RESEARCHES IN RADIO-TELEGRAPHY.[1]

RADIO-TELEGRAPHY, popularly called wireless telegraphy, has outlived the tentative achievements of its precocious infancy and obtained for itself a settled but important position amongst our means of communication.

This stage, however, has only been reached after a long struggle with experimental difficulties and much labour in analysing the processes involved. As many of these matters are of general scientific interest, it is proposed, during the present hour, briefly to summarise the results of some recent research.

It is well known that the nature of the earth's soil or surface between the sending and receiving stations has a great effect upon electric waves passing over it. If the surface is a very good conductor the wave hardly penetrates into it, but glides over the surface. If it is a poor conductor the wave penetrates into it to a greater extent, and the worse the conductivity the deeper the penetration.

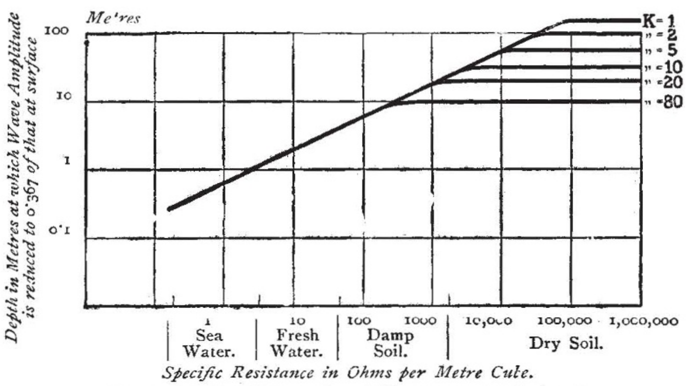

FIG. 1.—Depth of Penetration of Waves 1000 feet in length. (Dr. Zenneck.)

The materials of which the earth's crust is composed, with some exceptions, owe their electric conductivity chiefly to the presence of water in them. They are called electrolytic conductors. Substances like marble and slate, when free from iron oxide, are fairly good insulators. Dry sand or hard dry rocks are poor conductors, but wet sand and moist earth are fairly good conductors. Sea water, owing to the salt in it, is a much better conductor than fresh water. The following table gives some figures, which, however, are only approximate, for the specific resistance of various terrestrial materials in ohms per metre cube. It will be seen that dry sand or soils are of very high specific resistance, and damp or wet sand or clay fairly low.

TABLE I.—*Approximate Conductivity and Dielectric Constant of various Terrestrial Materials.*

Material	Specific resistance in ohms per metre cube	Dielectric constant. Air = 1
Sea water	1	80
Fresh water	100 to 1000	80
Moist earth	10 to 1000	5 to 15
Dry earth	10,000 and upwards	2 to 6
Wet sand	1 to 1000	9
Dry river sand	very large	2 to 3
Wet clay	10 to 100	—
Dry clay	10,000 and upwards	2 to 5
Slate	10,000 to 100,000	—
Marble	5,000,000	6
Mercury	0·000001	infinity

If our earth's surface had a conductivity equal, say, to that of copper, then the electric radiation from an antenna would glide over the surface without penetration. In the case of the actual earth there is, however, considerable penetration of the wave into the surface, and therefore absorption of energy by it.

Brylinski, and also Zenneck, have calculated the depth to which electric waves of such frequency as are used in radio-telegraphy penetrate into the sea or terrestrial strata of various conductivities. For mathematical reasons, it is customary to define it by stating the depth in metres or centimetres at which the wave amplitude is reduced to $1/\epsilon = 0{\cdot}367$ of its amplitude at the surface. I have represented in a diagram some of Zenneck's results calculated for waves of 1000 feet in length, and for terrestrial surface materials of various kinds, conductivities, and dielectric constants (see Fig. 1). You will see that in the case of sea water an electric wave travelling over it penetrates only to the depth of a metre or two, whereas in the case of very dry soil it would penetrate much deeper. Owing to the conductivity of the soil, this movement of lines of magnetic force through it sets up currents of electricity which expend their energy in heat. This energy must come from the original store imparted to the sending antenna, and therefore the wave is robbed of its energy as it travels over the surface.

Dr. Zenneck has discussed mathematically, in a very interesting paper, the effect of the conductivity and dielectric constant of the terrestrial surface, soil or sea, on the propagation of a plain electric wave over it, assuming the radiation to be from an ordinary vertical antenna, and the electric force therefore normal to the earth, and magnetic force parallel to it. The result is to show that there are, broadly speaking, three cases to consider. First, supposing the surface material to be a good conductor, then the wave moves over the surface and penetrates a very little way into it. The electric force in the air over the surface is a purely alternating force vertical to the earth's surface, and the magnetic force is an alternating force parallel to it, and there is very little subterranean electric or magnetic force (Fig. 2, A). This is realised approximately or most nearly in the case of radio-telegraphy over sea water. Secondly, let the earth be assumed to have a very poor conductivity and not a very large dielectric constant, then analysis shows that the electric force in the air has two components, one perpendicular to the earth's surface and one parallel to it, and the resultant is an alternating and a rotating force, the direction of its maximum value being inclined to the surface and leaning forward (Fig. 2, B). The wave-front therefore slopes forward. Also there is a subterranean electric force, showing that the wave is penetrating into the soil, and there is therefore dissipation of energy owing

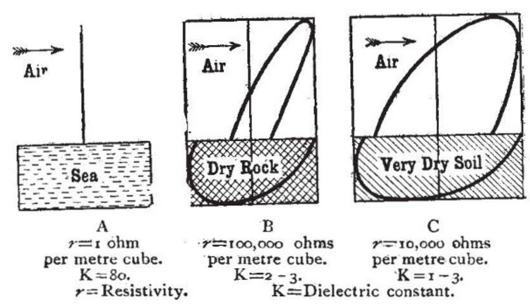

FIG. 2.

to the conductivity of the soil as the wave travels over the surface. This case is realised when the wave travels over land composed of dry soil having a small dielectric constant. Thirdly, let the earth be a very poor conductor, having a small dielectric constant from 2 to 3, and a specific resistance of about 10,000 ohms per metre cube. For example, very dry earth or sand. Then the investigation shows that the electric force in the air has two components, one parallel to the earth's surface and one perpendicular to it differing in phase, and the resultant is represented by the rotating radius of an ellipse, the maximum value or major axis of which is inclined forward in the direction of the wave motion (Fig. 2, C). At the

[1] From a discourse delivered at the Royal Institution, on Friday, June 4, by Prof. J. A. Fleming, F.R.S.

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same time there is some penetration of the wave into the earth, and consequent dissipation of energy.

Dr. Zenneck has considered the case of electric waves 1000 feet in wave-length, and has represented the final result by some interesting curves. He defines the effect of the absorption of energy by the soil by stating the distance in kilometres at which the wave amplitude would be reduced by the effect of this absorption to $0{\cdot}367 = 1/\epsilon$ of its amplitude at the sending station, altogether apart from the weakening due to the spreading of the waves out in a hemisphere, which we may call the spherical or space decrease. These curves are plotted to abscissæ representing the specific resistance of the soil (Fig. 3). You will see from this diagram that when a plane electric wave having the above wave-length is propagated over sea water, it would have to travel 10,000 kilometres before its amplitude would be reduced in the assigned ratio, and over fairly dry soil about 100 to 1000 kilometres; but over very dry soil, having a small dielectric constant, only about 1 to 10 kilometres. Also you will notice that the curves rise up again for still higher resistivities. This, of course, is as it should be. All the practical cases lie between two ideal extremes: the case of an infinitely perfectly conducting earth, in which case the waves would not penetrate into it at all, and the other case, an infinitely perfect non-conducting earth, in which the wave would

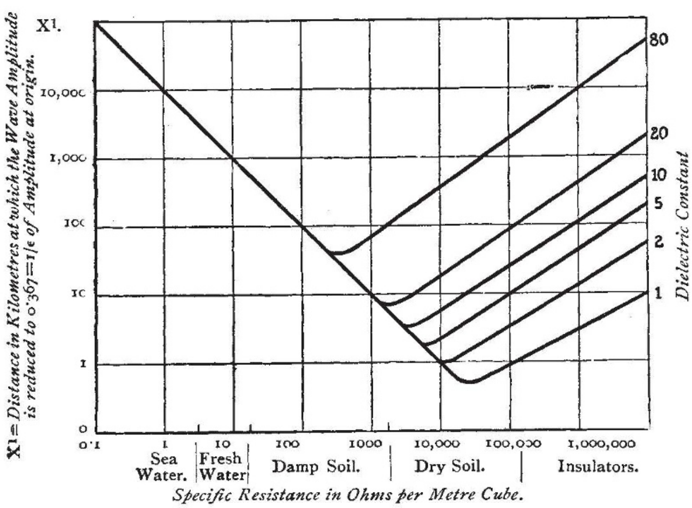

FIG. 3.—Curves showing the Distance in which Electric Waves 1000 feet (300 metres) in length have Amplitude reduced to $1/\epsilon$ by travelling over various surfaces. (Dr. Zenneck.)

penetrate into it, but would suffer no dissipation of energy. This theory is quite in accordance with practical experience in radio-telegraphy. Every receiving apparatus associated with an antenna of a certain height and kind must be subjected to waves of a certain minimum amplitude to give any appreciable signal. For all lower amplitudes that particular receiving arrangement is perfectly deaf. Now it is a matter of common experience that with a given radio-telegraphic apparatus and antenna it is possible to receive signals for greater distances over sea water than over dry land, and that if the soil is very dry the distance may be cut down very considerably indeed. This is not due merely to the difficulty of making what the telegraphists call a good earth at the sending station, it is due to the absorption of the wave by the earth for the whole distance which extends between the two stations. Hence, also, it is a common experience that when particularly dry weather is succeeded by wet weather the radio-telegraphic communication between two stations on land is considerably improved.

The next point in connection with the antenna to be noticed is the means adopted of setting up the oscillations in it. The universal custom at present is to excite oscillations in a reservoir circuit consisting of a condenser and an inductance by means of the spark or arc. If the spark method is used, then the condenser is one of relatively large capacity, and the inductance is kept small. If the capacity is measured in electrostatic units, and the inductance in electromagnetic units, the ratio of capacity to inductance may be something of the order of 5/1 or even

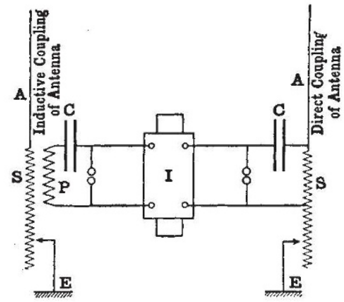

FIG. 4.

20/1. In this case the condenser is charged by means of an induction coil or transformer, and discharged across a spark-gap, and this discharge consists of intermittent trains of electric oscillations with a periodic time equal to the free natural period of the oscillatory circuit. These discharges are made to succeed each other from 50 to 600 times a second by using an induction coil with an appropriate interrupter, or else an alternator and a transformer. If the arc method of exciting the oscillations is employed, then the ratio of capacity to inductance must be much smaller, and the oscillations are excited in this circuit by a continuous current arc worked with a voltage from 200 to 400 volts or more, the arc being traversed by a strong magnetic field, and generally being placed in a chamber kept free from oxygen. The oscillations set up in the condenser circuit are then persistent or unbroken. The oscillations are excited in the antenna by coupling it inductively or directly with the condenser circuit (Fig. 4). If the former method is employed, then an oscillation transformer is used consisting of two coils of wire, one coil being inserted in the condenser circuit and one in the antenna circuit, and according as these coils are near or far apart they are said to be closely or loosely coupled. These two circuits have, then, each their own natural period of electric vibration, like tuning-forks, and they have to be adjusted to syntony. It is well known that under these conditions oscillations set up in one circuit immediately create oscillations of two frequencies in both circuits. This action can be easily illustrated by two pendulums, which are of the same length and are hung side by side on a loose string distinguished by red and blue bobs. If one pendulum is set swinging it imparts little jerks to the other and sets the latter in motion, but to do

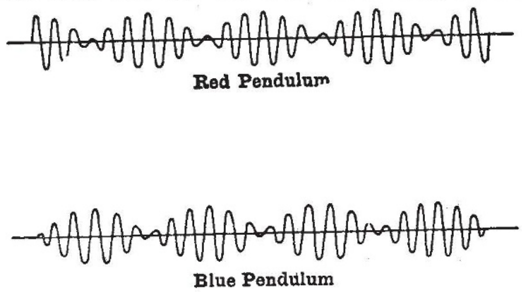

FIG. 5.

this the first must part with its own energy, and hence is gradually brought to rest. Then the operation is repeated in the reverse direction. The motion of each pendulum may then be represented by the ordinates of a curve such as those in Fig. 5. This kind of motion can,

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by a well-known theorem, be resolved into the sum of two oscillations of different frequencies. Hence each pendulum may be said to possess two rates of vibration. The same thing happens in the case of two closely coupled syntonic electric currents. If one circuit has free oscillations set up in it, the action and reaction of the circuits generates oscillations of two frequencies. Accordingly, when an antenna circuit is coupled to a condenser circuit we have oscillations of two frequencies set up in it, and waves of two wave-lengths radiated from the antenna. The presence of these two waves can be detected either by measurements made with the cymometer or by an oscillograph vacuum tube. In the first case, all that is necessary is to place a cymometer in proximity to the antenna and vary its oscillation constant. It will be found that there are two settings of the handle for which the neon tube glows brightly, and the scale of the instrument will indicate the wave-lengths of the two waves respectively.

Some instructive measurements of this kind have been made by Prof. W. G. Pierce in a recent research, and he has shown that the wave-length given by the formulæ which can be deduced from the theory of the operations are in agreement with actual measurements (Fig. 6). Another striking confirmation can be obtained by the oscillograph vacuum tube, invented by Dr. Gehrcke, of the Reichsanstalt, Berlin. This consists of a glass tube having

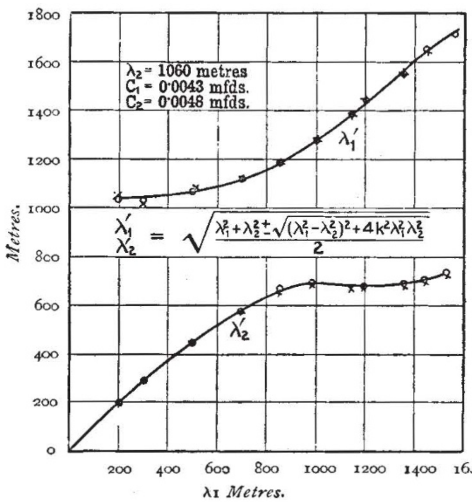

FIG. 6.—Pierce's Experiments on Inductive Coupling.

two strip electrodes in it nearly touching, which are made of nickel or aluminium. The tube is filled with pure nitrogen and exhausted to a pressure of about 10 to 20 mm. If such a tube has a high voltage applied to its terminals a glow light extends along the electrodes, the length of which varies with the electromotive force. Hence, if the tube is connected to a circuit in which an oscillatory discharge is taking place, the glow light along the tube will rapidly extend and contract. If the electrodes are examined in a revolving mirror, making from fifty to a hundred turns a second, the images of the glowing electrodes corresponding to each oscillation will be separated out, and if the oscillations are persistent or undamped we see a series of short bright lines alternately above and below a central line. If, however, the oscillations are damped, then we see in the mirror a train of images each decreasing in length (Fig. 7). On applying such an oscillograph vacuum tube to the circuit of an inductively coupled antenna, and examining in a revolving mirror the image of the electrodes, they will be seen to present an appearance as in Fig. 8, taken from photographs kindly given me by Herr Hans Boas, of Berlin. These oscillograms indicate that there are two oscillations present of different frequency, producing an effect similar to beats in music. Owing to the difference in frequency, the oscillations alternately reinforce and extinguish each other throughout the period, and as this type of oscillogram is only obtained with an inductively coupled antenna, it is a proof that in such a case there are two oscillations present of different frequencies. A similar result has been obtained by Prof. E. Taylor-Jones with low-frequency oscillations in coupled inductive circuits by means of an electrostatic oscillogram of his own invention. Looking at these photographs, it will be seen that each represents a single train of damped oscillations gradually dying away,

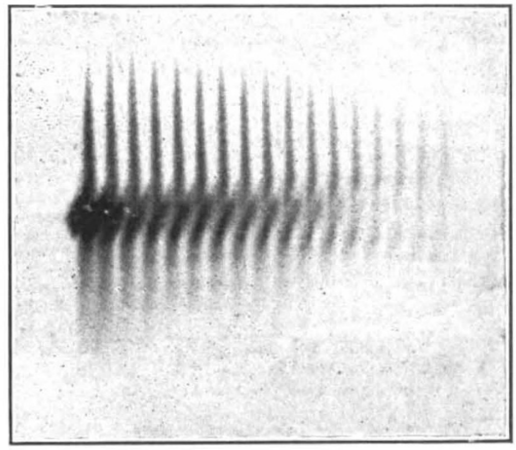

FIG. 7.—Oscillogram of Damped Oscillation (Antenna not connected) taken with the Gehrcke Oscillograph Vacuum Tube.

but that in each train of oscillations there is an alternate waxing and waning of the amplitude, which indicates that it may be considered to be composed of two superimposed oscillations of different frequency (Fig. 9).

Accordingly, in the case of wireless telegraph antennæ inductively coupled, we have in general two waves radiated of different lengths, and either of these can be made to affect suitably tuned receiving circuits. These waves have different damping and different maximum amplitudes.

One of the disadvantages of close inductive coupling is,

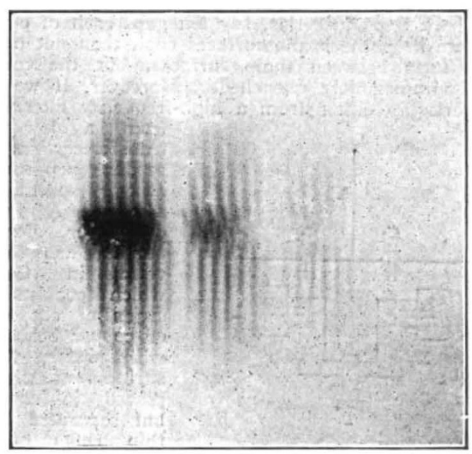

FIG. 8.—Oscillogram of Secondary Oscillation (Antenna connected) taken with Gehrcke Vacuum Tube.

therefore, that we must divide the energy given to the antenna between two waves of different length. As the receiving antenna is generally only tuned to one of these wave-lengths, we then capture and absorb only the energy conveyed by the waves of that wave-length. To meet this difficulty it has been the custom to employ a feeble coupling between the circuits of the oscillation transformer, so as to generate waves of only one wave-length. The objection then arises that the energy conveyed to the antenna is

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much reduced. It is, however, possible, as I have shown, to duplicate the receiving circuits so as to capture the energy of both the waves even with close coupling of the transmitter transformer[1] (Fig. 10).

A method of creating feebly damped oscillations has, on the other hand, recently been developed, generally known in Germany as Wien's method, or the method of quenched sparks, which is based on the fact that if we can quench or stop the spark in the condenser circuit after the first few oscillations, the oscillations of the antenna then take place freely and with a single frequency (Fig. 11).

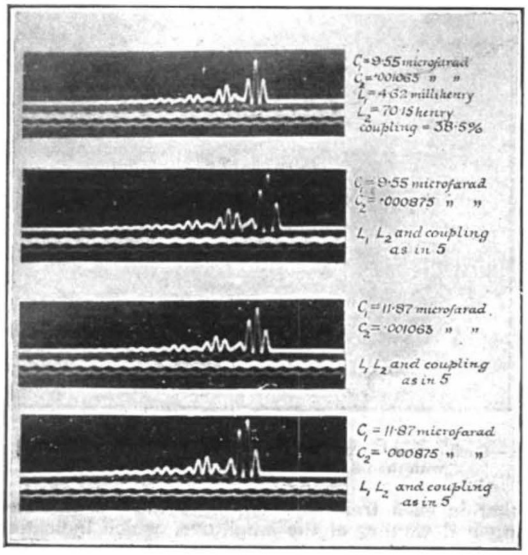

FIG. 9.—Oscillograms of Oscillations in Coupled Circuits by Prof. E. Taylor-Jones.

The principle which underlies this method is the well-known fact, to which particular attention was directed by Prof. M. Wien, of Danzig, in 1906, that the damping effect of very short sparks is extremely large. Hence if we form a spark-gap consisting of a large number of very small spark gaps in series, say ten gaps each of 0·3 mm., and if we keep the spark surfaces cool, then not only can no arc form between these surfaces, but the condenser spark is immediately quenched. Moreover, if we supply this spark-gap either from a high-frequency alternator or from a low-pressure transformer we can produce as many as 2000 sparks per second. A form of discharger for this purpose has been devised in Germany, which consists of a series of copper discs or copper boxes cooled with water, the flat surfaces of which are placed in contiguity, but separated by very thin rings of mica. The interspace between the boxes is not more than 1/125th part of an inch, and ten or twelve of these discs or boxes are placed in series (Fig. 12). The row of boxes takes the place of the ordinary spark balls, and is connected to the secondary terminals of a transformer, fed by a high-frequency alternator, and also connected to an oscillatory circuit. When the transformer is in action it produces a very large number, 1000 or more, oscillatory discharges of the condenser per second, each of which has a large initial amplitude, but quickly dies out. The inductively or directly coupled antenna hence receives a very large number of impulses per second, each of which sets up in it free electrical oscillations of one definite period.

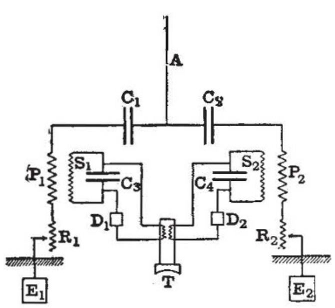

FIG. 10.—Method of utilising waves of both frequencies emitted by inductively-coupled Transmitting Antenna.

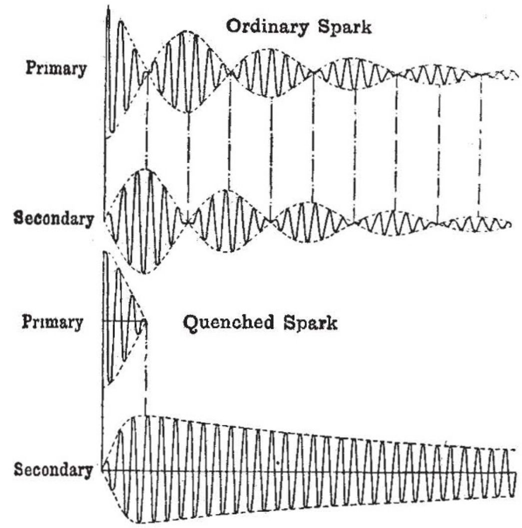

FIG. 11.—Oscillations in Inductively-coupled Circuits.

A discharger, composed of a single pair of metal plates with interposed separating paper ring, has been devised and employed by Von Lepel. In this case the plates are connected to the terminals of a high-voltage direct-current dynamo, and are shunted by a circuit having inductance and capacity, one of the plates being also connected to an antenna and the other to a balancing capacity.

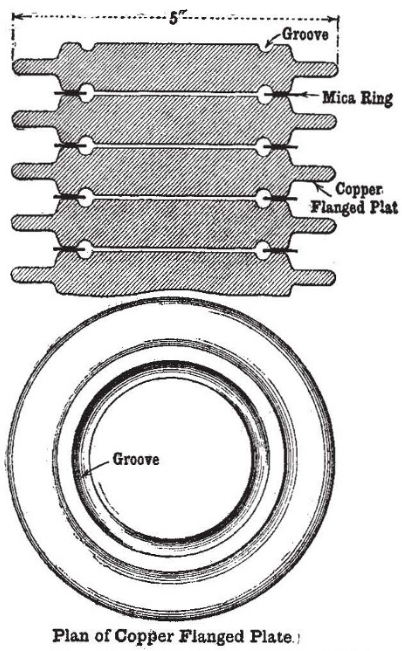

FIG. 12.—Plan and Section showing portion of Discharger.

These discharges, however, have not stood the test of prolonged practical use, and we cannot say, therefore, that they are comparable in value for telegraphic purposes with the well-proved inventions of Mr. Marconi.

(To be continued.)

[1] Since the delivery of this lecture, my attention has been drawn by Mr. J. Hettinger to an article by himself in the *Electrical Engineer* of October 26, 1906, in which he describes an almost identical arrangement devised by him for capturing both the waves of an inductively-coupled transmitter, and refers to a prior invention for the same purpose by Dr. Seibt.

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