the coating of the surfaces of a quenched spark-gap with silver instead of copper gives a great improvement in its efficiency and output; or again, a slight inaccuracy in the milling of the slots or teeth of a high-frequency alternator can produce a serious decrease in the available output. With the Goldschmidt machine, described on p. 209, it has been found that about 25 per cent of the high-frequency output is lost if the slots on the rotor are about 1 part in 1000 out of parallelism with the axis of rotation.

In the first place, we have the early attempts at spark transmitters, but these are of no importance as compared with modern methods. A coupled spark transmitter of this type rarely had an efficiency greater than 10 per cent, while the microphonic control of the output or of the rate of sparking would lower this figure still further.

When we consider the case of the quenched spark-gap transmitters we find a much better state of affairs. Under favourable conditions, efficiencies (in the sense used above) as high as 75 per cent have been claimed, while figures of 50 per cent to 60 per cent have been measured on many occasions.[1]

The Chaffee quenched spark-gap for generating sustained oscillations, although it has proved very satisfactory in operation for this purpose, does not appear to show such good efficiencies as the quenched spark-gaps operated on alternating current. In general it is found that this is the case with all types of quenched gaps used on continuous current. It arises through greater heating in the gap itself, and in the additional power loss in the series resistance that is essential with a direct current supply. The quenching action is also less efficient than with alternating current.

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[1] Reference Nos. 494, 495, 496.

A typical efficiency curve for a Chaffee gap is given in Fig. 204.[1] The rotary pattern of this gap [2] is said to yield a much higher efficiency than the stationary one.[3] Possibly this arises through a better quenching action with the rotating electrodes.

The employment of a multiphase supply current with either quenched or rotary spark-gaps [4] enables more favourable results to be secured.[5] The quenching action of the spark-gaps becomes much more efficient with a properly tuned alternating current supply using "resonance transformers" than when direct current is used, so that the losses are smaller and the overall efficiency higher.[6]

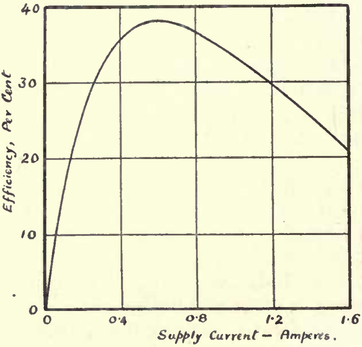

FIG. 204.—Efficiency Curve of Chaffee Spark-Gap (E. L. Chaffee).

An important point in connection with the operation of multiphase quenched spark transmitters is the harmful effect of the overlapping of successive wave trains in the aerial, as pointed out on p. 107. With quenched spark transmitters it is practically impossible to ensure that the sparks shall take place with such regularity in the separate phases, that the successive wave trains set up in the aerial shall assist one another if they overlap—as they are almost bound to do with very high spark frequencies. There is no such definite means with the quenched gap as with the rotary of determining the

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[1] Reference No. 146.
[2] P. 70.
[3] Reference No. 118.
[4] Pp. 105 and 109.
[5] Reference No. 527.
[6] Reference No. 498; see also No. 526.

actual instant at which each spark discharge shall take place. The irregular overlapping of the successive wave trains in the aerial circuit is detrimental to the efficiency of the set, since the aerial current is not so great as it otherwise would be if there were no neutralising and cancelling out of the oscillations by the interfering wave trains.

This effect of wave interference on the transmitter efficiency was brought out in some tests by E. J. Simon and L. Israel, to which a reference has already been made.[1] The curve given in Fig. 205 sets out the results of their experiments.[2] The abscissæ of this curve are the total effective resistances of the aerial circuit (including the radiation resistance), which was varied by adding non-inductive resistances in series with the aerial. The greater the resistance that is inserted, the greater becomes the decrement of the circuit,[3] and the more rapidly are the wave trains damped out. It is evident from the curve that the efficiency rapidly rises as the resistance is increased, reaching a maximum of about 60 per cent with 13 ohms resistance. This figure is approximately the same as that for one phase taken alone. Calculations showed that with this amount of resistance in the circuit the amplitude of each wave train had died down to about $\frac{1}{500}$th of its maximum before a fresh one commenced. The interference was therefore negligible under these conditions, whereas it had been very considerable before the resistance was added.

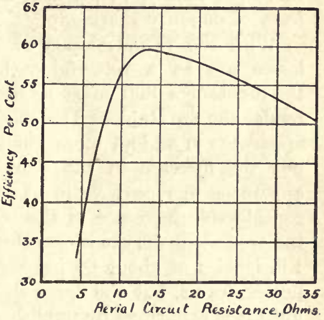

FIG. 205.—Efficiency Curve of Multiphase Quenched Gap Transmitter (E. J. Simon and L. Israel).

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[1] Pp. 106, 108.

[2] Reference No. 197

[3] The relation between the decrement of a circuit and its total resistance is given by

$$\delta = \frac{R \times 10^9}{2nL},$$

where R = resistance of circuit in ohms; n = frequency of the oscillations per second; and L = the total inductance in the circuit in centimetres; δ = decrement per complete period.

To adopt this expedient with the much higher sparking rates required for telephony would, however, be extremely wasteful of the high-frequency energy, since much larger resistances would be required to separate the wave trains. With very high sparking rates there is, however, a much greater tendency for the successive wave trains to fall into synchronism, so that the best arrangement is generally to omit any such damping resistances in any form.

The very effective quenching action of the mercury vapour spark-gaps should be conducive to high efficiencies. The losses in this apparatus are, however, found to increase with the frequency.[1] E. Weintraub has stated that efficiencies up to 70 per cent or 75 per cent are obtainable with his special form of mercury spark-gap.[2]

With the various kinds of arc oscillation generator, the losses are as a rule fairly high, on account largely of the resistances that must be inserted in the supply circuit to render the arc stable. The efficiency of the small sizes of arc apparatus is seldom more than 15 per cent to 20 per cent, but the increase in the size and output of this type of apparatus in recent years has at the same time resulted in considerable increases in the efficiency. Particularly is this the case when the arc is operated directly in the aerial circuit. Efficiencies of about 60 per cent have been claimed for the newest forms, but the figure should be accepted with caution until it is confirmed by published accounts of actual measurements.

In the usual mode of operating arc generators from a high voltage source at constant potential, there must of necessity be considerable losses in the series resistances. There are, however, grounds for expecting a higher overall efficiency by utilising a dynamo having a fairly steeply falling characteristic [3] instead of a constant voltage machine. It then becomes possible to dispense with a considerable portion of the usual series resistances, with a consequent diminution of the losses.[4] The desired falling characteristic of the dynamo may be very easily secured with a suitable compound wound machine, by connecting the compound or series field windings in the reverse direction to the usual, so that their field opposes and weakens

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[1] Reference No. 497.

[2] P. 83; also Reference No. 180.

[3] That is to say, a machine whose terminal voltage decreases rapidly as the load current is increased.

[4] Reference Nos. 499, 500.

the main shunt field by an amount that increases with the load. This effect may be further enhanced by using the "long-shunt" connection for a self-excited machine (Fig. 206). An adjustable diverter in parallel with the series field windings could be utilised to regulate the steepness of the characteristic of the machine, and so to adjust it to be the most suitable for the arc in use.

Very few actual measurements appear to have been made in connection with the generation of continuous oscillations by the "vacuum-valve" methods; as to the amount of high-frequency energy that can be drawn from a given-sized bulb and with a given expenditure of direct current energy in the plate and grid circuits; as to the extent of the necessary losses in the heating of the filament; and as to the efficiency of conversion from direct-current energy to high-frequency energy.

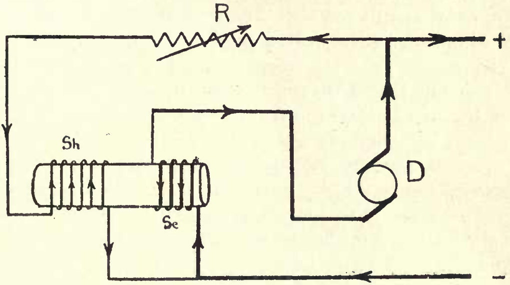

Fig. 206.—Arrangement of Compound Wound Dynamo to give Falling Terminal Characteristic.

The loss in the filament heating circuit will be more important in the smaller units than in the large ones. There is again considerable heating of the tube and electrodes when large currents are passing through the plate circuit, which must decrease the efficiency of the whole apparatus.

A fair proportion of the direct-current energy supplied to the plate circuit should reappear as high-frequency energy in the tuned circuits associated with the valve, and this efficiency of conversion should be fairly high (neglecting the filament heating losses). The overall efficiency may be taken as under 50 per cent.

The many advantages of this type of apparatus would probably outweigh any unavoidably low efficiency in large units. There is therefore yet very considerable field for experiment and research in this direction.

The alternator class of oscillation generators show on the whole fairly good efficiencies. The losses are entirely the copper losses in the windings, and the hysteresis and eddy current losses in the iron. With very high speed alternators, there is added to these a windage (air-friction) loss that may be fairly considerable. There is, however, an entire absence of any large direct heat losses such as occur in arc (and spark) apparatus. The 150 kw. Goldschmidt alternator installed at Tuckerton Station (U.S.A.) gives an output of 117 kw. in the aerial circuit for a direct-current input of 217 kw.—thus showing an efficiency of 54 per cent when operating continuously as required for telephony.[1] Efficiencies up to about 80 per cent have been claimed for these machines, but do not yet appear to have been realised in practice.

With all magnetic alternators for the generation of high-frequency currents very considerable loss is liable to occur through the hysteresis and eddy current losses in the iron, unless extreme care is taken in the lamination and preparation of the core, and in the choice of the most suitable steel. Considerable research has been carried out upon the losses that occur in iron plates of various thicknesses, at various frequencies. A good summary of these is to be found in recent papers by N. W. McLachlan.[2]

With electrostatic alternators there is the same source of loss through air friction at high speeds, but instead of iron and copper losses we have dielectric losses in the air and other insulating materials used in the construction of the machine, and eddy current losses in the metallic parts and conductors. Dielectric losses at very high frequencies may attain very considerable magnitude, unless great care is taken in the proper shaping of both the insulator and the conductor that is in contact with or in close proximity to it.[3] The electric stress in the insulating material must be reduced as much as possible.

It should be possible to design electrostatic alternators

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[1] Reference No. 501.

[2] Reference No. 503; also Nos. 502, 505, 506, 507, 508, 509, 510, and 513.

[3] Reference No. 512.

having an efficiency at least as high as, if not higher than, that obtainable with electromagnetic machines. It has been suggested that the windage losses in these machines might be diminished by running the whole machine in a vacuum. A very high vacuum would be necessary in order to prevent ionisation of the residual gas by the high potentials developed in the machine. Difficulty might then be experienced in maintaining the high vacuum joints unless the machine is either combined with or made to act as its own air-pump. A construction so that the parts of the machine itself served as a Gaede high-vacuum "molecular" air-pump might be a possible one with this end in view.[1]

Static frequency raisers on the whole give promise of very fair efficiencies, although they cannot reach the figure usually associated with a good transformer, on account of the extra sources of loss. Both the iron and copper losses increase considerably at high frequencies. Increased losses also occur through eddy currents and "skin-effect" in the windings. The iron losses must be kept down by fine lamination of the core, and the copper losses by careful stranding and insulating of the windings. The direct current magnetisation often used means an additional expenditure of energy on the input side, with consequent lowering of the efficiency.

Low-frequency measurements indicate efficiencies ranging between 60 per cent (Spinelli's arrangement) and 86 per cent (Taylor's 28 kw. frequency tripler). An efficiency of 90 per cent is anticipated for large installations. No measurements appear to be available for these frequency raisers at high frequencies. The efficiencies will be less at high frequencies, but not very much so if the design is carefully carried out. Measurements made with Joly's Frequency Tripler at about 10,000 $\backsim$ indicate an efficiency of the order of 33 per cent.[2] H. Boas has suggested an ingenious mode of increasing the efficiency of this class of apparatus by reducing the losses by heating the iron cores. Both hysteresis and eddy current losses fall off very rapidly at high temperatures. Temperatures up to 700° C. have been recommended.[3] The additional expenditure of energy required to maintain the cores at this temperature should also be reckoned in the final efficiency determination. Difficulties would probably be experienced in adequately insulating the windings at these temperatures.

[1] Reference No. 408. [2] Reference No. 415. [3] Reference No. 504.

The efficiency of the alternating current arc type of frequency raiser[1] has been studied in some detail by H. Rukop and J. Zenneck.[2] The alternating input to the arc at the initial frequency was measured by a wattmeter in the usual manner, and the output at the higher frequency deduced from the R.M.S. current in the circuit as measured by a hot-wire ammeter. With the oscillatory circuit tuned to three times the fundamental frequency, efficiencies of 49 per cent and 41 per cent were measured when the fundamental frequency of the supply was 4000 ∾ and 8000 ∾ respectively. The second test, giving an output current at 24,000 ∾, is approaching the practical cases required for wireless telephony. At very high frequencies the efficiency would apparently not be very good if it continues to decrease with further rise of frequency, as these figures appear to indicate. The reason for this falling off is probably to be found in the increase of the arc hysteresis at high frequencies partially neutralising the curvature of the arc characteristic upon which the method is entirely dependent.

We have up to the present been dealing entirely with the efficiency of the apparatus *inside* the transmitting station itself, as distinct from the efficiency of the actual transmission between the stations. This latter is often assumed as being the same whatever type of waves is being radiated from the transmitting station. Many recent measurements have, however, indicated a higher transmission efficiency for purely undamped waves as compared with damped wave trains, apart altogether from the relative efficiency of the detectors used in each case. On the other hand, some observers have not found any such effects. The differences, if any, would appear to be dependent upon the wave-length employed, and especially upon the distance between the transmitting and receiving stations. The locality on the earth's surface might possibly also exert some influence upon the result.

The importance of this difference in radiotelephony lies in the fact that in practically all cases undamped, or very nearly undamped, persistent waves are employed, as compared with damped waves for the great majority of (musical note) spark telegraphy.

For example, C. F. Elwell has described tests in which the undamped waves yielded inferior results as compared with an

[1] P. 235.

[2] Reference No. 433.

ordinary spark station, when working over short distances of a few hundred miles, but very much superior results for a range of 2000 miles. An arc was used as the source of the undamped waves.[1] G. Arco, on the other hand, favours the view that quenched spark and alternator oscillation generators yield exactly equal transmission efficiencies, even over long distances,[1] but this view is not borne out by L. W. Austin's experiments in this direction.[2] He found that the difference between damped and undamped wave transmission began to be marked at a range of about 1400 miles, and that the difference (in favour of the undamped transmission) *increased* with all further increases of range over that figure.[3]

The effect in any case is rather an obscure one, and is dependent upon so many variable conditions in the course of the transmission through the atmosphere that very extensive and exhaustive experiments on a large scale are required in order to arrive at any definite conclusions as to the mechanism of the variations. It would seem probable that the more uniform radiation of the undamped wave is capable of more exact reflection and/or refraction by the ionised layers of the upper atmosphere (the Heaviside layer), with the result that a greater quantity of energy ultimately reaches the distant station. The actual existence of this exact reflection (or refraction) has been demonstrated in the phenomena of interference which it has been shown are sometimes liable to occur with undamped wave transmission.[4] It appears that, on the whole, very long distance wireless telephone transmission (with undamped waves) may prove to be more efficient than wireless telegraphic transmission (with damped waves) over the same distances.

SOURCES OF CURRENT FOR WIRELESS TELEPHONE TRANSMITTING APPARATUS

With some forms of transmitting apparatus that have been described in previous chapters, alternating current is employed for feeding the apparatus. When this is the case, the provision of a high voltage supply, when such is necessary, is an extremely simple matter, as ordinary static step-up transformers (suitable to the frequency in use) may be

[1] Reference No. 515.
[2] Reference Nos. 516, 518.
[3] Reference No. 519.
[4] Reference Nos. 520, 521.

employed. When this initial frequency is moderately high —say from 1500 to 6000 ∾—very little iron is required in these transformers, especially if resonance of both primary and secondary circuits to the supply frequency is adopted; but care must be taken that what iron is employed is extremely well laminated, especially if the frequency is at all high.[1] In extreme cases fine iron wire cores have been used with advantage. With such apparatus the maximum permissible working voltage is determined not by the transformer, but by the particular spark, arc, or other working apparatus that may be in use.

In the operation of quenched spark-gaps from alternating current transformers it is often advantageous to design the transformer with considerable magnetic leakage, so that the secondary voltage falls off at the instant the discharge jumps across the gap.[2] This hinders the formation of an arc discharge across the gap. The extra magnetic leakage may be provided in a number of ways—for example, by designing the transformer with a magnetic shunt, which may be varied as desired, and by disposing the primary and secondary windings on opposite limbs of the core; or by the addition of an external inductance in either (or both) the primary and secondary circuits.[3] This latter method admits of greater flexibility to secure the most favourable results, since the value of the inductance may be very readily varied. Similar results may be secured by designing the supply alternator to have a steeply falling characteristic.

Where direct current is necessary to supply the transmitting apparatus the case may be very different. In certain instances ordinary supply voltages—say from 200 to 500 volts—may be directly utilised, but in a large number of cases higher voltages than this are required. This necessitates a special high voltage dynamo, which is usually rather a costly article. The reason for this is largely to be found in the difficulties encountered in the construction of the commutators for high voltage work. The voltage between adjacent segments of the commutator must be strictly limited to avoid any risk of flashing over, so that the number of segments becomes very large, especially with a multipolar machine. In practice machines up to about 5000 volts have been built,

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[1] Reference Nos. 522, 523, 524, 525.

[2] Reference Nos. 523, 524.

[3] Reference Nos. 528, 529, 530, 531.

and for higher values several machines must be connected in series.[1] In the ordinary way it is far from economical for wireless purposes to exceed about 5000 volts with direct current, except for very large and high power stations.

A simpler and cheaper arrangement for moderate powers may be obtained by the use of high-voltage rectifiers (see Chapter XX. p. 305).

These rectifying valves used in conjunction with an appropriate smoothing condenser and smoothing circuit have proved to be an extremely practical method for securing the necessary high-voltage supply for oscillating valve wireless telephone transmitters. The initial alternator supply frequency should be as high as practicable (in any case, over 150 ∾) so that the size of the smoothing condensers may be reduced. Best results are secured by the use of two valves so that both half-waves are utilised. The same A.C. supply may be used, if desired, for heating the filaments of the rectifying and oscillating valves.

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[1] Reference No. 526. See also No. 532.

CHAPTER XX

THE BRAUN TUBE OSCILLOGRAPH, AND ITS USES IN EXPERIMENTAL WORK

In any investigation into the working of any particular piece of apparatus with a view to determining a theory of its mode of operation, or its efficiency of working, it is very advantageous to be able to study the actual wave-forms, phase relationships, and other data connected with the currents and voltages in the various circuits. A much clearer idea of the working of any particular piece of apparatus is obtained when we can " see what is going on " inside.

For low-frequency circuits the ordinary Duddell oscillograph, or the Irwin hot-wire oscillograph, is suitable, especially when provided with a falling-plate or similar attachment for photographing non-repetitive phenomena. With the high frequencies in use in most circuits associated with wireless apparatus, this type of apparatus is quite useless, and the only form that can be used for this purpose is that known as the Braun Cathode-Ray Oscillograph. In this instrument use is made of a stream of rapidly moving cathode rays (*i.e.* electrons) in an exhausted tube. These can be deflected from their normal direction either magnetically or electrostatically by the currents or voltages to be investigated, and their movements traced on a fluorescent screen placed inside the tube. Owing to the very high velocities reached by the stream of electrons which constitute the cathode rays, and to their minute mass and inertia, they are capable of responding accurately to very small forces at very high frequencies. They are therefore able to delineate on the screen the correct wave shape of the currents or oscillations if suitable arrangements are made for that purpose.[1] Fig. 207 is a diagram of a typical form of Braun tube. It consists of a glass envelope,

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[1] Reference Nos. 533, 534, 535, 544.

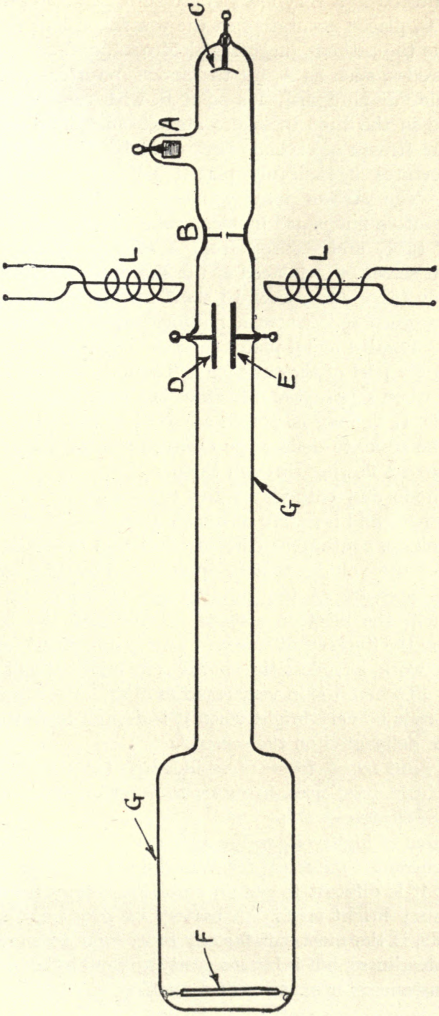

FIG. 207.—Braun Cathode-Ray Oscillograph.

G, G, exhausted to a very low gas pressure, and containing an electrode C, placed accurately in the central axis of the tube to serve as the cathode (negative electrode), and one or more side electrodes, such as A, for the anode (positive electrode). One or more diaphragms, such as at B, with very small holes are placed in the tube to secure an extremely fine pencil of rays. The stream of cathode rays must be directed through these apertures by suitably placed permanent or electromagnets. The stream may conveniently be further concentrated into a fine pencil by means of a coil wound coaxially with the tube, and excited from a storage battery. The fluorescent screen, F, is placed at the end of the enlarged bulb part of the tube, and serves to show up the position of the beam as a green spot where it impinges upon the fluorescent material. Parallel metal plates such as D and E are mounted in the narrow part of the tube for deflecting the beam electrostatically when a potential difference is set up between them. Small coils, L, L, may be placed adjacent to the same portion of the tube so as to deflect the electron stream magnetically by the current flowing through them.

The anode and cathode of the tube must be connected to the positive and negative terminals respectively of a source of high-voltage continuous current of several thousand volts. The higher the voltage that is applied to the tube, and the lower the pressure of the residual gas is made, the more intense does the electron stream become and the brighter the spot on the fluorescent screen. This is important for high-frequency work, as unless the spot is very bright it will not be visible at all when it is in very rapid motion. More especially must the spot be very bright when it is desired to photograph the curves delineated on the screen.[1]

In the most recent forms of oscillograph tube, hot filament cathodes have been used in order to secure a more copious emission of electrons.

As source of high voltage for such tubes, a special form of "heavy-current" influence (or Wimshurst) machine may be used, but it is difficult to obtain sufficient energy from them to yield very bright spots. A battery of very small storage or dry cells is the most satisfactory source, on account of its extreme steadiness, but is far too costly an item to be available in most instances for experimental work.

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[1] Cf. Reference No. 543.

Another possible source lies in the use of one of the forms of high-voltage vacuum rectifier, in conjunction with an ordinary step-up transformer on an alternating current supply.[1] The rectified current should be stored in a condenser in order to obtain a steady stream of energy for supplying the tube. Fig. 208 shows one arrangement in which the alternating current supply is stepped up by the transformer T, and connected to the condenser K through the vacuum-valve

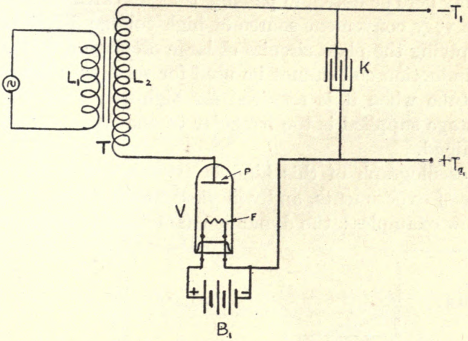

FIG. 208.—High Voltage Valve Rectifier for supplying H.T. Continuous Current.

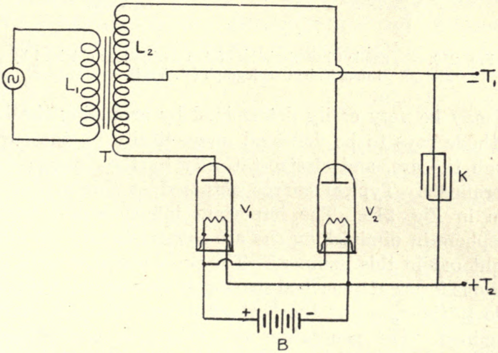

FIG. 209.—Double-Valve Rectifier for H.T. Continuous Current.

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[1] Reference No. 536.

rectifier V. B is a well-insulated storage battery for heating the filaments of this rectifier. A better arrangement is shown in Fig. 209, as both half-waves of the supply are then operative.[1]

It may here be noted, in passing, that this arrangement also forms a very convenient source of high-voltage direct current for supplying the plate circuits of large oscillating valves.

An induction coil cannot be used for supplying the oscillograph tube when it is required for high-frequency work, as the voltage supplied is too irregular to enable good curves to be obtained.

An oscillograph of this kind is available in a very great number of experiments, and will yield useful data. To name but a few examples: the dynamic characteristic of arc oscillations may be very easily determined by arranging the beam of cathode rays to be deflected magnetically by the current through the arc, and electrostatically by the voltage across its terminals. Typical curves obtained in this manner are shown in Fig. 210. The important influence of a coal-gas atmosphere in diminishing the arc hysteresis may be readily brought out in this manner.[2] The processes that take place in various forms of quenched spark-gap may be easily rendered visible to the eye, and the best conditions of operation thus determined. The generation of continuous oscillations by the Chaffee and similar spark-gaps has been demonstrated by this means.[3] A convenient connection for this purpose is shown in Fig. 211. The current deflecting coils L, L of the oscillograph tube O are connected in series with the secondary

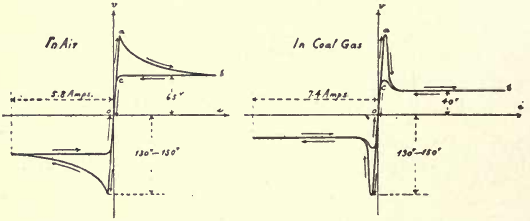

FIG. 210.—Dynamic Characteristics of Arc Oscillations obtained by Braun Tube Oscillograph (H. Yagi).

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[1] Reference No. 537.

[2] Reference No. 538.

[3] Reference Nos. 539, 540.

circuit L_2, C_2, coupled with the oscillation generator S (arc or spark-gap). The electrostatic deflecting plates D, E are connected across the same coils L, L. Since the resistance of the coils L, L may usually be neglected, the potential difference between the plates is given by

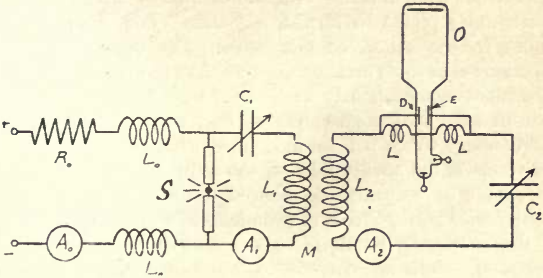

Fig. 211.—Arrangement of Braun Tube Oscillograph for Delineation of Cyclic Characteristics of Oscillations (H. Yagi).

$$v = \frac{L\,di_2}{dt},$$

that is, it is proportional to the rate of change of the current in the secondary circuit. Hence, if the axes of these two deflections are at right angles to one another, we obtain a cyclic diagram having the secondary current, i_2, for one axis, and the rate of change of this current, $\frac{di_2}{dt}$, for the other. If the oscillations are undamped, this diagram is an ellipse or a circle according to the adjustment of the scale of the magnetic and electric deflections. With damped oscillations the curve becomes a spiral. The number of convolutions of the spiral gives the number of complete oscillations of the secondary current between each impulse from the primary. Fig. 212 shows a few examples of this type of curve.

Fig. 212.—Types of Cyclic Characteristic Curves (H. Yagi).

The wave-form of the oscillations in a circuit may be delineated in the usual form—that is, with current or voltage as ordinates, and time as abscissæ—in a variety of ways, using the current coils in series with the oscillatory circuit, and the electrostatic plates to furnish a " time " deflection at right angles to the other, or *vice versa*. The difficulty usually experienced is to so arrange matters that the oscillations shall take place synchronously with the " time " deflection of the spot, in order that the cathode ray may trace out the identical curve many times per second, since without this repetition the trace of the spot would be too faint to be visible at all. One mode of securing the desired result is to connect the electrostatic plates across the condenser in the primary circuit of the spark-gap oscillation generator to furnish the time deflection, while the current coils are placed in series with either the primary or secondary circuit.

Various other arrangements are also possible. For instance, the wave-shape of arc oscillations has been deduced from the diagrams obtained by causing the oscillatory current to deflect the cathode beam magnetically, while a synchronous " sine " deflection is obtained for the other axis of the diagram by connecting the electrostatic deflection plates to a secondary circuit, which is very loosely coupled to the main oscillation circuit.[1]

These few examples will perhaps serve to illustrate the utility of the arrangement in examining the working of any piece of radiotelephone apparatus, though evidently they are not in any way exhaustive of its applications.

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[1] Reference Nos. 541, 542.

CHAPTER XXI

RECEIVING APPARATUS FOR WIRELESS TELEPHONY

In the preceding chapters, the chief features concerned with the generation, modulation, and transmission of the ether waves for wireless speech communication have been dealt with. The apparatus by which these same waves may be detected, and the speech rendered audible again at the receiving station, therefore remains to be briefly considered.

Since the waves utilised for speech communications are of the same nature as those customarily adopted for ordinary wireless telegraphic signalling, most of the receiving arrangements used for the latter purpose should also be available for receiving speech signals. A quantitative audible response is necessary in the receiver. It is therefore important to examine to what extent this condition is fulfilled by the various detecting arrangements in use.

The consideration of quantitative response, as well as their comparative insensitiveness, entirely rules out of consideration the early forms of coherers and detectors of like nature. The "auto-decoherer" types of coherer are more satisfactory as far as response is concerned, but they are too insensitive to meet the requirements of modern work.

The detector to be used must obviously be one that is suitable for actuating an ordinary form of telephone receiver, or some form of telephone relay or repeater, so that the received speech may be rendered directly audible or relayed on to land lines and heard in an ordinary telephone instrument at the far end. The most important detectors that are available for our purposes are, therefore, crystals, valves, audions, and similar receivers; magnetic or electrolytic detectors; and some forms of the heterodyne receiver.

Of magnetic detectors the most important is the well-known Marconi pattern, shown diagrammatically in Fig. 213, and complete in Fig. 214. The mechanism of the actions that take place in this detector when high-frequency oscillations are impressed upon the coil C (Fig. 213) are not altogether clear, and in fact it is quite possible that the precise action that does take place depends to a certain extent upon the adjustment of the magnets M_1, M_2.[1] In any case the iron

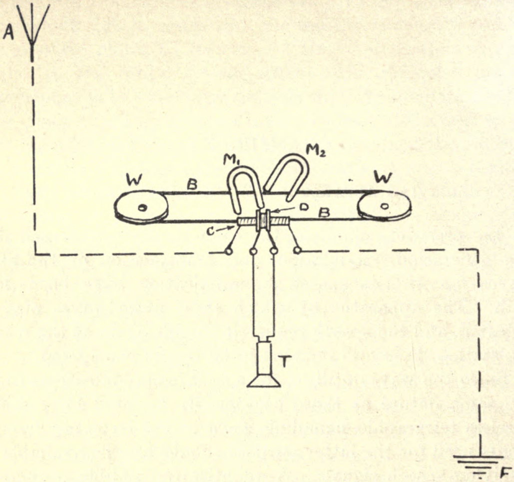

Fig. 213.—Marconi Magnetic Detector.

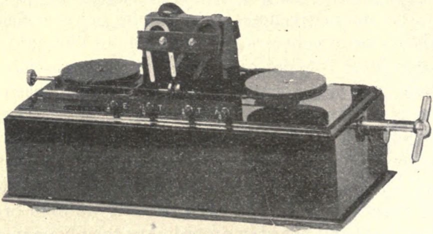

Fig. 214.—Marconi Magnetic Detector.

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[1] Reference No. 545.

band should be undergoing a state of magnetic change or reversal of magnetisation while it is passing through the coils, as it is then most sensitive to the action of the superposed oscillatory field from the coil C. It is desirable as a general rule to arrange the detector in a separate tuned circuit coupled to the aerial (Fig. 215) rather than directly in series with the aerial circuit as shown in Fig. 213. Sharper tuning can then be obtained, and a looser coupling can be employed.

Several other forms of magnetic detector have been devised by various experimenters, but their general principle is similar to that of the above pattern, and so need not be dealt with in detail.

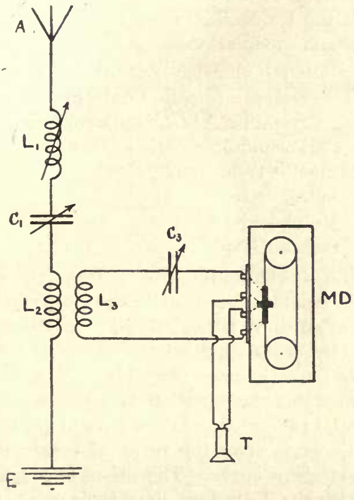

Fig. 215.—Circuits for Magnetic Detector.

Magnetic detectors as a whole are not nearly so sensitive as the majority of crystal and vacuum detectors, and their use for all classes of work is rapidly decreasing.

Electrolytic detectors—consisting of a minute point of wire, usually platinum, dipping into a dilute solution of acid—are very little employed at the present time. Their response is practically quantitative up to a point, beyond which it remains nearly constant for increased signal strength. Within these limits, therefore, they can be used for speech reproduction. The sensitiveness of good patterns is customarily intermediate between that of the magnetic and crystal receivers.

CRYSTAL RECEIVERS

Among crystal receivers practically all the usual combinations are available for use as wireless telephone receivers, although the most sensitive patterns should generally be chosen on account of the resulting advantages of the use of less power at the transmitter from the point of view of ease of generation and modulation.

The best combinations usually employed are :

" Perikon " (Zincite-Chalcopyrite).
" Crystallite " (Zincite-Bornite).
Carborundum-Steel.
Zincite-Tellurium.
Silicon-Steel.
Molybdenite-Copper.
Galena-Graphite.

Of these, the Carborundum-Steel, Perikon, and Zincite-Tellurium combinations are usually the most stable, and least liable to disturbance by either vibration or atmospherics.

With the Carborundum-Steel detector, it is essential to use an adjustable potentiometer (variable from zero up to about 2 volts), since this combination is most sensitive when a steady potential is applied to it—usually of value about 1 volt—in order to work upon the point of maximum curvature on its characteristic curve. The other two mentioned, viz. Perikon and Zincite-Tellurium, have their points of maximum sensitiveness either at or very near to the point of zero " boosting " voltage. With these a potentiometer is therefore not usually necessary, though occasionally better results may be obtained by the use of a very small applied voltage in the direction Zincite negative, and the Chalcopyrite or Tellurium positive.

The characteristic curve of a detector is the curve obtained by plotting the current passing through the detector for various applied " boosting " voltages against the applied voltage as abscissa. Some typical curves for crystal detectors are given in Figs. 216 and 217. It will be observed that these curves are far from linear, and that they show pronounced

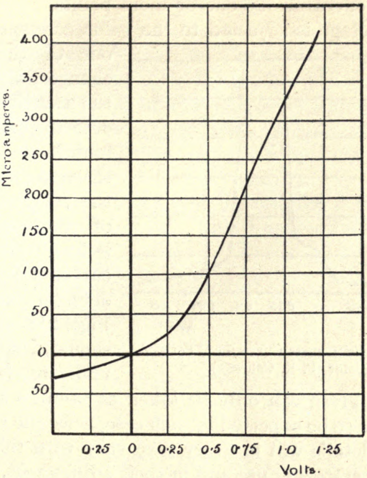

FIG. 216.—Characteristic Curve of Perikon Detector (P. R. Coursey).

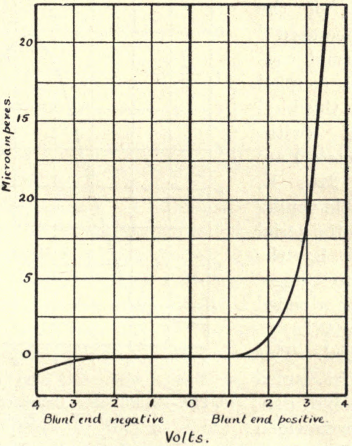

FIG. 217.—Characteristic Curve for Carborundum Detector (W. H. Eccles).

changes of curvature at one or more points. If the applied boosting voltage is adjusted to the value corresponding with one of these sudden changes of curvature, the sensitiveness of the detector will usually be found to be greater than at points where the change of curvature of the characteristic is less.[1] Sensitiveness curves for the above detectors are given in Figs. 218 and 219. It should, of course, be understood that the curves here given can only be taken as samples showing the *type* of curve to be expected in each case, since the exact shape, scale, and details will in every case vary with the particular samples of crystals in use and in their adjustment.

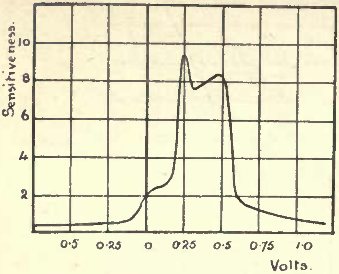

FIG. 218.—Sensitiveness Curve for "Perikon" Detector (P. R. Coursey).

The above-mentioned crystal combinations are all of fairly high resistance, and are therefore of the "potential-operated" type. The usual connections for a coupled receiver using this kind of detector (without potentiometer) are shown in Fig. 220. L_1 is an adjustable tuning inductance in the aerial circuit, and L_2 the primary of the jigger coupling the tuned detector circuit L_3, C_1 on to the aerial. This circuit may be tuned by the variable condenser C_1, across which the detector D and telephones T are shunted. The telephones

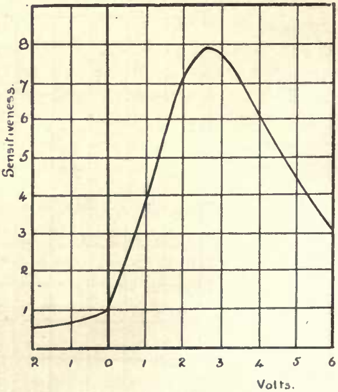

FIG. 219.—Sensitiveness Curve for Carborundum Detector (W. H. Eccles).

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[1] Reference No. 546.

are usually best placed in parallel with a small "blocking condenser" C_2, which forms a path for the high-frequency impulses from the condenser C_1, to allow them free access to the detector D, without their being damped out by the resistance and inductance of the telephone windings. This blocking condenser is usually a small fraction of a microfarad. The best value depends upon the telephones employed, and is best determined by actual experiment.

The telephones for use with a high-resistance detector must have many turns of fine wire. This implies that they also have a high resistance. A step-down telephone transformer should be used if low-resistance telephones are employed.

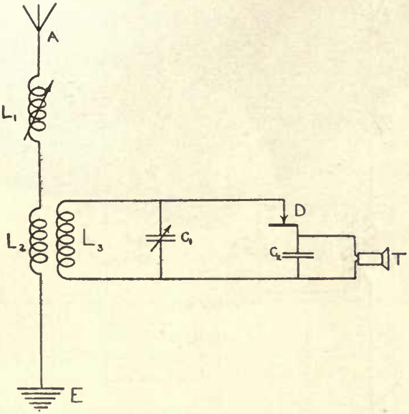

FIG. 220.—Circuit for "Potential-Operated" Crystal Detector without Boosting Voltage.

Fig. 221 shows the usual connection scheme for a crystal receiver with potentiometer and double crystal, enabling a second detector to be kept adjusted, and in readiness for instant use; and Fig. 222 a view of a similarly designed instrument constructed by the Marconi Company. The coupling between the coils L_2 and L_3 (Fig. 221) should be a variable one, since it is found that a fairly weak coupling is advisable in order to obtain purity of speech transmission, and to minimise interference from other telegraphic or telephonic stations, as well as from atmospheric disturbances.

The design of the tuning and coupling arrangements o these receivers does not depart in any way from those customarily used for telegraphic work; and the most important point is to ensure that the crystal receives the highest possible potential from the jigger secondary L_3. To this end the inductance of L_3 should be large and the condenser C_1 as small as possible consistent with good tuning, and taking into accoun any self-capacity of the coil, detector, and telephone connections which is additive to the capacity of C_1.

The response curve of a detector is a curve connecting the

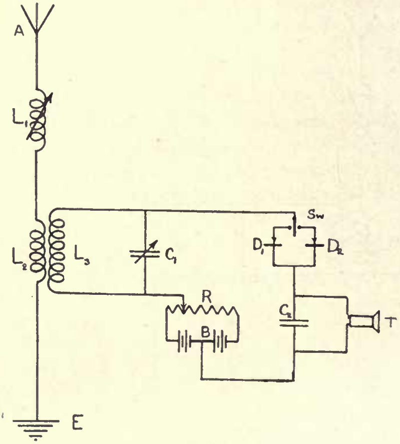

FIG. 221.—Circuits for Crystal Receiver with Double Detector and Potentiometer.

rectified current yielded by the detector with the square of the alternating potential difference applied to its terminals, or with the square of the oscillatory current flowing in the tuned circuit across which the detector is connected—that is to say, with a quantity proportional to the high-frequency energy supplied to the detector. The curve is therefore a measure of the sound produced in the telephones when a given oscillatory potential difference is applied to the detector—provided that the frequency of this applied potential is within the acoustic limit, or else that it is not continuous but has a group frequency well within the audible limits. In Fig. 223 are two

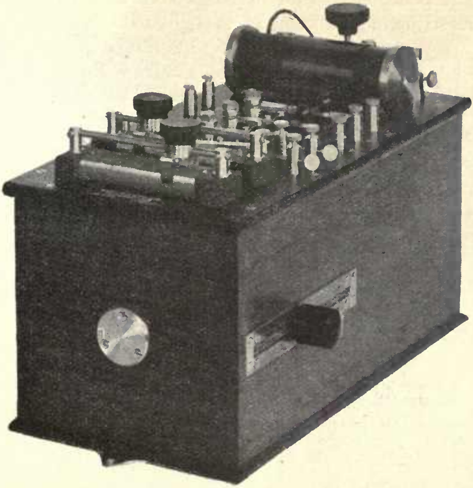

FIG. 222.—Marconi Crystal Receiver (Type 31A).

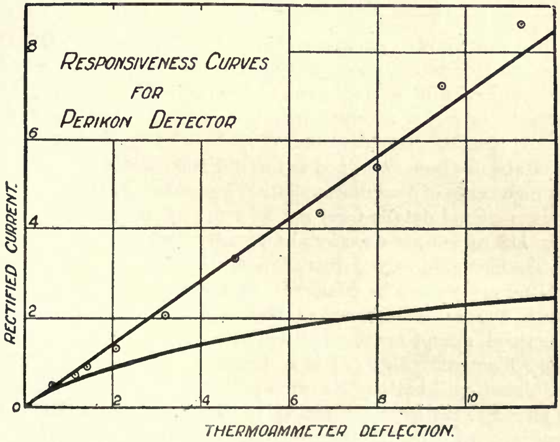

FIG. 223.—Response Curves for Perikon Detectors.

typical response curves for different Perikon detectors under different adjustments. One of these, it will be seen, is to all intents and purposes a straight line, while the second is decidedly curved. The straight line curve is the one to be aimed at since it would yield a truer response to the speech waves. Different adjustments of a given detector will be found to vary in this respect, but the great majority of sensitive points also yield an approximately linear response curve.

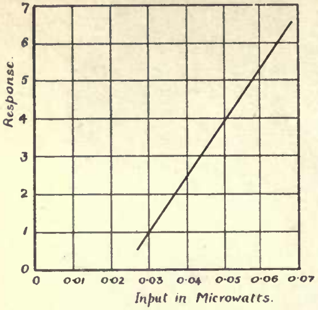

Fig. 224.—Response Curve for Carborundum Detector (W. H. Eccles).

Curve is taken at point of maximum sensitiveness of crystal—with 2·5 volts boosting voltage, and the blunt end of the crystal positive.

Fig. 224 is a similar curve for a Carborundum detector with a boosting voltage applied to bring it to the point of maximum sensitiveness.

Vacuum Receivers

The best known example of this type of detector is Fleming's Vacuum Oscillation Valve, in which use is made of the rectifying properties of a stream of electrons emitted from a hot cathode through a vacuous space between the hot cathode and a cold anode. The essential properties of this instrument have already been described as forming the basis of the various arrangements of vacuum oscillation generator, so that further constructional details need not be referred to in this section. Fig. 118 (p. 166) is a sectional diagram of one of these valves.

The complete valve forms a " potential-operated " detector, and may therefore be connected up for receiving purposes in much the same manner as the crystal detectors already described, except for the addition of a battery for heating the lamp filament. Fig. 225 is a diagram of the arrangement. A " boosting " battery B_2, with potentiometer resistance R_2, is joined in the circuit of the valve so as to work on the most sensitive point on the characteristic of the valve. Variation from zero up to about 15 or 20 volts is usually sufficient for this boosting voltage, depending on the characteristic of the particular valve in use. High-resistance telephones are necessary, unless a telephone transformer is used.

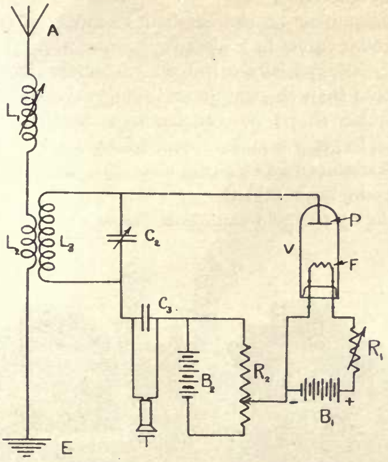

Fig. 225.—Connection Scheme for Fleming Valve Detector.

A typical characteristic curve for a valve of this type is given in Fig. 116 (p. 164), and a sensitiveness curve for the same valve in Fig. 226. The point of maximum sensitiveness coincides with a point of large change of curvature of the characteristic. A complete receiver with two of these valves is seen in Fig. 227. The sensitiveness of a good specimen of this type of valve is about equal to that of a good crystal detector. The instrument possesses the advantage

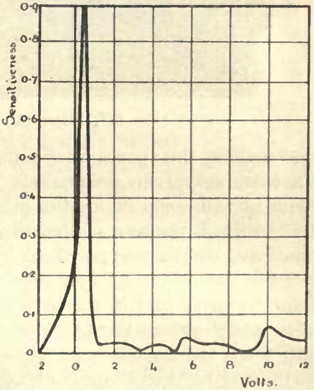

Fig. 226.—Sensitiveness Curve for Carbon Filament Valve.

of being much less liable to derangement by vibration, etc., than crystal detectors.

The development of the original Fleming valve into the three-electrode valve has already been described (p. 167). These valves are specially suitable as detectors, and are much more sensitive than the simple rectifying valve arrangements. The particular shape or construction adopted for these detectors is largely a matter depending upon the designer, provided that the three essential elements, filament, grid, and plate electrode, are retained.

By arranging the grid sufficiently close to the hot filament, and making the spaces in it sufficiently small, practically all the electrons reaching the anode (or plate electrode) from the filament will come under the influence of electric charges on the grid. A positive charge upon the grid will attract the electrons, and so prevent them from reaching the anode, *if a suitable path is provided for them by which they can flow away from the grid*, and if the grid has *sufficient surface area* to adequately collect them. A negative charge upon the grid will cause the electrons to be repelled back towards the filament, and will therefore also hinder their passage to the plate. Hence if an oscillatory potential is impressed upon the grid the general effect will be a *diminution* of the current flowing to the plate, since both half-waves of the alternations are to a

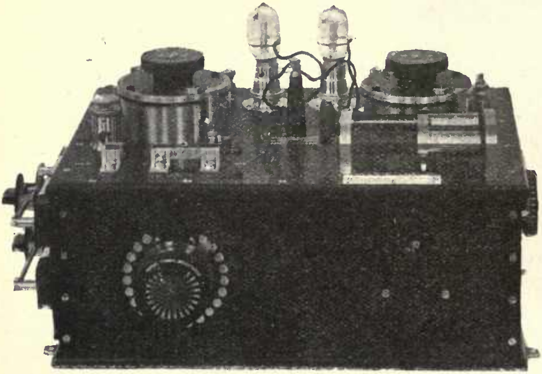

FIG. 227.—Marconi Valve Receiver.

certain extent effective in hindering the passage of electrons through the grid. Hence if suitable telephone receivers are connected in the plate circuit (Fig. 228), the steady current passing through them will decrease when a high-frequency potential is applied to the grid, by an amount depending, within limits, upon the value of the applied voltage. Within these limits the resulting response in the telephones is approximately proportional to the applied voltage. The expression "within limits" is used because if the applied potential is large enough it will cause the current in the plate circuit to be reduced to zero, after which no further increase in the potential can produce any effect.

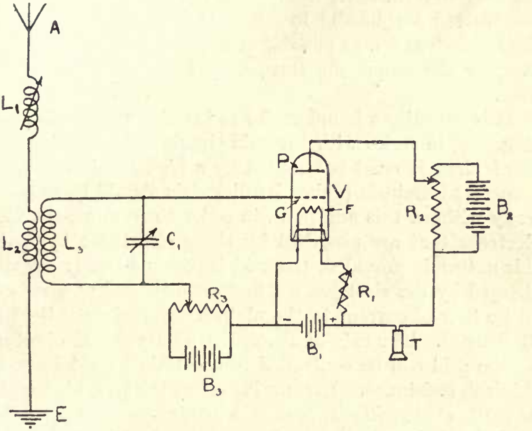

FIG. 228.—Arrangement of Valve Detector.

The conditions for practical working must be kept within these limits or the received speech will be distorted.

The connection scheme shown in Fig. 228 is evidently very similar to the arrangement for the simple valve, except that the connection from the tuning condenser C_1 is removed from the plate to the grid electrode of the valve. The small battery B_3, with potentiometer R_3, serves to adjust the normal potential of the grid electrode for the purpose of securing the greatest sensitiveness. The boosting voltage B_2 in the plate circuit should usually be variable up to about 30 volts.

To secure the best operation of these detectors in the manner outlined above, it is necessary that the grid should be capable of *absorbing* as many as possible of the electrons passing towards it when it is positively charged, in order to bring about a *decrease* in the plate circuit current. It must not merely attract the electrons without absorbing them, as that would bring about an *increase* in the plate circuit current.[1] For this purpose the grid must be constructed with sufficient surface area, that is to say, of fairly thick wire, while in some cases perforated metal sheet has been adopted. The conditions are therefore different from those obtaining in the similarly constructed amplifiers[2] in which it is desired that the grid shall absorb as few as possible of the electrons passing through it. For the amplifiers, then, very fine grid wires must be used.[3]

It is sometimes found useful to insert a small condenser C_2 (Fig. 229) in series with the grid circuit of the audion, but if this is done it must be shunted by a high-resistance leak, R_2, across its terminals (unless its dielectric should be sufficiently leaky without this addition), in order to form a path for the electrons that are absorbed by the grid. If no bye-path of this nature is provided, the grid becomes strongly negatively charged by the electrons settling upon it, and as a result the entire flow of current to the plate is stopped until the grid is discharged. The rate of absorption and removal of electrons by the grid can be controlled to a certain extent by varying this leak resistance. In some instances it is possible to operate an audion bulb *without* a leak of this nature across the condenser C_2, but this is only the case when there is strong ionisation of the residual gas in the bulb, so that there are a considerable number of positive ions in the neighbourhood of the grid to neutralise any accumulation of negative charge upon it. These conditions of strong ionisation are not always desirable, and should generally be avoided for best results.[4]

The grid leak R_2 may also be connected directly between the grid and the filament battery B_1 instead of across C_2.

An accumulation of a negative charge upon the glass walls of the bulb is also sometimes liable to bring about a cessation

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[1] As in the vacuum amplifiers.

[2] See pp. 169 *et seq.*, also Chapter XXII.

[3] See also Reference Nos. 550 and 551 for general account of the mode of operation and uses of the audion.

[4] For theory of action of gas in audion bulb, see Reference No. 630.

of the plate circuit current, especially when the bulb is a small one and therefore close to the enclosed electrodes. The complete enclosure of the filament and grid electrodes by a cylindrical "plate" electrode is of advantage in shielding the glass from the influence of such static charges.

The operation of these detectors is often liable to variation through gradual changes taking place in the vacuum—mainly through the liberation of occluded gases. It is generally advantageous to secure a very high vacuum and to carefully free all electrodes and glass work from occluded gases, as in the case of the high-voltage types of transmitting valves to which reference has already been made.[1]

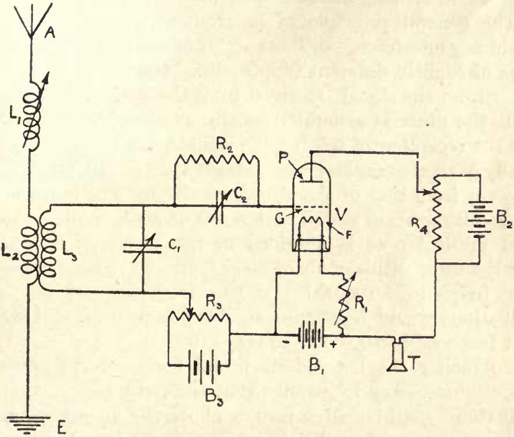

FIG. 229.—Arrangement of Valve Detector with Grid Circuit Condenser and Leak.

It has been suggested that a more definite residual gas pressure could be maintained in these valves used for detectors by enclosing inside the bulb some substance having the desired vapour pressure. The vapour pressure of mercury is usually too high, but silver amalgam is said to be particularly suitable for this purpose.[2]

The response of an audion detector is practically proportional to the received energy.[3]

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[1] P. 182.

[2] Reference No. 548.

[3] Reference No. 547.

Heterodyne Receivers

An extremely sensitive detector for continuous (undamped or nearly undamped) waves is that known as the Heterodyne Receiver. Many different forms of this receiver have been utilised from time to time, but more especially for telegraphic work.[1] It is possible, however, to adapt some of the forms for telephonic reception, and as the principle of these receivers is particularly well adapted to yielding a large response for a given amount of high-frequency energy, they may prove of some value for long-distance telephone work.

The general principle of heterodyne working is that of producing interference or " beats " between two sets of oscillations of slightly different frequencies. One set of oscillations arises from the signals received from the distant transmitter, while the other is generated locally at the receiving station. For the reception of telegraphic signals, the frequency of the locally generated oscillations is arranged to be but very slightly different from that of the signals received. The frequency of the resulting beats is well within the acoustic limit, so that a good musical note is obtained in the receiving telephones. For instance, with signals of 3000 metre wave-length (oscillation frequency = 100,000 ∾), the frequency of the local oscillations would be chosen at about 99,000 ∾, so that the beat frequency = 100,000 − 99,000 = 1000 ∾.

To render the heterodyne useful for receiving speech it becomes necessary to arrange that the frequency of the beat oscillations shall be either zero or above the acoustic limit, so that under normal conditions no sounds are heard in the telephones. The variations in the received energy (speech) will, however, be audible under these conditions, since there will be large variations in the strength of the " beat " current through the telephones. The advantage of the method lies in the amplification secured through the calling into play of the relatively strong local oscillations. With this arrangement it might under certain circumstances be useful to rectify the beat frequency currents before passing them through the telephones, especially when the beat frequency is high, as for telephony. One of the most useful and sensitive arrangements is shown in Fig. 230. A, L_1, L_2, L_3, E ; L_5, C_2, C_3, D, T forms an ordinary pattern of crystal receiver (compare with Fig. 220).

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[1] Reference Nos. 552, 553, 554, 555, 556.

The local oscillations are set up by some form of oscillation generator G, and are induced into the aerial circuit by means of the coupling between L_2 and L_4. Beat oscillations are therefore set up in the aerial circuit, and in circuit C_2, L_5, whence they affect the detector D and telephones in the usual manner.

As local source, G, of continuous oscillations, any suitable oscillation generator that is capable of yielding currents of the desired frequency and steadiness may be employed. A small direct current arc producing feeble oscillations (type I, see p. 117) is often used; but a small h.f. alternator, combined if necessary with a frequency raiser, is preferable from the point of view of steadiness of the oscillations—an essential feature for quiet reception free from disturbing noises in the telephones.

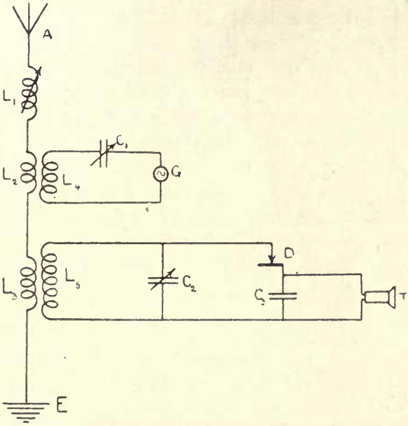

FIG. 230.—Heterodyne Receiver with Crystal Detector.

The best local oscillation generators of small power, for this purpose, are the "vacuum" oscillation producers of the three-electrode valve type. They are moreover possessed of the very desirable feature of extreme steadiness of oscillations. Another advantage is that the oscillation frequency can be varied very easily within wide limits, merely by adjusting one or two condensers in the various coupled circuits, until the best results are obtained to suit the particular waves being received. Any of the usual connection schemes for these oscillation generators[1] may be employed in this instance.

Evidently a valve type of receiver could also be employed as the detector in place of the crystal rectifier in the above arrangement (Fig. 230), quite apart from one being employed for the generation of the local continuous oscillations. Such an arrangement is still more sensitive than when using the crystal, and at the same time admits of greater selectivity for the required signals, as well as a louder response in the telephones. The circuit arrangement is sketched in Fig. 231.

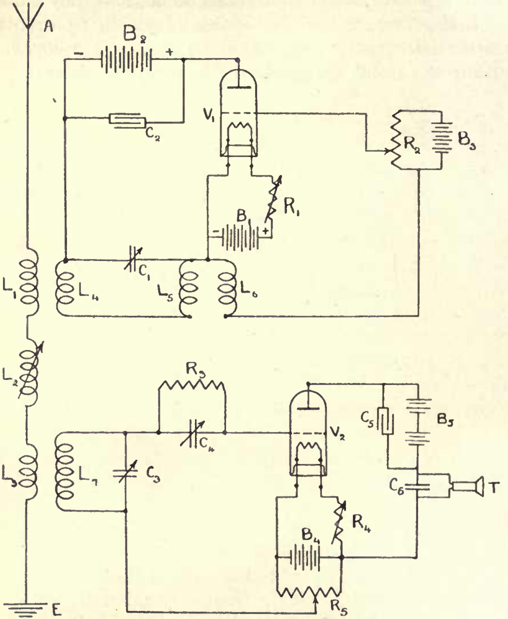

FIG. 231.—Heterodyne Receiver with Separate Valves for Local Generator and Detector.

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[1] See pp. 172 *et seq.*

The continuous local oscillations are generated by the valve V_1 in the usual manner. These oscillations are handed on to the aerial circuit by the coupling L_1, L_4, while the arrangement of audion valve V_2 serves as the detector. It may be noted, in passing, that the potentiometer resistance shunted across the filament heating battery B_4 forms a very convenient way of providing a small adjustable potential in the grid circuit without the addition of an extra battery for that purpose. The potential required on the grid to secure the best results is usually quite small, not exceeding one or two volts.

Another way in which the amplification advantages of heterodyne reception may be secured for telephone transmission is to arrange for the " beats " to have zero frequency, *i.e.* the locally generated oscillations are made the same frequency as that of the incoming waves. The only " frequency " then remaining to affect the telephone receivers is the " modulation " frequency, applied to the high-frequency wave, *i.e.* the speech frequencies themselves.[1]

Obviously the valve type receivers are most suitable for these arrangements on account of the steadiness of the frequency of the generated oscillations.

THE AUTO-HETERODYNE VALVE RECEIVER

We are now led to a consideration of the possibilities of combining the two valves used in the last described arrangement of heterodyne receiver into one bulb. This combination has been accomplished by arranging the detecting valve to generate the local oscillations, giving as good or even better results than when two bulbs are employed.

For this purpose some form of " return " coupling must be provided between the grid and plate circuits of the valve, so that oscillations may be set up. The frequency of these oscillations may be slightly different from those being received, so that beats are produced.

An arrangement has been patented by H. J. Round and the Marconi Company, using a valve both as local generator and detector for the beat oscillations. The connection scheme is shown in Fig. 233. The circuit C_3, L_5 is tuned to a different frequency from the circuit C_1, L_3. The beat frequency

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[1] Reference Nos. 686, 687.

is determined by the difference between them. A small condenser connected between the grid and plate electrodes is often advantageous.[1]

The usual circuit arrangements of this "Ultraudion" receiver as used by L. de Forest are shown in Fig. 232.[2] The tuned circuit C_1, L_3 coupled with the aerial is connected across the grid G and plate P of the valve V, instead of between the grid and filament as in the usual receiving arrangements. The detecting circuit including the telephones T is connected in the usual way between the plate and filament of the valve. Both condensers C_1 and C_2 should be of quite small value—say of the order of 0·0002 mfd. The arrangement serves to set up continuous oscillations in the circuit C_1, L_3, which react with the received oscillations to produce beats. These should be above the acoustic limit for telephonic reception as with the direct heterodyne receiver. The inductance L_4 in the plate circuit should be of considerable value and serves to steady the generated oscillations.[3]

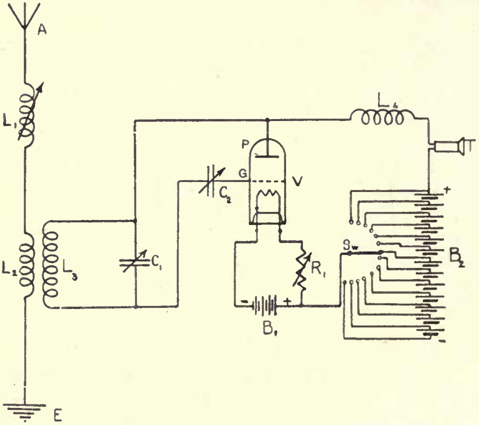

Fig. 232.—Ultraudion Detector (L. de Forest).

It has been shown by E. H. Armstrong that this circuit of de Forest's is really equivalent to providing a return coupling

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[1] Reference No. 558.
[2] Reference Nos. 557, 559.
[3] Cf. Reference No. 550.

between the two circuits (plate and grid), and is therefore equivalent to the more usual arrangement.

A great number of complicated circuit arrangements have been devised at various times with a view to combining the functions of local generator and amplifier, as well as that of detector, into one valve. These various combinations of circuits and different ways in which the same piece of apparatus may be used, run so closely into one another that it frequently becomes merely a matter of convenience as to which way their mode of operation is regarded. The important point in every case is obviously to obtain the most *sensitive*, *stable*, and *reliable* receiver best suited to the conditions in use. The number of possible circuit arrangements with valves is almost unlimited.[1]

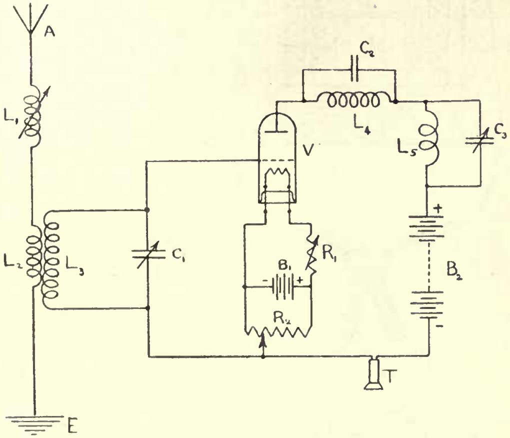

FIG. 233.—"Self-Heterodyne" Valve Receiver (H. J. Round).

THERMAL DETECTORS

One other class of detectors remains to be mentioned, viz. Thermal Detectors. Like the Crystal, Valve, and other receivers already considered, these are equally suitable for use as receivers for musical note spark telegraph or for tele-

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[1] Reference Nos. 550, 551, 560, 561, etc.

phonic working. Their great advantage lies in the simplification of the whole receiver which results from their use, and in the absence of delicate adjustments of any kind. Like crystal receivers, however, they may be burnt out by too powerful impulses.

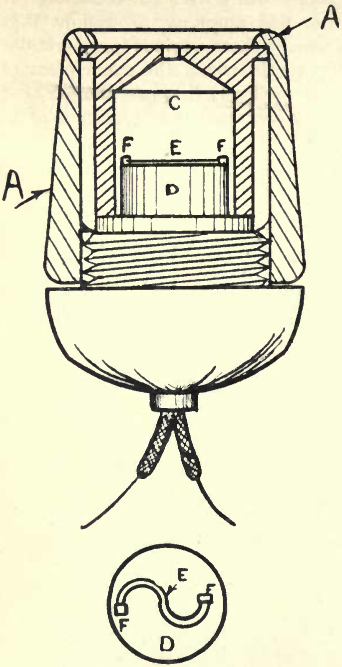

FIG. 234.—De Lange Thermal Telephone.

In principle these receivers consist merely of an extremely thin wire which is heated by the oscillatory currents which are passed through it, and thus causes varying expansions and contractions of the air inside the vessel in which the wire is enclosed. Sound waves are thus set up directly from the oscillations without the intervention of any rectifier or other detector.[1] Fig. 234 is a diagram of one form taken by this receiver. F, F are the two terminals between which the fine metallic bridge or filament E is formed. These terminals F, F and the conductor E are mounted upon the insulating support D, and enclosed in the cavity C, in the cover cap A. The size and shape of this cavity and the nature of the insulating support D are of considerable importance in securing the successful operation of the device. They form the basis of a large number of patent applications. Ebonite is customarily employed as the material for the cap A, and marble is recommended for the support D, though insulated metal or other materials may

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[1] Reference No. 562.

be employed. The support D while being a good electrical insulator should preferably not be too good a thermal one. The heating conductor E may be of very fine wire, such as Woolaston wire, or a very fine lamp filament, or may be deposited directly upon the insulator D, either electrolytically or by any other suitable process.

This receiver may be connected directly in *series* with a tuned oscillatory circuit coupled with the receiving aerial. This circuit should have a *small* ratio of Inductance to Capacity relatively to the values used for crystal and valve working.

The development of the modern successful forms of this receiver is largely due to de Lange.

CHAPTER XXII

RECEIVING AMPLIFIERS

THE last two types of valve receiver considered in the preceding chapter introduced the idea of strengthening or amplifying the received signal before rendering it audible with one of the usual patterns of detector. This amplification or strengthening was brought about by the additional energy derived from the local oscillations. It is possible to separate the functions of amplifying and detecting the signals in a number of ways. The advantages of amplification are to be found in the possibility of reducing the transmitter energy for a given range; but this procedure is at present very limited by troubles due to atmospheric interference.[1]

The amplifiers available for wireless telephone purposes may be classified into two distinct types:

(1) Electromagnetic and microphonic.

(2) Electron, gaseous, and vacuum amplifiers.

(1) ELECTROMAGNETIC AND MICROPHONIC AMPLIFIERS

This class includes such instruments as the Brown Telephone Relay and various forms of microphone "sound-intensifiers." These are available for use in conjunction with one of the forms of detector previously described,[2] since they are only capable of amplifying variations of a direct current or of a low-frequency alternating or varying current. The mode of operation of all the members of this class involves the employment of some form of microphonic contact or contacts, of which the resistance may be controlled by an electromagnet through whose windings is passed the "rectified" current from the detector.[3] This electromagnet may be caused to vary the

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[1] See Chapter XXIII. p. 347.

[2] Chapter XXI.

[3] The term "rectified" is here used in the general sense to include the

pressure or spacing between the contacts of the microphone in order to vary and control the resistance between its terminals.

The simplest type of all consists merely in the mounting of an ordinary pattern of microphone transmitter closely adjacent to a telephone receiver through which is passed the current to be amplified—that is, the current yielded by the detector—and connecting the two diaphragms by a tube or air-tight container (Fig. 235). T_1 is the telephone receiver connected by the terminals C and D into the detector circuit of the receiving apparatus. M is the microphone mounted close to this receiver and coupled therewith by the air column contained inside the tube A, which unites the two instruments. A second telephone receiver T_2 is connected to M through the battery B, and serves to render audible the amplified current flowing through the microphone. Two or more such combinations may be connected in series, but a limit is soon reached beyond which little further amplification is obtained.

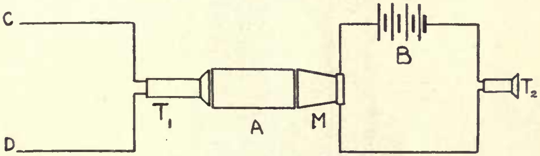

FIG. 235.—Microphonic Amplifier.

An improvement may be effected by mounting the microphone or microphonic contact directly upon the diaphragm of the first telephone T_1, and so saving the losses involved in the coupling together of the two instruments. The mass of material mounted upon the diaphragm must be kept very small or the movements will be largely damped out.

Amplifiers of this type have often been used in wireless receiving,[1] but chiefly for telegraphic work, when they can be tuned to the spark frequency in use.

S. G. Brown's Telephone Relay may be cited as one of the

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current yielded by the detector, whether or not it is a "rectifier" in the true meaning of the word. That is to say, it is intended to include the low or audible frequency currents yielded by the detector as a consequence of the high-frequency oscillations which are impressed upon its circuits from the receiving aerial.

[1] For instance, by the Telefunken Company, Reference No. 564.

best known and most developed examples of this class of instrument.[1] Its construction is shown in diagrammatic form in Fig. 236. It consists of a permanent magnet N, provided with two soft iron cores projecting from its poles, and surrounded by low resistance windings K. The extremities of these polar extensions are further provided with two soft iron pole-pieces P, placed parallel to one another and as close as practicable to allow of the necessary windings H around them. The armature or "reed" O is arranged opposite these pole-pieces, and carries one (flat) contact piece of carbon, iridium, osmium-iridium alloy or similar very hard material. The second (pointed) contact M is attached to the end of the screw J, passing through the lever L pivoted at Y and provided with a micrometer screw W, for very fine adjustments of the position of the screw J and contact M. Rough adjustments of the contact are made with the screw J. The microphone is formed by a minute air-space between these two contacts—a space of the order of 5 × 10^{-7} centimetre in thick-

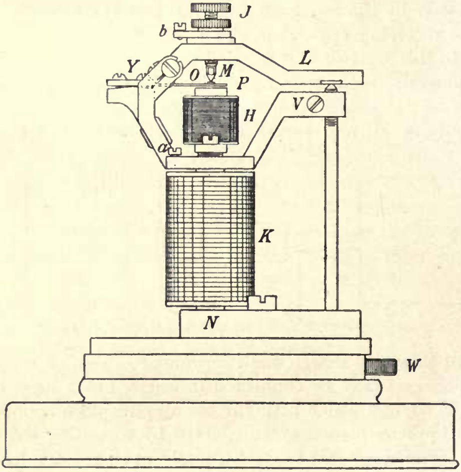

Fig. 236.—Brown's Telephone Relay.

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[1] Reference No. 565.

ness. At such very minute separations the resistance of the air-film between the contact surfaces becomes of quite moderate value, so that a single dry cell is able to pass currents of several milliamperes across the gap. Evidently with such microscopic gaps, equally minute variations in the spacing of the gap will cause considerable variations in its resistance, and therefore in the current passing across it. It further becomes almost impossible to maintain a constant normal separation of the gap by mechanical means alone, unless some automatic regulating arrangement is provided. This is furnished by the windings K, which are connected in series with the contact space and a single dry cell. A milliammeter serves to indicate the current passing across the gap and through the telephones. These windings K are connected so that the current flowing round them controls the length and resistance of the gap, in much the same manner as the series coil of an arc lamp controls the length of the arc.

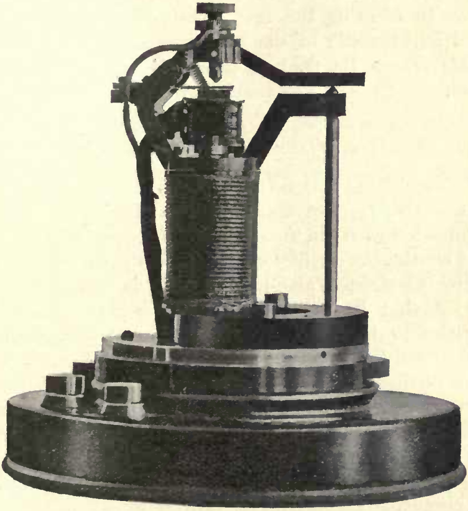

FIG. 237.—Brown's Relay—Type A.

The current to be amplified is passed through the high resistance windings H of many turns of fine wire, and so superimposes small varying magnetic fields upon the resultant field of the permanent magnet and windings K. A varying pull is thus set up on the reed O, and consequently minute variations in the length and resistance of the gap between the contacts O and M are brought about. The current flowing through the telephones may thus be very much larger than the initial current through the windings H. An amplification ratio of about 20:1 may be obtained. Very frequently the addition of a small drop of thin oil at the contacts is advantageous in securing the best results from the relay. Very careful adjustments of the relay are usually necessary, and for this reason its field of utility is apt to be somewhat limited.

(2) ELECTRON, GASEOUS, AND VACUUM AMPLIFIERS

The amplifying action that it is possible to obtain with the vacuum-valve type of apparatus has already been discussed in connection with the use of these instruments for the generation of continuous oscillations.[1] Evidently, therefore, any type of Three-Electrode Valve may be used as receiving amplifier, provided that it is constructed on a scale suited to the quantities to be amplified—small valves are required for receivers and large ones for oscillation generators.[2]

The distinctions between the use of these instruments as amplifiers and as detectors has already been dealt with[3]—the essential point in the former case being that the potential variations impressed upon the grid electrode shall be *faithfully reproduced* as variations of the current flowing round the plate circuit.

A great advantage of the vacuum amplifiers lies in the fact that they are available for amplifying high-frequency currents as well as low-frequency ones; while electromagnetic microphonic types can be used for low-frequency currents only. A double amplification is therefore possible, if desired, when these instruments are employed. The high-frequency energy received from the aerial can first be amplified (in one or more stages), then rectified by some suitable form of detector, and the resulting low-frequency "speech" currents further amplified before passing to the telephone receivers. The high-

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[1] Chapter XIII. p. 169.

[2] Reference Nos. 566, 567, 568, 569.

[3] P. 321.

frequency amplification is specially useful, as it enables more robust and reliable detectors to be employed than would otherwise be possible were this initial amplification omitted. Fig. 238 illustrates one arrangement for the amplification of the high-frequency energy before its rectification by an ordinary type of crystal detector. The jigger L_2, L_3 serves to couple the amplifier to the aerial, and L_4, L_5 the detector to the amplifier. The arrangement of amplifier and crystal detector is the same as if they were used independently of one

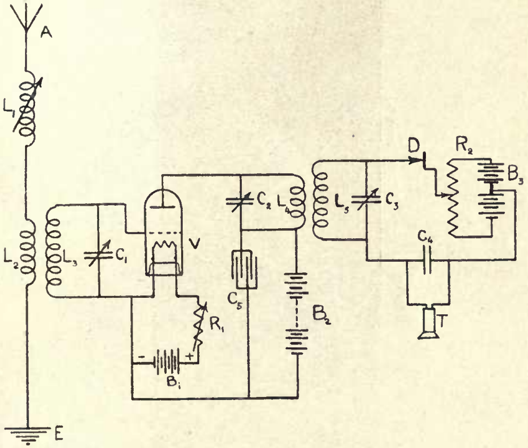

FIG. 238.—Arrangement of High-Frequency Amplifier and Crystal Detector.

another. Very sharp tuning and great selectivity can be obtained with this arrangement. Using one audion valve in this manner, an average amplification of about 10 : 1 can usually be secured.

Further stages can be added if desired in order to increase the amplification of the received energy (provided that the last valves are increased in size if it should become necessary, to enable them to deal with the larger currents).

A view of a typical amplifier outfit is shown in Fig. 125,[1] in which the valve bulb is seen mounted upon a box containing the necessary coupling inductances, condensers, battery adjusting switches, etc., for the proper operation of the amplifier.

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[1] Page 176.

A three-stage amplifier constructed on the same lines with three bulbs is shown in Fig. 239. See also Figs. 239A and 239B.

A further amplification with one stage may be secured by utilising what is generally known as the "return coupling" between the plate and grid circuits of the amplifier, such as is employed when using the amplifier for generating oscillations.[1] The application of this principle is due to C. S. Franklin. The arrangement is shown in Fig. 240. The coupling between the coils L_4, L_5 serves to return some of the amplified energy from the plate circuit back to the grid for further amplification. This coupling must be weaker than that required for the generation of oscillations if the valve is to retain its functions as a simple amplifier—otherwise it would become a species of self-heterodyne arrangement. The most satisfactory results are usually obtained when this return

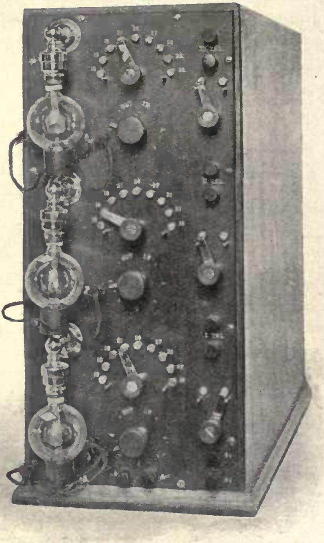

FIG. 239.—Three-Stage Audion Amplifier.

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[1] Reference Nos. 570 and 571.

coupling is adjusted until the oscillations are just not established. The addition of the return coupling has the effect of reducing the damping of the detecting system. This is of advantage, as the selectivity of tuning is thereby increased;

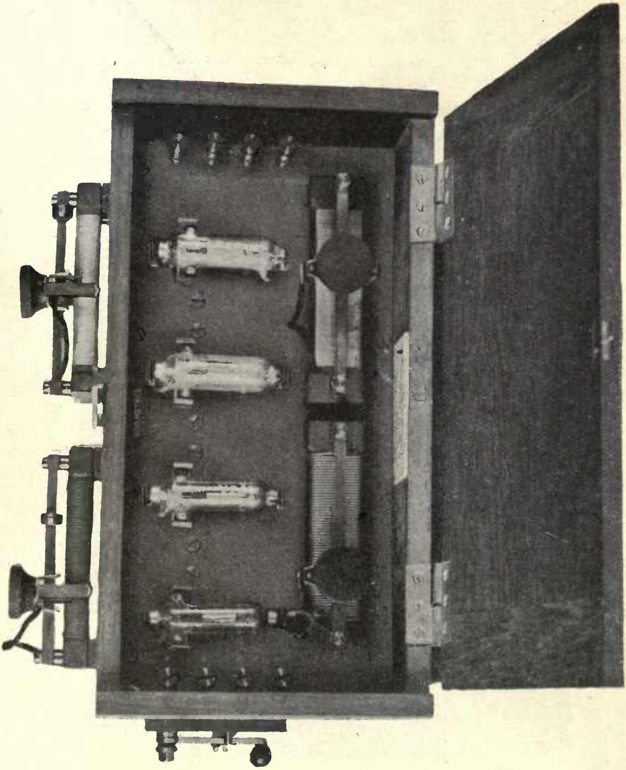

FIG. 239A.—Marconi Four-Valve Amplifier.

but the method should not be pushed too far, or the purity of the received speech may be impaired. The extra potentiometer B_4, R_3 is added to ensure that the crystal receives its proper voltage for efficient working, and does not become damaged by excessive voltage from the plate circuit battery B_2.

Another arrangement is indicated in Fig. 241. It differs from the one just described in the addition of the jigger

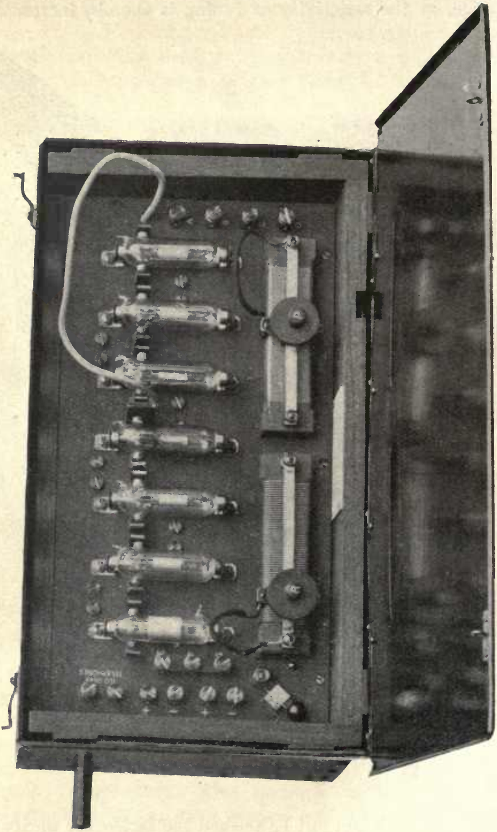

Fig. 239B.—Marconi Seven-Valve Amplifier.

for coupling the crystal on to the plate circuit of the amplifier.

The diagrams already given show a crystal detector in use

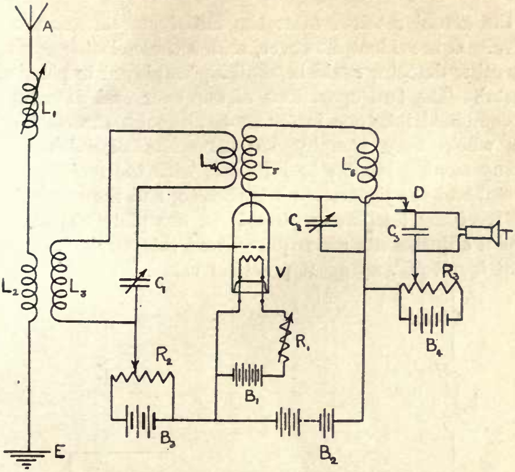

FIG. 240.—Combined Crystal Detector and Valve Amplifier with Return Coupling (C. S. Franklin).

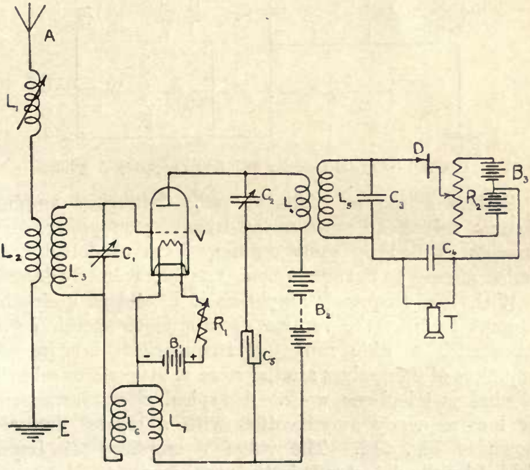

FIG. 241.—Arrangement of Crystal Detector and Valve Amplifier with Return Coupling (E. H. Armstrong).

as the actual receiver after the initial amplification by the valve. It is evident, however, that a three-electrode valve or any other detector could be similarly employed in place of the crystal. The two operations of amplifier and detector may be combined into one instrument, although the efficiency of the whole may thereby be somewhat diminished. This arrangement is similar to Fig. 241, with the omission of the crystal and the jigger coupling thereto, and the connection of the receiving telephones directly in the plate circuit. Very careful adjustments are required, and this particular arrangement is not of very great practical value.

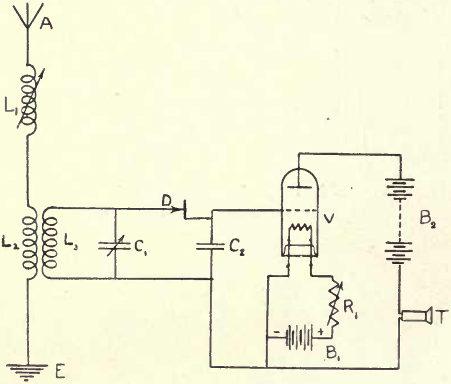

FIG. 242.—Crystal Detector with Low-Frequency Amplifier.

Besides acting as high- or radio-frequency amplifiers, vacuum valves can serve as low-frequency amplifiers for the currents yielded by some ordinary form of detector, in a similar manner to the microphonic amplifiers already described.

With low-frequency amplifiers it is seldom desirable to attempt to tune the various circuits, since speech currents cover such a wide range of frequencies. Low-frequency amplifiers of themselves are therefore of little aid to selectivity in wireless telephone work. A typical circuit arrangement for low-frequency amplification with a crystal detector is shown in Fig. 242. The valve V amplifies the impulses yielded by the detector D in the usual manner.

An important feature in connection with this arrangement is the proper choice of the valve amplifier characteristics, so that with the best value of the plate circuit voltage B_2 there is zero voltage across the detector terminals D—or rather such a voltage as will bring the detector to its point of maximum sensitiveness. Obviously this condition may not always be easy to obtain. The effect of varying the voltage of B_2 upon the value of the potential difference across the detector D is shown in Fig. 243, for a particular valve.[1] It may sometimes so happen that when the detector p.d. has a suitable value, the corresponding plate circuit voltage is not a good one for best working of the amplifier. Further adjustment may sometimes be obtained by varying the filament current of the valve ; or a reverse potentiometer could be inserted in series with the crystal to balance out the voltages derived from the grid circuit of the amplifier. Alternatively an inductive coupling could be used to unite the crystal and amplifier instead of the direct connection shown in the diagram.

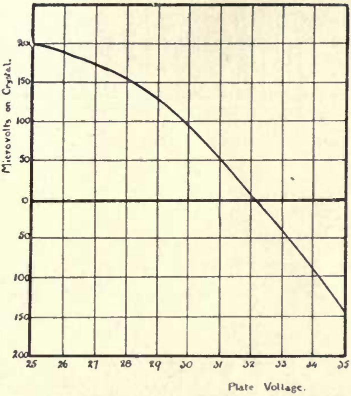

FIG. 243.—Connection between Crystal P.D. and Plate Circuit Voltage with Audion arranged as Low-Frequency Amplifier (H. Pratt).

It should be noted that the application of amplifying valves is not limited to the use of one valve alone. Evidently the output from the first high-frequency amplifying valve may be passed on to a second and a third valve, etc., using closed

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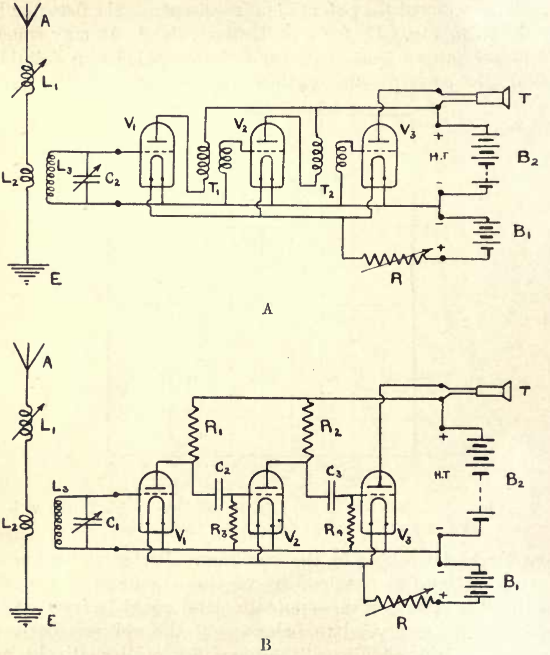
[1] Reference No. 572.

tuned circuits in each case to provide the coupling. Such an arrangement is extremely selective, but is not very commonly adopted in practice. In the more usual arrangements of modern amplifiers several valves are mounted together and supplied from common filament and high-tension (plate-circuit) batteries, with suitable coupling arrangements between the anode of one valve and the grid of the next. This coupling may be conductive, inductive, or capacitive—the last two being the most useful.



A

B

FIGS. 243A and B.—Typical Arrangements of Multivalve Amplifiers.

The general scheme of these two forms of coupling for multi-valve amplifiers is shown in Figs. 243A and B. Fig. 243A indicates an inductive coupling between the valves

V_1, V_2 and between V_2, V_3 by means of the transformers T_1, T_2. All the valve anodes are supplied from the common H.T. battery B_2, and the filaments from the common filament battery B_1. In common practice B_1 is usually either 4 or 6 volts; and B_2, 25 or 50 volts. The telephones T are inserted in the anode circuit of the last valve.

In the Fig. (B), the H.F. energy from the anode of the first valve is passed on to the next grid through the coupling condenser C_2. The high potential from the battery B_2 is fed into each anode circuit through the resistances R_1, R_2, and through the telephones T in the case of the last valve. Leak resistances R_3, R_4 are inserted between the grids and the filaments in order to prevent the accumulation of large negative charges upon the grid electrodes.

Various other combinations of circuits similar to the above are also employed—such for example as winding the transformers T_1, T_2 in high resistance wire (as has been done by H. Round)—but the ones shown may be taken as typical. For high-frequency amplification these transformers should be "air-cored"; but iron cores may be employed if desired for low-frequency amplifiers. The "resistance" amplifiers with capacity coupling (Fig. B) are available for either high- or low-frequency amplification with but slight alteration of the value of the condensers C_2, C_3. The resistances R_1, R_2 should be of the same order as the valve resistance, viz. of the order of 10,000 or 20,000 ohms; while the leak resistances R_3, R_4 may be 1 megohm or more.

It should be noted that a number of valves may be joined together by these schemes. Views of two amplifier units containing four and seven valves respectively are given in Figs. 239A and 239B. When several valves are used care must be taken to adequately screen the amplifier coils from all stray magnetic fields, from tuning coils, etc., or difficulties will be experienced in operation.

By providing a small coupling between the first and last valves of a multi-valve amplifier, continuous oscillations may be set up, so that the set may be used as a self-heterodyne receiver. This condition should usually be avoided for radiotelephone working.

As mentioned above either high- or low-frequency amplification may be used, or both may be used together. Clearest speech is usually secured by employing high-frequency amplification only, as with low-frequency amplification resonance effects are often obtained which cause distortion of the received speech.

One of the valves—usually the last one—of a multi-valve amplifier is generally provided with a separate filament rheostat in order that the filament current of this valve may be adjusted to enable the valve to be worked upon the best point of its characteristic for " detection " purposes. This point is near either the lower or upper bends in the characteristic—preferably the former.

Valve amplifiers are now becoming an almost essential part of modern receiving apparatus, and their use is quite essential under some circumstances—such, for example, as in some interference prevention arrangements.

CHAPTER XXIII

INTERFERENCE PREVENTION

ALL wireless signalling by the methods at present in use is subject to interference in one form or another, both from other wireless stations (deliberate or accidental) and from atmospheric disturbances. The former of these only occurs to any serious extent when a large number of stations closely adjacent to one another are all operating on very nearly the same wave-length, or when a very powerful transmitter is operating at close quarters to a receiving station even of different wave-length. This latter case, and also to a certain extent the former also, can be improved by using sharply tuned and loosely coupled receiving circuits,[1] and in some cases by the use of certain tuned interference reducing arrangements in addition.

With wireless telegraph signalling between ships in crowded waters this interference frequently assumes serious proportions, since most commercial vessels are operated upon the same wave-length (viz. 600 metres). Long-distance communication between powerful land stations is not subject to this trouble to so great an extent, both because the number of such stations is less, and also because the available ranges of long wave-lengths are also greater, so that greater differences can be allowed between stations in neighbouring areas.

The natural interference by atmospheric disturbances—or X's, strays, or static as they are variously called—is, however, one to which all stations are subject to a greater or less extent. It usually happens that the large land stations for long-distance work are more subject to this trouble than the smaller stations, very largely on account of their much higher and more extensive aerial systems.

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[1] Reference No. 573.

In wireless telegraphic signalling with musical note spark transmitters it becomes fairly easy to read the signals through moderate interference, either from other stations or from atmospheric disturbances on account of the distinctive note possessed by the transmitting spark. With continuous wave signalling using heterodyne receivers,[1] the maximum possible benefit may be obtained from this property by adjusting the musical note in the receiving telephones to be the most convenient one under the particular interference conditions prevailing at the time.

With wireless telephone working many of these advantages are lost, and it becomes desirable, and in fact necessary, to devise means for reducing to the utmost limit all interference troubles. At the same time it should be noted that the ear is naturally highly trained in sorting out spoken words from among even loud disturbing noises. Even when parts of the words are lost a certain amount of unconscious guessing always takes place to fill in the gaps.[2] The most important point is to reduce the interference from atmospheric disturbances.

Many proposals have been put forward from time to time as to ways and means of reducing the disturbing noises due to atmospherics, but although some of these are to a certain extent effective in reducing the undesired sounds, they frequently lead to a reduction in the strength of the signals as well. A really effective interference preventer and "static eliminator"—that is, one that will allow free passage to the desired speech or signals, and yet completely cut out all other sounds due to atmospherics—has, however, yet to be invented.[3]

THE BALANCED AERIAL METHOD

The great difficulty met with in designing apparatus for diminishing interference lies in the nature of the atmospherics that it is desired to eliminate. In most cases they are such highly damped impulses that they will set up vigorous oscillations in a circuit quite irrespective of the wave-length to which that circuit is tuned, so that ordinary methods of selection by sharp tuning are practically useless. The most successful methods so far devised are those which make use of this very property, by causing the X's to influence two circuits tuned to

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[1] See p. 324.

[2] Reference No. 582.

[3] Reference No. 580 gives a good survey of the subject.

different frequencies—which they will do practically equally—and arranging that one of these circuits shall be in tune with the desired signals while the other is not. If the oscillations set up in these two circuits are arranged to produce opposing effects in the telephones, the effect of the X's will largely cancel out, while the tuned signals will still be heard, since they influence one of the circuits only.

This result is best achieved by the use of two separate and complete aerial and receiving systems, one tuned to the waves

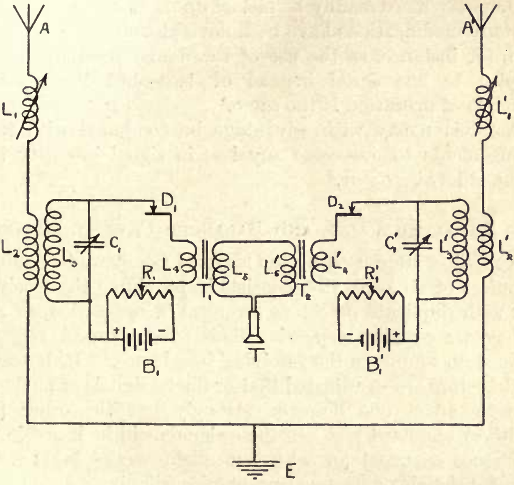

FIG. 244.—Balanced Aerial Interference Limiter.

to be picked up, and the other detuned just sufficiently to render it practically non-responsive to those signals, but still practically equally as responsive to atmospherics as the first system. In Fig. 244, A, L_1, L_2, E ; and A′, L_1', L_2', E are the two aerial circuits coupled with the tuned secondary circuits L_3, C_1, and L_3', C_1' respectively. D_1 and D_2 are the two detectors with the usual battery and potentiometer arrangements. Instead of the customary telephones, however, the primary windings L_4, L_4' of two telephone transformers T_1 and T_2 are inserted, one in each receiving circuit. Their secondary windings are connected in opposition in series with the telephones T. The signals produced in the two receivers therefore give rise to opposing effects on the telephones, so that if both systems are equally influenced by the same impulse very little sound will be heard. The desired signals will affect one receiving system very much more strongly than the other, so that they will be heard in the telephones in the usual manner.

With this arrangement, one aerial may often with advantage be made very much higher than the other, so that the distant station may more readily be picked up on this one.

Many modifications have been devised from time to time—such, for instance, as the use of the double receiving system coupled to one aerial instead of two—but the essential principle of operation is the same.[1]

Amplifiers may with advantage be combined with these arrangements to overcome any loss in signal intensity that might otherwise occur.[2]

THE BALANCED VALVE AND BALANCED CRYSTAL METHODS

A method often used by the Marconi Company to diminish the effect of atmospherics, consists in providing the receiving gear with duplicate detectors arranged in opposition, so that if they are equally responsive their effects cancel out and produce no sounds in the receiving telephones.[3] If, however, the detectors are so adjusted that ordinary signals of moderate strength affect one detector strongly but the other (less sensitive) one hardly at all, these signals will be heard in the telephones as usual (or with but slight weakening); while powerful signals or strong atmospherics will give rise to nearly the same response in both detectors, so that their effect on the telephones will be lessened by reason of the two detectors being in opposition.

The circuit diagram of the arrangement using crystal detectors is shown in Fig. 245. The same scheme is used for the balanced valves, merely replacing the crystals by two valve detectors. Owing to greater uniformity of action the valve arrangement is usually somewhat more effective than the crystals, although neither method gives very reliable results.

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[1] See also Reference No. 575.

[2] Reference No. 689.

[3] Reference Nos. 576, 583, 586.

AUSTIN'S INTERFERENCE PREVENTER

A somewhat analogous method has been used by L. W. Austin for diminishing the noise in the telephone receivers due to atmospheric disturbances.[1] The particular crystal arrangement favoured for this purpose is a silicon-arsenic contact, since this shows almost the properties of a self-restoring coherer with a sensitiveness approaching that of ordinary crystal detectors.

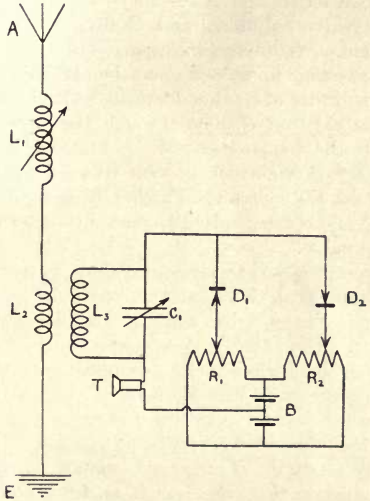

FIG. 245.—Balanced Crystal Receiver for reducing Atmospherics (H. J. Round).

If one of these combinations is joined between the aerial and earth connections of the receiver, or in shunt to any other suitable part of the receiving circuits (such as the secondary tuning condenser), it will remain practically unresponsive to signal waves of ordinary strength, but loud atmospherics will cause a momentary " cohesion " or lowering of its resistance, so that it forms a bye-path shunt or leak to earth for these impulses. The formation of this shunt, however, means that some portion at least of the desired signals will also be

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[1] Reference Nos. 577, 578.

shunted to earth as well as the atmospheric, so that the proper received signals will be momentarily weakened when each X occurs. This in itself constitutes a certain disadvantage.

Many other forms of leak resistance have been devised for this purpose, but the above crystal combination is one of the best.[1] This method is not usually so effective as the balanced valves.

VACUUM-VALVE INTERFERENCE LIMITER

It has been mentioned in the course of the descriptions of the various valve amplifiers and oscillation generators that the maximum current-carrying capacity of a valve is limited both by the voltage impressed upon the plate circuit and also by the temperature of the hot filament.[2] If either of these is reduced, the electron current through the valve is likewise reduced. If the temperature of the filament is maintained low, the saturation current is soon reached for quite small voltages in the plate circuit. Further increase of voltage will then produce no corresponding increase in the current flowing through the valve.

It has been proposed to utilise the above properties to limit the maximum strength of current that can pass into the detector from the receiving aerial.[3] Fig. 246 illustrates one arrangement. The valve V is connected in the usual manner of an audion valve high-frequency amplifier between the aerial and detector circuits. The filament of this valve, however, is run at such a low temperature that no amplification takes place, and that the valve is *just below* the saturation point for the normal strength of received signals. Any increased voltage applied to the valve—such as, from powerful atmospherics or loud interfering signals—are then unable to produce correspondingly increased currents through the valve. The response of the detector to these loud atmospherics or signals will therefore be no greater than for the normal reception. The disturbing sounds in the telephones will thus be less distracting than would otherwise be the case. It will be noticed that in the above diagram a small coil L_4 is included in the oscillation circuit C_1, L_3, and is coupled with the plate circuit of the valve limiter. This is for the purpose of neutralising any direct reception of signal energy by the detector circuit by reason of the capacity between the grid and plate electrodes

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[1] Reference No. 585. [2] See Fig. 129, p. 180. [3] Reference No. 579.

of the valve. It should be coupled in such a direction as to oppose this direct reception, so that no signals (however strong) may be heard when the valve filament is not heated. If this coil is omitted, loud atmospherics may get through to the detector without being cut down by the limiter. Several other variations upon this idea have been patented, but the general principle involved is the same in each. For example, F. P. Swan obtains a similar effect by a considerable reduction in the plate circuit voltage, so that the grid voltage becomes of the same order of magnitude, with the result that for one particular value of the latter the plate current reaches a maximum and decreases for either increase or decrease of grid voltage.[1]

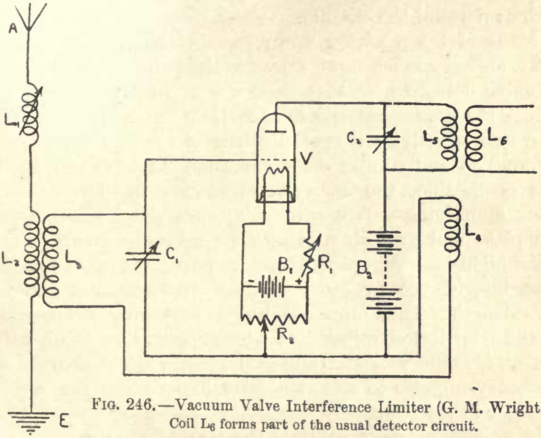

Fig. 246.—Vacuum Valve Interference Limiter (G. M. Wright). Coil L_6 forms part of the usual detector circuit.

G. M. Wright arrives at the same result by the use of two grids,[2] the extra grid being treated as the filament for connection purposes.

The Effect of the Type of Receiver upon the Response to Atmospherics

It is a well-known fact that increasing the selectivity of a receiver and working with a weaker coupling between the

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[1] Reference No. 581.

[2] Reference No. 584.

detector and aerial circuits is advantageous from the point of view of lessening the response to atmospherics and highly damped impulses, as compared with that to sharply tuned waves.[1]

This fact therefore indicates one field of utility for receiving amplifiers, since much weaker couplings may be employed when they are in use than are otherwise possible for a given signal strength. It must not be forgotten, however, that these amplifiers amplify the atmospherics as well as the signals, so that a limit is placed to the amplification that it is desirable to use, unless the coupling is simultaneously reduced. Trouble may also arise through stray electrostatic coupling between various parts of the circuits.

Many of the receiving arrangements described in Chapter XXI. are very much more selective than the ordinary crystal or valve detectors, so that their use also serves to partially reduce the unpleasant effects of "static" interference. This increased selectivity is specially true of the various forms of heterodyne and similar detectors using "beat" action. In this connection, the receivers described on pp. 324-329, using amplifying valves with a "return coupling" between the plate and grid circuits may be specially mentioned as being highly selective, and therefore possessing great freedom from interference by other stations working on a different wave-length. They must not, however, be operated too close to the "critical coupling" at which oscillations begin to be generated, otherwise a strong atmospheric might provide the necessary impulse to start these oscillations and give a false response in the telephones.

A special means of utilising these amplifying valves (with "return couplings") for diminishing the effect of X's has been disclosed by M. Pupin and E. H. Armstrong.[2] The action of a generating valve in a receiving circuit towards currents of the frequency for which the valve circuits are adjusted is somewhat analogous to a "negative resistance."

Hence an addition of "positive" (ordinary ohmic) resistance may be made to the circuit while yet retaining the ordinary characteristics of a circuit with small positive resistance as far as E.M.F.'s of the critical frequency are concerned. For all other frequencies, however, the added positive resistance alone is effective, so that undesired signals and impulses are greatly diminished in effect. By shunting the circuits

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[1] Reference No. 573.

[2] Reference No. 688.

representing the negative resistance by a slightly larger positive one, a magnification of the effective negative resistance may be obtained. Thus applying the ordinary laws of parallel resistances, suppose we put $+1000^{\omega}$ in parallel with -900^{ω}, the effective resistance of the two together

$$= \frac{1000 \times (-900)}{1000 + (-900)} = -9000.$$

Hence if $+9100^{\omega}$ is added in series with this combination, the effective resistance to signals of the proper frequency is $9100 - 9000 = 100^{\omega}$ only; whereas to other frequencies, practically the whole of the + 9100 ohms is effective in cutting down the effect of the impulse. The special valve arrangement of A. W. Hull, which operates as a negative resistance,[1] may also be employed in a similar manner to the above.

This arrangement has been styled in America a "Pliodynatron," on account of its amplifying properties.[2]

Atmospheric interference therefore places a serious bar to the otherwise attractive project of using very small transmitter energy and very great amplification at the receivers. Hence until a more effective "static eliminator" is invented, it is necessary to have resource to high power transmitters and relatively robust receivers, in order to secure perfectly reliable communication under all conditions of the atmosphere as regards transmission and interference.

Considerable advances have recently been made in the direction of improving arrangements for reducing interference. By the use of special aerials, provided with "cages" or screening arrangements, the effects of certain types of atmospheric may be reduced.

Greater success has been obtained in the elimination of "tuned" interference from powerful stations, by an application of the principles of the Direction-Finding Wireless apparatus. For this purpose closed coil "aerials"—or "frame-coils" as they are often called—may be used in conjunction with ordinary aerials. When the interference is coming in from one particular direction its effects may be largely balanced out by this method.

Amplifiers are practically essential for good results.

Certain types of Atmospheric (but not all kinds) may also be balanced out by special forms of frame-coil aerials used alone or in conjunction with ordinary forms of aerial.

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[1] See p. 188.

[2] See Reference No. 634.

CHAPTER XXIV

FIELDS OF USE FOR WIRELESS TELEPHONY AND SUMMARY OF RESULTS OBTAINED

The possible fields in which wireless telephony may be utilised are many and diverse, but those in which its commercial application is probable are relatively few. One reason at least for this statement is to be found in the competition of the old established wire telephone, and in the much greater secrecy of wire communication over wireless. As a well-known writer has recently aptly put it: "A wireless telephone talk is a talk upon the house-tops with the whole world for an audience."[1]

The practical utilisation of wireless telephone methods is therefore confined almost entirely to cases where the wire telephone cannot be used, or is rendered unreliable from exterior causes. Wireless telephony's most important field is consequently for long-distance, and especially trans-ocean work, and for communication with ships.

Until comparatively recently the effective speaking range of a wire telephone was limited to a few hundred miles at the most. This limit has been greatly surpassed by the introduction of the "loaded" telephone line with its greater freedom from distortion and its better "speaking" qualities.[2] By this means (coupled with the use of amplifiers), speech has

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[1] J. E. Kingsbury, in the 2000th Souvenir Number of the *Electrician*. Reference No. 587.

[2] A "loaded" line is one in which the natural self-inductance of the line wires is augmented either by the introduction of coils of high inductance, or by surrounding the copper conductor by a wrapping of iron wire. These two types are known, respectively, as "coil-loaded," and "continuously-loaded" lines respectively. O. Heaviside has shown that a line is "distortionless" when the product LS = the product CR, L = inductance of line; C = capacity; R = resistance; and S = insulation leakance of the line, all per mile length.

been transmitted between New York and San Francisco, a distance of 3400 miles.[1] For long-distance overland work, there is therefore little field for wireless telephone communication in competition with wire unless its installation should prove cheaper, and its maintenance less than the heavy charges involved in the expensive apparatus used on these long lines.[2]

Under certain natural conditions, however, wireless has already proved its superiority over wire telephone communication. This is the case through tropical jungles and other difficult country where the maintenance of lines is practically an impossibility. In certain countries, too, troubles due to insects, animals, and natives render the maintenance of a line a very difficult and expensive matter. As a further instance, it has recently been announced that the Chicago Drainage Board have recommended the installation of a wireless telephone between Chicago and its power generating station at Lockport, thirty-two miles away, because the telephone lines between these two places are subject to frequent damage by lightning.[3] In such places, and under such circumstances, the need for an effective "interference-preventer"[4] would probably be great.[5]

Another field of utility in land work is for communication with moving railway trains. As long ago as 1885, T. A. Edison and others experimented in this direction, using some of the earlier methods (induction), but nothing came of the arrangements through lack of commercial support. Comparatively recently wireless telegraphic communication with trains has been successfully introduced—notably on the Lacawanna and Delaware Railway, and on the Union Pacific Railroad—and some experiments have also been made with speech communication under similar circumstances.[6] There is possibility of considerable use for such installations, especially for "business" expresses between important cities. The aerial

[1] The above record for long-distance telephone line has been surpassed by the new line between Montreal and Vancouver, 4000 miles (November 1917). Reference No. 691.

[2] Each conversation between New York and San Francisco makes use of about £400,000 worth of electrical apparatus, and line material. [*Electrical World*, 65, p. 279 (1915).]

[3] Reference No. 588. [4] Page 348.

[5] Another and similar installation has since been contemplated by the Public Service Company, Illinois. Reference No. 690.

[6] Reference Nos. 589, 590, and 692, 695.

system on the train is usually supported horizontally, a short distance above the roofs of the coaches, and the wheels and rails are used for the earth connection. Communication is effected with an ordinary type of land station, and thence the speech could be relayed on to the local land telephone lines of the town or city. Fig. 247 shows the aerials on a railway coach.

A great field for the use of wireless telephony exists in its application to aircraft. The more extended use of aircraft, and the inauguration of passenger and mail air services will provide facilities for wireless communication particularly adapted for telephone work.

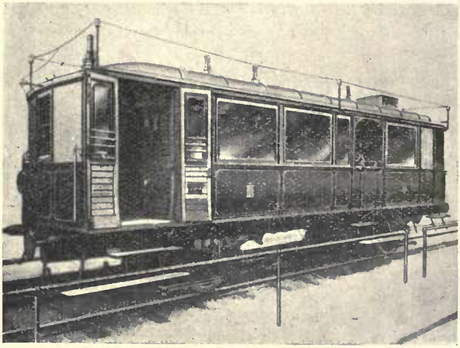

FIG. 247.—Aerial System on Railway Coach.

Good results have already been obtained over limited ranges using valve transmitters and receivers.

Where oversea telephonic transmission is concerned, either by submarine cable or by wireless, the comparison becomes very much in favour of the latter. In a submarine cable, the capacity of the line is large, and very considerable distortion of the speech takes place when there is any considerable length of cable in the circuit. Great improvements have taken place in cable construction of late, both by loading the cables,[1] and also by reducing the specific inductive capacity of the insulating medium. With the best of cables as at present

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[1] Both continuously-loaded and coil-loaded submarine cables are in use across the Channel.

constructed, however, speech transmission is quite impossible over great distances—such as transatlantic work—and it is here that one of the greatest fields for wireless speech communication is found.

As has already been mentioned, ordinary wire telephony and especially submarine cable telephony, is subject to distortion of the speech. The speech wave, during its transmission from one place to another along the wires, is subject to two changes: *attenuation* and *distortion.* The former is merely the gradual weakening of the received impulses with distance from the transmitting instrument, while preserving their original quality (and waveshape); while the latter is a change in the quality of the speech whereby the received sounds eventually become quite unrecognisable even although there may be ample total volume of sound in the receivers.[1] With wireless transmission we are merely concerned with *attenuation* alone, and not distortion, since the various speech harmonics are all impressed upon the *same wave* which travels at a uniform speed through space—viz. the velocity of light, 3×10^8 metres per second. Wireless transmission is therefore at a great advantage over cables for long-distance work.

For ship to ship and ship to shore work there is a certain field of utility for wireless telephone work, although the bulk of the traffic will doubtless continue to be handled by the wireless telegraph. In certain cases, however, when great rapidity of communication is important—such as with ships in distress—the telephone shows great advantages over the telegraph.[2] What is really required for this work is therefore some apparatus that is equally available for either telegraphic or telephonic work, with but little change in adjustment, and one that will equally affect any ordinary receiving apparatus. The latter condition is usually fulfilled with the types of crystal and valve receivers now commonly employed for wireless telegraph work. With the majority of the continuous wave generators available for telephony the former condition is not fulfilled unless some mechanical or other means are incorporated with the transmitter for cutting up the continuous stream of waves into intermittent groups so as to produce a

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[1] *Distortion* arises through the high-frequency harmonics of the speech wave becoming damped out quicker than the low-frequency ones.

[2] Reference No. 591.

musical note at the receiving station for telegraphic purposes. Such methods are usually rather inefficient. With arc and quenched gap continuous wave generators, it is possible to emit a musical note by shunting the gap with an oscillation circuit tuned to an audible frequency. Telegraphic signalling is accomplished by control of this low-frequency circuit. Such methods give quite good results.

For all wireless telephone work that is to be developed in any way for commercial purposes great reliability of the apparatus is essential, so that it can always be ready for instant use. Simplicity of operation is also desirable so that very highly skilled attention is not required. Another necessary feature is adequate means for relaying the wireless telephone instruments on to the land telephone circuits at both the transmitter and receiver, so as to avoid the necessity of the speaker attending at the wireless station in person in order to carry on a conversation. By such relaying the wireless telephone " trunks " would become available to all subscribers to public telephone systems. The amplifiers described in Chapter XXII. are capable of effecting the necessary junction between the wireless receiver and the land lines. The matter is not, however, one of simple relaying or repeating, since the same land lines are available for speech in both directions without any changing over from speaking to receiving, while the present wireless apparatus cannot be so used.

A necessary feature to be accomplished is therefore the successful duplexing of the wireless gear for work in both directions. The best method of carrying this into effect that has yet been devised is the one used for the Marconi Transatlantic wireless telegraph stations. The arrangement consists in separating the complete transmitting and receiving instruments from one another, and placing them in separate stations (several miles apart), connected together by land lines. The receiving station is equipped with a double aerial system, a main aerial for the reception of signals from the distant station, and a smaller balancing aerial arranged to be affected mainly by the nearby transmitting station. These two aerials are connected to produce opposing effects in the receiving gear after the manner indicated in Fig. 244 (p. 349). The main receiving aerial thus picks up the messages from the distant station, and passes them on to the receiver ; while both aerials are influenced almost to the same extent by the local transmitter, so that no effects are produced upon the receiving gear.

Any person carrying on a conversation over a similar wireless telephone arrangement would therefore speak into a microphone connected to the transmitting station apparatus, and listen in telephones connected to the separate receiving station.

Such a duplex arrangement is rather difficult to couple on to a single land telephone line to render ordinary subscribers' instruments available. The method, involving as it does, three aerial systems and two separate station buildings, is a very costly one to install, and is, moreover, impossible of application in certain circumstances—such, for instance, as on board a ship.

Many attempts have been made to devise various " bridge " or balancing arrangements, whereby the transmitting and receiving gear may be operated in one station, and so linked together that the transmitted impulses cancel out at the receiver without impairing the efficiency of the latter for the distant reception.[1] The modification of the heterodyne detector for telephone reception,[2] using beats of frequency just above the acoustic limit, may eventually provide a solution of the difficulty, utilising the continuous waves from the transmitter to provide the local oscillations required for the heterodyne. The transmitting and receiving wave-lengths must be adjusted to have the necessary frequency difference for this purpose.

The current limiting properties of vacuum valves may be turned to good account in these arrangements, in order to prevent damage to the receiver by the nearby transmitter.[3]

Up to the present time, the various forms of arc oscillation generator have proved to be one of the most successful means of generating the required high power oscillatory currents for the wireless telephone transmitter. A certain amount of skilled attention is required in order to obtain the best results, and to secure steady and persistent oscillations.

The quenched spark apparatus has not yet been developed to any very great extent for large power outputs of oscillations suitable for telephone work. The multiphase and rotary spark arrangements, and especially the multi-disc arrangements of the Marconi Company, are more promising.

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[1] Reference Nos. 592, 593.

[2] Page 324

[3] See for example Reference No. 687.

High-frequency alternators (including the Goldschmidt reflection alternator and similar machines), should require little attention in running beyond that usually given to high speed machinery, but their very high construction and installation cost mitigates against their extensive adoption. The machines so far constructed have also required a rather considerable expenditure on maintenance and repairs. The very high speeds required would introduce difficulties for ship work. The most useful alternator arrangement appears to be the combination of a moderate frequency alternator (say up to about 5000 ∾), with suitable frequency raisers to furnish the necessary energy at higher frequencies. The microphonic control of such arrangements is comparatively easy.

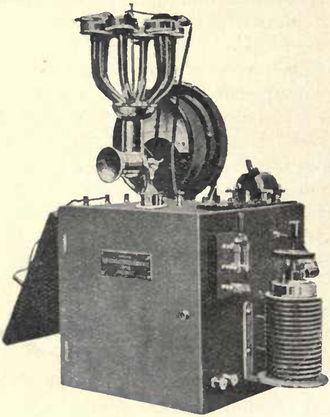

FIG. 248.—Dubilier Portable Arc Transmitter.

On the whole the most promising type of apparatus yet devised is the valve or vacuum oscillation generator. Very little care or attention is required for their operation. Whether they will yet be available for large power outputs—such as of 100 kw. or more—without the use of a huge number of small units in parallel, remains to be seen Recent developments in this direction appear distinctly promising. They possess the great advantages of being extremely reliable, of generating very steady oscillations, and of possessing the greatest facility for microphonic control of their output. The auxiliary apparatus is simple and suitable for general use without specially skilled attention, no high speed rotating parts are required, and the apparatus admirably fulfils the desideratum of being suitable for connection to the ordinary land telephone lines. Experimental installations of these transmitters have yielded the longest range (5000 miles) of any wireless telephone work yet accomplished.[1] The use of a large number of small valves in parallel was, however, too costly for commercial work. They have recently proved their worth in the difficult field of speech transmission to moving aircraft.[2] If the constructional cost of the valves can be reduced by the use of large units, and the fragile glass work eliminated, these transmitters should prove ideal for all kinds of wireless telephone work.

Photo: Frank C. Perkins.

FIG. 249.—Mr. Theodore N. Vail speaking by Wireless Telephone from New York to Mare Island, California, 2500 miles away.

[1] Reference Nos. 609, 610.

[2] Reference No. 614.

BRIEF RÉSUMÉ OF THE MOST IMPORTANT RESULTS THAT HAVE BEEN ACHIEVED IN WIRELESS TELEPHONY

1885. Experiments with the Induction System were carried out by Sir Wm. Preece at Newcastle-on-Tyne. A speaking range of 440 yards was obtained.

1894. Experiments with Conduction System successful for distance of 1½ miles across Loch Ness.

1887. The Induction System was utilised in mines. Telephonic communication was established between the surface and subterranean galleries of Broomhill Colliery, 350 feet deep, by A. W. Heaviside.

1899. The Conduction Wireless Telephone was installed between Skerries and Anglesea. Average distance between stations = 3 miles.

A similar installation was also put into use between Rathlin Island and the mainland of Ireland. Range of speech communication = 8 miles.

1900. Early experiments by R. A. Fessenden, with a special high-speed commutator, to obtain a rapid sparking rate. Speech transmitted by aether waves for about 1 mile, but articulation not very good.

1899–1900. Experiments made with A. F. Collins' electrostatic method were successful up to 200 feet range.

1902. The range of Collins' tests was extended to 3 miles. Articulation said to be perfect.

1902. E. Ruhmer, in the course of his extensive experiments with the Photophone method, succeeded in telephoning over a distance of about 4 miles on Lake Wansee, and subsequently at Kiel over a range of about 20 miles.

1906. Successful experiments carried out with a small high-frequency Inductor Alternator by R. A. Fessenden. Ranges up to about 20 miles obtained.

1906. Tests of Arc Transmitters made by Telefunken Co. between Nauen and Berlin—20 miles.

1907. The range of Fessenden's tests was increased to about 100 miles, using improved H.F. Alternators.

1908. Tests with the Colin-Jeance Arc Apparatus were made from the Eiffel Tower. A range of 30 miles obtained.

1908. Experiments by F. Majorana, using an arc oscillation generator with his liquid microphone, were carried out from Rome to a number of other stations—including ships. The range of successful speech communication was gradually extended from about 35 miles, to 156 miles (Rome to Sardinia), then to 180 miles (Rome to Maddalena), and eventually to 300 miles (Rome to Sicily).

1908. V. Poulsen succeeded in transmitting speech over a distance of about 150 miles, using his Arc Transmitter.

1909. Successful tests of Poulsen type Arcs between Milwaukee and Chicago (90 miles).

1909. Ranges of speech communication up to 75 miles obtained with Colin-Jeance Arc Apparatus; subsequently increased to 100 miles between Toulon and a French cruiser, and 90 miles between Eiffel Tower and Dieppe.

1910. Experiments with H. P. Dwyer's Arc gave perfect telephonic communication between San Francisco and Los Angeles—490 miles range.

1911. Range of speech communication from Nauen increased to about 350 miles (Nauen to Vienna).

1912. G. Vanni obtained a speech range of 600 miles between Rome and Tripoli, using the Moretti Arc Oscillation Generator and the Vanni Liquid Microphone.

1913. Experiments at Nauen Station, with 10,000 ∾ Alternator and Static Frequency Raiser, gave a range of 550 miles to Pola.

1913. Further experiments carried out with the Induction System in mines demonstrated its special utility for such purposes. Communication was successfully established between the surface and a level 800 feet deep.

1914. The T.Y.K. Arc System was first put into practical use at Toba.

1914. Successful speech communication from Brussels to Paris, 190 miles, using Moretti Arc Transmitter and Marzi's Carbon Powder Microphone.

1914. Experiments carried out by G. Marconi with the Oscillating Valve Transmitter on Italian war vessels. Ranges up to 45 miles were obtained, using very limited power at the transmitter.

1915. Tests of Oscillation Valve transmitters gave successful communication between New York and California, 2500 miles.

1915. The American Telephone and Telegraph Company carried out a series of very successful experimental tests with the valve type transmitters. Eventually the Atlantic was bridged between Arlington (Va., U.S.A.) and the Eiffel Tower, France, 3800 miles; and good speech communication was also established between Arlington and Honolulu, a distance of close on 5000 miles. Articulation was said to be faint, but very clear and recognisable.

1918. Considerable development of wireless telephone apparatus for communication with aircraft. Successful results obtained up to about 100 miles between aeroplanes in flight; and up to about 150 miles between aeroplanes and the ground.

1919. Successful wireless telephone communication established between the British Isles and Canada by special valve apparatus developed by the Marconi Company.

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