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Dedicated

TO

PROFESSOR M. WIEN, PH.D.

WITH

EXPRESSION

OF HIGHEST ESTEEM.

PREFACE.

ANY reader expecting this book to consist of a compilation of the so-called "systems" of Wireless Telegraphy will be deceived. I fail to see that such a compilation would be of use to anyone, believing rather that a simple and comprehensive unfolding of the fundamental principles and working methods of modern telegraphy by means of electric waves is the more appropriate. On these grounds I may claim the right to term my work objective. Besides, I can draw on the abundant store of personal practical experience I was able to gather as manager of the important experimental stations on the Baltic Sea (Sassnitz-Gross-Moellen) for Professor Braun, Siemens & Halske. Hence I hope to create interest in wider circles for this rapidly growing branch of science and technology, as well as to perform some service to those more closely concerned with the subject, by combining theory and practice.

It is for me a welcome duty to offer my thanks in this place to Dr L. Mandelstam, for his advice and skilful co-operation in the most recent attempts to develop a selective system of wireless telegraphy. I am also greatly obliged to the Gesellschaft für drahtlose Telegraphie "Telefunken," of Berlin, for the use of blocks and photographs, and also wish to express my thankfulness to Mr M. G. Fox, for his kind assistance in revising the English style of the manuscript.

G. EICHHORN.

ZURICH, *January* 1906.

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WIRELESS TELEGRAPHY.

CHAPTER I.

INTRODUCTION.

THE historical development of wireless telegraphy may be summarised briefly.

Every physicist knows that the scientific foundations were already most widely laid.

Michael Faraday's original and ingenious ideas of interpreting the action of forces at a distance broke the ice, and, transplanted into the brain of a Clerk Maxwell, generated that undying masterpiece, the electromagnetic theory of light. Rays of light, radiant heat, and rays of electrical energy, must be thoroughly identical in character, differing merely in the dimensions of their wave lengths: they must all be based upon electromagnetic oscillations in the all-penetrating universal ether, in which they spread at the same enormous velocity of 186,000 miles per second. Equally ingenious with the theory was the long-delayed proof advanced by Heinrich Hertz with his renowned investigations into the propagation of electrical energy. Besides, the laws of oscillating discharges for the generation of periodic electromagnetic vibrations were known through the labours of Helmholtz, William Thomson (Lord Kelvin), and Gustav Kirchhoff, and had been verified in all their details by that rarely-endowed experimenter Feddersen. The experimental conditions with which they worked, however, were not adapted for action at a distance, this being first accomplished by the special form of Hertz's arrangements. The uniform subjection of all radiant phenomena to the same laws then became clearly apparent, and we learned how to guide the mechanism of the ether at pleasure and to detect the results of its action at distant stations. Signalling, by means of electrical waves, through the free universal ether was made possible, and wireless telegraphy was born. If it be desired to speak of a "system" at all, it would be only just to talk of the Hertz system of electrical-wave telegraphy. As a matter of fact, in point of principle, there is nothing in modern wireless telegraphy that was not contained in the above-mentioned stage of development, brought to such a brilliant conclusion by the labours of Hertz.

Nevertheless, considerable time elapsed before the new revolutionary discovery found application in practice, this being impossible so long as one was restricted to the delicate appliances with which Hertz detected the propagation of electrical radiation.

In 1890 this obstacle was finally overcome, through the discovery by a French physicist, Branly, of a phenomenon which led to the production of the coherer, the soul of practical wireless telegraphy. In 1894 Lodge first employed the coherer for laboratory experiments. It was not, however, until 1895 that the use of a coherer outside the laboratory came into notice through Professor Popoff, who exhibited before the Military Academy in Cronstadt a registering device for aero-electrical discharges, wherein the electrical impulses were automatically indicated by means of a coherer in conjunction with a tapper.

The decisive turning-point was reached in 1896, by the labours of Guglielmo Marconi, who made a definite attempt to elaborate a system of wireless telegraphy by means of electric waves. True, he stood upon the secure foundation of the ingenious experiments of Hertz; but the persistence and skill with which he contrived to overcome the practical difficulties in his way, cannot be sufficiently admired. Thus Marconi was the first to actually telegraph over a distance of many miles without wires, thereby winning lasting renown.

However, the capacity of his instruments soon reached a limit. In Germany, too, the labours of Slaby-Arco led to no improvement, in point of principle; but the course of development was diverted into an entirely new channel with unexpected progress by the work of Professor Ferdinand Braun, of Strassburg.

By complete mastery of the existing material, well-designed application of scientific principles and appropriate use of technical appliances, he created the basis on which wireless telegraphy is now everywhere conducted. To the personal modesty of Professor Braun nothing is more objectionable than the fruitless conflict over the so-called "systems": and he would be the first to put an end to the envious and distracting outcry raised by the companies engaged in exploiting wireless telegraphy, and to use the name "Hertzian Electrical-Wave Telegraphy" as the worthiest title possible.

CHAPTER II.

THE ETHER AND ELECTRICAL OSCILLATIONS.

THE ETHER.

THE processes with which we have to deal in wireless telegraphy are carried on in that infinitely tenuous medium known as the ether, which penetrates all matter, and yet seems to stand in a very definite relation to it.

Almost contradictory to such a property is the extreme elasticity of the ether, by reason of which periodic vibrations are transmitted with a velocity which though finite is none the less enormous, namely, 186,000 miles per second.

One side of the physical character of the ether is revealed by its elastic tension, which is well defined both in value and direction, as may be shown by the lines of electric force. Tension curves of this kind form the electric field, and have their beginnings and ends in the bodies by which the field is excited.

Another physical property of the ether reveals itself in a kind of motion. Here we have apparently to do with a rotation or torsion of minute ether particles; and to this frictionless motion without change of position of the particles themselves the name "magnetic field" has been given.

There is still another manifestation of force by ether, namely, gravitation; but up to the present its nature has not been determined.

The electric and magnetic conditions of the ether have an invariable mutual relation, from which the laws of a periodically varying condition, the electromagnetic field, have been deduced. This forms the mechanism by means of which the rapid vibrations of light, with their delicate wave-curl, spread out in a similar manner and at the same velocity with the far slower oscillations of correspondingly greater wave length employed in wireless telegraphy.

Electric and magnetic forces are mutually perpendicular; and, as we have to deal with transverse vibrations, the electromagnetic energy is transmitted at right angles to both, this being the direction of radiation.

OSCILLATIONS.

We must now picture to ourselves the method in which electrical oscillations originate.

In the year 1847 Helmholtz first definitely expressed the conception that, under ordinary conditions, in discharging a Leyden jar (fig. 1) with a discharger (the path traversed by the spark being represented at F) we have to do with vibrations; that is to say, the electricity flowing through the wire of the discharger oscillates to and fro between the coatings like a liquid in a U-tube when its equilibrium is destroyed.

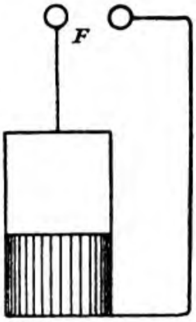

FIG. 1. — Circuit of Discharge of a Leyden Jar.

At the present time this demonstration can be fully elucidated. The difference of potential existing between the coatings of the charged jar sets the electricity in motion. A current is produced, and this continues to increase in intensity until a maximum value is reached, whilst the potentials concurrently decline to zero. The current in its onward path now charges the coatings in the opposite direction: its intensity sinks to zero, whilst the potentials are almost wholly restored. Both the charges and potentials are now of the opposite sign to what they were at first; the series of phenomena is repeated, but in the opposite direction, being then reversed once more, and so on, until the vibrations gradually die away, in consequence of loss of energy, and thus the stage of quiescence is reached. We have a permanent transmutation of the potential and kinetic forms of energy as in the case of a swinging pendulum.

It was to be expected that the phenomena of the discharge would be determined by relations existing between the dimensions of the electrical constants of the discharge circuit, namely, capacity, self-induction, and resistance, the definition of which terms we will assume to be understood. It was not, however, until the theoretical investigations of Sir William Thomson (Lord Kelvin) in England and Professor Gustav Kirchhoff in Germany, that a clear idea was obtained into the possible eventualities and the conditions to which they are subjected.

We will now proceed to mathematical deductions, valuing the above-mentioned constants in accordance with the conditions prevailing in the appliances used in wireless telegraphy.

In a discharging circuit in which C represents the capacity, L the self-induction, W the total resistance, and E the difference of potential between the coatings of the condenser (with a charge, Q), the discharge generates a current, i, in accordance with the equation

$$i = \frac{E - L\frac{di}{dt}}{W},$$ wherein t represents the time.

Moreover, $E = \frac{Q}{C}$ and $i = -\frac{dQ}{dt}$.

By substitution we obtain the differential equation

$$\frac{d^2Q}{dt^2} + \frac{W}{L} \frac{dQ}{dt} + \frac{Q}{CL} = 0.$$

This is satisfied by $Q = Ae^{at}$

Thus we obtain for a the equation

$$a^2 + \frac{W}{L} a + \frac{1}{LC} = 0,$$

whence

$$a = \frac{W}{2L} \pm \sqrt{\frac{W^2}{4L^2} - \frac{1}{LC}}.$$

If the roots are real, we have to do with a progressively decreasing discharge. If, on the contrary, the roots are imaginary, *i.e.* if

$$\frac{1}{LC} > \frac{W^2}{4L^2},$$

or

$$W < 2\sqrt{\frac{L}{C}},$$

we obtain, by introducing trigonometrical functions,

$$Q = e^{-\frac{Wt}{2L}} \left(B_1 \cos t\sqrt{\frac{1}{LC} - \frac{W^2}{4L^2}} + B_2 \sin t\sqrt{\frac{1}{LC} - \frac{W^2}{4L^2}} \right);$$

that is to say, the discharge becomes oscillatory, with the periods

$$T=\frac{2\pi}{\sqrt{\frac{1}{LC}-\frac{W^2}{4L^2}}}.$$

To determine B_1 and B_2, which, although arbitrary, may be taken as real, we may employ for our purpose the conditions

$$\text{for } t=0: \ Q=Q_0 \text{ and } \frac{dQ}{dt}=0.$$

This gives

$$B_1=Q_0$$

$$B_2=\frac{Q_0W}{2L\sqrt{\frac{1}{LC}-\frac{W^2}{4L^2}}}.$$

Hence we have

$$Q=Q_0e^{-\frac{Wt}{2L}}\left(\cos t\sqrt{\frac{1}{LC}-\frac{W^2}{4L^2}}+\frac{W}{2L\sqrt{\frac{1}{LC}-\frac{W^2}{4L^2}}}.\sin t\sqrt{\frac{1}{LC}-\frac{W^2}{4L^2}}\right).$$

By setting

$$t\sqrt{\frac{1}{LC}-\frac{W^2}{4L^2}}=2\pi\frac{t}{T},$$

we then have

$$Q=Q_0e^{-\frac{Wt}{2L}}\left(\cos 2\pi\frac{t}{T}+\frac{W}{2L\sqrt{\frac{1}{LC}-\frac{W^2}{4L^2}}}\cdot\sin 2\pi\frac{t}{T}\right).$$

The expression in brackets is of the form

$$a\cos x+b\sin x=c\sin(x+\phi),$$

in which ϕ represents the phase-displacement and is determined from

$$tg\phi=\frac{a}{b}.$$

Since

$$c=\sqrt{a^2+b^2}$$

then

$$Q=Q_0e^{-\frac{Wt}{2L}}\left(\frac{1}{\sqrt{\frac{4L}{CW^2}-1}}\cdot\sin 2\pi\frac{t}{T}+\phi\right).$$

When, as in our case, $\frac{W^2}{4L^2}$ can be neglected in comparison with $\frac{1}{LC}$ the expression for the duration of the vibration is:

$$T = 2\pi\sqrt{LC}.$$

The *damping* is found from the ratio between the values of two successive amplitudes, *i.e.*:

$$\frac{e^{-\frac{Wt}{2L}}}{e^{-\frac{W(t+T)}{2L}}} = e^{\frac{WT}{2L}},$$

which may be written as the logarithmic decrement, S:

$$S = \pi W\sqrt{\frac{C}{L}}.$$

Here we may already mention—though the matter will be reverted to later—that W does not represent the constant ohmic resistance, but constitutes in the appliances for wireless telegraphy, as in all discharges through the path of a spark, a still unknown function of the quantity of electricity, the potential and the frequency.

Hence there is a well-marked limit, defined by $W = 2\sqrt{\frac{L}{C}}$, separating aperiodic discharges from oscillating ones.

A representation of the progress of aperiodic discharges with two different resistances, both situated above the critical limit, is given in fig. 2. During the discharge the potential gradually sinks to zero, the time consumed increasing with the resistance. The resulting current increases to a maximum, and then sinks to zero again.

The progress of an oscillatory discharge is graphically illustrated in fig. 3, which represents a damped sinonical vibration. The potential and the intensity of the current diminish progressively, the maximum of the latter, however, coinciding with the zero points of the potential, and *vice versa.*

In both figures the abscissæ indicate periods of time, the ordinates the momentary potential. Both curves were plotted with an improved Helmholtz pendulum, made in accordance with the instructions of my esteemed instructor, Professor A. Kleiner of Zürich.

Of course, only the oscillations are applicable to wireless telegraphy, and it is evidently a point of extreme importance to keep the resistance of the path of the discharge as low as possible.

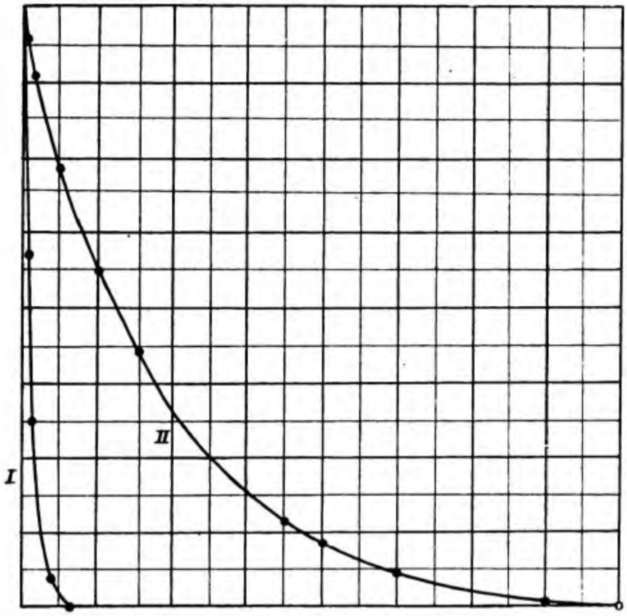

Fig. 2.—Aperiodic Discharges.

CLOSED OSCILLATION SYSTEMS.

As first employed by Professer Braun, it is now almost universally the practice to use a Thomson-Kirchhoff electrical oscillation circuit for **generating** powerful vibrations.

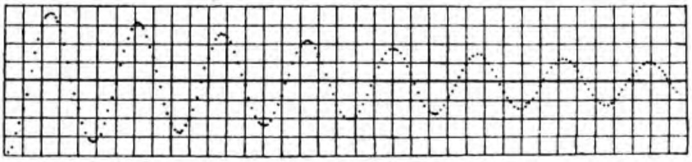

Fig. 3.—Damped Sinonical Vibrations.

The special arrangement of this apparatus is diagrammatically illustrated in fig. 4. To represent the capacity it contains two groups of Leyden jars, $C_1 C_2$, the outer coatings of which are connected together by means of the self-induction coil, L, whilst the inner coatings lead to the sparking terminals $F_1 F_2$, the poles of which are connected to the secondary poles of an induction coil.

When the primary current in J is interrupted, an induction impulse occurs, charging the one inner coating positively and the other negatively. When the discharging potential attains a value corresponding to the length of the spark-gap, the opposing electricities are compensated, the inner coatings through the spark-gap, the outer coating through the coil L. This compensation is oscillatory, and only possible along the path indicated, since the discharge cannot traverse the secondary circuit of the induction coil, owing to the very high self-induction, *i.e.* the excessive inductive resistance of the latter.

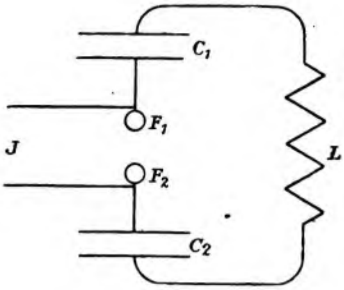

Fig. 4.—Braun's closed Oscillation Circuit.

An oscillation circuit of this kind is entirely closed during the discharge, but it consists of two symmetrical halves, in which equal quantities of electricity move simultaneously in opposite directions, so that no appreciable external effect is produced. The case is analogous to that of a tuning-fork held freely in the hand absorbing a very large amount of energy when struck; the prongs, however, vibrate simultaneously in opposite directions, and the ear is only able to detect a very faint sound, even at a short distance.

To formulate the case in electrophysical terms, it must be stated that to each current element belongs a diametrically opposed element of equal length and direction; in each the current is of equal amplitude and phase, but of opposite sign, regarded from a point at a great distance. The distance between the current elements is small in comparison with the wave length, as the whole circuit is small compared with the wave length. Therefore the partial-fields of the two current elements act against each other and the amplitude at the resulting field nearly equals the difference of the amplitudes of the partial-fields, *i.e.* they almost compensate each other. It may also be said that such a condenser circuit, the individual wave length of which is very great in comparison with the length of the discharger (L), produces practically no external lines of force. Consequently, in accordance with the axiom of Poynting, it radiates little or no energy.

These preliminary considerations may be summed up by the statement **that a closed condenser is only suitable for generating electrical oscillations.**

OPEN OSCILLATION SYSTEM.

From the foregoing it is evident, therefore, that other means had to be adopted in order to transmit the electrical energy to a distance. This is accomplished by the Hertz oscillator, the principle of which can be seen by reference to fig. 5.

A straight wire, *a b* (with or without the metal plates C_1C_2 for increasing the capacity), is interrupted by a spark-gap F, connected in turn with the secondary poles of an induction coil J. The discharge of such an **open system** also proceeds in oscillations, provided the known condition for their production is fulfilled; and at each semi-oscillation the poles of the system become alternately positive and negative by the backward and forward flow of the charge. The two halves of the wire, however, take up not only potential but also an appreciable amount of current, so that lines of magnetic force are developed in planes perpendicular to the axis of the wire. The conversion of electrical energy into magnetic energy begins after the electrical lines of forces have attained their numerical maximum, and then commence to withdraw into the conductor.

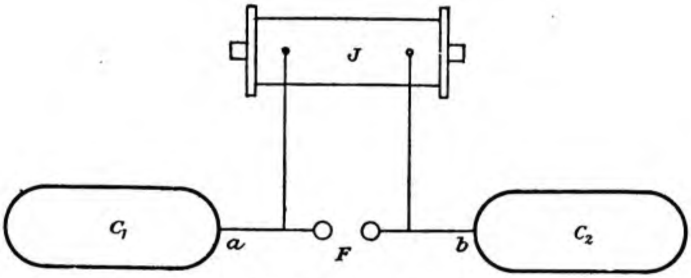

FIG. 5.—The Hertz Oscillator.

Hertz pointed out the peculiar property of the external lines of force (those which have extended furthest away from the conductor of the electrical vibrations), namely, that they separate from the rest as closed lines of force, which pass off into space and return no more. The initial energy is thus diminished by that appertaining to the separated portion, *i.e.* the energy of **radiation.**

These Hertzian rays traverse space with the velocity of light, and transmit their energy through great distances.

The true source of radiation, however, resides, not in the vibrant conductor, but at a distance of one quarter wave length therefrom, since electrical and magnetic oscillations are mutually retarded, in point of time, by a quarter period. Hence, within the first quarter wave length, electrical and magnetic forces are alternatively of equal and opposite signs, whereby a portion of the energy returns to the oscillator. Beyond this limit, however, differences of time and locality cause the two forces to act in the same sense, so that there the point of radiation is to be found.

Both the electrical and the magnetic forces are of an oscillating nature, oscillating in the periods of the discharge, an electromagnetic wave resulting. Consequently, the wave length can be found from the known equation $\lambda = T \times V = \frac{V}{n}$; wherein λ, T, n, V express the wave length, time of vibration, number of vibrations per second, *i.e.* frequency, and velocity of transmission ($= 3 \cdot 10^{10}$ cm.) respectively.

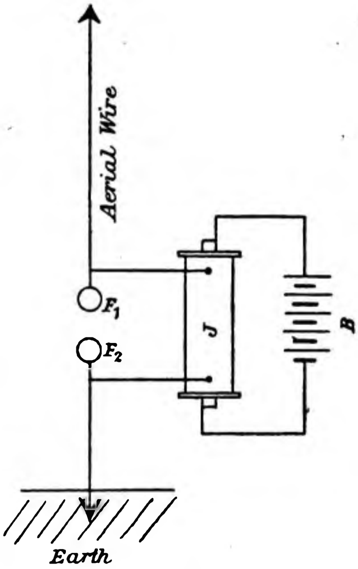

FIG. 6.—Marconi Transmitter.

Marconi in the course of his practical experiments devised arrangements like the one illustrated in fig. 6. This will be easily recognised as a Hertz oscillator arranged vertically, the one half consisting of a wire extending high up in the air (aerial wire or antenna), and the other half of an earth connection. Marconi himself failed to recognise properly the importance of his air wire, believing that he had to deal with very small waves, generated at the ball terminals and radiated from the entire length of the upright wire He was led into this error by the Righi radiator, which he used without antennæ in his earlier experiments, and in which the dimensions of the so-called Righi balls actually determined the wave length, which amounted to not more than a few millimetres.

The complete theory of a rod conductor for electrical vibrations (fig. 7) was enunciated by V. Bjerkness and M. Abraham, from whose results we select the following, as specially important for our purpose.

When the ratio of thickness and length of the rod is sufficiently small (rod-shaped rotation ellipsoid) we have a decided fundamental vibration, the wave length of which is equal to twice the length of the rod.

In addition there are formed approximately harmonic upper vibrations, which, however, are negligible in practice, their intensity being inappreciably small and their cessation occurring earlier than that of the fundamental vibration.

The period of this vibration depends on the dielectric constant of the surrounding medium. An antenna covered with insulating material is of greater capacity than one of naked wire, and therefore gives a somewhat greater wave length.

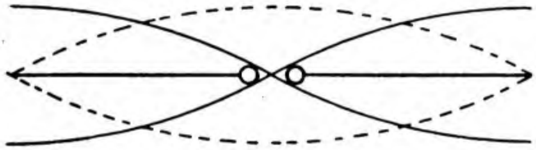

FIG. 7.—Rod Conductor for Electrical Vibrations.

Damping by radiation decreases constantly with the diminished thickness of the rods. The importance of the cage antennæ, or nets used in practice—that is to say, a system of wires laid parallel or conically—resides chiefly in the attainment of increased radiation. As will be more fully dealt with later, P. Drude has shown that, in respect to the increase in the specific periods, such a system of antennæ is equivalent to a single antenna of large diameter; hence, according to the Poynting axiom, these multiple antennæ are also equivalent, in point of radiation, to a single antenna of greater radius (compare also p. 47 *et seq.*).

The current distribution of the rod-shaped conductor (antenna) may be considered as the superposition of a wave running up to the free extremity and of another wave of equal amplitude, but opposite sign of current reflected there. A stationary wave is formed as represented by the dotted lines in fig. 7; whilst the distribution of potential is indicated by the continuous lines, and is naturally directly opposed to that of the current. Nodes of the current are invariably formed at the free ends, *i.e.* the magnetic force disappears at these points. The prolongation of the antennal axis represents node lines of magnetic force, and the radiation of the energy of vibration consequently occurs in a lateral direction and not axially.

The chief effect obtained by Marconi in replacing the one half of the excited oscillator by an earth connection was to increase the wave length. Earthing acts like reflection, in so far as the effective wave length is doubled and is then equal to four times the length of the aerial conductor down to the earthing point. In this first practical appliance for wireless telegraphy, the energy is both generated and radiated. A short examination of the conditions with regard to energy will soon enable us to decide on the advisability of such a method.

The energy is determined by the expression $\frac{CV^2}{2}$, in which C is the capacity and V the discharge potential. The capacity of a simple aerial wire is very small. Even if large metal surfaces were suspended therefrom, as was proposed by Lodge, the gain would be slight; and in any case a limit is quickly imposed, on practical grounds. In fact, the discharge potential alone would come into consideration; and this is determined by the length of the spark-gap. Now the resistance of the latter increases very rapidly with the length, especially when the quantities of electricity passing over are small. The damping of the vibrations by resistance is excessive, and we soon approach the critical limit of the oscillatory character of the discharges. True, Professor Braun, by introducing a subdivided spark-gap (which we shall have occasion to describe later), enabled this factor of energy to be considerably increased, so that it is now possible to transmit signals over a distance of nearly two hundred miles by simple Marconi apparatus; but, as we shall shortly see, the development of wireless telegraphy has brought us to a territory in which new demands presented themselves.

At all events, it may be concluded, from these considerations, that the best course is to utilise **the open oscillation system solely for the dispatch of energy.**

CHAPTER III.

COUPLED SYSTEMS.

THE COUPLING.

In acoustics, when it is desired to obtain the maximum tone from a tuning-fork, it is necessary to mount the latter on a sounding box, or resonator, responding to the same note. Now, we have already compared the tuning-fork to the closed circuit of electrical oscillations: and the best analogy for the open system is the sounding box. The aerial wire and the sounding box fulfil identical functions, namely, to transmit to the environment the energy of the relatively undamped system with which it is coupled. It is, of course, necessary in electricity also to provide for the fulfilment of the condition of resonance (or, better, syntony) between the two coupled oscillation systems, in order to increase the radiation of energy to a maximum. In this case the store of energy in the closed circuit is exhausted most quickly; this arrangement is utilised to the best advantage, when as much energy is supplied as is radiated.

With regard to the connection of the closed circuit with the open oscillator, Professor Braun distinguishes between "direct coupling" (fig. 8) and "indirect" or electromagnetic coupling (fig. 9). However, as we shall see later, there is no fundamental difference between them.

The oscillations are generated solely in the comparatively slightly damped condenser circuit of high energy capacity (primary system), which is completely closed by the spark-gap in discharging; and they are transmitted thence to the strongly damped aerial wire, *i.e.* an open, uninterrupted metallic path of low energy capacity (secondary system). We have here to deal with compulsory oscillations.

The effective wave lengths are determined by the frequency, damping, and coupling.

THE COUPLING.

A sufficient definition for the coupling is

$$\tau^2 L_1 L_2 = L_{12}^2,$$

wherein $L_1 L_2$ represent the coefficients of self-induction of the primary and secondary systems, L_{12} the coefficients of mutual induction, and $\tau^2 = \tau_1 \tau_2$ the coefficients of coupling. The limits for the degree of coupling are determined by $0 \leqq \tau \leqq 1$. A perfectly rigid coupling, $\tau = 1$, or $L_1 L_2 = L_{12}$, *i.e.* where all the lines of magnetic force of the primary system must traverse the current plane of the secondary system, is impossible in appliances for wireless telegraphy, owing to the high self-induction of the free aerial wire.

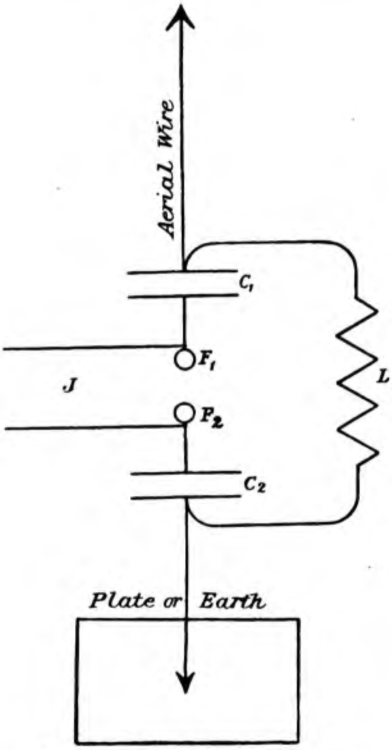

FIG. 8.—Braun's Direct Coupling.

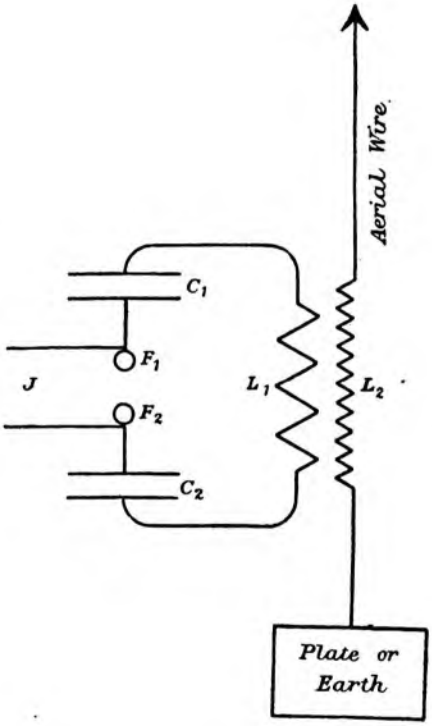

FIG. 9.—Braun's Indirect Coupling.

At the lower end of the same is a coil (the other end of which is connected to the "compensating counter-capacity" or to earth) for effecting the inductive excitation. The larger this coil, the firmer the coupling, in consequence of the higher mutual induction, and *ceteris paribus*, the shorter must the aerial wire be in order to maintain the self potential of the entire secondary system unchanged. Such shortening, however, is effected at the expense of the energy of radiation; and it is also counter to the dictates of experience, namely, that the aerial wire should be as high as possible in order that it may project above surrounding objects.

In practical wireless telegraphy, the degree of coupling therefore varies only between perfectly loose coupling ($\tau = 0$) on the one hand, and fairly close coupling on the other. With respect to the effective oscillations—syntony of the individual systems being assumed—the theoretical possibilities are reduced in this manner to two eventualities. By this means the limits of practicability and the maximum results obtainable in any case can be easily surveyed. This we shall also see from the theoretical results obtained by M. Wien, discussed in Chapter V.

The coupling may also be appropriately defined in another way. If we let λ_0 represent the wave common to both systems in the uncoupled condition, and λ_1 and λ_2 the resulting deformed waves after coupling, the following equations apply, damping being neglected.

For the longer waves, $\lambda_1 = \lambda_0 \sqrt{1 + \tau}$.

For the shorter waves, $\lambda_2 = \lambda_0 \sqrt{1 - \tau}$.

For the degree of coupling τ we can deduce, with a fair amount of accuracy, a proportionality to $\frac{\lambda_1 - \lambda_2}{\lambda_0}$.

In this manner the degree of coupling can also be determined experimentally with ease, by measuring the waves present in the coupled system with the aid of the ondameter described in Chapter VIII.

COMPENSATING THE AERIAL WIRE.

Before concluding these general considerations with regard to the transmitter of wireless telegraphy, it will be necessary to deal with the important problem of the best method of "compensating" the aerial wire.

In fig. 10 the secondary system is again illustrated diagrammatically in symmetrical arrangement. At one end of the coil is the aerial wire, and at the other a perfectly equivalent symmetry wire. At the symmetrical centre Z we have a potential node, and at *a* and *b* current nodes. These symmetrical arrangements, on which theoretical calculations are based with regard to the duration of oscillation of the entire system, can rarely be realised in practice. Moreover, the symmetry wire has proved unfavourable, in consequence of increased damping through the generation of heat in accordance with Joule's law, and through radiation. Clearly enough, however, it cannot be simply omitted, but must be replaced by a more efficient substitute. The importance of the symmetry wire, and the best substitute for the same, namely, metallic surfaces, were first theoretically elucidated by J. Zenneck. This observer formed the conclusion that the point of attack of the inductive excitation must be at a place of electrical movement (belly of the current), in order to excite oscillations of maximum intensity. This certainly seems quite obvious.

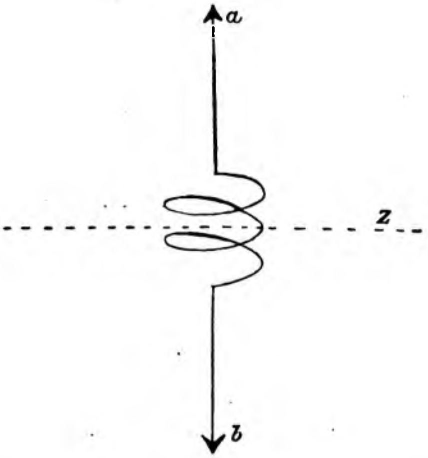

Fig. 10.—Secondary System with Symmetrical Attachments.

Hence the relative position of the coupled systems must be such as is shown in fig. 11. On the other hand, fig. 12 indicates a false relative position, since in this case the primary coil is situated opposite a current node in the secondary system. If the symmetry wire be cut off in this fashion, it must be supplemented by metallic surfaces, so that the belly of the current may return to the right position.

Fig. 13 gives the arrangement then obtained; and it follows—not merely from the foregoing, but also from purely theoretical considerations advanced by P. Drude—that we have to deal with well-defined conditions demonstrating the error of assuming that "earthing" is equivalent to a compensating counter-capacity. It would be more accurate to say that, in case of need, recourse may be had to earth connection also; but this is quite impracticable when the soil is of badly conducting material. Earthing has also the drawback of causing considerable disturbance, by introducing atmospheric discharges.

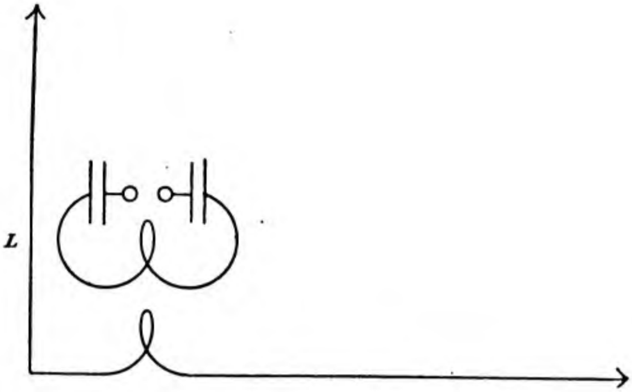

FIG. 11.—Correct Relative Position of the Coupled Systems.

I have determined experimentally the dimensions of the compensating metallic surfaces, the results coinciding almost exactly with the formula (see pp. 50, 55) deduced theoretically by Drude nearly a year later. This circumstance, and other experiments made in the same connection, lead me to consider it improbable that the

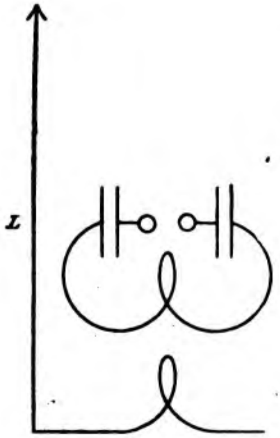

FIG. 12.—Incorrect Relative Position of the Coupled Systems.

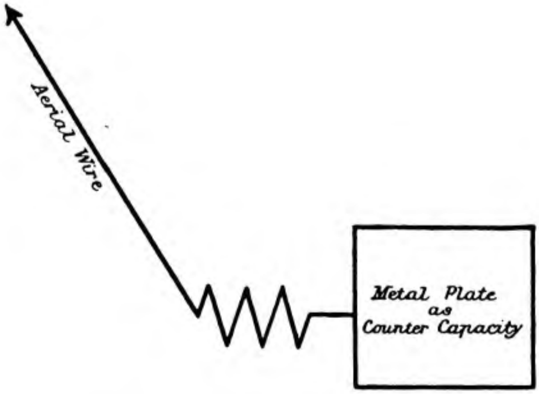

FIG. 13.—Symmetry Wire Supplemented by Metal Plate.

earth plays any important part in wave transmission. On account of "earth resistance" in this sense, many at present hold the idea that the metal surfaces should be as large as possible; but according to my researches, with the growing size of the compensating surfaces the theoretical size is at first very quickly and then gradually approached until we reach a corresponding maximum, which in practice shows itself to be the optimum.

If the aerial wire be grounded, it must of course be borne in mind, as already mentioned, that the vibration is thereby lowered; and besides—as L. Mandelstam theoretically deduced—the coupling becomes closer.

CHAPTER IV.

THE RECEIVER.

We will now turn to a brief preliminary consideration of the receiving instrument and its development.

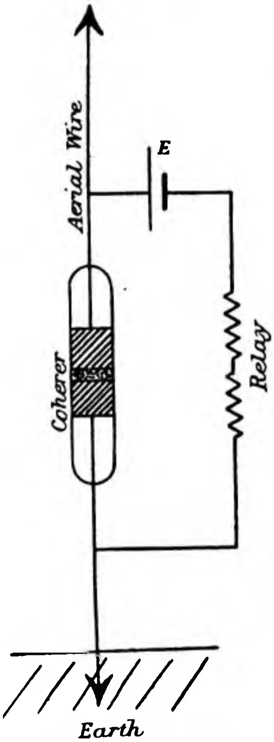

Fig. 14.—Arrangement of the Coherer.

The important component for detecting the electrical impulse is the coherer. This consists, as shown in figs. 14 and 15, of loose metallic powder or granules, packed into a small space *r* between the terminal surfaces of two metallic electrodes *m*, the whole being enclosed in a glass or ebonite tube. One electrode is connected to the aerial wire collecting the electrical impulses, the other to the earth. In its ordinary condition, the coherer forms an imperfect contact, the high resistance of which in the circuit of the element E prevents the passage of the current. As soon, however, as the electrical impulses are received, the resistance of the coherer sinks to a very low value. A current then passes, and, by means of a relay, actuates a more powerful circuit (Battery B), as shown in fig. 15. In addition to a Morse instrument, this circuit includes a tapper for the purpose of gently shaking the coherer into the non-conducting state again after each exposure to radiation, and thus making it sensitive to new impulses. Through shorter and longer radiation we obtain in this manner the dots and dashes of the Morse alphabet, and thus wireless messages are received.

Opinions differ widely as to the actual manner in which the coherer acts, and correspondingly numerous theories have been advanced. It is hardly necessary to repeat them, beyond giving a bibliographical list in the Appendix, to which those who are interested in the matter may refer.

Of importance, however, are the properties of the coherer, which have now been definitely established and may be summarised as follows. The coherer reacts on fluctuations in potential, even when the amounts of energy are exceedingly minute and transitory. Its sensitiveness to the rapidly alternating differences of potential of the vibrations pulsating in the receiver is so enormous that the most sensitive galvanometer is inferior by comparison.

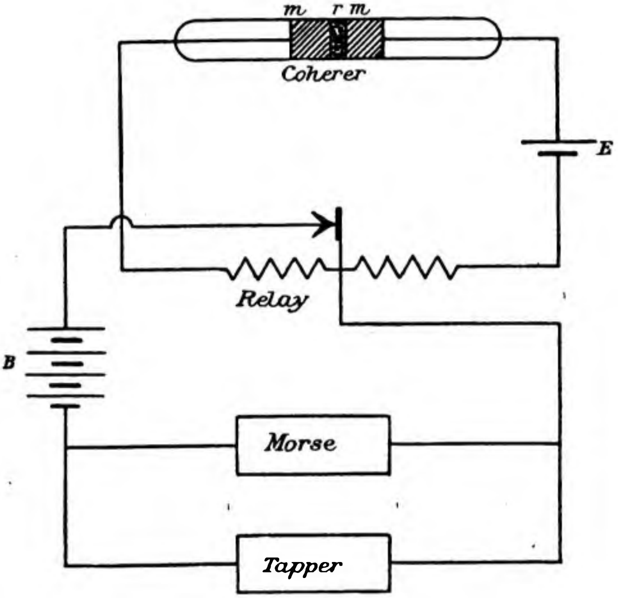

FIG. 15.—Arrangement of Receiving Instrument, with Coherer, Relay, Morse, and Tapper.

In its ordinary condition the coherer must be regarded as high resistance and low capacity; and it is just these two properties that have rendered possible the evolution of the modern receiver, which—omitting intermediate stages of development—is illustrated diagrammatically in fig. 16.

In this case, also, coupled systems are employed. A primary circuit with the capacity C and the self-induction L_1 is connected with the attachments (aerial wire—counter-capacity). The coherer is situated in the completely closed, induced secondary circuit with the small capacity C_r and the high self-induction L_2. The secondary system is thus developed into an independent and but slightly damped form, capable of resonance. The capacities are furnished by variable air condensers.

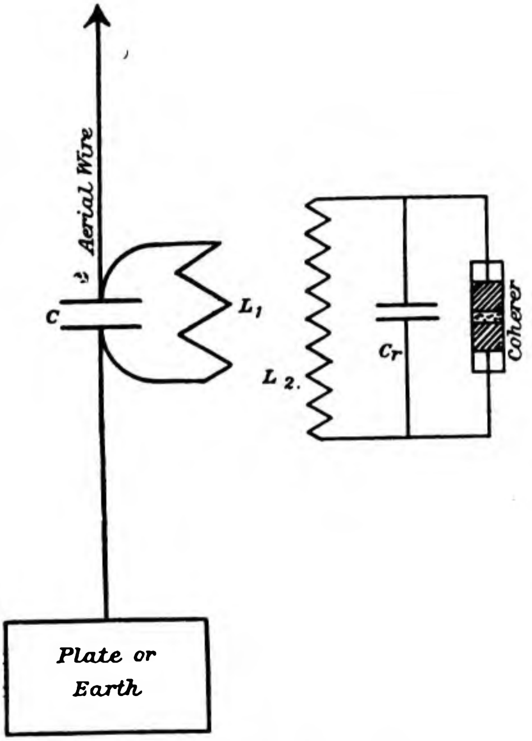

FIG. 16.—Receiver with Tunable Secondary Circuit.

As we shall soon see, a decisive part is played by the suitable distribution of capacity and self-induction, and of the degree of coupling between the attachments and the primary circuit, as well as between the latter and the secondary system.

Such an arrangement would be impossible if the coherer had to be regarded as a high capacity or as a conductor.

The accurate tuning of the receiver to the effective oscillation of the sender is not merely possible, but essential, especially in the secondary system. The capacity of the attachments for the primary circuit, and the small capacity of the coherer for the secondary circuit must be reckoned as supplementary capacities in tuning.

If the sender had anything approaching the ideal properties of such a highly developed receiver, the sphere of activity of wireless telegraphy would be capable of far wider extension than now possible.

CHAPTER V.

THEORETICAL RESULTS FURNISHED BY THE SENDER.

It was stated on p. 12 that the theory of the simple Hertz oscillator, in the form used by Marconi, was elaborated by V. Bjerkness and M. Abraham. As the Marconi sender now possesses little more than historic value, the principal results already given appeared to be sufficient.

With regard to the modern coupled system we are chiefly indebted to M. Wien for his very lucid theoretical explanations, which I have the greater inducement to reproduce, inasmuch as they are the base of the recent work carried on at the Braun-Siemens Baltic experimental station by me in conjunction with L. Mandelstam, for the purpose of establishing a system of selective electric wave telegraphy, *i.e.* wireless multiplex telegraphy, which object was accomplished with a degree of perfection previously unattained.

Additional valuable work has been done, especially by P. Drude, M. Abraham, and L. Mandelstam, in respect of the thorough elucidation of the phenomena of vibrations in these coupled systems. These works we shall have occasion to refer to frequently.

Coupled vibrating elastic systems had previously been dealt with, in a general manner, by M. Wien in his publication on the reaction of a resonant system. He took, as a starting-point, the interesting acoustic experiments conducted by Warburg in 1868; also the theoretical labours of J. von Geitler on undamped coupled electrical systems (electric- or force-coupling), and the work of Galitzin and Overbeck on magnetic- or acceleration-coupling. In his publication *On the Employment of Resonance in Wireless Telegraphy*, the developed equations were applied to the special conditions of the coupled electrical system of wireless telegraphy, more particularly in connection with inductive electromagnetic-coupling.

In considering the case of resonance, Wien assumed the primary and secondary systems as each having a single degree of freedom. This is a special instance in the domain of the vibrations of systems with several degrees of freedom, the laws of which are elucidated by Lord Rayleigh in his "Theory of Sound."

The reasons why very close coupling is impossible in apparatus for practical wireless telegraphy have been already stated on p. 15; and it was on these grounds that Wien very properly neglected the square of the damping and coupling in comparison with the square of the frequency.

Hence we have as a starting-point the two simultaneous differential equations of the coupled elastic systems for damped oscillations, and they run as follows for the force coupling:—

$$\text{I.}\left\{\begin{array}{l}\dfrac{d^2x_1}{dt^2}+2h_1\dfrac{dx_1}{dt}+K_1^2x_1+\tau_1K_1^2x_2=0\,.\\[2ex]\dfrac{d^2x_2}{dt^2}+2h_2\dfrac{dx_2}{dt}+K_2^2x_2+\tau_2K_2^2x_1=0\,.\end{array}\right.$$

This furnishes the differential equation of the fourth order:

$$\text{II.}\left\{\begin{array}{l}\dfrac{d^4x}{dt^4}+\dfrac{d^3x}{dt^3}2(h_1+h_2)+\dfrac{d^2x}{dt^2}(K_1^2+K_2^2+4h_1h_2)\\[2ex]+\dfrac{dx}{dt}2(h_2K_1^2+h_1K_2^2)+K_1^2K_2^2(1-\tau_1\tau_2)=0\,;\end{array}\right.$$

and this in turn, for $n=\delta+i\nu$, the biquadratic equation.

$$\text{III.}\left\{\begin{array}{l}n^4+2(h_1+h_2)n^3+(K_1^2+K_2^2+4h_1h_2)n^2+2(h_2K_1^2+h_1K_2^2)n\\+K_1^2K_2^2(1-\tau_1\tau_2)=0.\end{array}\right.$$

$$\text{IV.}\left\{\begin{array}{l}\text{The roots have the form :}-\delta\pm i\nu_1\\\text{and }-\delta_2\pm i\nu_2.\end{array}\right.$$

The same applies to acceleration-coupling, which differs from force-coupling in dimensions of the second order alone, which can be neglected for the electrical system. The two simultaneous differential equations for acceleration coupling are

$$\text{V.}\left\{\dfrac{d^2x_1}{dt^2}+\tau_1\dfrac{d^2x_2}{dt^2}+2h_1\dfrac{dx_1}{dt}+K_1^2x_1=0.\qquad\dfrac{d^2x_2}{dt^2}+\tau_2\dfrac{d^2x_1}{dt^2}+2h_2\dfrac{dx_2}{dt}+K_2^2x_2=0.\right.$$

By introducing the electrical dimensions of the primary and secondary systems:

W_1 and W_2 for the resistances,
L_1 and L_2 for the self potentials,
C_1 and C_2 for the capacities, and
L_{12} for the coefficient of mutual induction,

we have the

Number of vibrations in 2π seconds . . $K_1{}^2=\frac{1}{L_1C_1}$; $K_2{}^2=\frac{1}{L_2C_2}$.

Damping $= h$ . . . . $h_1=\frac{W_1}{2L_1}$ $L_2=\frac{W_2}{2L_2}$.

Coefficient of coupling $= \tau$. $\tau_1=\frac{C_2}{C_1}\cdot\frac{L_{12}}{L_1}$; $\tau_2=\frac{C_1}{C_2}\cdot\frac{L_{12}}{L_2}$.

Consequently for the oscillating potential V of the electro-magnetic coupled system, we have :

$$\text{VI.}\begin{cases}\frac{d^2V_1}{dt^2}+\frac{C_2}{C_1}\cdot\frac{L_{12}}{L_1}\frac{d^2V_2}{dt^2}+\frac{W_1}{L_1}\frac{dV_1}{dt}+\frac{V_1}{L_1C_1}=0\,.\\ \frac{d^2V_2}{dt^2}+\frac{C_1}{C_2}\frac{L_{12}}{L_2}\frac{d^2V_1}{dt^2}+\frac{W_2}{L_2}\frac{dV_2}{dt}+\frac{V_2}{L_2C_2}=0\,.\end{cases}$$

With the individual systems in perfect syntony, the number of oscillations per 2π seconds will be: $n_1=\frac{1}{L_1C_1}=n_2=\frac{1}{L_2C_2}$.

The coefficients of coupling: $\tau_1=\frac{L_{12}}{L_2}$ $\tau_2=\frac{L_{12}}{L_1}$.

$$\tau=\sqrt{\tau_1\tau_2}\,.$$

According to IV. the solution of the differential equations must be

$$V_1=A_1e^{-\delta_1 t}\sin(\nu_1 t+\phi_1)+B_1e^{-\delta_2 t}\sin(\nu_2 t+\psi_1)$$
$$V_2=A_2e^{-\delta_1 t}\sin(\nu_1 t+\phi_2)+B_2e^{-\delta_2 t}\sin(\nu_2 t+\psi_2).$$

Hence there are formed, in general, two common but mutually independent oscillations, differing in number, ν_1 and ν_2, and in damping, δ_1 and δ_2.

The relations of the amplitudes A_2/A_1, B_2/B_1, and $\nu_1\nu_2$, $\delta_1\delta_2$, are determined by the constants n_1 and n_2, h_1 and h_2, τ_1 and τ_2, of the individual systems. The absolute values of A_1B_1 and the phase constants $\phi_1\phi_2$, $\psi_1\psi_2$, are arbitrary, or rather depend on the initial conditions, *i.e.* on the method of exciting the oscillations.

The relation between the amplitudes in both systems is determined by the following equation, in which the influence of the damping ($\delta_1{}^2$) may be neglected with reference to the number of oscillations ($\nu_1{}^2$).

$$\frac{A_2}{A_1}=\frac{\nu_1^2\frac{L_{12}}{L_1}}{\sqrt{(\nu_1^2-n^2)^2+4\left(h_2\nu_1-\delta_1\frac{n^2}{\nu_1}\right)^2};}$$

and accordingly

$$\frac{B_2}{B_1}=\frac{\nu_2^2\frac{L_{12}}{L_1}}{\sqrt{(\nu_2^2-n^2)^2+4\left(h_2\nu_2-\delta_2\frac{n^2}{\nu_2}\right)^2}.}$$

The roots of our equation of the fourth degree (III.) are (IV.):

$$\pm i\nu_1-\delta_1=\pm i\,(Q-R)-\left(\frac{h_1+h_2}{2}-S\right)$$

$$\pm i\nu_2-\delta_2=\pm i\,(Q+R)-\left(\frac{h_1+h_2}{2}+S\right),$$

wherein $Q=\sqrt{\frac{a}{2}-\frac{a^2-4c}{8a}}$; $\left.\begin{matrix}R\\S\end{matrix}\right\}=\sqrt{\frac{\sqrt{(a^2-4c)^2+8ab^2}\pm(a^2-4c)}{16a}}$;

and $a=n_1^2+n_2^2+\frac{(h_1-h_2)^2}{2}$; $b=-(h_1-h_2)\,(n_1^2-n_2^2)$.

$$a-4c=(n_1^2-n_2^2)^2-(2h_1-h_2)^2(n_1^2+n_2^2)+4\tau^2n_1^2n_2^2.$$

It is now necessary to consider that in coupled systems of wireless telegraphy we have to deal with very unequal damping of the component systems. For the case of resonance ($n_1=n_2=n$), we shall have

$$a=2n^2-\frac{(h_1-h_2)^2}{2},\ b=0,\ a^2-4c=-4(h_1-h_2)^2n^2+4\tau^2n^4.$$

$$Q=n\sqrt{1-\frac{\tau^2}{4}},\ R=\sqrt{\frac{\tau^2n^2-(h_1-h_2)^2}{4}},\ S=0.$$

We have now to distinguish between two classes—

Class A, in which the coupling predominates;

Class B, in which the damping is the prime factor.

Class A is limited by $\tau n>h_1-h_2$.

Hence $\delta_1=\delta_2-\frac{h_1+h_2}{2}$

and $\nu_1=n\sqrt{1-\frac{\tau^2}{4}}+\sqrt{\frac{\tau^2n^2-(h_1-h_2)^2}{4}}$;

$$\nu_2=n\sqrt{1-\frac{\tau^2}{4}}-\sqrt{\frac{\tau^2n^2-(h_1-h^2)^2}{4}};$$

or, since $\tau^2 n^2$ may be neglected, for reasons already given:

$$\nu_1 = n + \tfrac{1}{2}\sqrt{\tau^2 n^2 - (h_1 - h_2)^2},$$
$$\nu_2 = n - \tfrac{1}{2}\sqrt{\tau^2 n^2 - (h_1 - h_2)^2}.$$

Result: **Equal damping and unequal number of oscillations.**

Class B is limited by $\tau n < h_1 - h_2$.

Then $\nu_1 - \nu_2 = n$,

and
$$\delta_1 = \frac{h_1 + h_2}{2} + \tfrac{1}{2}\sqrt{(h_1 - h_2)^2 - \tau^2 n^2},$$
$$\delta_2 = \frac{h_1 + h_2}{2} - \tfrac{1}{2}\sqrt{(h_1 - h_2)^2 - \tau^2 n^2},$$

or approximately,

$$\delta_1 = h_1 + \frac{\tau^2 n^2}{4(h_2 - h_1)},\ \delta_2 = h_2 - \frac{\tau^2 n^2}{4(h_2 - h_1)}.$$

Result: **Equality in the number of oscillations, but unequal damping.**

Before going on to discuss further the two classes, we will briefly summarise a purely general theory enunciated by L. Mandelstam for any coupled sender, the damping being assumed as slight.

For an arrangement with m closed oscillation circuits, in which $c, f,$ and p represent the equal capacities and self-inductions respectively, we have for the fundamental oscillation,

$$n = \frac{\pi}{2\sqrt{PC}}\left(\frac{4m}{\pi}\sin\frac{\pi}{4m+2}\right);$$

wherein $C = mc$ and $P = mp$, denoting respectively the total capacity and self induction.

For $m = 10$, the bracketed fraction differs from 1 by merely a small percentage, *i.e.* with reference to the fundamental oscillation such an arrangement replaces (m being sufficiently large) an open system (aerial wire) of equal self-induction and capacity. This applies equally to the distribution of current and tension.

In the case of two coupled systems, the primary closed and the secondary open, Mandelstam established for calculating the frequency n the equation,

$$\frac{1}{L_1 n} - C_1 n = \frac{L_2}{L_1}\sqrt{\frac{E}{L}}\ \frac{\sin n\sqrt{LEl}\ \sin n\sqrt{LEl_1}}{\sin n\sqrt{LE(l + l_1)}};$$

and for calculating the current amplitudes A and B,

$$A\left(\frac{1}{C_1}-L_1n^2\right)-Mn^2B=0\,;$$
$$AMn^2+(L_2n^2-f)\,B=0\,.$$

Here C_1 and L_1, C_2 and L_2, represent the capacity and self-induction of the primary and secondary systems respectively; M the coefficient of mutual induction; E and L the capacity and self-induction per unit of length; l and l_1 the lengths of the secondary attachments f a trigonometrical function dependent on n, p, c, and m.

The equation for the frequency has an infinite number of real roots corresponding to the upper oscillations. In the interval,

$$\frac{\pi}{\sqrt{\text{LE}l}}>n>0\,,$$

there are two real roots, corresponding to the two main oscillations.

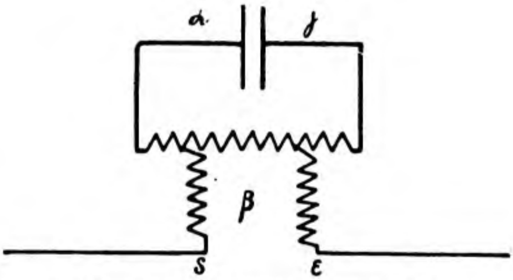

Fig. 17.—General Scheme for Coupled Senders.

These two deepest oscillations alone come under consideration in practice; and one of them is deeper, the other higher, respectively than the deepest and highest individual oscillations of the two systems.

Mandelstam also shows how the direct coupling (fig. 17) can be traced back to the inductive coupling, the unity of principle having been previously demonstrated by J. Zenneck. All the equations concerned retain their form, provided L_1 be understood to represent the self-induction $\alpha\beta\gamma$, L_2 the self-induction $\delta\beta\epsilon$, and M that of the portion of L_1 and L_2 common to both. The direct coupling possesses the advantage that, in order to obtain the same degree of coupling, the number of windings in the aerial wire can be smaller than with inductive coupling.

We will now revert to the special deductions of Wien, the results of which may be formulated as follows:—

A. *In close coupling* (but not quite fast coupling, which, as repeatedly mentioned, is practically impossible), when given absolute syntony of the component systems, one of the resulting oscillations is as much above the common specific tone as the other is below it. Both have practically the same damping, namely, equal to the arithmetical mean of the dampings of the component systems.

In consequence of the unequal frequency of the two resulting oscillations, beats occur throughout the entire oscillation, and occasionally give rise to increased amplitudes of potential. Wien also shows that if the specific tones of the component systems did not exactly correspond, the resulting frequencies would be more divergent than in case of syntony (perfect resonance). Beats are then present at the outset only, and disappear the sooner the greater the difference is in the two frequencies.

B. *In the case of loose coupling—i.e.* when damping is the prime factor—only a single oscillation is effective, the numerical value of whose frequency coincides with the common specific tone of the component systems (which should be equalised as closely as possible, in order to obtain maximum resonance). The damping is slight, since by means of perfectly loose coupling it can be reduced to the relatively small value of the damping of the primary circuit. (Theoretically there result two equal frequencies with very divergent damping; but the one damping is enormous, nearly equal to that of the open system, so that the corresponding oscillation, which is of weak energy, disappears almost immediately, and can therefore be practically disregarded.)

COMPARATIVE MEASUREMENTS IN THE SENDER. CONSEQUENCES OF THEORY.

In the measurements performed at the Baltic experimental stations the results obtained were completely in harmony with those of theory.

In the resonance curves (fig. 18), obtained with the aid of the ondameter, the description and functions of which will be found in Chapter VIII., the abscissæ correspond with the wave lengths, the ordinates with the squares of the current intensities which are registered by the Riess thermometer of the ondameter.

The curve in full lines refers to class A (close coupling).

Two waves result: $\lambda_1 = 230$ metres, and $\lambda_2 = 330$ metres.

In this case the dampings are unequal because the specific wave lengths of the component systems were unequal, measuring λ prim. 260 metres and λ sec. 280 metres respectively.

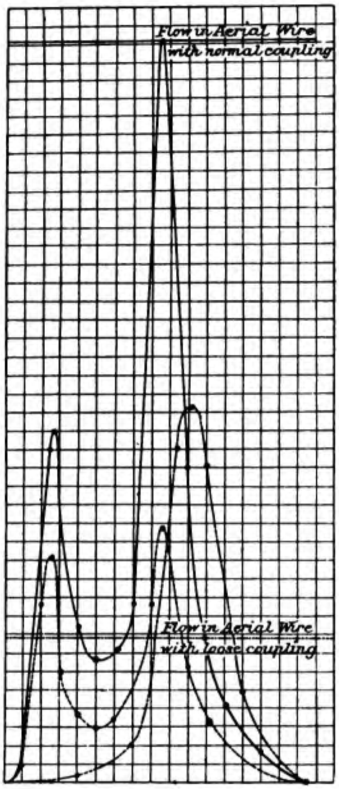

FIG. 18.—Resonance Curves.

The resulting deeper oscillation is the more slightly damped one, as indicated by the dotted curve. The latter is obtained by artificially increasing the damping in the resonance circuit, whereby the already strongly damped upper oscillation is influenced to a smaller extent than the less damped deeper oscillation.

Class B (loose coupling) is indicated by the curve ·· — ·· — ·· — (the component systems were in syntony in this measurement). It reveals the presence of only a single effective oscillation; and at the same time a comparison of the resonance curves with the corresponding level of the flow in the aerial wire (marked by horizontal lines in the figure) confirms the fact that the damping has throughout the lowest value in loose coupling.

Turning again to the measurement in class A, and assuming perfect syntony of the component systems, together with the following data:—

Specific wave length, $\lambda = 280$;

consequent frequency, $N = \dfrac{3 \times 10^{10}}{2{\cdot}8 \times 10^{4}} = 1{\cdot}07 \times 10^{6}$;

or per 2π seconds, $n = 2\pi \times 1{\cdot}07 \times 10^{6} = 6{\cdot}723 \times 10^{6}$.

Primary self-induction, $L_1 = 3{\cdot}5 \times 10^{3}$ centimetres;

hence primary capacity, $C_1 = \dfrac{1}{n^2 L_1} = 0{\cdot}0063$ microfarad.

Also $L_2 = 4{\cdot}5 \times 10^5$ centimetres;

hence $C_2 = \frac{1}{n^2 L_2} = 4{\cdot}917 \times 10^{-5}$ microfarad;

mutual induction, $L_{12} = 1{\cdot}3 \times 10^4$ centimetres.

Resistance of primary circuit estimated at 0·5 ohm at the most, hence $W_1 = 0{\cdot}5 \times 10^9$ centimetres.

W_2, the so-called "effective resistance," which would replace all the losses of energy, is determined from $W_2 = 2L_2 \sqrt{\gamma} = 318$ ohms $= 318 \times 10^9$ centimetres, wherein γ, the log. radiation decrement, is determined, according to Abraham, by

$$\gamma = \frac{2{\cdot}44}{ln\frac{2l}{r}} = 0{\cdot}33\,.$$

The length of the aerial wire $l = 65$ metres.

The "effective" radius r (see p. 47) $= 10$ cm., bearing in mind the multiplex antenna (net) used.

The dampings are

$$\text{primary } h_1 = \frac{W_1}{2L_1} = 7{\cdot}143 \times 10^4\,,$$

$$\text{secondary } h_2 = \frac{W_2}{2L_2} = 3{\cdot}53 \times 10^5\,.$$

The degree of coupling:

$$\tau = \sqrt{\tau_1 \tau_2} = \sqrt{\frac{L_{12}}{L_2} \times \frac{L_{12}}{L_1}} = 0{\cdot}3276 \text{ and } n\tau = 2{\cdot}2 \times 10^6\,.$$

The resulting numbers of oscillations per 2π seconds should be

$$n_1 = n + \tfrac{1}{2}\sqrt{\tau^2 n^2 - (h_1 - h_2)^2} = 7{\cdot}814 \times 10^6\,,$$

$$n_2 = n - \tfrac{1}{2}\sqrt{\tau^2 n^2 - (h_1 - h_2)^2} = 5{\cdot}632 \times 10^6\,;$$

or the frequencies

$$N_1 = \frac{n_1}{2\pi} = 1{\cdot}2435 \times 10^6\,,$$

$$N_2 = \frac{n_2}{2\pi} = 0{\cdot}89635 \times 10^6\,.$$

The experimental results (in the absence of syntony) were $\lambda_1 = 230$ metres; $\lambda_2 = 330$ metres.

or exp. $N_1 = 1{\cdot}3 \times 10^6$,
exp. $N_2 = 0{\cdot}9 \times 10^6$.

Consequently in the case of syntony (resonance) the difference in the frequencies is a minimum.

With syntony, both the resulting oscillations would have dampings of no appreciable difference, namely,

$$=\frac{h_1+h_2}{2}=\frac{(0{\cdot}714+3{\cdot}53)10^5}{2}=2{\cdot}122\times10^5,$$

or the log. decrement

$$=\frac{2{\cdot}122\times10^5}{N}=\frac{2{\cdot}122\times10^5}{1{\cdot}07\ \times10^6}=0{\cdot}198 \text{ or}=\frac{1}{5{\cdot}1}.$$

It is evident that close coupling is not very favourable for the production of well-developed resonance, since in the optimum event ($h_1=0$) the damping of the emitted waves could not be reduced by more than half.

Wien showed that close coupling must be utilised in quite a different direction. We know that for different points in space the maximum amplitude values of the oscillating electric and magnetic forces diminish with the distance. The values of the amplitude of potential are, however, the decisive factor, for the coherer at least.

Now, with close coupling, the amplitude ratio—disregarding the quadratic correction terms—is:

$$\frac{A_2}{A_1}=\frac{n+\sqrt{\tau^2n^2-(h_1-h_2)2\tau_2}}{\tau n};$$

or, assuming τn to be large in comparison with h_1h_2, approximately:

$$\frac{A_2}{A_1}=(1+\tau)\sqrt{\frac{\tau_2}{\tau_1}}=\left(1+\frac{L_{12}}{\sqrt{L_1L_2}}\right)\sqrt{\frac{L_2}{L_1}}=\left(1+\frac{L_{12}}{\sqrt{L_1L_2}}\right)\sqrt{\frac{C_1}{C_2}};$$

and

$$\frac{B_2}{B_1}=(1-\tau)\sqrt{\frac{\tau_2}{\tau_1}}=\left(1-\frac{L_{12}}{\sqrt{L_1L_2}}\right)\sqrt{\frac{L_2}{L_1}}=\left(1-\frac{L_{12}}{\sqrt{L_1L_2}}\right)\sqrt{\frac{C_1}{C_2}}.$$

After half a beat $\left(\frac{1}{2N\tau}\right)$ the phase of the two oscillations in the secondary system is identical; and, neglecting the damping, the maximum potential will be

$$V_2=A_2+B_2=\left\{A_1+B_1+\tau(A_1-B_1)\right\}\sqrt{\frac{L_2}{L_1}};$$

that is to say, only slightly removed from $(A_1+B_1)\sqrt{\frac{L_2}{L_1}}$,

or from $$V_1\sqrt{\frac{L_2}{L_1}}=V_1\sqrt{\frac{C_1}{C_2}}.$$

Hence, by close coupling, the amplitude of potential will be increased $\sqrt{\frac{L_2}{L_1}}$ fold that of the primary potential.

In our example, this would give

$$\sqrt{\frac{L_2}{L_1}} = \sqrt{\frac{4{\cdot}5 \times 10^5}{3{\cdot}5 \times 10^3}} = 11{\cdot}4 \text{ times the primary potential.}$$

Owing to the damping during the half beat,

$$\frac{V_2}{V_1} = \sqrt{\frac{L_2}{L_1}} \times e^{-\frac{\delta_1}{2N_\tau}} = 8{\cdot}4 \text{ is more correct.}$$

We operated in the primary circuit with a spark-gap 1 cm. across, corresponding to about 30,000 volts; so that the maximum amplitude of potential of the emitted series of waves was

$$8{\cdot}4 \times 30{,}000 = \text{about } 250{,}000 \text{ volts.}$$

Considerations of energy will render the matter still clearer.

The energy of the primary system is

$$E = \frac{CV^2}{2}$$

i.e. for our example $\quad = \dfrac{6{\cdot}3 \times 10^{-18} \times (30{,}000 \times 10^8)^2}{2}$

$$= 2{\cdot}835 + 10^7 \text{ ergs} = 2{\cdot}835 \text{ watt sec.}$$

This energy is not very great in itself, but is expended in a very short space of time. As the log. decrement $\frac{1}{5{\cdot}1}$ expressed, we have 5·1 oscillations before the amplitude has receded to $\frac{1}{e}$ times its initial value. We will assume six oscillations, but will make the restriction that of the total energy during this time of $6 \times 0{\cdot}93 \times 10^{-6}$ sec., only one-third is converted into useful radiation, so that we thus obtain an effect of

$$\frac{2{\cdot}835}{3 \times 6 \times 0{\cdot}93 \times 10^{-6}} \;.\;.\;.\;.\; \text{watts} = \text{about } 169 \text{ kilowatts,}$$

or about 229 horse-power.

Hence by close coupling the potential energy of the primary circuit is explosively expelled by means of the secondary system. We obtain *maximum efficiency and therefore transmission through maximum distances, though at the cost of selective possibilities.*

In class B, namely, with loose coupling, we have to do with only a single effective oscillation with the damping,

$$\delta_1 = h_1 + \frac{\tau^2 n^2}{4(h_2 - h_1)}.$$

Hence, by perfectly loose coupling, the damping can be reduced to the relative low value of that of the primary circuit, thus fulfilling the condition for the development of a decided resonance.

How does the matter stand, however, with reference to the maximum amplitude of the potential? The amplitude ratio is

$$\frac{A_2}{A_1} = \frac{n\tau_2}{2(h_2 - \delta_1)};$$

or, since δ_1 is small compared with h_2,

$$\frac{A_2}{A_1} = \frac{n\tau_2}{2h_2} = \frac{nL_{12}}{2W_2} \times \frac{L_2}{L_1}.$$

To make the relation clear we will perform another calculation with the dimensions already used.

At the border between the two classes we have $\tau n = h_2 - h_1$,

hence $$L_{12} = \frac{(h_2 - h_1)\sqrt{L_1 L_2}}{n} = 1{\cdot}52 \times 10^3.$$

Let us now consider the coupling to be loose, and take $L_{12} = 1{\cdot}3 \times 10^3$.

The coupling is $\tau = 0{\cdot}03$, hence about $\frac{1}{10}$th of the close coupling of our example.

Now $$\delta_1 = h_1 + \frac{\tau^2 n^2}{4(h_2 - h_1)} = 1{\cdot}144 \times 10^5,$$

hence the decrement is $\frac{0{\cdot}1144 \times 10^6}{1{\cdot}07 \times 10^6} = \text{about } \frac{1}{10}$.

We thus have already twice as many oscillations as with close coupling (for which the decrement was about $\frac{1}{5}$th).

On the other hand the amplitude ratio is

$$\frac{A_2}{A_1} = \frac{n \times L_{12}}{2W_2} \times \frac{L_2}{L_1} = 1{\cdot}77,$$

or only about one-fifth that with close coupling ($= 8{\cdot}4$).

With still looser coupling,

$\tau = 0{\cdot}33 \times 10^{-2}$ (*i.e.* $\frac{1}{100}$ of close coupling),
$L_{12} = 1{\cdot}3 \times 10^{2}$
$\delta_1 = 0{\cdot}718 \times 10^{5}$,

hence the decrement $= 0{\cdot}067 =$ about $\frac{1}{15}$.

$$\frac{A_2}{A_1} = 0{\cdot}18 \left(= \text{about } \frac{8{\cdot}4}{47}\right).$$

We get, therefore, thrice as many oscillations as with close coupling, but with the amplitude of potential diminished forty-seven times.

Consequently, loose coupling affords the possibility of generating feebly damped waves and thus obtaining sharper resonance, though at the cost of intensity.

CHAPTER VI.

THEORETICAL RESULTS AND CALCULATIONS.

THEORETICAL RESULTS AND CALCULATIONS IN RESPECT OF SENDER AND RECEIVER.

THE design of a modern receiver has already been explained by a sketch on p. 22, the primary circuit having high capacity and low self induction, with these conditions reversed in the secondary circuit, the idea being to increase the amplitude of potential, since the coherer reacts on maximum differences of potential.

In pursuing the matter further we will make use of the diagram fig. 19, all four systems being in unison (R = 280 metres).

A. *Closely-coupled Sender and Receiver.*

In this case the frequencies in the receiver will be analogous to those in the sender, thus,

$$\nu_3 = n\left(1+\frac{T}{2}\right) = \nu_1 ; \ \nu_4 = n\left(1-\frac{T}{2}\right) = \nu_2 ,$$

and the dampings,

$$\delta_3 = \delta_4 = \frac{h_3+h_4}{2} ;$$

or if we regard the fully closed secondary receiving system as being undamped,

$$\delta_3 = \delta_4 = \frac{h_3}{2} = \frac{h_2}{2} .$$

It is not worth while to try and ascertain the possibility of a decided resonance between closely coupled sender and receiver; for, as might be expected, this is not greater than in the simple original form of Marconi apparatus, *i.e.* it is practically non-existent.

The advantage again lies in another direction. If the damping of the effective wave were the same in the case of close coupling as in a simple Marconi system, we should now have in the receiver—as a consequence of the 50 per cent. lower damping—an amplitude twice as great as in the simple systems. However, by means of the secondary coil with numerous windings, the amplitude of potential $\left(\frac{V_4}{V_3} = \sqrt{\frac{L_4}{L_3}}\right)$ is increased at least 3-fold. Bearing in mind also the previously ascertained 8·4-fold increase of the potential amplitude in the sender, we arrive at the result that (neglecting the disturbances introduced by the increased distances, such as earth curvature, etc.), a combination of closely coupled sender and receiver enables us to telegraph over a distance $2 \times 3 \times 8{\cdot}4 =$ about fifty times greater than could formerly be done with the simple Marconi systems which were effective up to about fifteen miles.

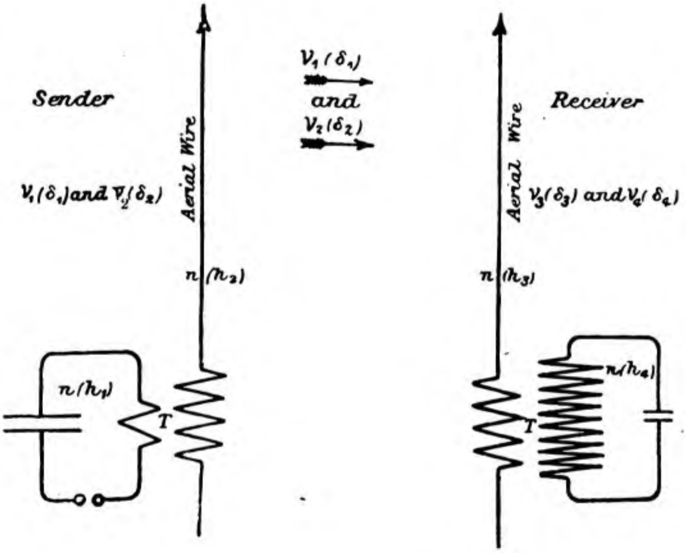

FIG. 19.—General Scheme for Sender and Receiver.

In this direction, therefore, resides the advantage of relatively close-coupled systems; and distances of 450 to 600 miles can in this way be bridged over with ordinary installations. Bearing in mind, however, the enfeebling influence of obstructions and the curvature of the earth, the range of normal installations is reduced to about 300 miles, as practical results have demonstrated. Moreover, this presupposes the existence of favourable atmospheric conditions, namely, moist, un-ionised air. If the atmosphere is not of this character, as is usually the case after a long spell of dry weather, a further 20–30 per cent. must be deducted from the range. The conviction that a large margin of safety must be taken into calculation, coupled with the ever-increasing distances attempted, led to the necessity of supplying larger amounts of energy in the form of effective electric waves. The fulfilment of this endeavour was, however, opposed by difficulties of no slight character, arising from various scientific and technical causes. Nevertheless, this problem also has been solved by Professor Braun, by his method of increasing the effective energy, the principle of which will be described on p. 51 *et seq.*

B. *Loose-coupled Sender and Receiver.*

We have seen that in the sender there is only a single effective oscillation, with the damping $\delta_1 = h_1 + \frac{n^2\tau^2}{4(h_2 - h_1)}$, *i.e.* with the damping of the primary circuit by perfectly loose coupling.

Similarly we have in the receiver,

the frequencies $\nu_3 = \nu_4 = n$,

and the dampings, $\delta_3 = h_3 - \frac{n^2\mathrm{T}^2}{4(h_3 - h_4)}$; $\delta_4 = h_4 + \frac{n^2\mathrm{T}^2}{4(h_3 - h_4)}$,

wherein T represents the coefficient of coupling in the receiver.

Since $h_3 = k_2$ is great in comparison with h_4 there is again practically only a single oscillation with the damping δ_4 to be considered.

The secondary circuit of the receiver is completely closed, so that the damping h_4 is very slight; and by perfectly loose coupling, the damping δ_4 could thus be reduced to the very low value h_4.

Unfortunately, owing to the much greater damping δ_1 of the effective sender wave, there is still no advantage in fully utilising this possibility in the receiver.

In order to find the resulting amplitude ratio, Wien reverted to a result of the Bjerkness theory for simple systems. Bjerkness finds for the maximum amplitude of the receiver

$$\mathrm{M} = \frac{\mathrm{A}}{2nh_1} \times \left(\frac{h_2}{h_1}\right)^{\frac{h_2}{h_1 - h_2}} = \frac{\mathrm{A}}{2nh_2}\left(\frac{h_1}{h_2}\right)^{\frac{h_1}{h_2 - h_1}},$$

Hence the maximum amplitude remains the same, whether a strongly damped sender oscillation excites an undamped receiver, or whether the effective wave is undamped, and the receiver has the same damping as the sender in the first case. Consequently the equations for compulsory damped oscillation under the influence of a periodic force (the periodicity of which determines the amplitude of both the coupled systems) are applicable.

For the amplitude a_2 in coupled elastic systems, Wien found

$$a_2 = \frac{-E \times \tau_2 K_1^2}{\sqrt{\{(\kappa_1^2 - n^2)(\kappa_2^2 - n^2) - 4h_1 h_2 n^2 - \tau_1 \tau_2 \kappa_1^2 \kappa_2^2\}^2 + 4n^2\{h_1(\kappa_2^2 - n^2) + h_2(\kappa_1^2 - n^2)\}^2}},$$

or for our case:

$$A_4 = \frac{A\nu^2\tau_4}{\sqrt{\{(n^2-\nu^2)^2 - 4h_3 h_4 \nu^2 - \nu^4\tau^2\}^2 + 4\nu^2(n^2-\nu^2)^2(h_3+h_4)^2}}.$$

For $\nu = n$, and neglecting $\nu^2\tau^2$ in comparison with $4h_3h_4$, the maximum amplitude is

$$M_4 = \frac{A\tau_4}{4h_3h_4}.$$

On the other hand, Bjerkness finds for the maximum, M, of his resonance curve, that is to say, for the maximum potential amplitude in the resonator of the simple systems in unison,

$$M = \frac{A \times X^2}{4\pi\gamma}\left(\frac{\delta}{\gamma}\right)^{\frac{\delta}{\gamma - \delta}},$$

wherein X indicates the duration of oscillation, γ and δ the log. decrements in sender and receiver.

For equal damping ($\gamma = \delta$): $M = \frac{A}{4\pi} \times \frac{X^2}{\gamma} \times \frac{1}{e}$;

or by introducing the damping h_1 instead of the decrement

$$M = \frac{A}{2nh_1} \times \frac{1}{e},$$

wherein n represents the number of oscillations in 2π seconds, and $e = 2{\cdot}71828$ . . . . the basis of the natural log.

In our case, therefore, the maximum amplitude for the simple system is

$$M_0 = \frac{A}{2nh_3 e}.$$

Since $h_4 = \delta_4 = \delta_1$, then

$$\frac{M_4}{M_0} = \frac{n\tau_4 e}{2\delta_1} = \frac{nL_{34}e}{2\delta_1 L_3}.$$

Let us take still another calculation. L_{34} is determined by the equation given for δ_4, neglecting the small value h_4.

$$\tau^2 = \frac{L_{34}^2}{L_3 L_4} = \frac{4 h_3 \delta_4}{n^2}.$$

Let
$$\delta_4 = \frac{\delta_1}{9},$$

then
$$L_{34} = \frac{2}{3n}\sqrt{h_3 \delta_1 L_3 L_4}.$$

We have the following data:

$$\begin{aligned} n &= 6{\cdot}7 \times 10^6, && \text{(p. 30)} \\ h_3 = h_2 &= 3{\cdot}5 \times 10^5, && \text{(p. 31)} \\ \delta_1 &= 0{\cdot}72 \times 10^5, && \text{(p. 35)} \\ L_3 = L_2 &= 4{\cdot}5 \times 10^5, && \text{(p. 31)} \\ L_4 = 9L_8 &= 40{\cdot}5 \times 10^5, && \text{(p. 37).} \end{aligned}$$

Hence
$$L_{34} = 2{\cdot}13 \times 10^4,$$
and the amplitude ratio,

$$\frac{M_4}{M_0} = \frac{n L_{34} \times 2{\cdot}718}{2\delta_1 \times L_3} \ldots = 5{\cdot}9.$$

The calculation shows that, given an equal amplitude of the effective waves, the amplitude in the receiver is about six times as great as in the simple system, and about twice as great as with relatively fast coupling. Nevertheless, on the other side we have seen that the low damping necessary to secure such an effect in the receiver could only be obtained through loose coupling in the sender, thus giving rise to a nearly 47-fold diminution of potential amplitude in comparison with close coupling.

The normal range of about 300 miles for the latter is therefore diminished to $\frac{300 \times 2}{47}$, or about 12½ miles when loose-coupled sender and receiver are used.

The slighter the damping, the sharper the resonance, and therefore the smaller the dissonance can be between simultaneous effective oscillations, without the possibility of mutual disturbance.

By means of the graphical illustration reproduced in fig. 20, wherein the amplitude of the secondary system is represented as a function of the dissonance, Wien clearly demonstrated the greater sharpness of resonance in loosely-coupled systems than in the simple system; there is a still greater contrast when the loosely-coupled systems are compared with close-coupled systems.

The ratio between the maximum amplitude of the secondary system in unison and the corresponding amplitude in case of dissonance may be termed "ratio of sensitiveness." Neglecting small dimensions, and with small dissonance $n-\nu$, Wien finds for this ratio of sensitiveness,

$$\frac{M_4}{A_4}=\sqrt{\frac{(n-\nu)^4}{h_3^{\,2}\delta^2_{\,1}}+\frac{(n-\nu)^2}{\delta_1^{\,2}}+1}.$$

If the value of the same be estimated at 2–4 according as the receiver is assumed to be 2–4 times as sensitive to the correct frequency as to a deviating one, it is easy to calculate the "necessary dissonance" $n-\nu$ (contained in the above expression) for which no mutual disturbance occurs. Usually the value 2 is sufficient for the "ratio of sensitiveness"; but if the simultaneous effective oscillations differ in strength, say as the result of different distances, 4 is the lowest value that should be chosen. The "necessary dissonance" fluctuates accordingly between about 5 per mille and 5 per cent. of the frequency.

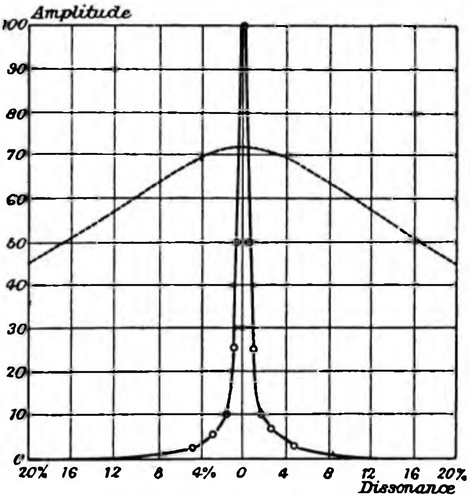

FIG. 20.—Amplitude Curves as Function of the Dissonance.

The wave lengths usual in practice, by reason of the limited height of the masts, vary between about 100 and 500 metres, or, expressed in frequencies, between 3×10^6 and 6×10^5 sec.

With a dissonance of 5 per mille it is possible, in accordance with the equation $3\times10^6=6\times10^5\left(1+\frac{5}{1000}\right)^x$, to send messages simultaneously with $x=322$ senders, without disturbance. Similarly, with a dissonance of 5 per cent., 33 senders could be used, though, as we have seen, the range is relatively shorter.

However, to obtain such a high selective capacity at the expense of the intensity or distance seems an unnecessary detrimental luxury, so long as wireless telegraphy is restricted to its present chief sphere of application, namely, for military and naval purposes.

As the experiments at the Braun-Siemens Baltic stations have demonstrated, the employment of the above described loose-coupled receiver with a sender coupled to a degree approximating the boundary of loose coupling is sufficient, even in the case of the unfavourable "distance ratio" 1:10 and for a maximum distance of about 125 miles, to enable messages to be transmitted to a certain station simultaneously from several stations, working with effective wave lengths differing by about 10 per cent.

Such a system of *multiplex wireless telegraphy*, developed on these lines, should prove sufficient for some time. The absolute reliability of this system was demonstrated two years ago by the author before the authorities of the Imperial German Navy, after having been in regular work for two months.

The method of coupling up the circuit for this multiplex telegraphy will be described later.

The tuning of sender and receiver in loose-coupled systems is not only possible but essential, more particularly with regard to the primary circuit of the sender and the secondary circuit of the receiver. These must be tuned with almost perfect accuracy, since even the smallest discordance due to a few per mille variance from absolute syntony will immediately annul the otherwise powerful signals. Owing to the technical perfection of the apparatus, not the slightest difficulty in realising such sharp tuning is encountered in practice.

Disturbance in loose-coupled systems by close-coupled senders can be guarded against by using the latter for long distance work and long wave lengths only, whilst for short distances the messages are dispatched and received with loose-coupled systems and with waves of a much smaller size.

Notwithstanding the enormous progress made in theoretical development and the practical application of the same, no revolutionary encroachment on the existing domain of ordinary telegraphy will be possible until we are able to operate with controllably sustained electrical oscillations of sufficient frequency, instead of more or less strongly damped series of waves as at present. The seemingly feasible project of wireless telephony by means of electrical oscillations also suffers from this limitation.

SPECIAL THEORETICAL RESULTS OF PRACTICAL IMPORTANCE.

We have already seen that the value W occurring in the formulæ is not represented by the constant ohmic resistance. Even when measuring free oscillations in a completely closed circuit (by means of the Helmholtz pendulum at the Physical Institute of Zürich University, Professor A. Kleiner), Heinrich Mayer finds that the effective resistance increases approximately with the square of the frequency.

Almost simultaneously, Dolezalek, in measuring the coefficients of induction of coils, found that, in the case of alternating currents with over 300 oscillations per second, a considerable increase of resistance occurs in comparison with the values from direct current or slow alternating current. He also records a diminution of the self-induction with the duration of oscillation, whereas Mayer found a considerable increase, which Dolezalek attributes to the presence of high capacities.

Wien, in his publication on the flow of rapid alternating currents through wire coils, made a theoretical examination of the experimental results obtained by Dolezalek. In fact, theory demonstrates that the effective resistance must increase with the square of the frequency. The occurrence of eddy currents in cases of high frequency causes the lines of flow to be forced progressively inward, the mean radius of the circuit being reduced and the self potential diminished.

The practical result is that, in accordance with the proposals of Dolezalek, the use of solid wires for the induction coils has been replaced by thin insulated wires, twisted together in the form of cord. Such divided wires ought to have practically identical resistance, self induction, and mutual induction. Hence the "Deutsche Gesellschaft für drahtlose Telegraphie" (German Wireless Telegraphy Co.) makes all its conductors of cords, prepared by a special process, the several wires of which are only 0·1 mm. in diameter. This plan of dividing and twisting the wires renders corrections practically unnecessary.

The ohmic resistance of the primary circuit with the spark-gap is determined by the latter alone in all well-designed modern installations. According to a communication to me from Professor Drude, which also appears in his publication on the damping of condenser circuits with spark-gaps, the results furnished by his measuring experiments show that the resistance W of the spark-gap is not even approximately constant, but varies considerably with L and C. Hence it is not possible, even by selecting a large L and small C, to obtain small log. decrements $\left(\gamma = \pi W \sqrt{\frac{C}{L}}\right)$.

The labours of Zenneck, Braun, Drude, and Abraham, with regard to the spark-gap, the distribution of capacity and self-induction in the primary circuit, and other decisive factors, furnish the following considerations of practical importance.

The increase of the primary initial potential with the length of the spark depends chiefly on the radius of the spark-gap balls. With large balls the potential increases approximately in proportion to the length of the spark-gap, up to several centimetres. It is therefore advisable to use large ball caps for the spark-gap, in which event the maximum amplitude in the secondary system will also increase with the growing primary potential at a relatively rapid rate up to a sparking distance of several centimetres.

The modification of resistance in the spark-gap is a function of the quantity of electricity passing. With large capacities, of more than about 200 cm., the spark resistance, for a gap of about 0·5 cm., is of minimum value; these represent the most favourable conditions. Enlarging the spark-gap increases this resistance, slowly with large capacities, more quickly when these are small. In normal installations the spark resistance should not exceed 0·1–0·2 ohm.

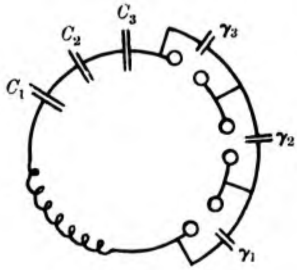

FIG. 21.—Spark-gaps in Series.

Under given conditions there is always an optimum length of spark, *i.e.* one in which the percentage of total energy absorbed by the spark is minimal. If this point be neglected, the increased spark damping in most cases causes a greater amount of loss than the gain effected by increasing the initial potential. These considerations led Professor Braun to introduce a series of spark-gaps, as illustrated in fig. 21. Instead of a simple long spark-gap, use is made of a number of small gaps arranged in series. The distribution of potential to correspond most suitably to the spark-gaps is effected by means of small supplementary condensers, γ_1, γ_2, γ_3. The capacity of these so-called "potential distributors" is negligible in proportion to the total energy of the system; and its oscillations can, if necessary, be cut out entirely by large inductive resistances. In this manner any desired potential of discharge can be economically utilised by employing the most favourable length of spark.

In the primary circuit the spark damping is the decisive factor, and must be kept as low as possible by the use of large capacities; the self-induction will then be correspondingly small. This applies also to the case of loose coupling, though on the ground of the log. decrement, one would otherwise be disposed to draw an opposite conclusion with reference to the distribution of capacity and self-induction for the attainment of minimum damping in the primary circuit, which, as mentioned before, is the main point to be considered in loose coupling.

To obtain the smallest possible decrements it is by no means unimportant to connect the wires from the inductor as closely to the spark as possible, *i.e.* at the potential nodes of the produced oscillation.

In the case of relatively close coupling, the advisibility of having L as small and C as large as possible, is clearly evident for other reasons. This has already been shown by Wien, who demonstrated that the secondary potential amplitude is raised to $\sqrt{\frac{L_2}{L_1}}$ times that of the primary potential.

Drude finds generally that only a single thick primary winding should be used, dispersion being prevented as much as possible by "dead" self-induction (self-induction without inductive action).

These considerations, moreover, formed the basis on which Zenneck, some years back, carried out his first practical experiments for Professor Braun; and they led him to the construction of a (patented) sender-transformer, the primary of which had only one winding, or two windings coupled up in parallel. Unfortunately, these and many other results obtained by this painstaking and ingenious worker have been entirely neglected by his successors; otherwise some very advantageous scientific and technical arrangements of installations for wireless telegraphy would have been generally known years ago.

Zenneck had previously found, by trial, that there is always an optimum degree of coupling for installations with relatively close coupling, at which degree a maximum amplitude of potential in the secondary system is attained. Drude finds that this optimum degree of coupling should be $\tau = 0{\cdot}6$, but admits that the final increase to the optimum is asymptotic, *i.e.* that relative maxima are obtained with much lower degrees of coupling. J. Zenneck made some careful practical experiments extending the degree of coupling to $\tau = 0{\cdot}6$, and found a great discrepancy between his results and those derived from Drude's theoretical deductions with regard to the relation between the maximal amplitude in the secondary system and the degree of coupling. Especially, the experiments seem to point out that it is to no purpose to have the degree of coupling more than 0·30–0·35.

In theory it is assumed that the decrement of the primary circuit remains constant during an oscillation, and that it is independent of the degree of coupling. In oscillation circuits with *spark-gaps* this is certainly not the case, and hence the difference between theory and practice.

Besides, for reasons already stated, such close couplings as $\tau = 0{\cdot}6$ are generally impossible in installations for wireless telegraphy.

With regard to the secondary system, Drude employs for the calculation of its individual wave length a formula which we reproduce, with others of importance, on p. 54 *et seq.* However convenient such a calculation may be, it is only unconditionally applicable provided the position of the antenna approximates to the ideal case of a free wire. The condition of an absolutely free wire is only satisfied when its distance from any object in the neighbourhood is at least very great in comparison to its own length. Practically this cannot be attained, but, as done at the Baltic stations, it is advisable to hold the aerial wire as free as possible by the use of insulated ropes. Furthermore, the upper stay ropes holding the mast were attached somewhat lower down the mast than constructive security warranted; and they were insulated by insulation bolts above and below. Usually, however, practical conditions are of a much less favourable character; and it is altogether preferable to excite the secondary system independently, by mounting a spark-gap in the aerial wire and thus exciting the latter as a Hertz oscillator, the specific wave length being then determined experimentally by means of the ondameter (see p. 60). In any case a comparison of the results with a calculation based on the Drude formula will always be interesting.

Incidentally it may be here mentioned that the wave length can also be approximately estimated. In most cases the current distribution in the aerial wire is almost sinonical, and the belly of the current lies in the centre of the secondary coil. Therefore, for the wave lengths λ we get the equation $\frac{\lambda}{4}$ = length of the antenna plus half the length of the windings of the secondary coil.

For a multiplex secondary system, Drude also formulated the following :—

"A multiplex antenna (cage antenna), which may be heterogeneous (partly multiplex and partly simple), 'acts' like a simple antenna of a single wire the radius of which is equal to the radius (when the wires are few) or the diameter (when the wires are many) of the mean sectional area (reckoned as a circle) applicable to the total length and enclosed by the antennæ wires.

"The advantage of using multiplex antennæ in the senders in wireless telegraphy resides to some extent in the diminution of the frequency, but more particularly in the increase of radiation. Both these results are best attained by the use of thick antennæ. Multiplex antennæ are therefore advisable on both grounds, since they are able to replace the heavier thick antennæ.

"The checking action of a coil towards alternating current is greater in proportion as the windings are closer, and the less the radius exceeds that of the straight wire conducting the alternating current."

In the sense employed by Drude, this "act" implies, in the first place, that the multiplex antenna is equivalent to a simple antenna of greater radius, in so far as the wave length of the sender is concerned, that is to say, it induces an augmentation of the period. According to the axiom of Poynting and the inalterable relative position of the electric and magnetic lines of force at a greater distance from the sender, it results as a further consequence that the multiplex antennæ effect an increase in the radiation. With regard to these statements of P. Drude, we should like to draw attention to the following remarks by J. Zenneck, which undoubtedly deserve the closest attention. A simple and a multiplex antenna of the same frequency, and whose dimensions of cross section are very small compared with those of length, have in a distance which is great in comparison with the wave lengths, the same field when the current amplitude in both is the same. With the same potential (spark-gap) the current amplitude is much larger in the multiplex than in the single antenna. The relations can best be shown by the following. From the theoretical considerations of Hertz may be derived the following equation for the field intensity E (in the equatorial plane which is alone to be considered in wireless telegraphy):—

$$E_0 = A \cdot \frac{l}{\frac{\lambda}{2}} \cdot \frac{i_0}{r},$$

in which A represents a constant factor dependent on the system of measurement, l the length of the aerial wire, λ the wave lengths, i the current mean value in the antenna, r the distance from it, and the index o the amplitude.

When a simple antenna is replaced by a multiplex antenna of the same length, and of the same wire radius, the potential amplitude being given, there are two changes—

(a) the frequency and hence the ratio $\frac{l}{\frac{\lambda}{2}}$ (b) the current amplitude i_0.

The ratio $\frac{l}{\frac{\lambda}{2}}$ has been discussed by Drude, with the result that in respect of its individual period a multiplex antenna is equivalent to a simplex antenna of a greater radius. Hence it follows that in both the ratio $\frac{l}{\frac{\lambda}{2}}$ has the same value. As is shown by the experimental measurements of Drude, this ratio for a multiplex antenna, the cross section dimensions of which are small compared with those of length, varies only slightly from that of a simple antenna of the same wire thickness.

This ratio consequently plays only a minor part in practice.

But in regard to the current amplitude a comparison of simple and multiplex antennæ of the same length and wire thickness leads to the following relation :—

I. $\frac{i_1o}{i_2o} = \frac{C_1}{C_2}$ when the antenna is used as a simple Marconi sender or a secondary system in a loose-coupled Braun arrangement.

II. $\frac{i_1o}{i_2o} = \sqrt{\frac{C_1}{C_2}}$ for antennæ used as secondary systems in close-coupled Braun arrangements.

Here C indicates the capacity per length unit; the index 1 refers to the multiplex, the index 2 to the simple antenna.

As the capacity per length unit of the multiplex antenna is much larger[1] than that of a simple antenna, it follows that the current amplitude, and hence the amplitude of the electric field intensity E in the case of the multiplex antenna, is also considerably larger than in the case of a simple antenna. In this fact lies the real importance of a multiplex antenna, not in the alteration of the period with its accompanying minute change of the field intensity.

The superiority of multiplex antennæ over the simple forms may also be expressed in the following way. From M. Abraham's publication on wireless telegraphy it follows that the attainment of maximum potential on the upper extremity of the aerial wire is less important than maximum amplitudes of current at the lower end of the antenna. However, according to M. Wien, this current amplitude is nearly proportional to $\sqrt{C_1C_2}$, wherein C_1 and C_2 represent the primary and secondary capacity. Hence the multiplex antennæ act more favourably in consequence of their greater capacity. For the same reason of strengthening the current in the antenna, it is therefore necessary to minimise the primary self-induction as well, a result at which we have already arrived by another path.

For the current amplitude, Abraham finds the following additional axiom:—

"If, with a given antenna of the capacity C_2 (in microfarads), directly coupled with a primary condenser circuit, it be desired to obtain the highest possible increase in the maximum amplitude of the effective waves, the primary self-induction L_1 must be selected in accordance with the equation $L_1 = 6{\cdot}7 \times 10^5 C_2$."

There consequently results an optimum for L_1 and a corresponding one for the primary capacity C_1; any further increase of the latter would excessively augment the radiation and thereby weaken the maximum wave amplitude occurring after half a beat. These considerations, however, are restricted to relatively close-coupled arrangements of sender and receiver. In loose coupling, the chief point to attain is the production of protracted oscillations, even at the expense of the wave amplitude.

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[1] According to J. A. Fleming (*Cantor Lectures on Hertzian Wave Telegraphy*, p. 14; London, 1903) the capacity of a multiplex antenna whose component wires lie pretty close together is about $\sqrt{N}$ times (N = number of wires) larger than the capacity of a single antenna of the same length and wire thickness; a multiplex antenna of 50 wires would show approximately 7 (resp. 2·6) times the effect of a corresponding single antenna.

Moreover, as results from Brandes' measurements, with multiple antennæ the amount of the radiation in relation to the existing energy, *i.e.* the radiation decrement, is greater than with simple antennæ; hence the use of the former ensures better utilisation of the primary energy.

For the so-called "counter capacity," already frequently mentioned, namely, a metallic surface, S, which forms the electrical counterpoise for the antenna of the length l, Drude finds the equation

$$\sqrt{S} = \frac{0{\cdot}603 l}{\text{brigg. log. } l/\varsigma},$$

in which ς represents the "effective" radius in the sense already described.

According to Drude, the different modes of action of the various couplings furnish valuable information on the nature of the indicators to be used in the receiver. The coherer reacts on differences of potential, and therefore is evidently the most suitable indicator when close coupling is used, the chief property of which resides in the production of maximum amplitudes of potential. With loose coupling, however, the integral effect is the main point, so that Rutherford's magnetic indicator seems more suitable in such cases than the coherer. The reason for this is that alterations in the damping make far less difference to the maximum amplitude than to the integral effect; hence when damping is mostly to be considered, the coherer suffers from a certain indifference. For loose-coupled apparatus it is preferable to use an antenna with relatively high self-induction (coils in the vicinity of the belly of the current) in order to prolong radiation.

At great distances, r, the action of the sender on the receiver, diminishes like the amplitude of intensity of the electric and magnetic field, and consequently like $\frac{1}{r}$. The radiation is proportional to the square of the resulting field intensity.

CHAPTER VII.

BRAUN—ENERGY SYSTEMS.

It has already been stated that the energy available for radiation is determined by $\frac{1}{2}CV^2$, in which expression C represents the capacity and V the discharge potential of the condenser circuit. The dimensions of the capacity *per se* are subjected to a natural limitation by the length of waves obtainable in practice because of the relatively short masts. Besides, an increase of the capacity at the expense of the self-induction soon reaches a limit. Furthermore, insuperable difficulties, both theoretical and practical, oppose the increase of the discharge potential.

The way out of this dilemma was discovered by Braun in a method of arrangement, the general principle of which is illustrated in fig. 22.

Here, n equal condensers C are connected by n equal self-inductions L in series to a circuit which is closed by the spark-gaps at the moment of discharge. The charging of the condensers, however, is effected in parallel with low potentials only, by means of the large ohmic or inductive resistances W_1, W_2, W_3, which have nothing to do with the oscillations.

The total available energy is therefore

$$\frac{1}{2}\left(\frac{C}{n}\right)(nV^2) = \frac{1}{2}nCV^2,$$

and that, too, with an unchanged duration of oscillation, since

$$T = 2\pi\sqrt{nL\frac{C}{n}} = 2\pi\sqrt{LC},$$

as for a simple oscillation circuit.

Braun also proves that the spark discharge is equiphasal throughout, and that each spark has only the damping corresponding to the partial potential difference V.

With an n-fold energy we can thus work the n oscillation circuits with the same economy as a simple one.

The energy can be utilised in many different arrangements. Thus fig. 23 shows the method of inductive coupling, whilst an instance of direct coupling for exciting n separate aerial wires is given in fig. 24.

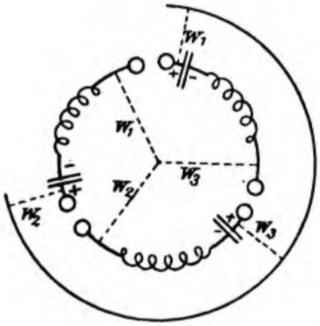

FIG. 22.—General Scheme of Braun's Energy System.

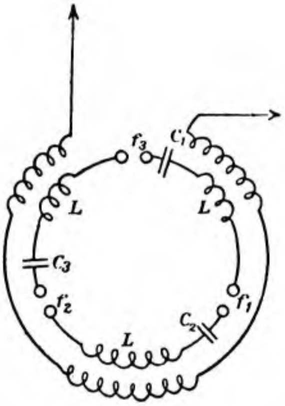

FIG. 23.—Braun's Energy System.

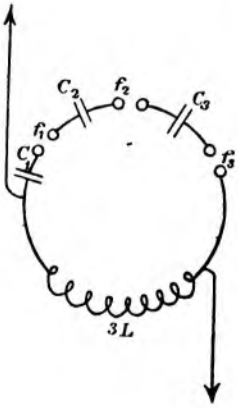

FIG. 24.—Braun's Energy System.

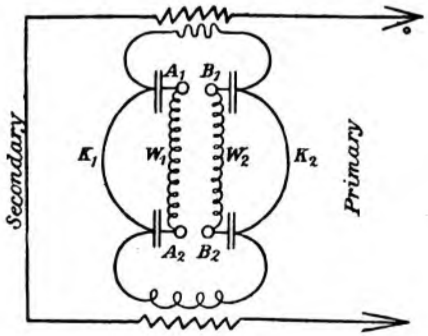

FIG. 25.—Energy System used at the Baltic Stations.

The form of arrangement illustrated in fig. 25 was used with great success at the Baltic stations. The condensers are connected in parallel, for charging with the large resistances W_1W_2. The induction-free "coupling arcs" K_1K_2 ensure that when the discharge takes place in A_1B_1, the spark in A_2B_2 must pass simultaneously and in an equiphasal manner. The secondary systems were suitably connected in series.

PRINCIPAL FORMULÆ.

Owing to the irregular conditions it is impossible to calculate the *capacity* of the Leyden jars used in the primary condenser circuit; and even measurements performed by known static methods, or with the telephone bridge, give entirely useless values. Thus, measurements, made at the normal frequencies of the oscillations used in wireless telegraphy, gave variations up to 30 per cent. This is due to the losses of energy in solid dielectric glass, these losses increasing with the number of oscillations and in accordance with the manner in which the "residue" is developed. A condenser in which a residue is formed often takes several minutes to attain its maximum charge, so that it cannot act up to its full capacity in the very short time occupied by the oscillations. The difficulties arising from these and other factors in the way of accurately measuring the wave lengths generated in the primary condenser circuit, have now been removed by the use of a resonance circuit, containing an adjustable condenser with ideal properties, the capacity values of which, resulting from various adjustments, can be determined with great exactness, and if necessary reduced to "dynamic" capacity. This instrument is the "ondameter," or, better still, "frequency meter," to which reference has been made in the previous pages, and of which a description will be given in the next chapter.

The self-induction of coils in which the dimensions of the rectangular section of the annular space occupied by the wire windings are small in comparison with the mean diameter of the coil (as is the case both in the induction coil of the ondameter, and in the primary coils in the sender and receiver) can be calculated according to the well-known Stefan formula, as modified by Drude, by introducing the necessary correction on account of the rapidly alternating currents used in electrical wave telegraphy. This formula runs:

$$L=4\pi r n^2\left[\left(1+\frac{h^2}{32r^2}\right)\text{log. nat.}\ \frac{8a}{\sqrt{h^2+\delta^2}}-y_1+\frac{h^2}{16r^2}y^2\right]+\text{log. nat.}\ \frac{y}{\delta}-\Delta,$$

wherein
n = number of windings,
r = radius of coil,
$h = (n-1)g$ = height of coil,
g = pitch of the windings,
δ = thickness of the bare wire.

For y_1 and y_2 the values should be taken from Stefan's tables and that for Δ from Drude's tables.

The reasons for replacing thick wire in inductive coils by cords consisting of a number of separately twisted strands made of very thin wire have already been given.

The self-induction of long, narrow coils, such as are used in the secondary system of the receiver, is calculated by Drude from the formula

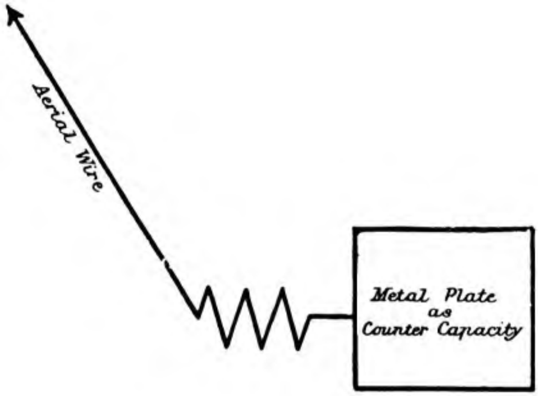

FIG. 26.—Secondary System with Counter Capacity.

$$L = \frac{l^2}{h},$$

wherein
$l = 2r\pi n$,
r = radius of coil,
n = number of windings,
$h = (n-1)g$ = height of coil,
g = pitch of windings.

For calculating the individual periods of the secondary system (the practical use of which is dependent on a formerly mentioned condition) Drude gives the relations

$$\beta = \text{brigg. log. } \frac{l}{s} \times \frac{f}{n}\sqrt{\frac{h}{2r}} \times \phi,$$

and hence the specific wave length λ according to the formula

$$tg\frac{\pi}{2} \times \frac{\lambda_0}{\lambda} tg 2\pi\frac{l}{\lambda} = \beta,$$

wherein $$\tfrac{1}{2}\lambda_0 = fl_1.$$

Here $l_1 = 2r\pi n$ represents the length of wire in the coil, l the length of the antenna, ς its "effective" radius (see p. 47 *et seq.*), n the number of windings on the coil, $h = (n-1)g$ the height of the coil, g the pitch of the windings, $2r$ the diameter of the coil. The values for f (a function of n, $\frac{h}{2r}$, $\frac{g}{\delta}$, and ϵ) and for ϕ (a function of $\frac{h}{2r}$ and $\left.\frac{g}{\delta}\right)$ are to be found in Drude's tables: δ represents the thickness of the wires, and ϵ the dielectric constant of the core.

For the already defined "counter-capacity," we refer to the Drude formula, given on p. 50,

$$\sqrt{S} = \frac{0{\cdot}603l}{\text{brigg. log. } l/\varsigma}.$$

At the Baltic stations the "net" or "cage" of the aerial wire was mounted on rings 20 centimetres in diameter, and therefore had an effective radius $\varsigma = 0{\cdot}1$ metre; furthermore, $l = 65$ metres, so that the dimensions, S, from the formula were 13·93 sq. metres, whereas the result of the empirical determination was S = 13·7 sq. metres.

The counter-capacity of the secondary system, diagrammatically represented in fig. 26, is now usually formed of a surface of wire gauze. With "direct" coupling, coils of suitable dimensions have to be interposed between the condenser circuit and the counter-capacity.

CHAPTER VIII.

MEASUREMENT OF WAVES.

THE ONDAMETER.

THE principle of determining the frequency by the resonance was expounded by Hertz-Bjerkness. It was first applied to the practice of wireless telegraphy by J. Zenneck, and though Zenneck's apparatus was very cleverly developed, in a technical sense, by J. Dönitz, the

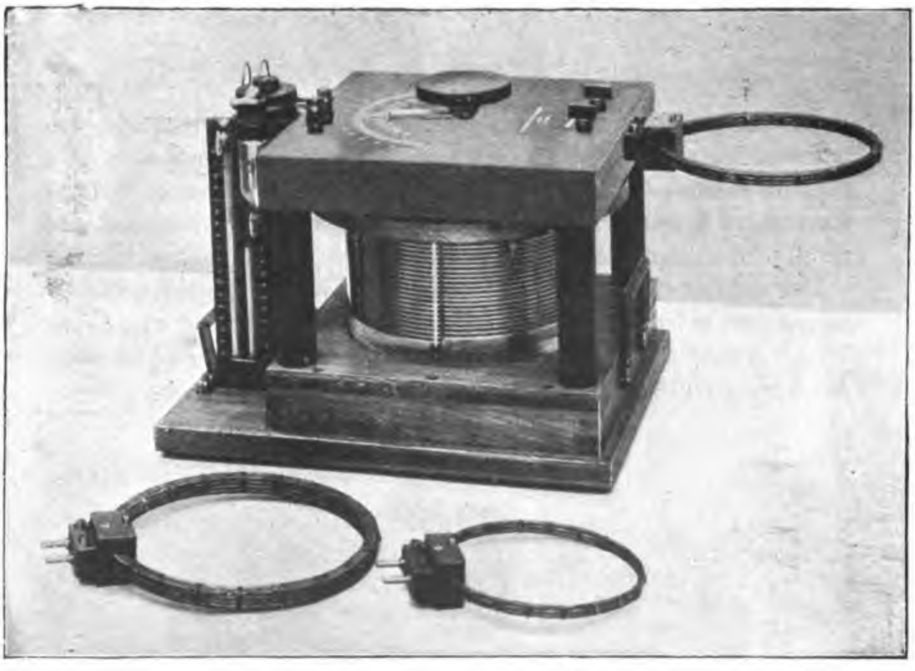

FIG. 27.—Ondameter.

name under which it is generally known, viz., "Dönitz's ondameter," is hardly justified.

This ondameter (or, more properly, "frequency meter"), fig. 27, consists of a closed oscillation circuit, in which the dimensions of the capacity are made to vary within wide limits. When subjected to the action of an oscillating system, it is excited to oscillate in sympathy. The resulting currents (which are read off on a Riess thermometer, the indications of which are proportional to the squares of the current intensities) reach a decided maximum as soon as perfect resonance is attained. Hence the same wave length is then

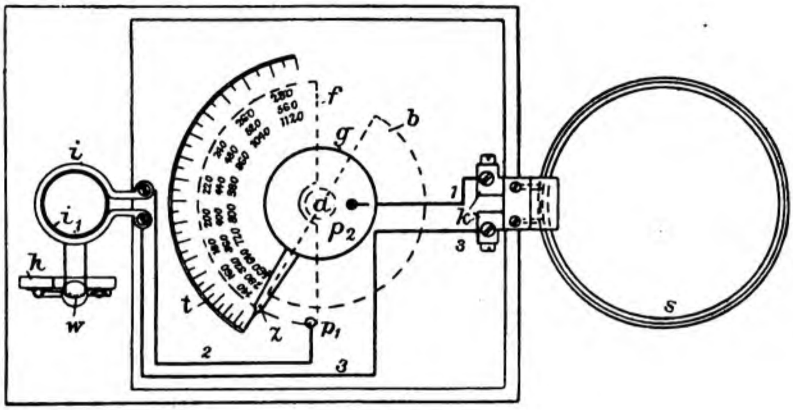

FIG. 28.—Plan of Ondameter.

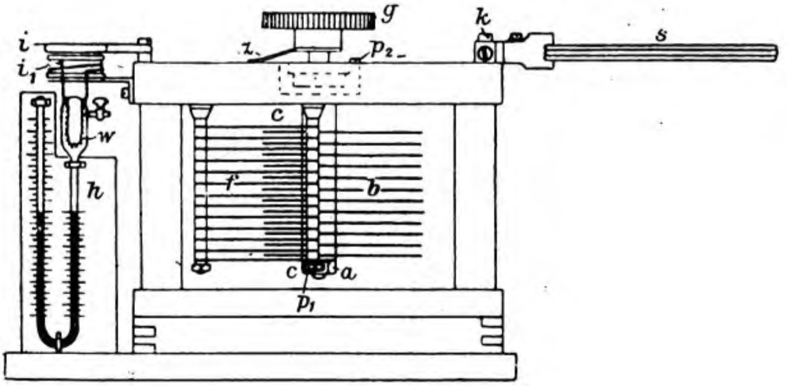

FIG. 29.—Ondameter Elevation.

present in both systems, and can be read off on the scale of the oudameter.

Figs. 28 and 29 represent a plan and elevation respectively of the instrument. So that a variable capacity may be available, the condenser is composed of two sets of parallel semicircular plates, one of which, *f*, is fixed, and the other, *b*, can rotate on the axis *a*. Both sets are mutually insulated, the component members of each set, however, being in metallic connection and connected with the poles p_1 and p_2.

By turning the knob *g* the movable plates are caused to enter the intermediate spaces between the fixed plates, whereby the effective surface, and therefore the capacity, is gradually increased. The condenser is immersed in a bath of vaseline oil, *c* (boiled in order to expel air bubbles), for the purpose of securing more complete insulation, and to increase the limits of capacity, owing to the greater dielectrical constant of vaseline oil in comparison with air.

The self-induction coils *s* are connected to the terminals *k* by a plug contact, and the thermometer (hot-wire instrument) *h* is also included in the oscillation circuit. This latter connection, however, is inductive (not direct), a primary winding *i* in the condenser circuit inducing the secondary windings i_1, the ends of which are connected to the hot wire *w*.

The inductive excitation of the thermometer is for the purpose of enabling the extent of the indications to be regulated by altering the distance between the primary and secondary windings. The instrument is fitted with three different self-induction coils, which are interchangeable and of such dimensions that the resulting three limits of measurement follow each other in close order, so that all wave lengths between about 100 and 1000 metres can be measured.

To the knob *g* is connected the pointer *z*, which moves over the scale *t*. This scale is inscribed, in three rows, with the wave lengths corresponding to the three coils and the momentary adjustment of the condenser.

To use the instrument, say for measuring the frequency of the *primary condenser circuit* of the sender, it is operated in the manner illustrated in fig. 30. The coil L_1 of the exciting condenser circuit is placed above the coil L_2 of the oudameter W, so that the latter is traversed by lines of magnetic force from the former. By gradually altering the capacity *Cv*, the flow becomes progressively stronger, as is shown by the rise in the thermometer T; and finally the adjustment of the condenser reaches the stage at which the intensity of the current attains a maximum, whereupon any further adjustment of the condenser results in a fall in the thermometer. At this maximum (*i.e.* the attainment of resonance), the effective wave length is denoted by the position of the pointer on the scale.

A point to be kept in mind in these measurements is that the distance a between the planes L_1 and L_2 must be sufficient to preclude any reaction of the resonator circuit on the exciting oscillation circuit by the induced current. In other words, the coupling must not be too close, otherwise—as we have seen in the theoretical section—a deformation of the oscillation will occur. The optimum degree of coupling is about $a = 3$ cm. If the distance be increased, *i.e.* the coupling made looser, the position of resonance of course remains the same, but the indications of the thermometer will be naturally of smaller amplitude, so that the adjustment for resonance cannot be made with the same sharpness. If there are several oscillations present (as we have seen to be the case with close-coupled systems), the different amplitudes of the thermometer indications enable a conclusion to be formed of the various amplitudes of the effective waves.

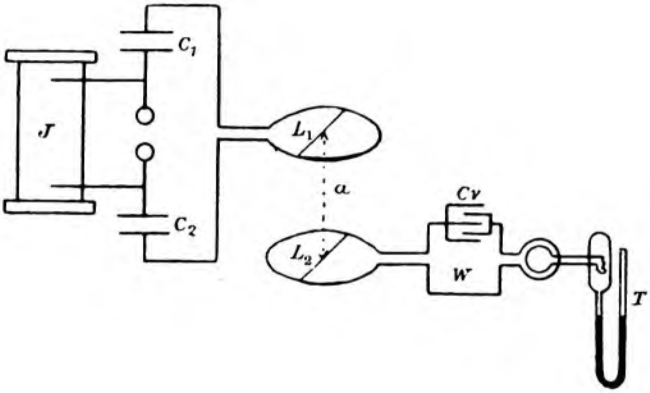

FIG. 30.—Measuring the frequency of the Primary Condenser Circuit, with the aid of the Ondameter.

Moreover, the flow may develop in very different ways. Sometimes the level of the liquid in the thermometer will remain almost stationary for a considerable time, until it shoots up quickly, the state of resonance being reached; and it will fall with equal rapidity when that condition is exceeded. At other times the thermometer indications rise slowly until the maximum is attained, and then sink gradually.

Hence the sharpness of the resonance can be determined in the case of different oscillations, and conclusions drawn as to their different dampings (p. 30).

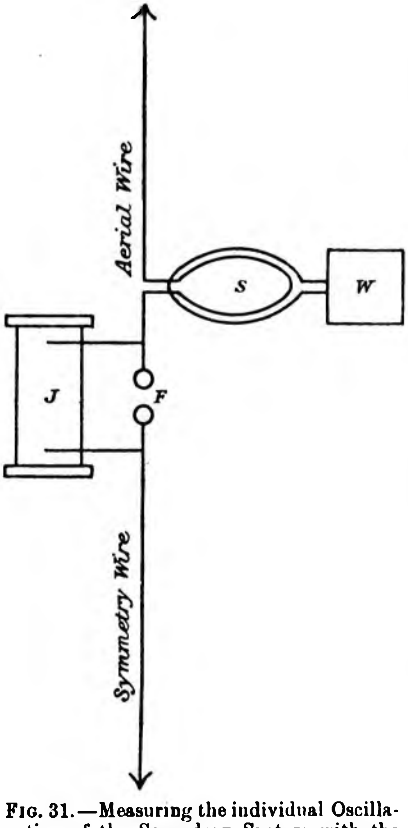

FIG. 31.—Measuring the individual Oscillation of the Secondary System with the Ondameter.

The measurement of the individual oscillation of the *open secondary system* is performed with the ondameter in the manner illustrated in fig. 31. By introducing a spark-gap, F, the secondary system is excited as a Hertz oscillator, and induces the coil of the ondameter W by a loop S. The ondameter is then set for resonance in the manner just described.

Before this latter measurement is performed, the aerial wire must be brought into the position in which it will actually be used; for the capacity of the wire depends on its relative position to the earth and other adjacent objects, so that a change in position will also cause an alteration of the specific periods.

Finally, the ondameter also enables the effective oscillations in the *complete coupled sender* to be determined (namely, a single oscillation with loose coupling, and two oscillations with close coupling), inasmuch as an inductive action is exerted on the ondameter by means of a loop in the aerial wire (which in this case is no longer fitted with a spark-gap).

A simpler ondameter, though insufficient for accurate determinations, is the measuring rod (fig. 32) of Professor Slaby. Here again the principle of resonance is applied, barium-platinum cyanide being

Fig. 32.—Slaby's Measuring Rod.

employed as the indicator. On approaching the free end to a point of high potential variation in the system under examination, the cyanide is excited.

CHAPTER IX.

MANAGEMENT OF A STATION.

THE construction of a station for wireless telegraphy proceeds by the following chief stages. In the first place, the aerial wire or aerial wire system is set up in an approximately vertical position, by mounting it, in a properly insulated manner, on high masts, or, in the case of movable stations, attaching it to kites or balloons. Then the necessary dimensions of the "counter-capacity" are determined either by calculation or experiment. In the latter event a symmetry wire, exactly equivalent to the aerial wire, is stretched out as a counterpoise, the effect of flow being next determined in the aerial wire by means of a Riess thermometer, mounted in the vicinity of the belly of the current. The symmetry wire is afterwards replaced by successively increased metal surfaces, until approximately the same current effect is produced.

The next step is the determination of the specific period of the secondary system, and of the primary condenser circuit, separately, by the aid of the ondameter and the most accurate mutual adjustment possible.

A decision has now to be made in favour of either loose or relatively close coupling, according as it is possible or necessary to obtain sharp tuning (at the expense of intensity, *i.e.* range) or an extensive range, *i.e.* intensity (at the cost of tuning properties at the receiver).

In order to fully utilise the specific advantages of the different couplings the construction of the aerial wire system must be modified in accordance with the class of coupling employed. For loose coupling, types allowing of gradual radiation must be chosen, *i.e.* aerial conductors with maximum conductivity and high self-induction, which is partly distributed uniformly in the aerial conductor and partly concentrated in coils in the vicinity of the current maximum.

For close coupling, on the other hand, highly radiating aerial wires of low self-induction are to be used, that is to say, they should be set up in the shape of a cone or harp, with a number of separate wires mounted in parallel.

The aerial wire of the sender is also used in connection with the receiver, by the aid of a switch. The optimum of the degree of coupling, and also the adjustment of the receiver to the effective wave length, can be determined with great accuracy by calculation or experiment. This point will be discussed later.

For the sake of completeness it should be mentioned here that, according to Drude, very close coupling ($\tau^2 > 0{\cdot}6$) in the sender—which however, is generally impossible—is attended with a more strongly damped upper free oscillation and a more slightly damped lower one. If this be employed with a loose-coupled receiver, the frequency of the latter must be smaller, in the proportion $1 : \sqrt{2}$, than that of the two syntonised sender oscillation systems taken separately. With this very close coupling the damping of the lower free oscillation possesses only half the value it has with ordinary cases of close coupling, *i.e.* is only equal to half the arithmetical mean of the dampings of the two individual systems of the sender.

According to Wien, the same reduction in damping can also be attained at the boundary of the aforesaid two great classes, *i.e.* when the coupling is exactly equal to the difference in the damping of the component systems. In such event, *ceteris paribus*, the period of oscillation of the component system must be adjusted to that of the lower free oscillation, by doubling it. To attain this object, the self-induction of the secondary system must be doubled, thereby reducing the damping to one-half. The further necessary doubling of the capacity in the primary circuit results also in the doubling of the energy of oscillation. Since there is only a single effective oscillation present, there are consequently no disturbing undulations, as happens with close coupling; and this circumstance is naturally an additional advantage. Such an arrangement, however, merely represents a compromise ; and the only possible way to secure *accurate syntony* is, as we have already seen, to employ *loose coupling in both sender and receiver.*

The arrangement of a complete installation will be more clearly seen by a reference to the sketch, fig. 33. This shows the installations at the Baltic stations, and is more easily examined than a sketch of up-to-date installations, which are in a state of greater technical perfection, giving rise to more complicated details.

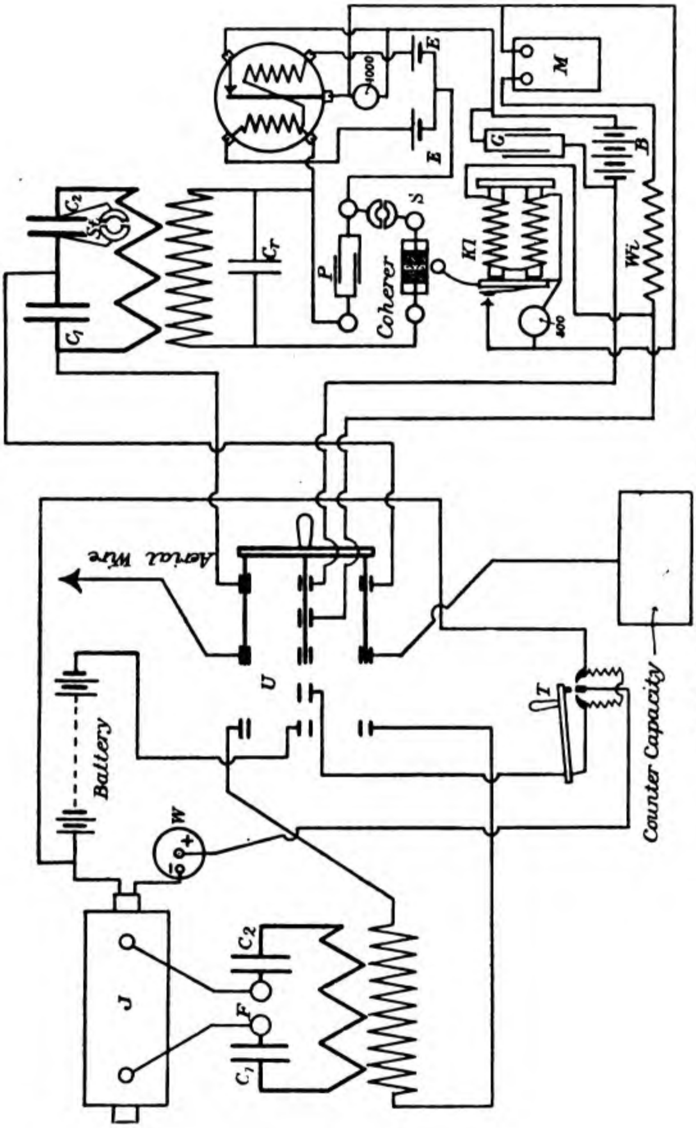

FIG. 33.—Mounting a Complete Station.

On the left of the figure is the sender, and on the right the receiver. In the middle, between them, is the switch, U, by means of which the attachments (aerial wire, counter-capacity) can be connected with

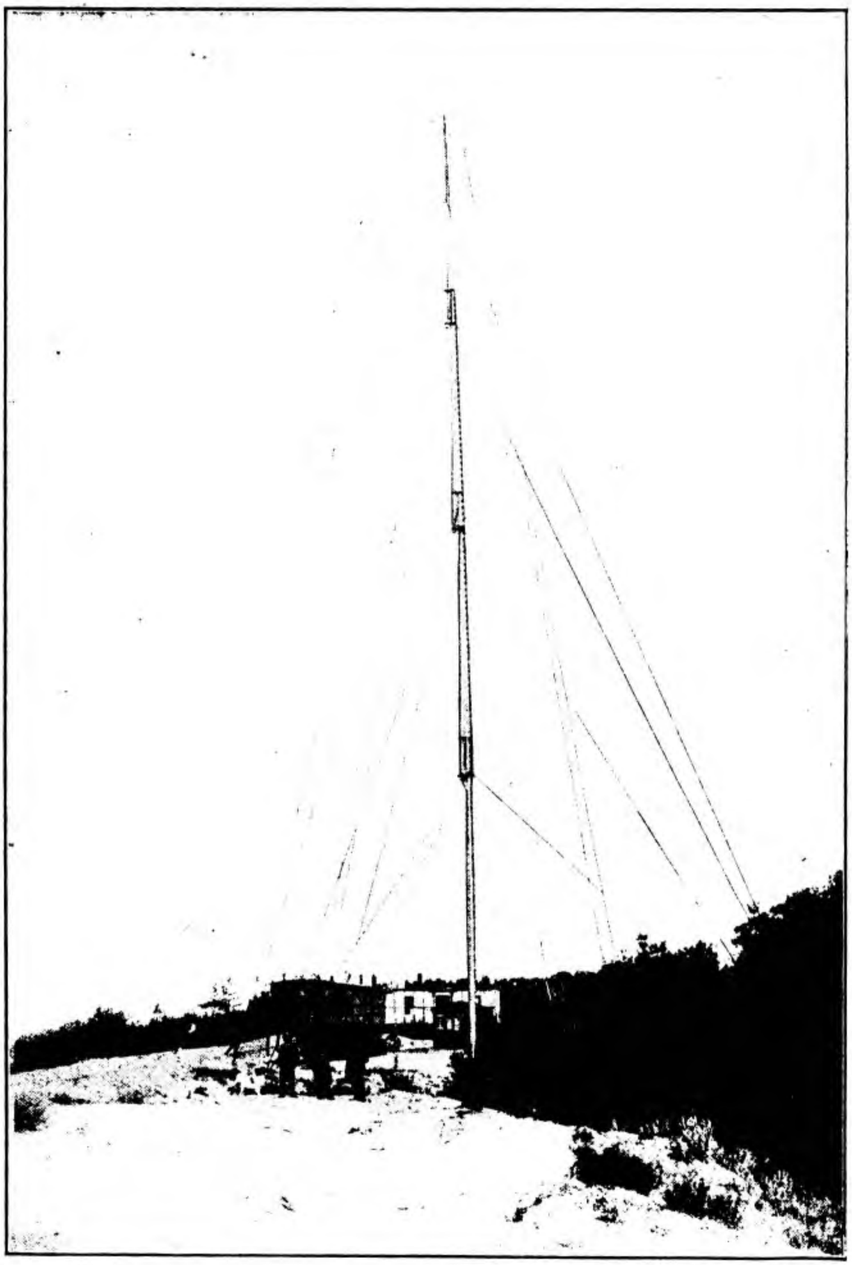

FIG. 34.—A Baltic Station.

the sender and receiver in turn. The lever of this switch consists of three horizontal metal bars, fastened together by the insulated vertical traverse, fitted with a handle.

When the switch is turned to the left, the aerial wire above and the counter-capacity below are connected with the secondary coil of the sender. At the same time the middle bar closes the circuit from the battery or electric power station. This circuit contains the primary coil of the inductor J, the interruptor W (Wehnelt, turbine or hammer commutator), and the signalling Morse key T, in parallel arrangement is the so-called magnetic blow-out, *i.e.* a transverse magnetic field for the purpose of dispersing the sparks at the breaking contact.

With the secondary terminals of the inductor is connected the primary oscillation circuit with spark-gap.

To receive messages, the switch is turned over to the right, *i.e.* to the position shown in the drawing. In this position the outer bars connect the attachments with the primary oscillation circuit of the receiver, whilst the middle bar closes the circuit of the local battery, B, which also includes the Morse register M and tapper KI.

The primary receiver circuit contains the two relatively large adjustable air condensers C_1C_2, of which the former may be short-circuited by a plug contact whenever necessary, so as to adjust at once the primary circuit to a different wave length. This possibility of easy adjustment is of special use, when several waves are simultaneously effective. In the secondary circuit is a small adjustable air condenser, Cr. On the other hand, the terminals of the secondary coil are connected to the coherer by means of a small mica condenser P, which does not obstruct the oscillations, but must be attached to prevent short-circuiting of the relay current of the two parallel coupled dry cells E. To protect the relay, its circuit is opened by means of the plug contact S, when signals are sent off. To prevent any unfavourable influences on the coherer there were provided a small condenser, G, parallel to the battery, a 1000-ohms resistance coil parallel to the relay contact, and one of 500 ohms parallel to the tapper contact; otherwise at each of these latter points, sparks, exciting the coherer, would be formed in consequence of the breaking current. The resistance coil Wi was for the purpose of dividing the current for the Morse register and tapper according to requirements, and thereby regulate the force of the blow struck by the latter.

A photographic view of the outside of one of the Baltic stations is shown in fig. 34.

CHAPTER X.

MODERN APPARATUS AND METHODS OF MOUNTING.

An important factor in the sender is the provision of a suitable source of electricity for charging the condenser circuit.

For short ranges, ordinary inductors with a vibrating interruptor would be sufficient, a type of which is illustrated in fig. 35, supplying primary energy up to 350 watts, at a maximum of 110 volts. These are provided with a condenser of suitable dimensions for preventing interruption sparks.

Where greater power is required, the so-called resonance inductors (fig. 36) are now exclusively used, this type being the outcome of our experience with the spark-gap, because of its irregularities. The spark-gap enables the condenser circuit to be charged up to a certain potential, *i.e.* it stores up the energy of the circuit until a certain discharge potential is reached. At this point we have a sudden fall in potential, whereby the oscillations are set up, and when they have ceased the spark-gap must at once become again non-conducting, in order that the cycle may recommence. The pauses between the single discharge complexes are enormously great in comparison with the duration of the latter themselves ; but this is necessarily the case, since otherwise there would be the possibility of the spark-gap not returning to its non-conducting state. In such event there would be a permanent equalisation of the charges through the spark-gap to a lower potential, a luminous arc would be formed, and the spark become "inactive." With the resonance inductor this phenomenon is impossible. In it the generated electricity flows to and fro in slow oscillations until the maximum amplitude corresponding to the discharge potential is reached, and the spark-gap is suddenly traversed.

The self-induction of the secondary winding of the inductor (which in this case is made of the thickest wire possible, in order to diminish the ohmic resistance), and the capacity of the Leyden jars with which it is joined. cause a decided slow oscillation of definite periodicity, about 50 per second, as now generally employed in power stations. When such an inductor, secondarily laden with a capacity, is connected with a normal alternating current of 50 periods, the primary alternating current and the secondary induced current are in resonance. An important point to be kept in mind in this connection is the degree of coupling between the inductor and the source of current. With "close" coupling there would be just as many discharge complexes as primary alternations, *i.e.* 100 sparks for 50 periods. Consequently, this would not correspond with the function already described, which is to be performed by the resonance inductors. This is only feasible with close coupling, both between the two alternating currents of the inductor and also between the latter and the source of current, this being an alternating current machine containing a certain amount of self-induction in its armature. A check coil is mounted between the machine and the primary winding of the inductor; and the optimum degree of coupling is obtained by the suitable adjustment of these two self-inductions to the primaries of the inductor.

Now we obtain the aforesaid phenomenon, namely, that the energy of several successive alternations in the work of magnetising the inductor is accumulated to a maximum corresponding to the spark-gap, whereupon a discharging spark passes. Hence there are fewer sparks than primary alternations in the inductor. The same primary energy is now distributed among fewer discharges, but these are of a more powerful character.

To obtain the desired speed in telegraphing, it is of course impossible to go below a certain limit, about 30 sparks per second.

With a primary energy of from 350 watts to 1·5 kilowatts, use may be made of either the well-known mercury turbine interruptor (a photograph of which is shown in fig. 37, representing a type fitted with Cardanic suspension for naval stations); or else current transformers are used. The latter are either direct transformers—single machines (fig. 38), or mounted in sets of two machines—a continuous current motor and an alternating current generator (fig. 39).

The transformer is mounted in such a manner that automatic blocking occurs between the transformer and the receiving instru-

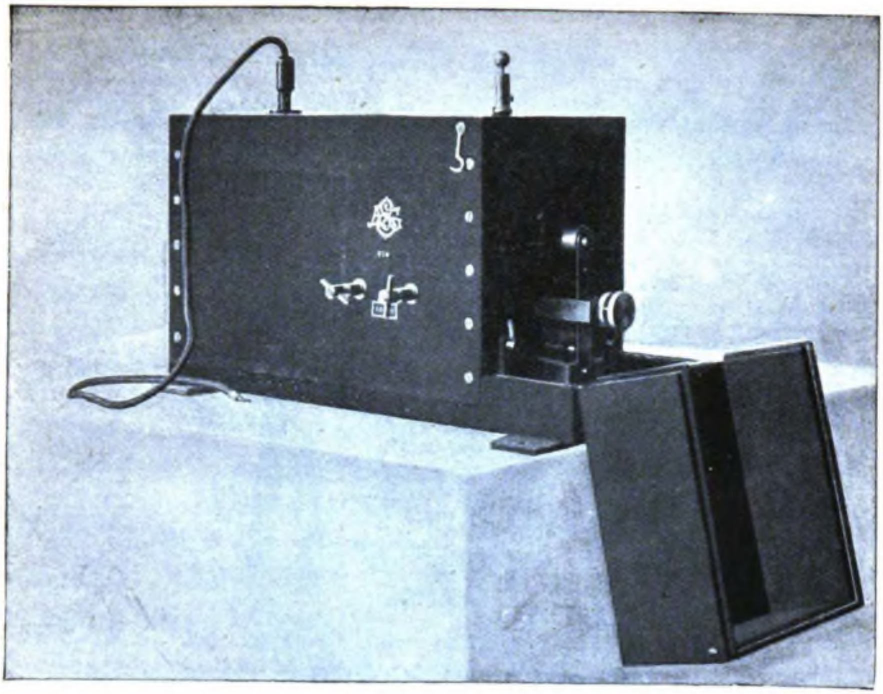

FIG. 35.—Inductor with Hammer Interruptor.

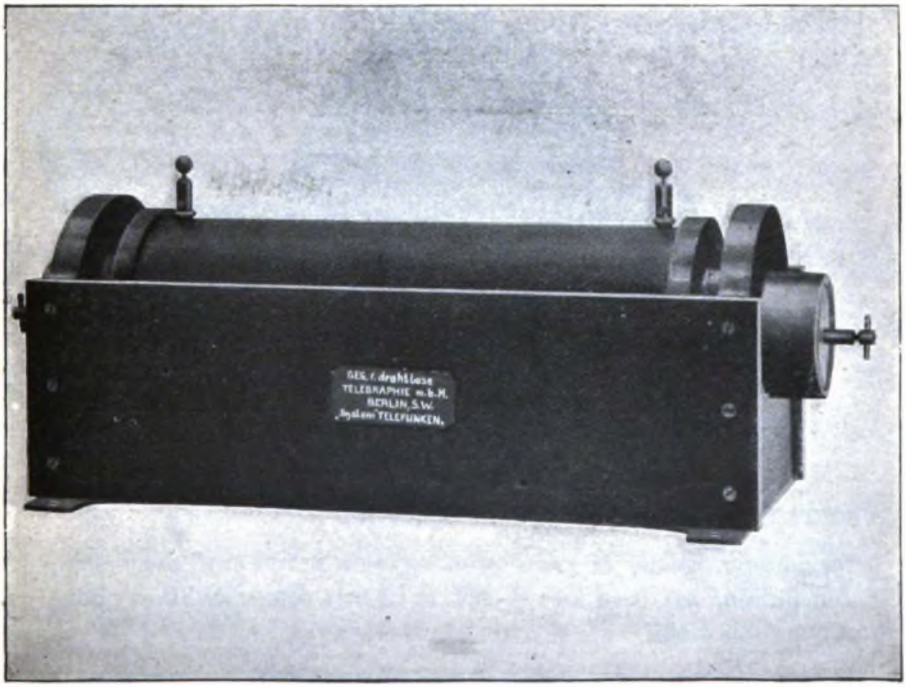

FIG. 36.—Resonance Inductor.

ment, so that when the receiver is set for receiving signals, the transformer is switched out. Conversely, when the apparatus is set for sending signals, the motor does not begin to run until the starting commutator has been turned back to its first degree and then gradually switched out.

FIG. 37.—Mercurial Turbine Interruptor, with Cardanic Suspension, for Naval Stations.

FIG. 38.—Current Transformer.

The Morse keys are either equipped with electromagnetic spark extinguishers, as in fig. 40, or else are constructed as automatic minimum current cut-outs (fig. 41).

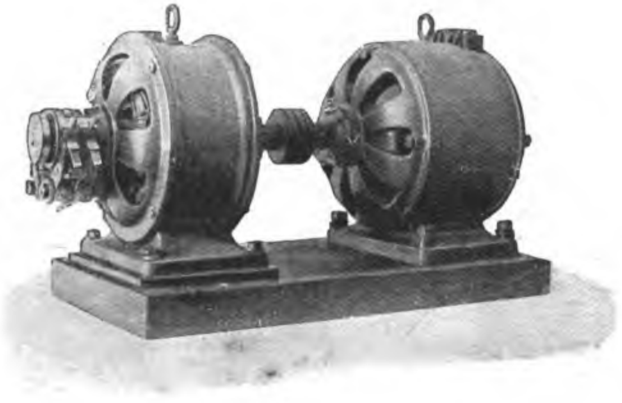

Fig. 39.—Current Transformer.

In large stations worked with current intensities of more than 40 amperes, several platinum contacts are connected in parallel.

The only spark-gaps now employed by the "Telefunken" Wireless Telegraphy Co. are of the "multiplex" type, with potential dividers (see p. 44). Fig. 42 illustrates one of these dischargers, as employed for portable stations in the German military airship corps.

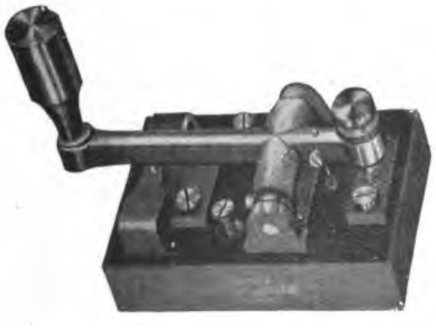

Fig. 40.—Morse Key, with Magnetic Blow-out.

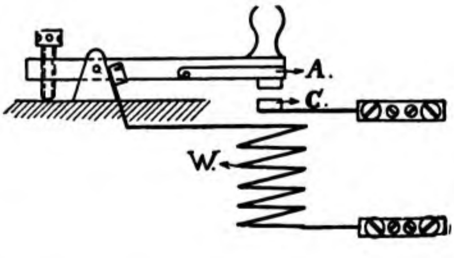

Fig. 41.—Morse Key, with Automatic Minimum Current Cut-out.

In fixed stations, the dischargers (fig. 43) are covered with felt, for sound-deadening purposes; but ventilation takes place at each discharge.

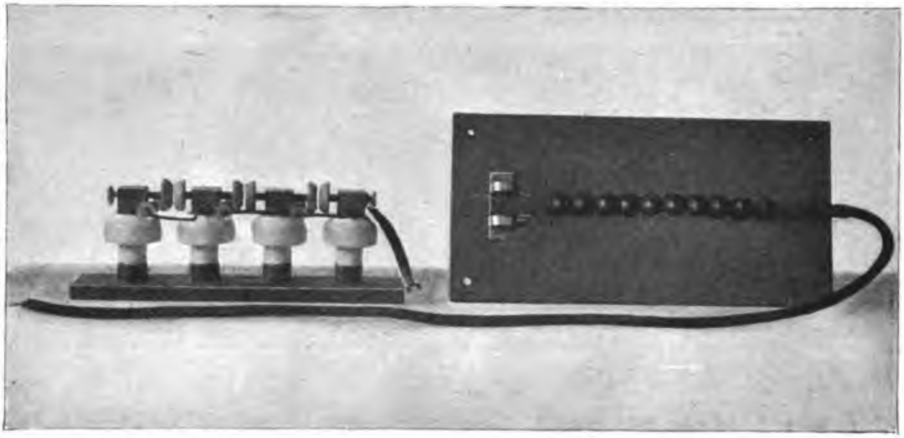

Fig. 42.—Discharger (Multiplex Spark-gap).

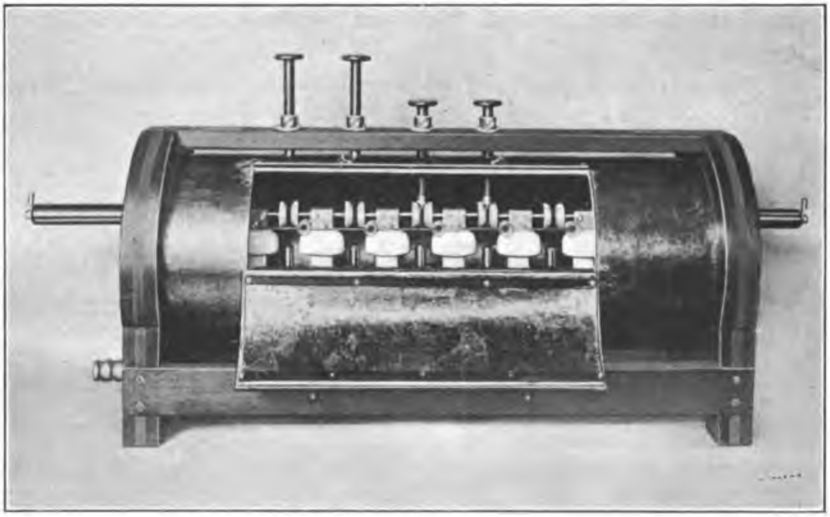

Fig. 43.—Multiplex Discharger for Fixed Stations.

The *excitation circuits* for coupled senders consist of (*a*) one "multiplex" discharger—usually with three spark-gaps; (*β*) a Leyden jar battery, and (γ) a self-induction coil generally variable. Fig. 44 shows a normal form of construction for use on shipboard. In this instrument the wave can be varied from 120 metres up to 1000 metres in length. Fig. 45 illustrates an excitation circuit for the portable stations mentioned above; and in this apparatus two different waves may be excited, by changing the plugs at P_1, P_2. The mounting is "direct," as represented in the diagram, fig. 46.

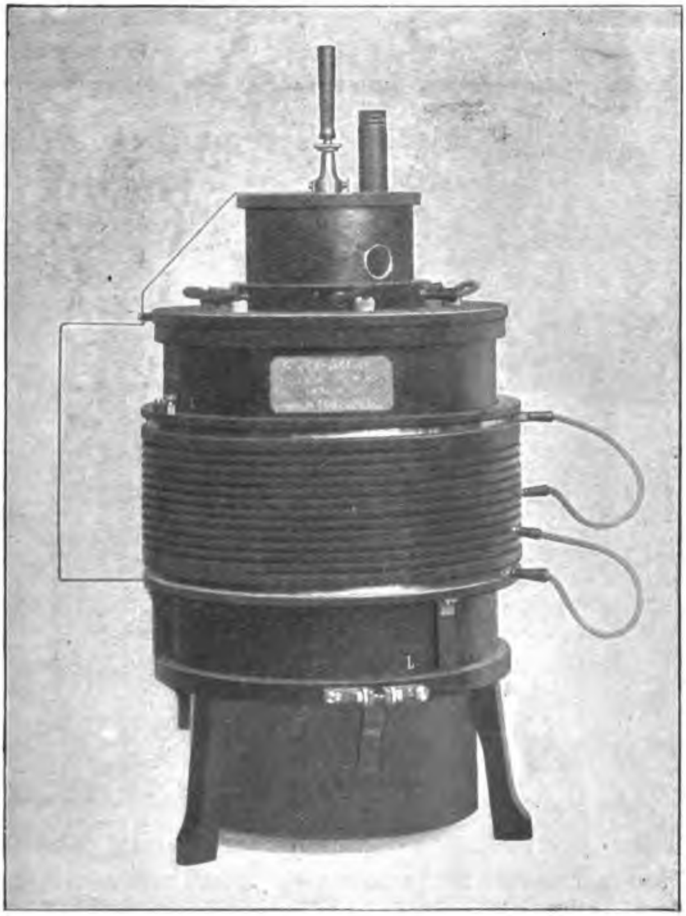

FIG. 44.—Excitation Circuit in Coupled Senders (type for use on board ship).

For various practical reasons, no provision is made in these portable stations—in which single aerial conductors, 200 metres in length, are suspended from balloons or kites—for constantly varying the waves, but only for producing two definite waves, one of which corresponds to the normal oscillation, the other to the first upper octave.

The employment of an "electrical counterpoise" (instead of earthing), the theoretical importance of which has been already explained, and which consists of wire gauze, is specially advantageous in this case. It obviates the difficulties encountered in these movable stations when seeking for "suitable earth," and also prevents, within the limits of possibility, the atmospheric disturbances so detrimental to the receiver, and otherwise rendered inevitable by the great height of the aerial wire. The excitation circuit consists of the constant capacity C, to which the high potential is supplied, the "multiplex" spark-gap F, and an induction coil L. Only part of this latter is placed in the circuit for exciting the short wave, by inserting a plug at P_1, whilst for exciting the long wave all the windings are placed in the circuit by plugging at P_2. On the one hand, the excitation

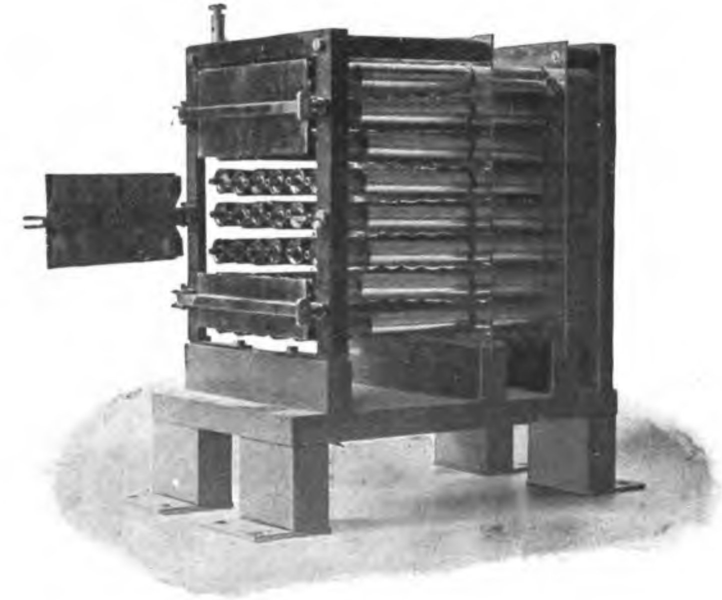

FIG. 45.—Excitation Circuit (for portable stations).

circuit is connected to the aerial wire, and on the other to the coils S_1S_2, the self-induction of which, in conjunction with the capacity of the wire gauze, effects the counterpoise of the aerial wire. S_1 is employed in the case of the normal vibration, and S_2 with its octave. When exciting the long wave, the "coupling" to the excitation circuit amounts to 15 per cent., but to only 10 per cent. when the short wave is being excited. The dimensions of the coils S_1 and S_2 correspond to those of the wire gauze and the waves emitted.

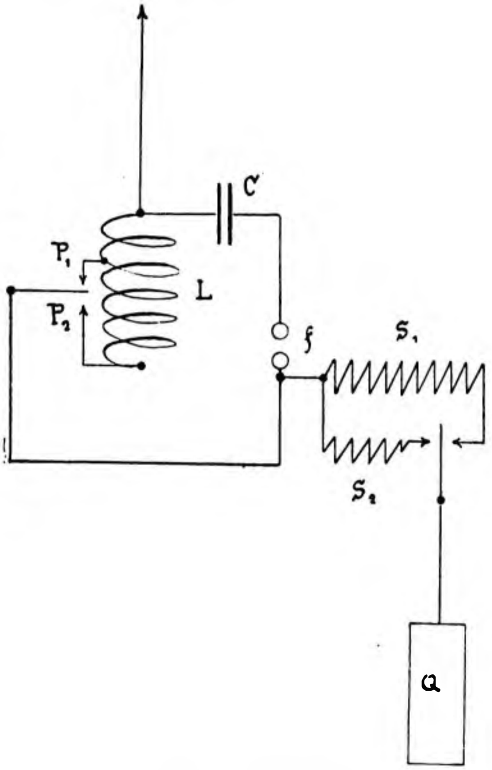

FIG. 46.—Method of Mounting the Sender in Portable Stations.

Of the next three photographs, fig. 47 shows the construction of a Leyden jar system, with (fig. 48) the appurtenant induction circuit and (fig. 49) a specially constructed "annular multiplex spark-gap," with annular electrodes. These apparatus are employed by the Telefunken Company in its 1000-kilometre stations.

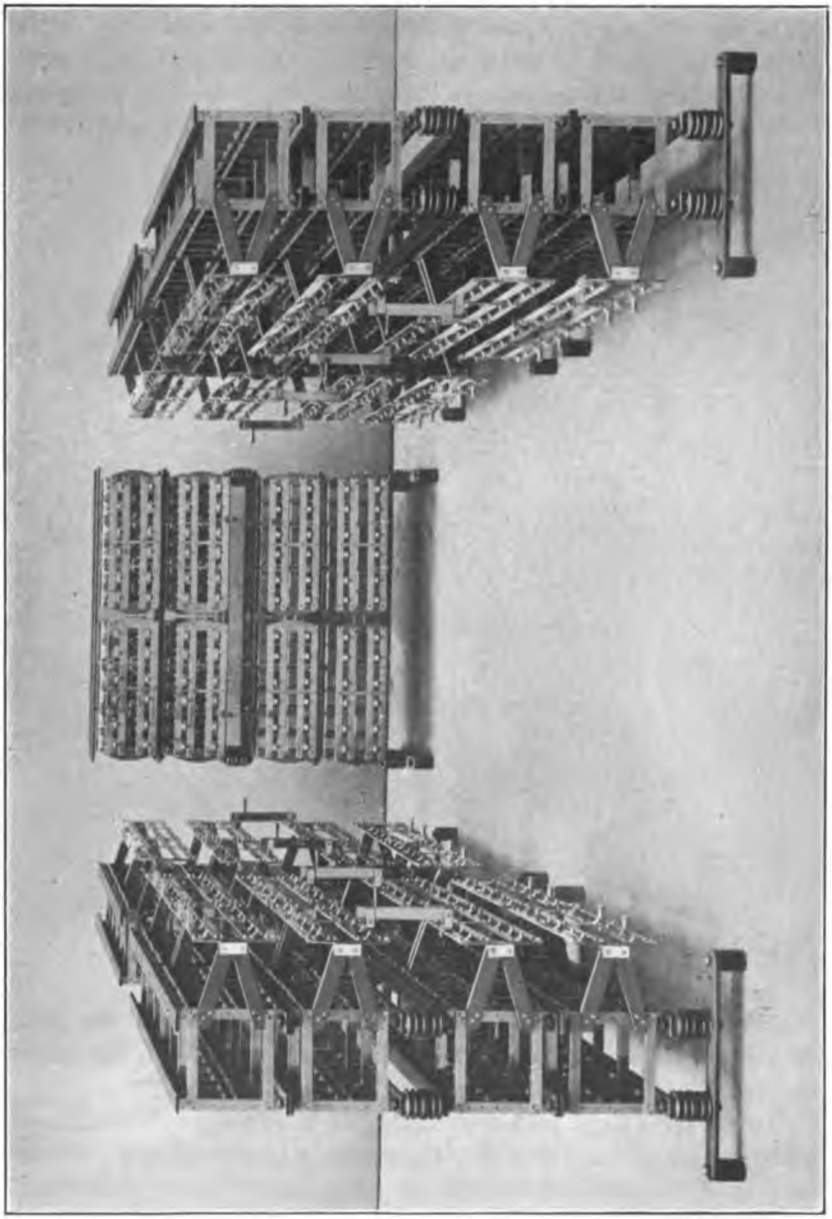

FIG. 47.—Leyden Jar System.

Finally, we may mention the newest and most interesting type (fig. 50) of current generator, as used in the lightly constructed portable stations of the Telefunken Company, with a range of 25 kilometres on land. A small continuous-current dynamo, with a capacity of about 100 watts, is mounted on a bicycle frame. Motion is transmitted from the fly-wheel to the dynamo by a cord and aluminium pulley of suitable design. The gearing is of such proportions that with normal pedalling a spark 4 mm. long is obtained in the inductor.

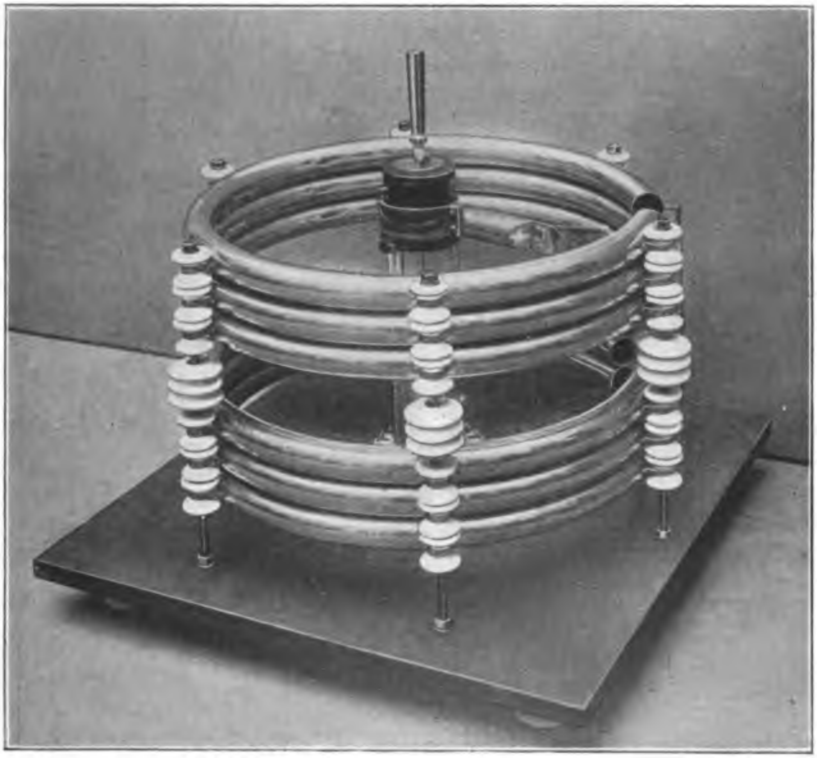

FIG. 48.—Primary Induction Circuit.

In these light portable stations, the mast for carrying the aerial conductor is made of telescopic steel tube. The complete station, with sender and cycle frame dynamo, weighs only about 4 cwts., and can be easily carried by two to three horses or eleven men.

As already mentioned, one and the same aerial wire or wire system is generally employed to serve both sender and receiver. When signals are being sent, the receiving apparatus is separated from the aerial conductor by a main switch, while conversely the sender is disconnected when the instrument is set for receiving. In modern installations these operations are performed with a single handle; and to enable these to be done, a "spark-gap" switch is arranged in the aerial conductor. In "sending," sparks traverse this gap and connect the aerial conductor with the sender; but in "receiving," no sparks pass, and the sender is automatically disconnected from the aerial conductor.

Fig. 49.—"Annular Multiplex Spark-gap."

COHERER AND OTHER DETECTORS FOR ELECTRIC WAVES.

In connection with the receiver, we will now consider its main component, the coherer, taking the so-called steel coherer (fig. 51) first.

FIG. 50.—Current Generator for Light Portable Stations.

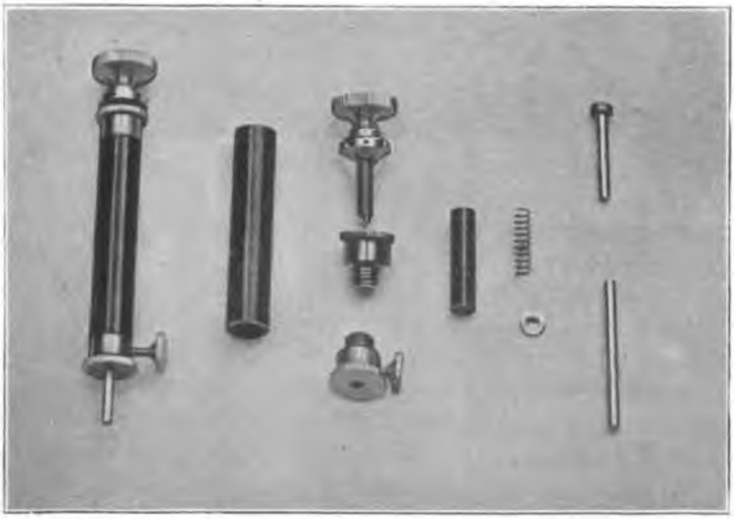

FIG. 51.—Coherer.

This consists of two steel electrodes, adjustably mounted by means of a screw and held in a tube of hard rubber. In the very small space between the highly polished inner surfaces of the electrodes are placed about thirty to forty steel granules. The smaller the number of granules, the greater the sensitiveness of the coherer; so that by increasing or diminishing their number, and by adjusting the electrodes, any desired degree of sensitiveness can be obtained. A further refinement in this connection consists in mounting the one electrode of the coherer between the poles of a small open annular magnet, which can be adjusted by gearing, so that the coherer may be magnetised to either polarity or entirely demagnetised, thereby modifying the coherence of the granules and the sensitiveness of the coherer.

FIG. 52.—Coherer.

In another form of coherer (fig. 52), there are two silver electrodes in a glass vacuum tube, the terminal surfaces being ground so as to leave a small wedge-shaped intermediate space for the reception of a mixture of silver and nickel granules. The instrument can be turned so as to bring the granules into a larger or smaller space, thus regulating the sensitiveness.

A large number of appliances have been devised for replacing the coherer, which occasionally exhibits very tricky antics; and a few of the most recent of these "detectors" will now be briefly described.

The first claim to our notice is undoubtedly possessed by the Schloemilch detector, the external appearance of which is shown in fig. 53.

The inventor of this detector connects an ordinary polarisation cell, with platinum electrodes immersed in dilute acid, to a source of current having an E.M.F. slightly exceeding that of the cell. Consequently a current passes, and the electrolyte is decomposed with slight liberation of gas. If now the cell is exposed to electric waves, an immediate strengthening of the current is evidenced by a more violent disengagement of gas. Schloemilch found that the action is greatly strengthened when the surface of the positive electrode is extremely small, whilst that of the negative electrode may be of any suitable size. At present the positive electrodes have a diameter of only 0·001 mm. and a length of 0·01 mm. On reversing the electrodes the aforesaid phenomenon disappears almost completely, a proof that the gas liberated at the smaller electrode plays an important part.

FIG. 53.—Schloemilch Detector.

The strength of the current, and consequently the liberation of gas on which the sensitiveness of the cell depends, can be regulated by a resistance. The more intense the electric irradiation, the more powerful the reaction of the cell. The nature of the phenomenon has not yet been accurately determined, but it seems to be a species of depolarisation. The cell can now be connected in the usual manner with a relay, in order to actuate the working circuit with a Morse register. No tapper is used, the cell always automatically resuming its normal condition after the action is over.

Moreover, the cell can also be connected with a telephone, which renders audible the fluctuations produced in the current by the effective electric waves. In this latter connection the Schloemilch detector is of inestimable service, the more so in that it is insensitive to vibration. The illustration (fig. 54) shows the simplest method of mounting, the cell lying direct in the aerial wire. The connecting in parallel of a very large condenser C is to minimise the damping influence of the cell, notwithstanding the high ohmic resistance, since this condenser affords an undamped bye-pass for the oscillations. At the same time, of the total energy oscillating in the receiving wire, only a small amount per oscillation, corresponding to the low potential generated at the high capacity condenser, is absorbed by the cell. Far more accurate syntony is, however, obtained by inductive mounting. This can be arranged by simply turning a switch lever, so that the cell is included in an inductively excited, closed

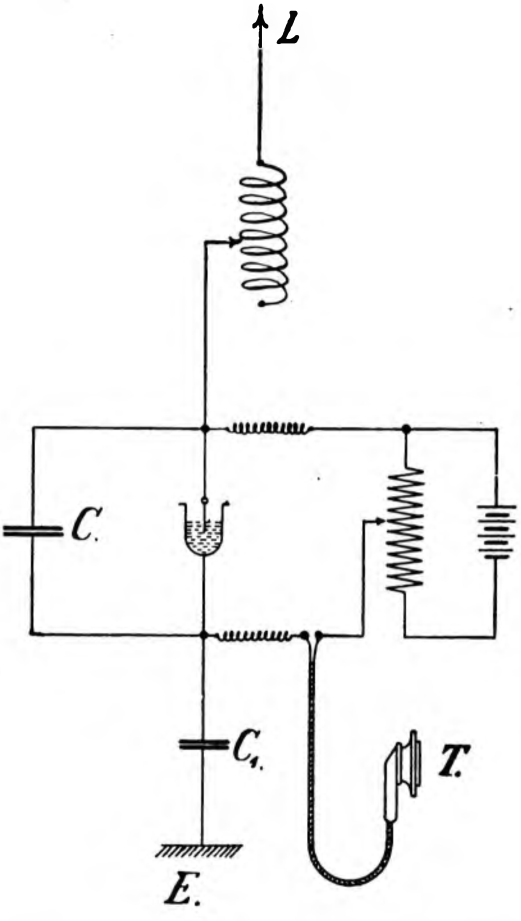

Fig. 54.—Method of Mounting the Schloemilch Detector.

secondary oscillation system. A condenser mounted in parallel with the cell diminishes its damping influence on the secondary system.

Figs. 55 and 56 show the latest types of the apparatus, which is actually the simplest and most reliable receiver for wireless telegraphy. For this reason a more detailed description of the mounting and working of this electrolytic detector should be of interest.

Fig. 57 shows the course of the high-frequency oscillations.

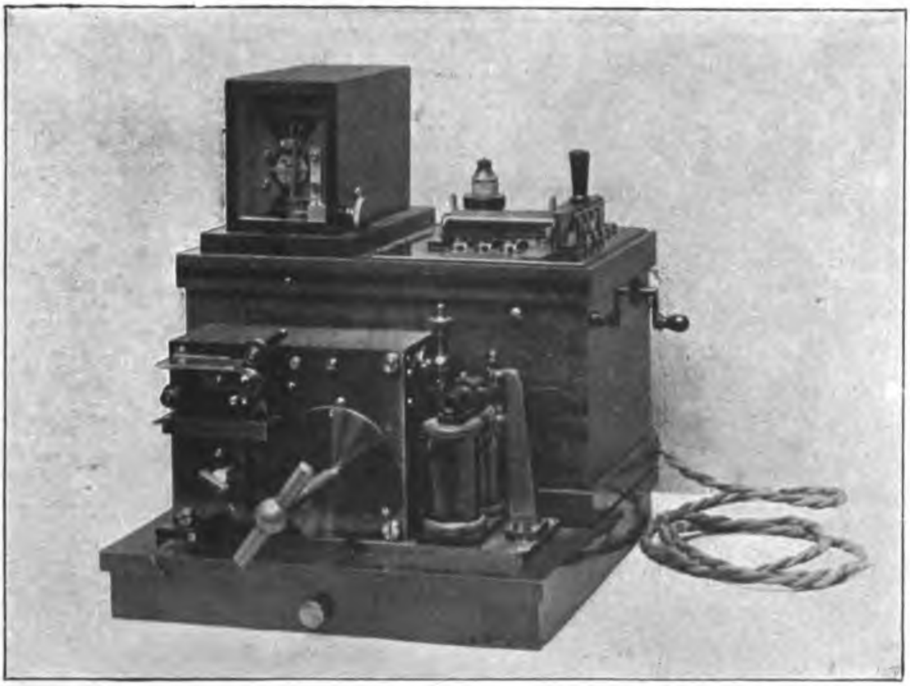

FIG. 55.—Receiver with Schloemilch Detector and Morse Register.

After connection of the aerial wire and the laying in of the main switch through the spring contact 1, 2, the high-frequency currents reach a condenser (3, 4) of a larger capacity, which serves for barring the battery circuit of many receiving apparatus switched parallel and interchangeable, as also for preventing short-circuiting of the cells by the discharging coil (20, 19), which will be explained later on. The oscillations then pass the syntonising coil 5, 6, and the variable condenser 7, 8. The first serves to lengthen the aerial wire when necessary, whilst, on the other hand, the variable condenser serves to shorten the specific oscillation of the aerial wire. The terminals 7, 8 are usually connected by a short circuit piece. From point 9 the leads for the high-frequency oscillations branch out. They pass, on the one hand, through the switch 10, 11, across the detector 12, 13, through the switch 14, 15, and on through the earth-switch 16, 17, to the earth-terminal 18, and from there to the earth. On the other hand, a branch leads over to the plug-contact 21 towards the variable condenser 22 to point 23, and from thence through the switch-terminal 15 back to the other pole of the detector. With the plug-contact 9, 21, the variable parallel condenser 22, 23, which serves for syntonising, can be completely switched off in case of need.

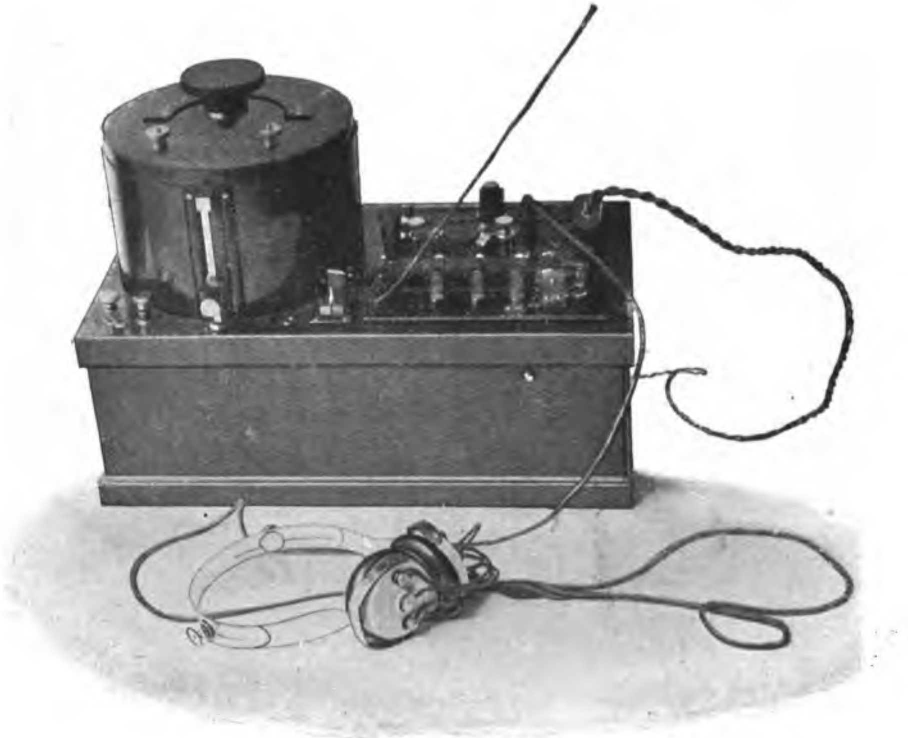

FIG. 56.—Receiver with Schloemilch Detector and Telephone.

To let atmospheric charges flow direct to the earth, a choking-coil 20, 19, is applied at the point where the conductor is joined up with the apparatus, and this coil is connected with the earth by the switch 16, 17, and the terminal 18.

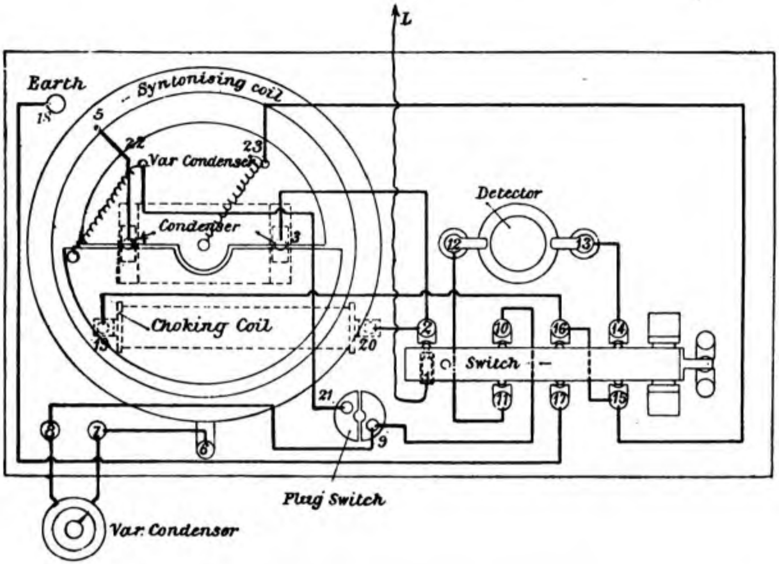

FIG. 57A.—Course of the High-frequency Oscillations.

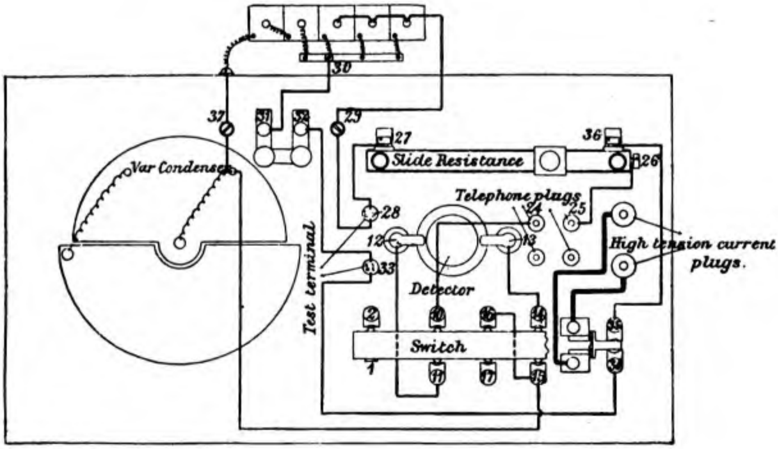

FIG. 57B.—Showing the Battery Circuit.

The battery consists of three dry cells, connected in parallel, which are permanently closed by the slide-resistance 27, 36, and two cells connected in series, which are placed in a row with this combination. The tension of the first set can be varied, through the resistance within the limits of 0 to 1·5 volt, and one of these values can be added to those of the series of cells at will.

Starting from the parallel cells 29, 30, the current passes through the switch 31, 32, to the negative test-terminal 33. The switch 31, 32, is intended for interrupting the permanent circuit when the apparatus is not being used in order to prevent unnecessary exhaustion of the cells (for instance, in transport, during which time the switch lever must be closed by way of precaution). After the current has passed the switch 34, 35, it arrives through the slide-resistance 36, 27, at the positive test-terminal 28, and then passes back to the end terminal 29.

The real principal circuit, in which the telephone and the detector are situated, must next be considered.

Starting from the latter, the current passes from its terminal 12, through the brown leads to the switch 11, 10, then through the black wire to the telephone 24, 25. The connection contacts of the latter are so arranged that either one or two telephones may be used, the connection in the latter case being either parallel or in series.

The contact 25 is further connected with the regulating-slide 26, which forms a part of the regulating resistance, and the current reaches the positive pole of the cells connected in parallel through the point 27, the test-terminal 28, and the terminal 29. It then passes through both cells in series to the point 37, through 23, the switch 15, 14, and so back to the negative terminal of the detector 13.

The working of the apparatus is simple in the extreme. The accessible terminal 31, 32, of the battery current is first closed after removing the cover, and the detector is then fixed in such a way that the pole signs marked on the latter coincide with those of the contact pieces on the apparatus.

For the telephone, four symmetrically arranged plug-switches are provided, which are laid between the detector and the strong current plug-connection, of which the two placed nearest the observer are directly connected with the leads, whilst the other two can be switched to these either parallel or in series. The parallel and series mounting can be performed in a simple way by means of the spring-contact, which is quite visible on the underside of the cover. The object of the spring-contact is to enable the telephones to be connected up in such a way (with regard to their several ohmic resistances, as also to the current fluctuations which become weaker in long-range telegraphy) that the maximum strength of sound is obtained from them.

To enable the detector to be adjusted to its maximum sensitiveness, the telephone is held to the ear and the position of the regulating slide is altered, till the faint rushing noise, produced by the over-displacement of the regulating slide, disappears abruptly. The correct adjustment of the slide with new apparatus will be found close to the limit of the lowest voltage range, as in calculating the dimensions of the apparatus allowance is made for variations in the voltage of the cells, the occurrence of which will necessitate adjusting the slide.

After the adjustment has been effected the working of the detector is tested by touching the metallic casing of a coherer-tester with a detector-terminal and by listening in the telephone for the emission of sounds.

Syntonising in receiving.—This is quickly done, as no further material (coils and so forth) is necessary, and the whole of the syntonising material (with the exception, perhaps, of an earth condenser) is attached to the apparatus, simply by joining the plug-connection of the hard-rubber-lever to the aerial wire and the earth-terminal E with the earth.

To enable the apparatus, which is in connection with the aerial conductor, to be attuned to the wave-length of the counter station, a previously determined sign of the Morse alphabet is repeatedly sent from the latter with mean intensity, and the slide of the syntonising coil is shifted till a maximum strength of sound in the telephone has been obtained. With simple aerial wires of mean capacity it is advisable to adjust the parallel condenser beforehand to a capacity which corresponds to about 40° on the scale. If the self-induction of the syntonising-coil and the parallel condenser be now more or less modified, the most advantageous combination will be found in a short time. When the apparatus has been tuned in this way, the adjustment of the voltage-regulating slide is again altered slightly, as the detector voltage can only be adjusted accurately when syntonisation is being effected.

Another very useful detector, though only applicable in conjunction with a telephone, is that newly introduced by Marconi. In this instrument the known phenomenon of magnetic hysteresis is utilised, the arrangement being that shown in fig. 58.

An endless cord S of thin soft iron wires is led in front of the poles of a magnet M, and there traverses a coil of insulated copper wire, connected on the one hand with the aerial wire L and on the other with the earth (E). On this coil is wound an insulated secondary coil, in which the telephone, T, is included. Normally the iron is prevented by hysteresis from immediately following the rapidly alternating magnetisation; but when the primary coil is traversed by electrical waves the residual magnetism is suddenly dispersed for the moment. Hereupon the current impulse induced in the secondary coil excites the telephone and renders the wireless Morse signal audible. This complex device, provided as it is with moving parts, gives only the same effect as the simple Schloemilch cell.

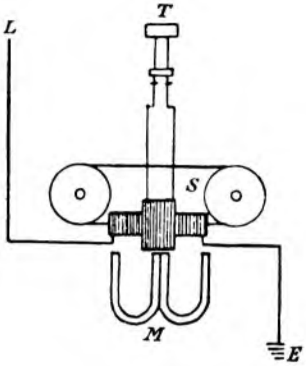

FIG. 58.—Marconi Detector.

An extremely sensitive wave recorder is Rutherford's magnetic indicator. Part of the wire composing the resonator is coiled round a magnetised steel needle. The electric oscillations influence the magnetisation of the needle and thereby cause the deflection of a second magnetic needle suspended close by, and whose movements can be observed with the aid of a mirror and telescope (as in a galvanometer).

It has been mentioned already that this indicator is preferably used in loose-coupled systems, in which the integral effect is the main point.

An interesting new type of indicator is the Lodge-Muirhead coherer, which is described as follows in the catalogue of the Lodge-Muirhead Wireless and General Telegraphy Syndicate, Limited.

"The illustration (fig. 59*) shows the form of coherer, which requires no tapper, but is kept perpetually sensitive by the rotation of a small steel disc just separated from a column of mercury by a film of mineral oil. The impulse of electric oscillations breaks down the oil film and establishes momentary cohesion between the steel disc and the mercury. No effective contact occurs between the wheel and the mercury, notwithstanding the immersion, because

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* Block kindly lent by *The Electrician.*

of the film of oil; but the slightest difference of potential applied to the two, even less than one volt, is sufficient to break the film down and complete a circuit, which, however, the rotation of the wheel instantaneously breaks again. The spark is so sudden that for its purposes the wheel is for the instant virtually stationary, and yet the decohesion is so rapid that signals can be received in very quick succession.

"The definiteness of the surfaces and of the intervening layer makes the instrument remarkably trustworthy, and the thinness of the insulating film makes it very sensitive. In fact, a single cell of a battery cannot be employed as a detector, because it is of too high a voltage for the film to stand. A fraction of a volt is employed by means of a potentiometer device—usually from 0·3 to 0·5 of a volt—and it is adjusted to suit circumstances.

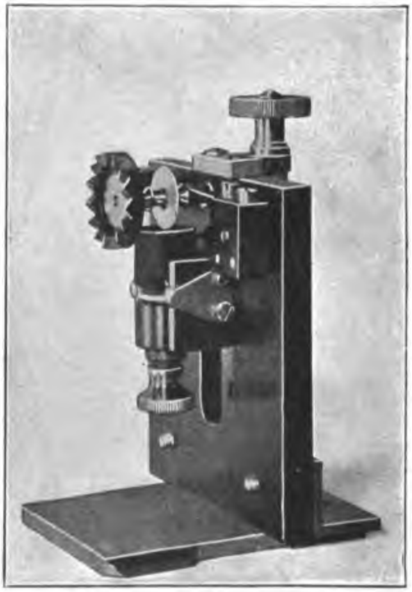

FIG. 59.--Lodge-Muirhead Coherer.

"The battery acts through the coherer direct on a low-resistance recorder, without any relay, and the record on the strip shows every character of the arriving pulses, and exhibits any defect in the signalling. Provided that every joint and contact, except the one intended to be filmed, is thoroughly good, the coherer is so definite that defects may in general be sought for at the sending end. The signals are picked up and recorded precisely as they are emitted, as has been tested by intercalating a siphon recorder in a much diluted tapping circuit at the sending end, so as to get a record with which to make comparison. The traces obtained at the two ends are identical to a surprising degree.

"The mercury level has an adjustment which is easily made. One precaution is to keep the rim of the wheel clear of dust, which is done by a cork or leather pad pressed lightly against it by a spring.

"The instrument is not at all sensitive to tremor, and requires no particular delicacy of adjustment. The wheel has to be positive, the mercury negative.

"A telephone in circuit, through a transformer or otherwise, affords an easy method of discriminating the signals by ear. The speed of the wheel gives another convenient adjustment to suit various circumstances."

In fig. 60 we have a specimen of script kindly furnished by Professor A. Tobler of Zürich.

"If the rapidity of the sparks at the transmitting station is insufficiently great, the signal becomes a broken or wavy line, and not a steady deflection; but if the rapidity be increased this waviness disappears and the recorder needle is simply held over, giving a steady long deflection to represent a dash, and a momentary one to represent a dot."

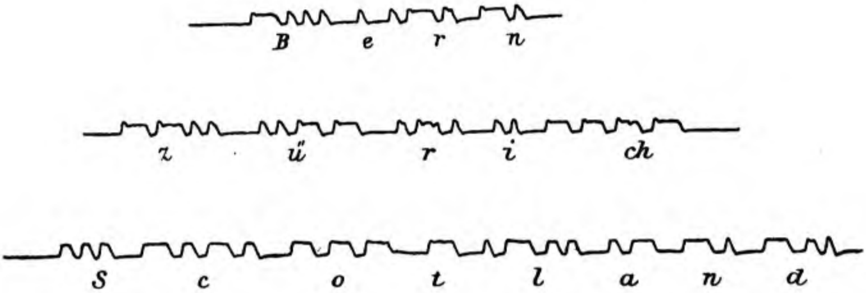

FIG. 60.—Specimen of Script with a Lodge-Muirhead Coherer.

Mention may also be made of the Neugeschwender or Schäfer plate, as the prototype of an "anti-coherer," *i.e.* a wave indicator in which the transitory resistance is increased instead of being diminished as it is in the coherer.

A glass plate is coated with a deposit of silver, which has been scored with a diamond graver, the plate being afterwards varnished.

The resulting gap is, however, imperfect, being bridged over by extremely fine metallic threads. These bridges are probably temporarily destroyed by the heat of minute sparks, the resistance being thereby increased. As soon as the action stops, the metallic vapours are re-condensed and the original value of the resistance is restored.

Finally, we will just refer to the Fessenden detector, in which the heating effect of the electrical waves induces fluctuations of resistance in bolometer wires.

The foregoing description of detectors makes no claim to completeness, and is merely intended to throw light upon the best known principles of detecting electrical waves.

RECEIVING APPARATUS.

A complete receiving apparatus, with steel coherer but without oscillation circuit, is illustrated in fig. 61.

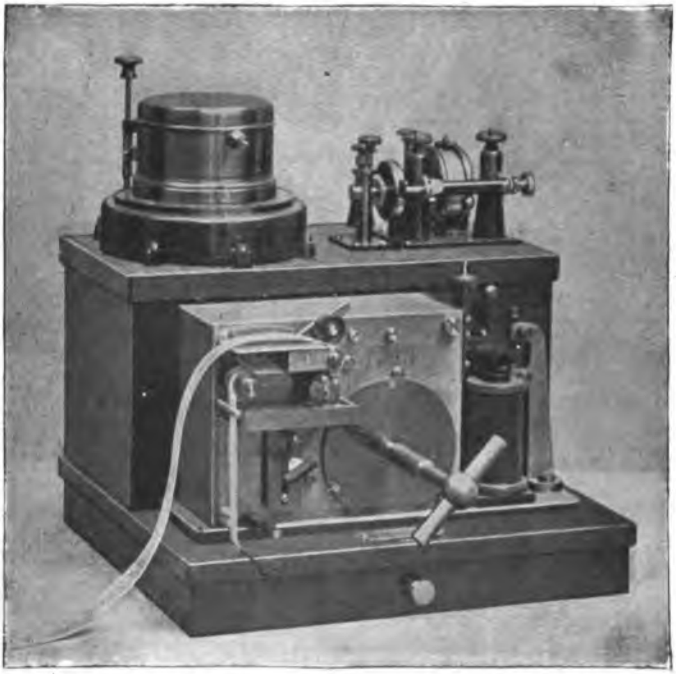

FIG. 61.—Receiving Apparatus.

The relay is mounted on the left side of the hinged cover of a wooden box, the coherer, tapper, and magnetic regulator being mounted on the right side. An ordinary Morse register is visible in front.

The box contains the cells and the supplementary coils and mica condensers aforesaid.

A modern type, with silver-nickel coherer, is shown in fig. 62.

Fig. 63 represents a very light and compact pattern, specially designed for portable stations.

FIG. 62.—Receiving Apparatus.

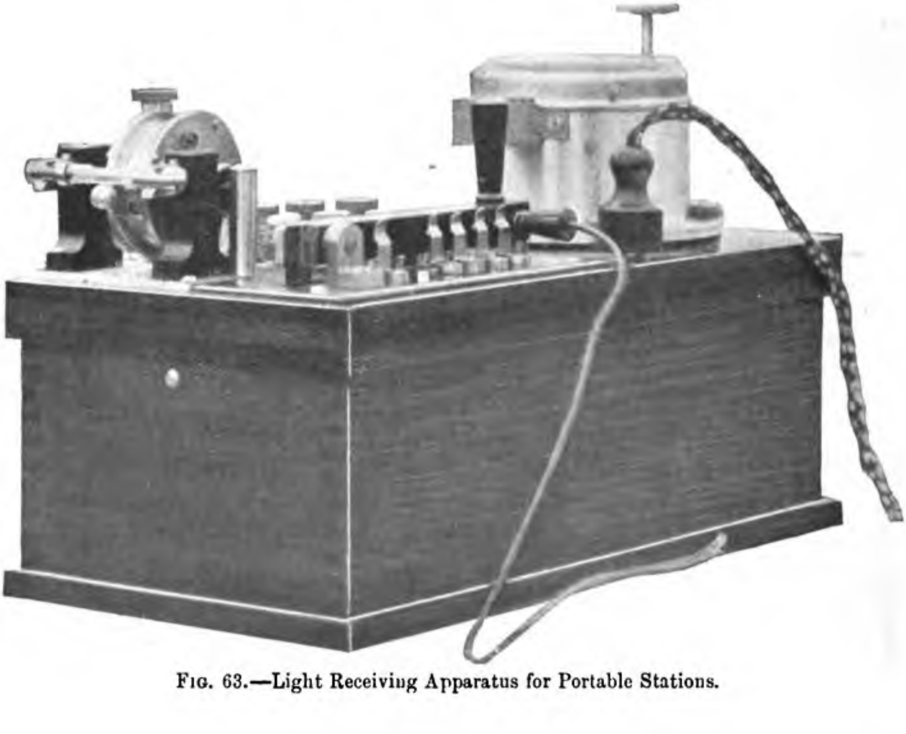

FIG. 63.—Light Receiving Apparatus for Portable Stations.

The polarised relays always used are specially guarded against the mechanical vibrations of the tapper. For ships' use, the whole receiving apparatus—including Morse register—is fitted with easy springs to absorb any vibration from the engines. Such an arrangement is shown in fig. 64.

The tapper is made for a high frequency, and is of the smallest possible dimensions.

A main switch on the receiving apparatus serves to change from receiver to transmitter, cutting out all local circuits at the receiving station, or blocking the primary current in the transmitter.

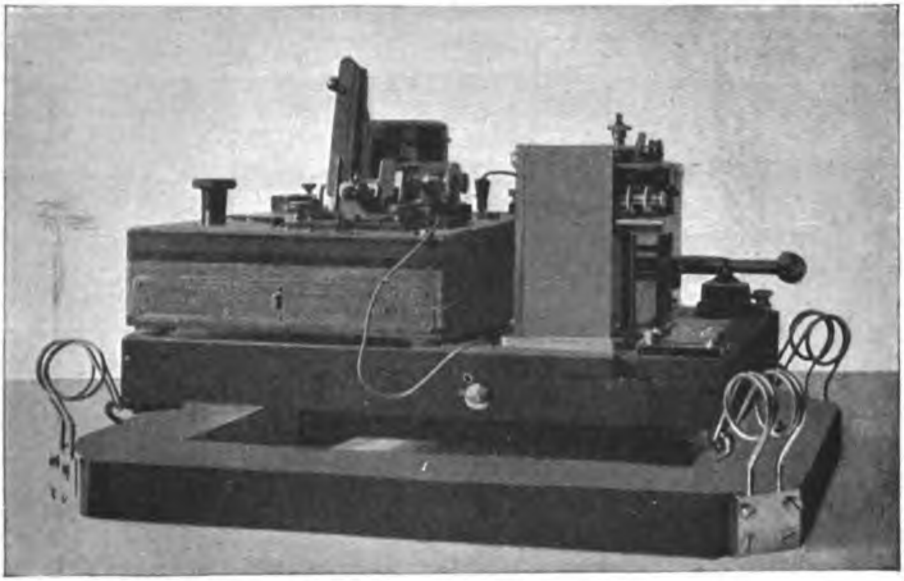

FIG. 64.—Receiving Apparatus for use on board Ship.

As mentioned, sparking at the relay or the tapper is entirely avoided by using various ohmic resistances or polarisation batteries.

RECEIVING OSCILLATION CIRCUITS.

For oscillation circuits or receiving transformers various types have been devised, according as close or loose coupling is resorted to in the receiver. With close coupling, the transformers (fig. 65) consist of a single coil, so arranged that any number of the windings may be brought into use by means of adjusting slides.

The mounting adopted with close coupling—in which, as already stated, accurate syntonising is impossible—is represented in fig. 66. In this, F is the granular coherer, K a constant condenser, the capacity of which is very great in proportion to that of the coherer—

Fig. 65.—Receiving Transformer for Close Coupling.

which the Baltic station experiments first demonstrated to be very small—and can therefore be disregarded with reference to the frequency of the system. J is an induction coil with three variable contacts, *a*, *b*, and *c*. The tuning of the coherer circuit is effected by changing the position of the slide *b*. By means of the slide *c* the other windings are short-circuited and prevented from oscillating with the rest. The conductor *b c* is earthed by means of a variable condenser C, and the aerial wire connected to the slide *a*. The aerial wire can be tuned, both by changing the number of windings between *a* and *b*, and by means of the condenser C. Consequently the larger the number of windings *a b* for a given wave-length, and the correspondingly smaller the condenser C, the closer will be the coupling and the more imperfect the tuning.

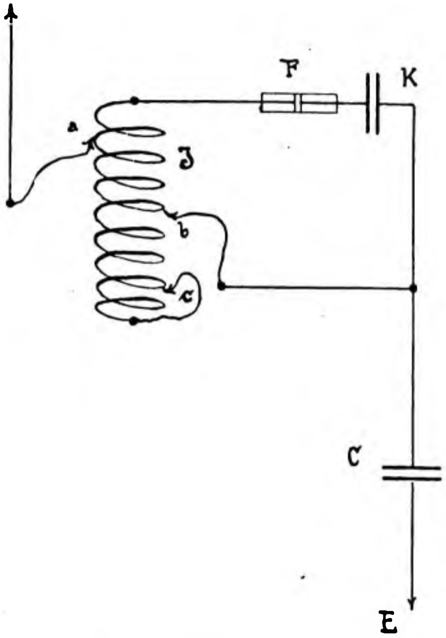

FIG. 66.—The Mounting in the Receiver for Close Coupling.

The mounting of the loose-coupled oscillation circuits in the receiver — which system is the only applicable one for securing accurate tuning—has been already described on p. 22. The construction is illustrated in fig. 67. Any desired degree of loose coupling can be obtained by adjusting the outer primary coil. The secondary coil is inside, and is surmounted by the variable air condenser of the secondary circuit. The number of effective windings, and therefore the self-induction of the secondary coil, can be varied by means of a slide.

The mounting adopted at the Baltic stations for obtaining

FIG. 67.—Receiving Oscillation Circuits with Loose Coupling.

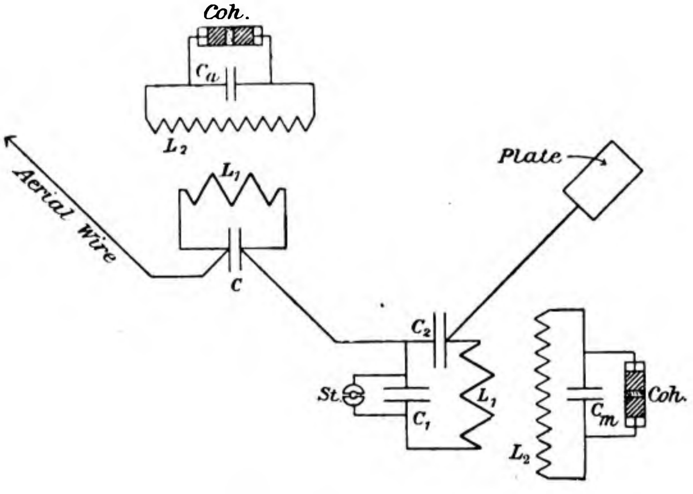

FIG. 68.—Mounting for Multiplex Telegraphy as used at the Baltic Stations.

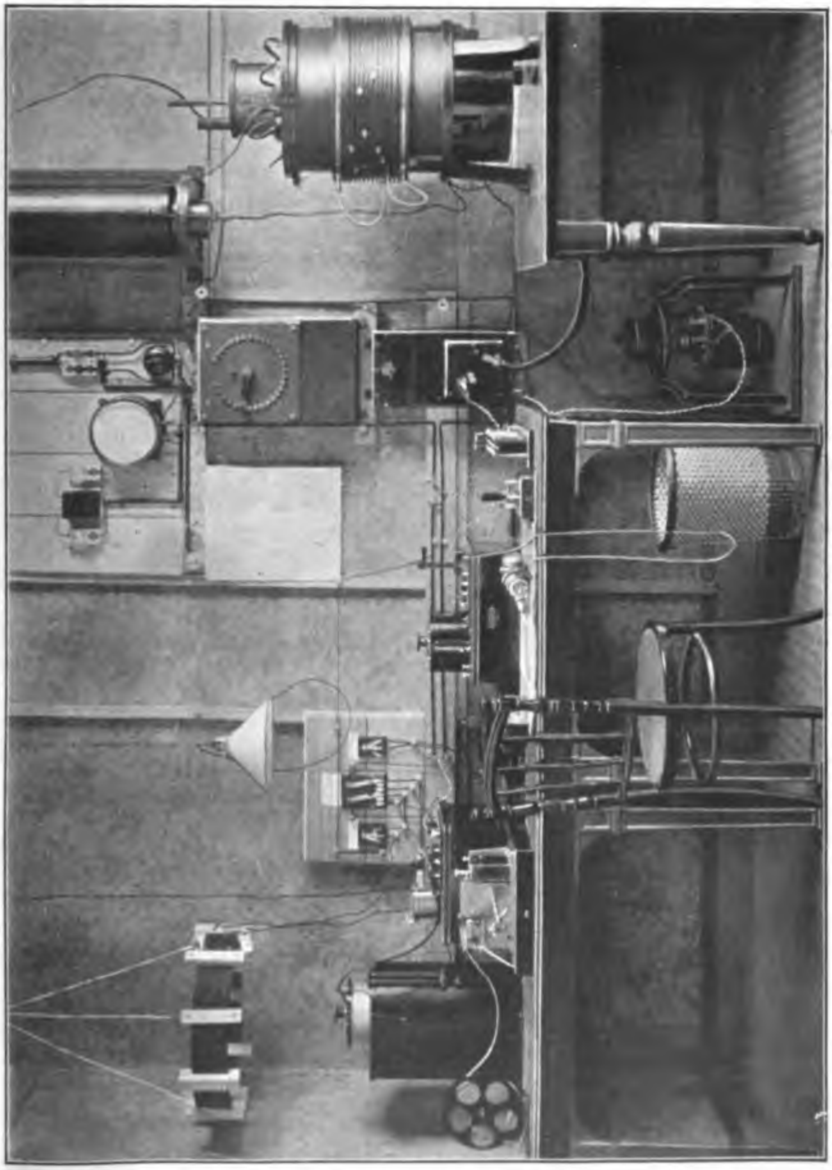

FIG. 69.—Wireless Telegraph Station.

absolutely reliable *multiplex wireless telegraphy*, is made clear by fig. 68. The oscillation circuits were excited by the same aerial wire. The attachments were coupled direct, but relatively loosely, with the primary circuits, and the latter excited the secondary circuits, the coupling between the two being very loose. The difference between the two effective wave lengths amounted to only about 10 per cent. in the case of a highly unfavourable distance ratio of 10 : 100 miles.

This method of mounting is unqestionably not the best. Theoretically, the use of only one aerial wire entails joining of same with the various oscillation circuits by different degrees of coupling, in which case losses of energy are inevitable. The best plan—though unfortunately not the simplest in practice—is of course the use of several distinct antennæ for the different oscillation circuits.

Fig. 69 represents the interior of a fully equipped wireless telegraphy station. To the right are the sending apparatus, whilst the receivers are mounted at the left of the long table. From the descriptions already given the reader should feel himself quite at home in this up-to-date telegraph station.

CHAPTER XI.

CONCLUSION.

BY strenuous labour in both the scientific and the technical branches, wireless telegraphy has been raised within a single decade, from the smallest beginnings to an indispensable means of communication. This will constitute a lasting memorial of our progressive age, a visible sign of the intelligence and high endeavour, love of work, and capacity of appreciating the deeds of our leading spirits. It also shows how unremitting labour for securing ideal benefits to mankind is not only an ennobling moral influence, but also may lead to practical results outstripping the wildest dreams of imagination. Who would have thought it possible to waft messages across the ocean without any visible means of transmission! Of course progress has been accompanied by a clamour for more, the requirements advanced showing how far we are still from the ideal goal, which appeared so near when the real principles involved were first clearly recognised.

We have seen that at present the work has to be carried on with oscillatory discharge complexes, which even in the most favourable conditions (perfectly loose coupling) produce only relatively slightly damped wave series. The pauses between the sets of discharges are infinitely long in proportion to the time they themselves occupy, the situation being comparable to that of a sea, perfectly quiet all day long except for a single minute's disturbance by waves. In reality, we excite merely a series of short electrical tone impulses which, on account of the wide interval between them, cannot even be regarded as a chain of impulses.

What a difference there would be in the practical utility of electric oscillations were we able to generate and maintain, at will, persistent electric tones of sufficient frequency! Our most modern alternating generators are cumbrous devices for producing very slow oscillations (about fifty per second), whereas, for wireless telegraphy, a mean frequency of about a million per second is required. Here is a worthy and profitable subject for inventive skill, and one whose solution might lead to perfectly incalculable results.

As was quite natural, the value of wave telegraphy was at first appreciated only in comparison with the range of distance covered; and though this progressively increased, it was not until the introduction of the Braun coupled systems that any imposing dimensions were attained. We have seen that the energy can be brought to exert itself instantly by the use of close coupling, so that vibrations of an explosive character are produced, but that while these can penetrate to great distances, they excite any receiver, whether syntonised or not. As we have seen, it has also become possible to render any amount of energy effective in the form of electrical waves, so that at present stations with a range of 600 miles represent merely ordinary types.

It has already been pointed out that an excess of energy has always to be allowed for in practical wireless telegraphy, because the transmission of the energy varies greatly with the weather. Bright sunshine lessens the action considerably; and a still more unfavourable effect on the transmission of signals is produced by protracted spells of dry weather, during which the air becomes ionised. On the other hand, when the ionisation has been destroyed by rain, the original efficiency is at once restored. A soft, damp state of the atmosphere is best for the operations of wireless telegraphy, though the ordinary man would be inclined to think the opposite. For these reasons modern stations are always arranged to develop three times the maximum efficiency required for their range.

The explosive emission of energy resulting from close coupling must naturally be attended with great drawbacks when several stations are working simultaneously at short distances apart.

Recently, however, more delicate methods of operating have come into use by the introduction of loose coupling. We have seen how the reduction of the damping through resistance is attained at all points of the oscillation track, especially in the primary sender circuit by subdividing the spark-gap and constructing it of the most suitable length. In the receiver, the secondary system especially has been elaborated into an independent and almost undamped oscillator, to secure the clearest resonance with an effective sender oscillation.

Fig. 70.—Wireless Telegraphy at Pilot Stations.

Thus, with loose coupling, space is traversed by weak but elongated electric tones, which will only excite the identically tuned receiver by resonance, leaving all untuned receivers unaffected.

On loose coupling in both sender and receiver rests the principle of attaining maximum freedom from disturbance and the possibility of selective or multiplex wireless telegraphy.

True, the oscillations still traverse space and can be caught by any syntonised receptacle, and, what is worse, to catch the messages we only need the extremely sensitive telephone detectors, which react with any impulse, though the attainment of perfect resonance is immediately revealed by a maximum of sound in the telephone.

This impossibility of maintaining secrecy in the messages is an undoubted defect of the new system of communication in comparison with telegraphy through wires, in which the connection is established between certain mathematical points only. The drawback may be lessened by using a secret code which prevents the meaning of the wireless message being understood by others. Furthermore, the removal of the difficulty by the employment of a system of *directed* wireless telegraphy has been under consideration; and Professor Braun recently announced at a meeting of the German Shipbuilders' Association at Berlin, that he had solved the problem, in principle, by using several differently-phased oscillations simultaneously ("phasenverschobene Schwingungen"). For this purpose Braun employed several antennæ in which oscillations partly of the same and partly of different phases were excited. Furthermore, he showed an easy method of producing several oscillations of the same frequency but of a different phase. In this way it is possible to obtain different actions in different directions, *i.e.* a "directed" wireless telegraphy. Nevertheless, the practical results do not seem, so far, to have reached the level of theoretical requirements.

Despite these limitations, the practical utility of wireless telegraphy is undeniable, and increasing in importance. To illustrate this more clearly, we may review its chief spheres of activity.

The first proofs of the usefulness of wireless telegraphy were afforded by its application at pilot stations (fig. 70), and at present almost all such stations, and fire- and life-boat stations, are equipped with the apparatus (fig. 71). Many lives and much property have been saved by this means. The enormous superiority of electric waves to optical signals is nowhere more apparent than in bad and especially foggy weather, since the small waves of light are shattered against the comparatively large globules of fog, whereas the latter are, as it were, carried onwards by the gigantic electric waves being unable to check their advance.

The new method of communication is also increasing in usefulness for the commercial purposes of the mercantile marine. The advantages are self-evident, since important news can be transmitted between ships and shore, for hours, and even days, after leaving or before entering port; and in case of accident or sea-damage, aid can be rendered promptly. Hence the number of coast stations are being constantly increased on every sea, and nearly all the large liners are now fitted with wireless telegraphic apparatus. This can be used at a low, fixed rate; and in some cases wireless messages of general importance are published on board in newspaper form.

Fig. 71.—Wireless Telegraphy at Light-ship Stations.

Special importance, and rightly so, is attached to wireless telegraphy in military circles. Probably no large man-of-war is without the necessary apparatus for wireless signalling, now that

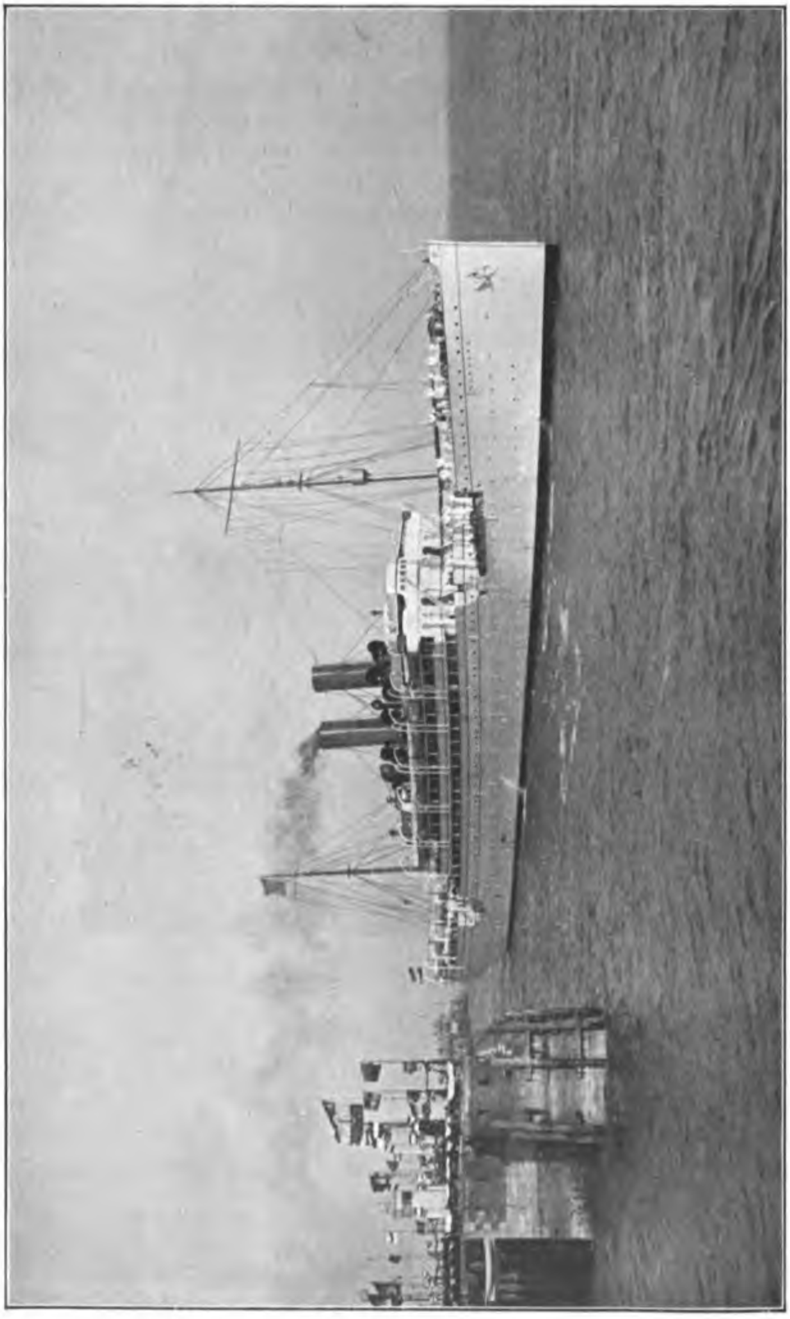

FIG. 72.—Yacht of the German Emperor with Wireless Telegraphy Installation.

technical skill has overcome the special difficulties arising from the presence of large masses of iron and restricted accommodation.

Fig. 72 shows the German Imperial yacht *Hohenzollern* with wireless telegraphy installation.

Incalculable advantage is secured by the possibility of thus transmitting orders from a flagship to the rest of the squadron, the individual members of which again are in close mutual touch by the same means. The centralisation of authority and increased facility for making reports and reconnoitring are also accompanied by a great saving in fuel and an increased sphere of operations, whilst the establishment of communication with the shore forts secures the inestimable advantage of co-operation between land and sea forces.

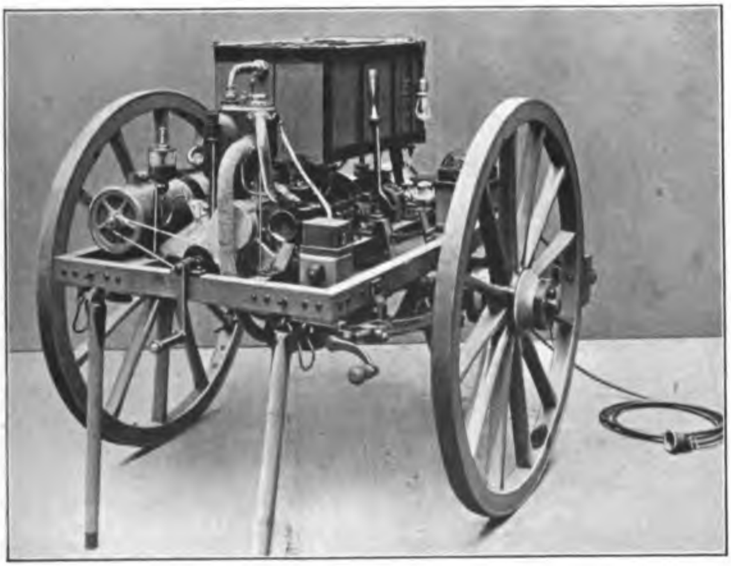

FIG. 73.—Portable Wireless Telegraphy Station (waggon containing the source of power).

A special application of wireless telegraphy to military purposes has been carried out in the German army. The chief problem was to obtain apparatus sufficiently portable to accompany marching troops, especially cavalry, even off the high roads. This difficult task was accomplished by the Telefunken Company by mounting all the station apparatus, including the current generators, on light army transport vehicles capable of going over any road or country, the air conductors being elevated by means of kites or balloons instead of masts.

Fig. 73 shows the waggon conveying the source of power, namely, a benzine motor with condenser and all accessories, together with a dynamo generating a current of 120 volts at 20 ampères = about 2·5 kilowatts.

Fig. 74 shows the second waggon carrying the apparatus. The corps consists of an officer, a non-com. and five privates, in addition to the drivers; and is shown on the march in fig. 75.

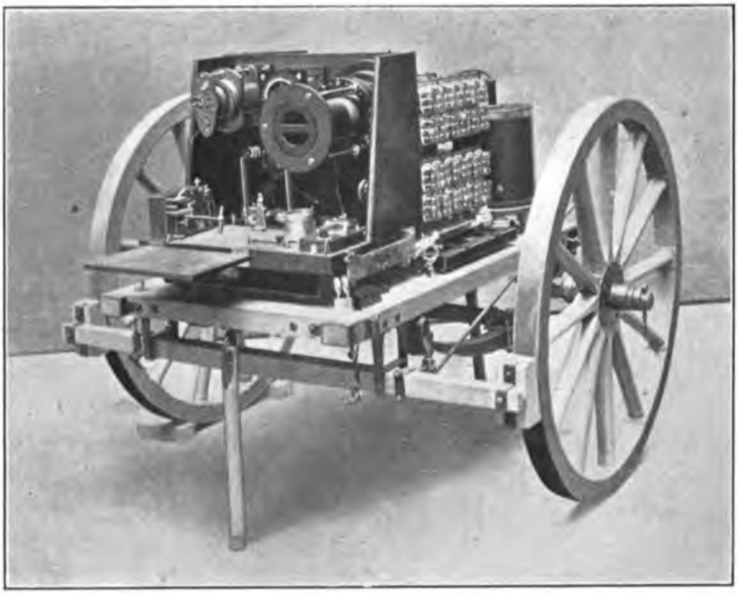

FIG. 74.—Portable Wireless Telegraphy Station (waggon conveying the apparatus).

Fig. 76 represents the unlimbering of a train and the setting up of apparatus for work, an operation taking only a very few minutes from the time of arriving on the ground.

These portable stations have answered admirably in numerous manœuvres, following the most rapid cavalry movements, and enabling full communication to be established between commanding officers over distances equal to several days' march.

In order to direct the attention of students in high schools and universities to the importance of research in wireless telegraphy, the

FIG. 75.—Portable Wireless Telegraphy Station on the March.

FIG. 76.—Portable Wireless Telegraphy Station—Train Unlimbered.

Telefunken Company has constructed models illustrating the *modus operandi* of the full-size apparatus.

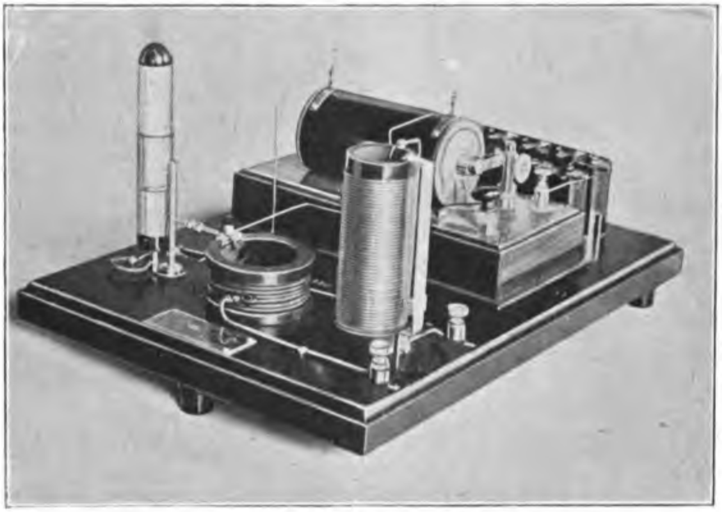

Fig. 77.—Sender of Demonstration Apparatus.

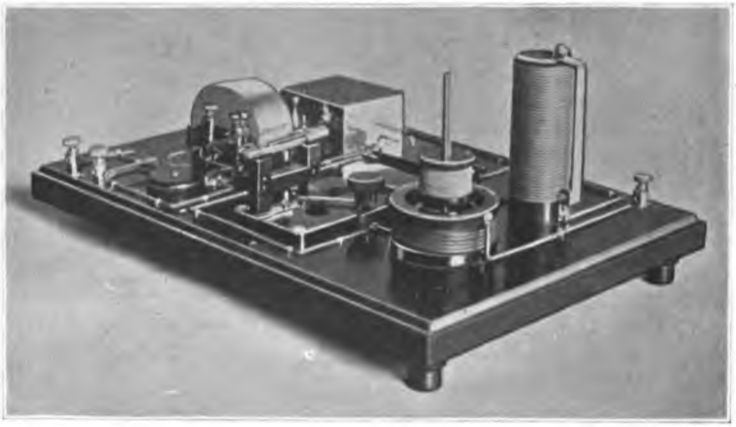

Fig. 78.—Receiver of Demonstration Apparatus.

Figs. 77 and 78 represent sender and receiver, but without aerial conductor, whilst fig. 79 illustrates a complete sender with slow-radiating aerial fitting, the latter consisting of a vertical copper wire, with terminal capacities attached top and bottom

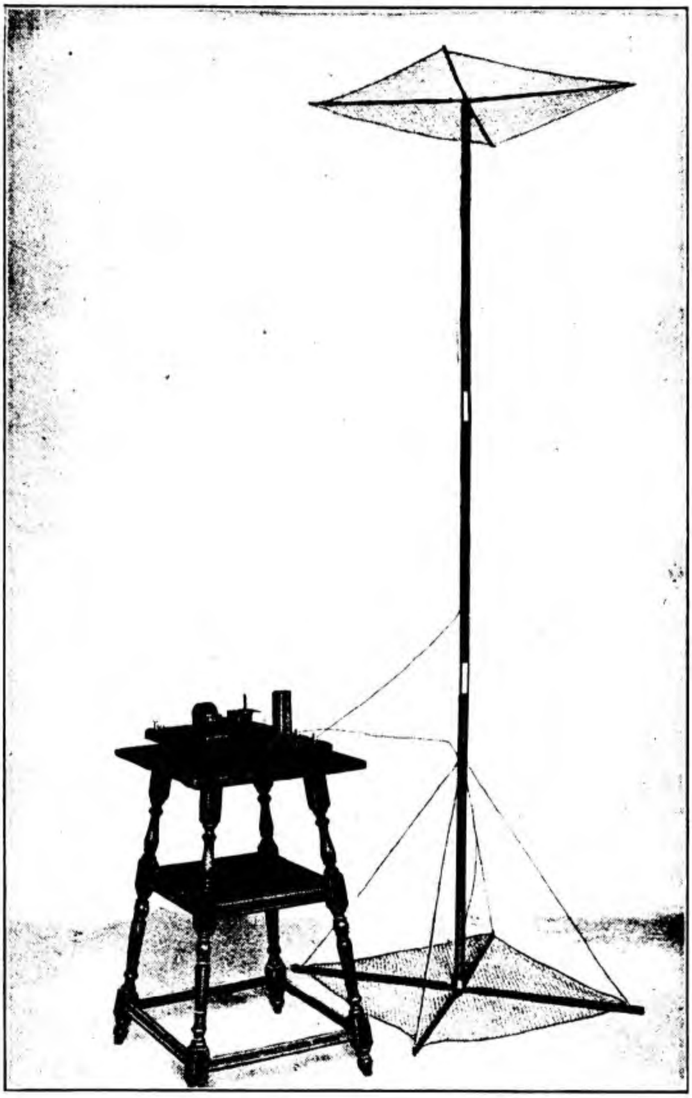

Fig. 79.—Complete Sender of Demonstration Apparatus for Wireless Telegraphy.

(aerial-wire—counter-capacity). In the centre of the aerial conductor is mounted a coil for coupling purposes, and also a variable self-induction (large bare wire coil) to regulate the wave length of the aerial conductor.

By the use of loose coupling in sender and receiver, these models can be employed to demonstrate not only the transmission of wireless messages, but also the selective or multiplex wireless telegraphy with three different wave lengths.

The foregoing review of the successive development of wireless telegraphy will have clearly illustrated the enormous advance that has been made in a comparatively short time. For a while it seemed threatened with grave danger. In consequence of fantastic reports the general public was led to overestimate the new means of communication to such an extent that the days of the cable were looked upon as over. Naturally a reaction set in, and hot enthusiasm was replaced by its antithesis. Nevertheless, the strenuous labour of professionals, and the recognition that wireless telegraphy has its natural limitations, have rescued it from discredit and directed public opinion into a healthy channel of active interest. Wireless telegraphy is destined to supplement and not displace the cable, and its aid will be the more valuable since the cost of installation and maintenance is lower than that of cable work. In fact, for a range of 600 miles the prime cost of a wireless installation is at most only one-tenth, and the cost of maintenance one-third that of a cable system. The special field of wireless telegraphy is that in which communication is to be established as quickly as possible, either temporarily or between movable points.

The last stages of development have (to use an expression of Hertz) placed us in the position of no longer being compelled to make *in electricis* music with wooden clappers, for we now have a whole range of tones at our disposal for the purpose.

We are still far from the goal, achieved in acoustics, of uniting great intensity with the highest resonance possibilities, and for the present have to be content with the choice between the two.

Such higher aims can only be realised by close co-operation of science and technology, which is in no field so essential as in wireless telegraphy.

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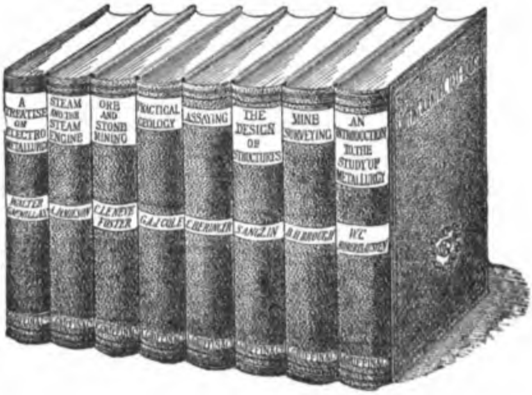

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