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WIRELESS TELEGRAPHY MANUAL,

VOL. I.,

FOR THE USE OF

TELEGRAPHIST RATINGS

IN

H.M. FLEET.

1912.

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PREFACE.

It is hoped that the effect of this book will be to introduce the subject of Wireless Telegraphy to the student in such a manner that he will not be frightened away from the subject before he has got a grasp of its principles.

There is no doubt that at first sight the subject presents many difficulties, upsetting, apparently, all our preconceived ideas about electricity—even Ohm's law has to be modified. Again, as in all new sciences, many new words and expressions appear, which are still somewhat loosely used by different writers, greatly to the confusion of the student.

The Service man who intends to take up wireless turns first to the official publications on the subject. He at once finds himself confronted by many Annual Reports of the Torpedo School, the Wireless Manual, and several handbooks of the various installations in the Service. Now, except in the case of the last-named books, the information is useful to a great extent, but a large amount is out of date.

This unfortunate state of affairs is unavoidable, on account of the rapidity with which changes follow each other, but the consequence is that the student has no starting point from which to work, and will probably go ashore and buy a book on the subject.

Without wishing to detract in any way from the value of these latter books, it may be said that they do not meet the present requirements. They may be roughly divided into two headings. Firstly, the elementary books, written for the "man in the street," giving much interesting, but hardly useful historical information, and little theory. Secondly, the theoretical book, filled throughout with differential equations which completely baffle the man of average attainments. Further, such books usually presuppose a knowledge of the theory of alternating currents on the part of the student.

From this book it is hoped that practical and theoretical instruction may be obtained sufficient for the efficient working of the Service instruments, and perhaps for the appreciation of the principles governing their design, while the examples given illustrating the enormous utility of curves may tempt the student to undertake some elementary mathematical work, of which an outline is given in the Appendix. A very slight knowledge of Algebra and Trigonometry will probably suffice for the comprehension of all the work in this book, and an attempt will be made to exhibit the principles, without the formidable array of technicalities usually employed, of the differential calculus.

By confining ourselves to broad principles instead of to details of interest at the moment of writing, it is hoped that the book may, for some time at least, represent a foundation on which the Telegraphist may build a sound knowledge of his trade. The importance of the good education of the Telegraphist Ratings of the Fleet cannot be over-estimated. Day by day the necessity for rapidity and reliability of communication increases, for as the speed of ships increases, so more rapidly do new tactical situations succeed each other.

The information that an Admiral requires is short, accurate, and *timely*; not detailed, verbose, and consequently *late*.

For the success of W.T. in war, then, it will be seen that the first requisite is good telegraphy. The telegraphist must be able to read weak as well as rapid signals, and, further, be able to read through atmospheric, accidental, and even deliberate hostile interference.

In addition to these qualifications, a thorough knowledge of the theory and of the care and the repair of his instruments is necessary before he can be called a good operator. Practice will make a telegraphist; it is hoped that this book will help to turn out good operators.

From considerable experience among the telegraphists of the Fleet, the writer is of the opinion that they do not sufficiently appreciate the value of a thorough grounding in the principles of direct currents. The elementary principles of electricity and direct current practice can be but lightly touched upon in this book, so broad is the field we have to cover, and so well has the subject been treated in Vol. I. of the Torpedo Manual; but it would be of enormous advantage to themselves and to the Service, if the telegraphist ratings would but realise that they must walk before they can fly.

It is the application of this principle that may possibly make the early part of this book somewhat tedious reading to the senior ratings, but it is for the coming generation that the book is primarily written.

CHAPTER I.

Induction and Capacity.

The student who starts with no knowledge of electricity whatever cannot do better, before reading further, than make himself thoroughly familiar with the first three chapters of the Torpedo Manual, Vol. I., 1911, which is easily obtainable.

In those chapters steady currents principally are dealt with, whereas in wireless we are concerned very intimately with currents which change their strength and direction from instant to instant, sometimes at very short intervals of time. Such currents are called "alternating" or, in the case of the very rapidly alternating currents used in the wireless circuits proper, "oscillating."

In the case of steady currents commonly in use we are concerned but very little with the phenomenon of Induction between two adjacent circuits, or with that of "self-induction," still less with that of storage of electrical energy in a condenser. Before, therefore, we undertake the investigation of what actually happens in a W.T. circuit, it will be necessary to get a thorough grasp of the meaning of "Capacity" and "Inductance," since upon these two qualities of a circuit the whole science of "wireless spark telegraphy" depends.

Capacity.

The capacity of a conductor may be defined as "the property "it has of storing up electrical energy in the dielectric (or "insulator) which separates it from earth, or from another con- "ductor." It will be seen, then, that without an insulator there can be no storage of energy. The storing of energy is consequently an attribute of the dielectric or insulator. The two opposed conductors, separated by the dielectric, are merely necessary in order to distribute the charges over the surfaces of the dielectric, surfaces over which the charges would otherwise be unable to move, owing to the dielectric being also an insulator. The whole arrangement is called a "condenser."

It is sometimes convenient to regard a "positive" charge as consisting of a "surplus" of electricity in one place, which can only be produced conjointly with the production of a "negative" charge or "deficit" in another place.

Imagine a pair of scales with the pans equally weighted. No movement takes place and there is no evidence of the existence of the weights. The system is in equilibrium.

So two plates separated by a dielectric show no visible or sensible evidence of the presence of electricity.

Now, however, remove some weights from one pan to the other. At once a difference of pressure is felt, and movement will result unless a finger is put on the lighter pan to prevent it rising. So, too, when we alter the distribution of the charges on the two plates of a condenser, we shall have a surplus on one side and a deficit on the other. There will be a tendency (E.M.F.) for the electricity to move, and thus form a current, since the surplus tries to go back and make good the deficit, unless we prevent motion by interposing an insulator which is now called the dielectric.

Now in the case of the scales, the more weights we transfer, the harder it will be to prevent motion, and our finger is in a state of strain. Again, the greater the charge (or difference between surplus and deficit) in the condenser the greater the E.M.F. tending to produce movement and consequently the greater the strain on the dielectric, which may eventually puncture.

It will be seen then that the holding power or capacity of a condenser cannot be likened to that of a pint pot, but to that of a boiler or (better still) a bicycle tyre, into which any number of cubic feet of steam or air can be pushed provided we have a sufficiently powerful pump and provided the receptacle will not burst. If we had no such incompressible unit as the gallon of water we might describe the capacity of a boiler as so many cubic feet of air at so many pounds pressure.

So it will be seen that a small condenser may be holding just as many "coulombs" (or units of quantity) of electricity as is a large one; but the pressure in the small one must be higher than that in the large one.

The unit of capacity is called the Farad, and is the capacity of that condenser which takes one coulomb to charge it up to one volt pressure. Two coulombs would charge it to two volts. Three coulombs put into a condenser of half farad capacity would have to have six volts behind them in order to get in. We see, then, that the unit of capacity has been so chosen that—

$$Q = SE^{*}$$

Where Q = number of coulombs put in,
S = the number of farads,
and E = the number of volts to which the condenser is charged.

Remember that the coulomb is that quantity of electricity which passes a given point in a circuit when one amp is flowing for one second. A current strength given in amps really means so many "coulombs per second." In order to become familiar with the use of letters instead of figures, we can say—

$$Q = CT$$

* Whenever two letters are written close together, it is intended that the numbers which they represent should be *multiplied* together (*see* Appendix).

Where Q = coulombs that have gone past.
C = current strength in ampères.
T = time the current has been flowing in seconds.

From the above reasoning it follows at once that, if we want to put a large quantity of energy into a condenser we must have :—

A large condenser whose dielectric is capable of standing a high pressure without puncture.

A source of high pressure of the order of 10,000 to 20,000 volts.

With regard to the first consideration we remember that the capacity of a condenser depends upon :—

(1) The area of the dielectric charged ; that is, the area of the conducting plates, for without the conductors the charge cannot "spread" over the dielectric.
(2) The thickness of the dielectric.
(3) The substance of which the dielectric is composed.

To take the above in order :—

(1) The bigger the area, the bigger, obviously, is the capacity.
(2) The thinner the dielectric, the bigger the capacity.
(3) The bigger the "Dielectric co-efficient" or "S.I.C." (Specific Induction Capacity) of the material used, the bigger the capacity.

Regarding the puncturing pressure, some materials have a greater "dielectric strength" than others of the same thickness. Further a thick plate is stronger than a thin one, but not stronger in proportion. Thin plates will stand more volts *per unit of thickness* than will thick ones. For this reason condensers are often built up of several sections of thin-plated condensers placed in series with each other so that the voltage is shared by sometimes as many as eight thicknesses of dielectric.

The care employed in selecting the dielectric and the method of building up also affects the voltage at which it will puncture.

With reference to the second consideration above, the source of pressure, the pressure we have in the mains of a ship is far too low for spark telegraphy, and so artificial means have to be employed to obtain this high voltage.

Before we leave this subject it will be well to notice that to charge a condenser up to a given pressure the *time* taken to do so will depend, among other things, upon the capacity of the condenser. A large condenser will take longer to charge up than will a small one. This is a most important consideration from a wireless point of view, for in the study of steady currents the element of time did not concern us at all and it was consequently rather liable to be ignored.

It will be well to remember that in the case of the bicycle tyre a much greater effort is required to impel the last few pumpsful of air to enter than the first few. We are therefore justified in talking about a condenser producing a back pressure which rises as the condenser becomes charged up and eventually equals the applied pressure. When this happens no further flow of current into the condenser takes place. The back pressure at any instant is the Potential to which the condenser is actually charged at that instant and is sometimes called the "terminal potential" or "terminal P.D." of the condenser, being the pressure across the condenser terminals measured in volts.

Induction.

Induction takes place when a current is started or stopped in one of two adjacent circuits. This subject is very clearly treated on p. 49 *et seq.* of the Torpedo Manual (1911).

It will there be seen that if two circuits lie near each other but are insulated from each other, the starting or stopping of a current in one circuit will produce an induced current in the other circuit whose direction is always in opposition to the change that is going on in the first circuit.

Further, it is not necessary for the current in the first circuit to start absolutely from zero, or to die quite away, for all that is required to produce the induced current is that the current in the first circuit should be changing in strength. Well, in direct current circuits we are almost always dealing with constant unvarying values, and so the phenomenon of induction hardly effects us at all, except at the moment of switching on or off.

Should, however, the current in the original circuit be constantly changing in strength and direction, which is the very essence of an alternating current, then the induced current will change in direction and strength also.

The strength of the induced current at any moment will depend chiefly upon the rate at which the original current is altering, and its direction will, by Lenz' law, always tend to be in the reverse direction to that of the change in the original current.

The calculation and measurement of the amount of electro-magnetic induction between two circuits will not be attempted here. Bear in mind for the present that the words induction or mutual induction always refer to cases where we are dealing with *two* circuits, and their mutual interactions.

Self-induction.

We know, from a study of the experiments described in the Torpedo Manual, that the inductive effect of one circuit upon another gets stronger as we move the coils closer and closer together.

Suppose, now, that the two coils are brought very close together indeed—that the two are made from the two strands of a twin flexible wire, for example.

Here the effect of starting and stopping a current in one wire will produce a very strong opposing E.M.F in the other wire. Finally, suppose that the insulation between the two strands of wire is abolished and that we are consequently left with but a single stranded coil.

Exactly the same effect will occur here, so that as the current increases in strength in the wire, there will be an opposing E.M.F. set up in the *wire itself* which is trying to prevent the rise of the current. When the current is stopped there will be an E.M.F., induced in the wire itself, which will tend to keep the current flowing, that is, to oppose the change in current strength.

This self-induced E.M.F., is said to be the result of *self-induction*, and it will be seen that any one circuit must possess this property to a greater or less degree, whereas it takes at least two circuits to produce the effects of induction, or, more properly, mutual induction.

The magnitude of the opposing E.M.F. will depend upon the rate at which the lines of force cut the wire, and of this we shall see more later. The self-induced E.M.F., can never *prevent*, but only *delay* the alteration in current strength.

Another way of looking at the matter may be helpful.

The phenomenon of self-induction exactly corresponds with one of the properties of "mass" in mechanics.

We know that all bodies mutually attract each other for some (at present) unknown reason. This is why an object will fall to the ground when let go from a height. It is, however, with another property of matter that we have to deal. Irrespective of the proximity of the earth or other masses of matter, every substance possesses "Inertia."

This word expresses a "sleepiness" or dislike to being set in motion, but it must not be forgotten that objects when once in motion have an equal dislike to stopping or to having the direction of their motion altered. We are accustomed to call this property of a *moving* body "momentum."

Inertia is proportional to the mass of, or amount of matter in, a body. Momentum is proportional to its mass and to its velocity or speed of travel.

A rifle bullet and a paving stone have very different amounts of inertia, but may both have the same momentum, for the bullet might be travelling much faster than the stone. It will be seen that inertia is only felt when a change in motion is attempted, either in starting from rest or in stopping, either in speeding up when under way or in slowing down. So also self-induction is not in evidence when currents are non-existent or are of uniform strength from instant to instant, but only when an attempt is made to start, stop, or change the strength of the current.

Hence self-induction may be defined as the "inertia" of a circuit to any change of current strength.

The next question is, how does self-induction show itself?

Returning to the heavy body which possesses inertia, we ask ourselves, "What happens when we try to start up a heavy body from rest to motion?" Well, for the first time we notice that the body has developed a will of its own. It resists our efforts to get it under way. It pushes against us.

Perhaps some of this resistance may be due to friction, so we put that out of court by supposing that we have a truck with well-oiled wheels on a smooth level road.

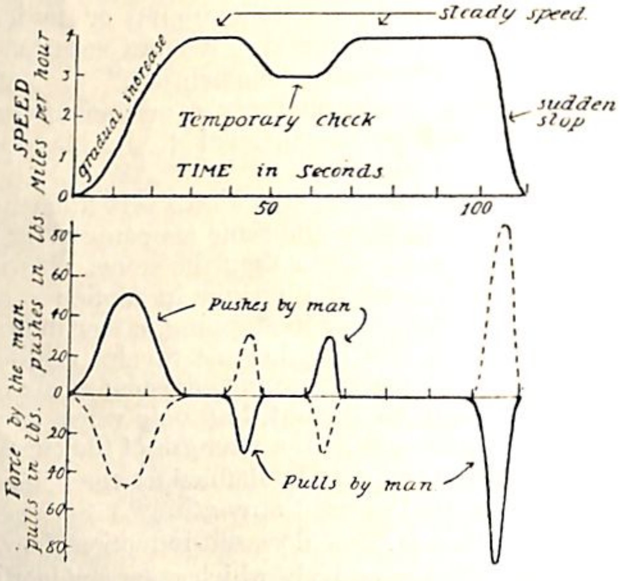
Start it up from rest. It resists our efforts till we get up the desired speed in spite of its opposition. By this time its opposition has ceased, and the truck runs along the road at a uniform speed with no effort at all, except that required to overcome a very small amount of friction. We see that while we were increasing its speed it pushed back against our hands.

Now reduce speed. The truck flies forward and pulls us after it. With a spring balance we might measure the amount of these pushes and pulls. Now remember that all this is due to the inertia of the truck, and inertia is proportional to mass. So *for a given rate of increase or decrease of speed* a heavy truck will give a big back or forward pressure and a light one a small back or forward pressure. Again, *for a given truck*, we shall get a big or small back or forward pressure according to the *suddenness or slowness* with which we try to alter speed.

We see then, that the amount of pull or push exerted by the truck against us is proportional to the mass of the truck and to the rate at which its speed is being changed.

Take the case of a hammer driving in a nail. Although the head of the implement may only weigh a pound or two, yet by the fact of its downward motion being *suddenly* arrested we get an enormous forward pressure on the head of the nail.

Fig. 1.



N.B.—The dotted line shows pressures exerted by the truck, in opposition to those applied by the man.

The application of this enormous *sudden* pressure on the face of an anvil, however, causes no apparent motion in the anvil, both on account of the suddenness of the blow and of the disparity of the inertiæ of the two bodies, the mass of the anvil being many times more than that of the hammer-head. Notice that the nail possesses but little inertia.

To accustom ourselves to reading curves, the speed of the truck from instant to instant, and its corresponding back pressure on the man's hand at like instants are shown in Fig. 1.

Several things may be noticed about these curves. The upper one gives a speed in M.P.H. (miles per hour) for any instant of time we like to name. It will be seen that the smallest divisions of the horizontal scale have a value of ten seconds each, while the divisions on the vertical scale are of one M.P.H. each. The horizontal measurements are called "abscissæ," and the vertical ones "ordinates." The reader should practise copying this curve, using different scales for ordinates and abscissæ, and see how the steepnesses of the slopes are thereby altered, although the form of the curve and the readings of any speed at any instant will be the same as before. In drawing a curve regard should be had to the maximum number of units that have to be shown in each case and to the size of the paper. Here we have nearly two minutes and four M.P.H. to be shown.

Notice that when the speed is uniform the curve becomes a straight line. Further it is *horizontal*. Whenever speed is being altered, the curve slopes. If speed is on the increase, the slope is upwards from left to right and is called positive; if on the decrease, it is downwards from left to right and is called negative. It will be seen that a "decrease" is really a "negative increase."

Most important of all, the *steepness* of the curve indicates the *rate* at which the speed is altering at that instant.

The steeper the curve, the more sudden the alteration. Now if these alterations in speed were to be expressed in units of "acceleration" or "retardation" the sort of unit we should talk about would be "miles per hour" (or feet per second) added (or subtracted) every hour (or second) at that *instant* with which we are concerned.

We could, by measuring the steepness of the curve at various points, plot another curve showing "acceleration" and "retardation" of the truck at various instants of time.

The first curve is called a "velocity-time" curve, and the second would be an "acceleration-time" curve.

The firm-line curve of the two lower curves actually is an acceleration-time curve, because we saw that for a given truck the push or pull *necessary* to start or stop respectively was proportional to the rate of change of speed. Notice that the time scale is the same in both curves.

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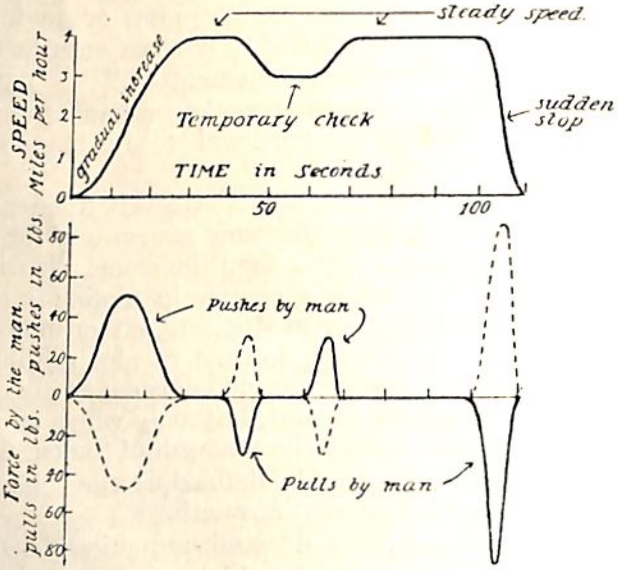

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When the upper scale is horizontal, its steepness is zero. Hence, whenever the speed becomes uniform, no pull or push is needed. Pulls are represented below the zero line and pushes above it, a "pull" being regarded as a negative "push." The curve at the bottom is a curve of steepnesses of the upper one.*

Enough has now been said to indicate the amount of information that a curve may be made to convey, and how vastly superior it is in physical measurements to a mere table. The reader is advised to make himself curves from any table of information that is at hand, such, for instance, as the rise and fall of stocks, rise and fall of the barometer, making a curve of steepnesses for each, thinking out what the latter means, and from his curves endeavouring to predict the price of the stock or height of the barometer for the following day.

It is to be hoped that this digression has not obscured the main issue before us, namely, that an electrical circuit possesses a property called Self-induction, which exactly corresponds to that of Inertia in matter.

Consequently some circuits have a larger self-induction than others. For one fixed circuit we have one fixed self-induction, with one exception that will be dealt with later.

Again, this property manifests itself *only* when the current in the circuit is being altered in strength. The evidence of the presence of self-induction is the "back E.M.F." which opposes any change in the current strength.

The amount of the back E.M.F. depends upon the amount of self-induction, and upon the rate at which the current is altering in strength. It must be carefully borne in mind that one circuit can produce large or small back E.M.F.'s according as the current is varying rapidly or slowly. The back E.M.F.

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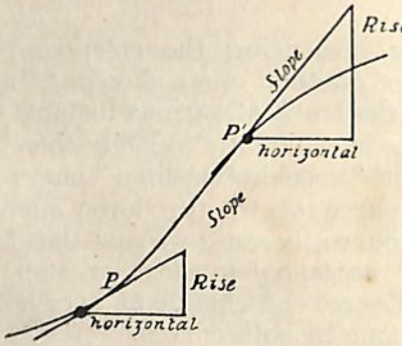
* The steepness of a slope at any point, P or P', would be measured as so much rise in so much horizontal measurement, and expressed as 1 in 100, 1 in 60, 1 in 6, and so on. It is frequently written as a fraction $\frac{\text{Rise}}{\text{horizontal}} = \frac{1}{100}, \frac{1}{60}, \frac{1}{6}$, &c. Thus a slope of 1 degree is $\frac{1}{57}$, of $10° = \frac{1}{6}$, of $45° = \frac{1}{1}$. For those who know a little Trigonometry it will be seen that the steepness is expressed by the tangent of the angle of slope, as is explained in Appendix.



is then proportional to the self-induction multiplied by the rate at which the current is altering.

The magnitude of this back E.M.F. will therefore be—

$$E = \text{Self-induction} \times \text{Rate of Change of current.}$$

By measuring the rate of change of current in amps. per second, and by choosing a suitable unit of self-induction, this formula may be made to give the back E.M.F. in volts.

Now as regards its direction. When the induced E.M.F. is a backward "push" we shall call it "negative," when a forward "pull," "positive." Again, when the current is increasing in strength we call its rate of change a positive one; when decreasing in strength, on the other hand, its rate of change (*i.e.*, of increase) is negative. Tabulating results:—

Negative $E = L \times$ Positive rate of change, and

Positive $E = L \times$ Negative rate of change, where L is the self-induction in both cases.*

We remember that the back E.M.F. of self-induction can never *prevent*, but can only delay the change of current strength, and that, as in the case of the man and truck, an equal and opposite pressure must be exerted by the source of E.M.F. in order to force the current to change in spite of the induced E.M.F. tending to prevent that change.

Hence it follows that the applied E.M.F. which is being used at any instant to overcome the back E.M.F. is of the same magnitude as the back E.M.F. at that instant, and that its direction is positive for a positive rate of change and negative for a negative one. This is expressed by $E = + L \times$ rate of change of current (*see* footnote).

A careful distinction must be made between the back E.M.F. of self-induction and the applied pressure necessary to overcome it. Since they are equal and opposite, merely having different signs, they are liable to be confused.

Self-induction of different Circuits.

Now, as shown in the Torpedo Manual, the shape of a circuit has a great effect on its self-induction. Practically, any circuit having a large magnetic field has also a large self-induction. The applied pressure used up in overcoming this back E.M.F. is not really lost, but employed in creating the magnetic field. "Nothing for Nothing" is the rule of nature, and we pay for the magnetic field by having to wait for the current to rise to its full steady value.

To make a circuit into a strong magnet we have a long piece of wire, wind it up into a coil or helix, and put an iron

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* Those who have done a little Algebra, and who know that the product of two quantities having the same sign is positive, while that of those with different signs is negative, will see that this formula can be expressed mathematically as—

$$E = -L \times \text{Rate of change of current.}$$

core inside it. Hence the self-induction of a circuit may be altered by bending it about. Its *resistance* cannot be so varied.

Now iron is inserted into the core of the coil because it is said to be more "permeable" to magnetic lines of force than is air. For the same number of ampère-turns, we have a much stronger magnet with the iron than without it. Best pure soft iron is about 3,000 times more "permeable" than air.

Finally we see that the self-induction of a coil of wire depends upon the—

(1) Length of wire.
(2) The way it is wound up.
(3) The permeability of the surrounding or neighbouring medium.

"Reluctance" is used to express the opposite of "permeability"—a very "permeable" substance has a small magnetic reluctance.

The unit of self-induction, sometimes called the co-efficient of self-induction, is the Henry.

The word "inductance" is often used, meaning "self-induction." Properly speaking, inductance should be held to include self and mutual induction. This slight distinction is not of great importance.

A coil of wire would have a value of one henry if a back or forward E.M.F. of 1 volt were generated when the current was varying at the rate of 1 ampère added or subtracted every second.

For instance, the current changes at a rate of 4 amps. per second, and the back E.M.F. is 8 volts. L here is 2 henries.

The time taken for the current to rise to a given value is a very important consideration. Theoretically, the full strength as given by Ohm's law is never reached when the circuit has inductance. For example, the shunt coil of a dynamo may have an inductance of 100 henries. After 23 seconds the current is still only nine-tenths of its full value.

The behaviour of coils with iron cores is very complicated, on account of the fact that the permeability of iron varies with the state of "saturation" of the iron, and therefore the inductance of such coils cannot be said to be constant under all conditions. In W.T., however, we are chiefly concerned with wires having nothing more permeable than air near them, and so can consider the inductance of a given coil of wire to be, for all practical purposes, fixed and invariable as long as we do not alter their shape or length.

Taking again the shunt dynamo coils, it will perhaps be instructive to notice what happens when the circuit is broken. Here the back E.M.F. becomes a "forward" pressure, tending to keep the current flowing.

Assuming the voltage to be 100, and the resistance of the coils 10 ohms, the steady current will be, by Ohm's law, 10 amps.

Now break this circuit and consider the current to die away to zero in one-tenth of a second. The current is dying at a rate of 10 amps. in one-tenth second, which is 100 amps. per sec.

Hence, back E.M.F. = − L × (rate of change of current).

The rate of change is − *ve.*

= (− 100 henries) × (− 100 amps. per sec.).

= + 10,000 volts,

which is 100 times as great as the ordinary output voltage of the dynamo.

For this reason special safety arrangements in the shape of blow-outs, sparking-pieces, &c., have to be made for large switches and controllers, especially those operating inductive circuits, in order to render this "inductive kick" harmless.

In wireless itself, advantage of this rise of voltage is taken, in the buzzer transmitters, whose inductive kick, occurring every time the make-and-break opens, is utilised to charge the transmitting condensers.

Notice that on switching "on" a switch there will be no spark, but on switching "off" a spark will occur whose size will depend upon the magnitude of the original current and the inductance of the circuit just switched off.

It may be that the spark, which of itself may do no damage, will strike a low-voltage metallic "arc" across the break of the switch, which would cause great damage by the enormous heat developed. It is to destroy this arc that "magnetic blow-outs," are sometimes fitted.

Again, the insulation of the circuit may be severely strained by the inductive kick, just as water flowing in a pipe may, if suddenly checked, burst the pipe.

A given piece of wire may have very different inductances, as in Fig. 2.

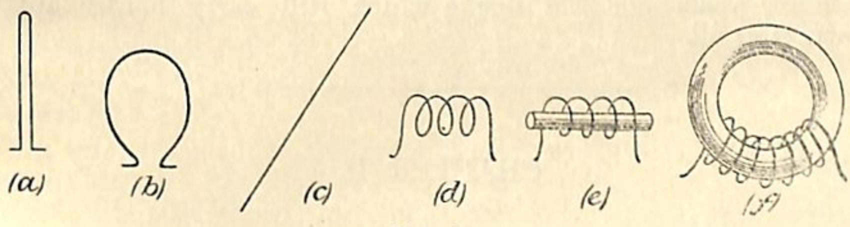

FIG. 2.

(*a*) is "non-inductive," being "on the bight." The current in one leg induces a current in the other, which is not in opposition to the original current. The two halves of the circuit each produce a magnetic field opposed to that produced by the other half. Hence there is no field and consequently no inductance.

(*b*) comes next, then (*c*), (*d*), and finally the coil with an iron core in (*e*).

If the iron form a complete ring the inductance is still greater. This is shown in (*f*).

Resistance.

Resistance is very fully dealt with in the Torpedo Manual, but it may not be out of place here merely to define it as "that Property of a conductor whereby energy appears in "the form of heat on the passage of a current through the "conductor."

Notice also that resistance depends upon—

(1) The length of the conductor;
(2) Its cross section, or thickness;
(3) The material of which it is made;
(4) To a slight extent upon its temperature.

Regarding—

(1) The longer it is, the higher its resistance.
(2) The thicker, the less is the resistance.
(3) The worse the conductor the higher the resistance. "Conductivity" (or "conductance") is the opposite of resistance.
(4) Resistance of most materials increases as the temperature rises.

With the exceedingly rapidly alternating currents used in W.T. we shall find that the current does not distribute itself evenly throughout the cross-section of the conductor in which it is flowing, but is confined more or less to the surface of the wire. Hence the "effective conductivity" of the wire is less than for direct or slowly alternating currents, and the "effective resistance" consequently increased.

This will be dealt with more fully later, but for the present we may notice that conductors for these currents will have to be specially designed in order to prevent them having a great deal of waste material inside which will carry hardly any current at all.

CHAPTER II.

The Oscillator.

We have seen that when a condenser is charged, there is a tendency for the charges to re-unite through the substance of the dielectric, the latter being in some sort of state of strain or compression. We say, then, that the space intervening between the two charges is full of lines of electric force, sometimes called "tubes of force," which are continually trying to shorten themselves, obeying the impulse of the two charges to re-unite and mutually cancel each other.

Similarly when a current flows along a wire, a magnetic field exists around that wire whose intensity varies with the current strength, and whose lines (or tubes) of magnetic force are always tending to shorten.

Further, it should be noticed that adjacent lines of force, whether electric or magnetic, mutually repel each other and that they have their ends always resting on two points either of opposite electrification or of opposite magnetisation.

Now we at once ask the question, what are these lines of force which are not visible and which cannot be physically grasped? The only reply that can be offered is a rather unsatisfactory one, and is that we believe all electric and magnetic phenomena to be due either to the disintegration of the atoms of which all matter is composed, or else to the rearrangement of their constituent parts. This process of movement causes stresses and consequent movements or strains in what is called the *ether*. Now we conceive the ether to be an almost infinitely elastic and infinitely tenuous substance which surrounds, permeates, and fills all matter, however apparently "solid," and all space. The earth is immersed in a limitless ocean of ether. We move about in a sea of it.

Now the region near a charged body, or that between two unlike electric charges, is called an electric field.

That in the neighbourhood of a current-carrying wire is called a magnetic field.

These fields are conceived to be regions where the ether is in a state of strain or movement, a state which can be detected by the phenomena produced.

Suppose an electric field exists between two points. Connect them with a conductor. The charges re-unite along the conductor, forming a current in that conductor. The electric field disappears. The current in the conductor, however, means that we have thereby created a magnetic field at right angles to the wire, and therefore at right angles to the original lines of electric force.

It will be seen, consequently, that in discharging the condenser we have not lost the energy stored up in the electric field, but merely allowed it to appear in another form, that of a magnetic field.

Similarly, move a conductor across a magnetic field. At once we get the electric field produced owing to the wire having its ends at different potentials.

Hence a movement of either kind of field creates the other kind, the new one always being at right angles to the old one.

Now light and heat, both being forms of energy, have been proved to consist of ether motion, and also all motions of the ether, whether electric or magnetic, are propagated at the same speed as light.

The speed of light has been measured by many scientists and has been found to be 186,000 miles, or approximately 300,000,000 metres per second.

Notice that *time* is required for the propagation of a current along a wire, no less than for the propagation of an electrical disturbance through the ether. Indeed, it is not yet demonstrated how far we are justified in talking of a current flowing *along* a wire, since nearly all the evidence of the presence of the current exists outside the wire. We can, however, safely say that the wire guides the current and strikes out a line of maximum magnetic disturbance.

Electricity, whether produced by friction, chemical action, or by the movement of conductors in a magnetic field, is identical in its nature, as also is magnetism in whatever way produced. The three commonest ways of producing a difference of electrical pressure referred to above are generally called frictional, voltaic, and dynamic respectively.

Wherever there is a charge, stationary or moving, there are, emanating from the charge, electric lines of force which end at other electric charges. Wherever there are moving electric charges or currents, there are also magnetic lines of force, these lines being always at right angles to the direction of motion of the charges and to the electric lines of force proceeding from them.

Finally, motion, or state of strain, in the ether, which are the forms these lines of force assume, travels with the speed of light, and the fields of force, although more pronounced and therefore more easily detected near the moving charges, are really all-pervasive. They permeate all space and have no limits.

Imagine a large bicycle pump to be alternately thrust in and out in the centre of a large hall. While the air was being suddenly expelled from the pump, a wave of compression, which becomes weaker as its distance from the pump increases, travels outwards to the *farthest* confines of the hall.

When the plunger of the pump is withdrawn, a wave of rarefaction, also starting from the centre, progresses outward to the *farthest* confines of the building.

So in the same way it may reasonably be supposed that starting a current produces a state of strain in the ether in one direction, while stopping it releases that strain.

In both cases the action starts at the point where current is produced, and progresses outward with the speed of light, and a little consideration will show that it can have no limit, though it soon ceases to be perceptible except under certain conditions which will be described later.

It is the function of wireless telegraphy to produce these ether movements at will.

Now these impulses of electric and magnetic force which are required to make our presence felt by the distant ship or station are best obtained by forcing a rapidly alternating current to flow up and down an aerial wire.

·This might be done by constructing an alternating dynamo and connecting its terminals to the aerial wire and earth respectively, but there are many difficulties in the way of doing this. To construct a dynamo giving a current alternating sufficiently rapidly, and also to have a considerable current output, is a very difficult matter. Such dynamos have, however, been constructed, and it may be anticipated that they will be heard of in the future as a commercial possibility.

Discarding this means of production for the time, the feasibility of wireless telegraphy was first demonstrated in the discovery by Heinrich Hertz, in 1886, that the effects of the discharge of a condenser through an inductance could be detected at a distance. The discharge of a condenser was previously known to be oscillatory in character (*see* p. 1), provided certain conditions were fulfilled, but it was the work of Hertz which made W.T. possible.

The Oscillator may be defined as consisting of a condenser whose terminals are joined by an inductance, having a spark gap in series sometimes, but not always.

Before proceeding with the oscillator, it will be necessary to increase our vocabulary somewhat.

In a circuit carrying a current, if the magnetic field or flux surrounding the wire does not alter its direction from instant to instant, the current is said to be direct or uni-directional. The current may vary in strength from instant to instant, and so become pulsative or intermittent, without changing its. direction. It is still, therefore, a direct current. It may be mentioned that the other evidence of the presence of a current, namely, the *heat* developed, may tell us the strength of the current, but will not in any way show us its direction.

If, on the other hand, the magnetic field changes its direction at regular intervals of time, then the current also is changing its direction at *regular* intervals of time, and such a current is said to be *alternating*. Such a current also alters in *strength* from instant to instant. Starting, say, from zero, it will rise to a maximum in one direction, die away to zero, reverse, rise to a maximum in the other direction, and die away to zero again. The whole series of changes just described is called a "cycle" or "complete alternation," and may be repeated continuously. The time taken to complete the above cycle is called the "period," "periodic time," or "complete period." This must be carefully distinguished from the "semi-period," or "half-period," by which is meant the interval of time between any two successive reversals.

The number of complete cycles or alternations performed in one second is called the "frequency" or "periodicity," and is generally denoted by the letters "n" or "f", or else by the sign "~".*

Thus, 100 ~ means that the frequency is 100, or there are 100 complete alternations carried out in 1 second. There would be 200 reversals of current and field per second, the periodic time would be 1/100th of a second, and the semi-period 1/200th of a second.

Frequencies are spoken of as being "high" or "low", but it must be remembered that such terms are purely relative or conventional. Thus 50 or 100 ~ would be called a low frequency, while one of 10,000 or 100,000 ~ would be described as a high frequency. There is no hard-and-fast line of demarcation between the two. When the frequency rises to the order of a hundred thousand, the current is generally called an oscillatory one, or an electric "oscillation."

In W.T. we are chiefly concerned with high frequency currents, or oscillations of a frequency ranging from 50,000 to one or two million cycles per second, and we have first to consider the mode of representing them.

Alternating currents in general are best delineated by means of a "wave diagram," that is to say, a curve of current and time. The ordinates (*see* p. 9) represent the strength and direction of the current, at various instants of time, time being shown as abscissæ.

Take a horizontal straight line to represent time. Divide this line up into equal intervals, and at the points thus found erect perpendiculars above or below the line.

The lengths of these perpendiculars will represent the strength of the current in ampères at their own several particular instants of time, the lines being drawn upwards when the current is in one direction, and downwards when the current has reversed and is flowing in the other direction.

The gradual increase and decrease (sometimes called "fluctuation") of the alternating current, first in one direction and then in the opposite direction, are then represented by the ordinates of an undulating curve, as in the figure.

To construct such a curve proceed as follows:—

Take any line AX on which to mark off time (Fig. 3).

With centre C and radius CB, describe the circle as shown. This radius will represent, to the scale we happen to be using, the number of ampères in the alternating current when at its maximum value. Divide the circumference of this circle into any number, say 8, of equal parts.

Select the length BX along the horizontal line, representing, to the proper scale, the time period in seconds of the alternating current which is to be drawn. Usually, this time will be a small fraction of a second.

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* The latter is called "cycles per second," or, more commonly, "cycles." In this book we shall use "f" and "~".

Subdivide the length BX into as many equal parts as those into which we have just divided the circumference of the circle. Number the subdivision marks on the circle and horizontal line to correspond, as shown in the example.

Draw vertical and horizontal lines, marking the points of intersection of each corresponding pair of lines.

Through the points so found, of which in this case there are nine, draw a wavy curve.

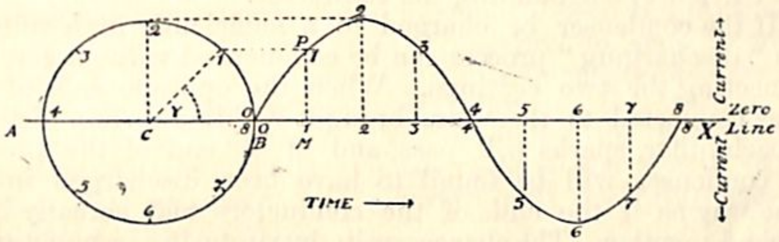


FIG. 3.

It will be noticed that we may call the abscissæ *degrees* instead of time, since the length BX represents the whole circle, which contains 360 degrees (*see* Appendix). In this case, the sub-divisions, such as the length BM, will in our example represent 45 degrees each.

The elementary theory of the dynamo, given in the Torpedo Manual, clearly explains that an armature having slip rings instead of a commutator, will generate an alternating current in the outside circuit. Further, it is indicated that a complete cycle is generated, in a two-pole machine, every time the armature completes a revolution, that is, every time one of its bars sweeps out 360 degrees.

Now the curve we have just drawn—and the student is advised to draw them for himself to different scales—is sometimes called a sine curve, because all its ordinates, such as PM, are proportional to the sine of the angle which BM represents, that is, of the angle (in this case) marked Y.

In addition to the method of measuring angles in degrees, of which 90 go to the right angle, another method is in use: This system is called the "circular" measurement of angles, and its use will be demonstrated later.

We now return to the subject of the Chapter, viz., the investigation of the discharge of a condenser.

It will be convenient to assume, for the present, that we have at our disposal a condenser, whose dielectric is capable of standing a high voltage without puncture, already charged up with a quantity of electricity to a high pressure.

The charges on the two coatings of the dielectric are trying to reunite through the material of the dielectric.

Owing to the dielectric being also a good insulator, they are at present unable to satisfy their mutual attraction.

Now connect the two coatings together by a conductor of low resistance. The charges can now move, and the positive or surplus charge moves to make up or neutralise the negative or deficit charge. This movement of charges means that a current flows. There is, consequently, a magnetic field brought into existence, surrounding the conductor.

If the condenser be charged to a sufficiently high voltage, this "discharging" process can be commenced without actually connecting the two coatings. When the opposite ends of the wires connected to them are brought within a certain distance of each other, sparks will pass, and at the end of the process the condenser will be found to have been discharged in the same way as if the ends of the conductors had actually been touched together. The charges unite by rupturing or puncturing the air insulation between the ends of the wires.

Now originally we had, stored in the dielectric of the condenser, an amount of electrical energy. We have seen that by the above method we can "discharge" the condenser.

What has become of the energy which we had previously stored? Energy is as indestructible as matter, and must therefore reappear somewhere else, and possibly in another form.

In this case, where we had a spark, a portion of the energy has appeared in the form of light, heat, and noise from the spark itself. The rest of the energy has been used in raising the temperature of the conductor, and lastly in radiating lines of force out into the surrounding ether.

Taking the same state of affairs again, we will now investigate more closely, and follow step by step, what happens during this process of discharge of the condenser. We shall, perhaps, remember that the conductor was assumed to be of low resistance.

Starting from the moment when the insulation of the air-gap previously referred to is punctured, we see that the first thing to happen is that a current is formed in the conductor, owing to the $+ve$ charge getting under way on its journey towards the $-ve$ charge.

Now as the charge leaves the condenser, the terminal voltage obviously drops, so that there is less and less voltage tending to drive the current forward as time goes on. Now this current at first finds itself opposed by the back E.M.F. of inductance produced by the wire itself.

No wire, however short or non-inductively wound, can be entirely without inductance.

The initial voltage of the condenser is therefore employed partly in forcing a current against the action of resistance, and partly in overcoming the back E.M.F. of inductance. Eventually the back E.M.F. is entirely overcome. The back E.M.F. has dropped to zero, and the current and its attendant magnetic field have therefore risen to their maxima. Further, at this instant, the terminal voltage of the condenser and the consequent electric field have fallen to zero. The condenser is then empty, the dielectric having no electric lines of force at all. The wire, however, is carrying a large current, which may even attain a momentary value of several thousands of amps., and is therefore surrounded by a powerful magnetic field.

Now this current, which had previously been counting upon the condenser for all the volts it required to keep it going, suddenly finds itself without any "visible means of support" and consequently commences to die away.

Owing to the inductance of the conductor, the back E.M.F. of inductance, which had previously opposed the growth of the current, now reappears as a forward pull, retarding the disappearance of the current.

The moving charges, which constitute the current, do therefore continue their motion and re-enter the condenser, charging it up *in the reverse* direction to that occupied by the original charge. While this charging is in process, the terminal voltage of the condenser is, of course, rising, and the forward pull of the back E.M.F. of inductance is conversely falling. Finally the current will have completely disappeared and all the energy will have returned to the condenser, except a small portion used up in producing light, heat, and noise, as before explained.

The condenser, therefore, will have been charged up with opposite polarity, and with not quite so high a voltage as at first.

The action now recommences in the opposite direction to what we had before. The current in the wire starts, grows in spite of the inductance, and the condenser becomes discharged. The current then goes on flowing, because of the inductance and in spite of the back pressure of the condenser, into the condenser and charges it up in the same direction as the original charge. Again there will have been energy expended in forming heat, &c., and so the second re-charge will be less than the first.

The whole process above described forms a complete cycle of alternating current in the conductor, only it will be seen that it is a current of peculiar nature.

Each swing of current is weaker than its predecessor, owing to its originating voltage being less, and consequently the oscillations will die away after a few swings till they are either so weak as to be negligible, or else do not possess sufficient energy to jump across the spark gap.

Such is the action of the "oscillator," which consists of a condenser whose coatings are either completely or nearly completely connected by a wire possessing inductance. Fig. 4 (*a*) and (*b*).

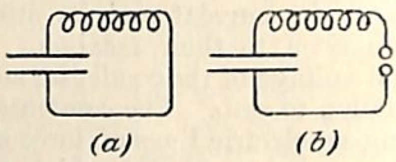


FIG. 4.

As no wire can be utterly without inductance, so no wire can be completely without resistance. Accordingly it will be seen that this decaying action, or "damping," of the oscillations is not entirely avoidable even when no spark gap is used, but the damping due to resistance can at any rate be reduced to a very small amount.

Damping may also be due to energy radiated out into space at each swing, in addition to that which disappears in heat, light and noise, and it is with this factor that we shall in future be very intimately concerned.

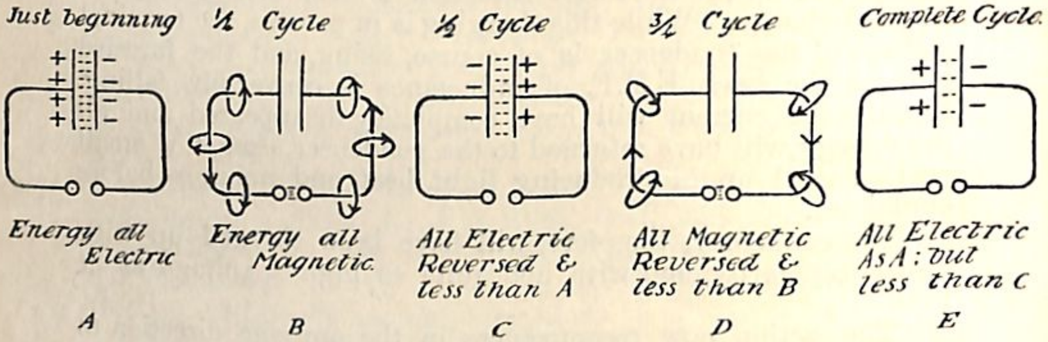


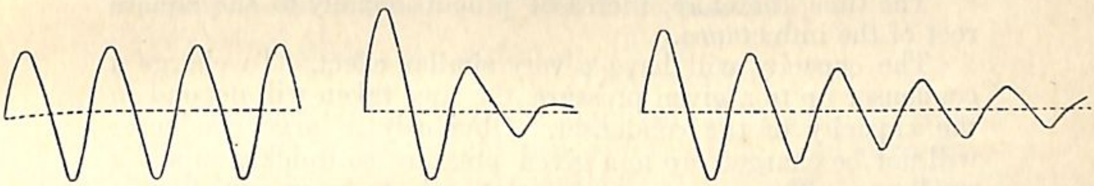
FIG. 5.

We have seen, in the above-described action, that just before the spark gap breaks down and the discharge commences all the energy is electric (*see* Fig. 5 A.) That remaining at the end of the first quarter-cycle it is all magnetic (B). After performing half a cycle it is all electric, but in the opposite sense and less in amount (C). At the end of three-quarters of a cycle it is all magnetic, but with the direction of the lines of force reversed and reduced (D). At the end of the complete cycle (or oscillation) the energy is again all electric and in the original sense, but still less in amount on account of the losses which have taken place during the transformations, and which are shown by the heat developed in the wires, and by the light, sound and heat generated in the spark gap if the latter arrangement be in use (E). At all intermediate points of the cycle, other than those enumerated above, the energy is partly electric and partly magnetic.

The total number of swings (each swing having its own discharge across the spark gap) will depend on the proportion of charge left over at the end of each swing. If a large amount of energy be taken from the circuit at each swing, there will obviously be but little left for the next one, and consequently the oscillations will rapidly come to an end. In such a case there is said to be "heavy" or "strong" damping, whereas a "lightly" or "feebly" damped circuit is one from which but little energy is taken at each swing, and in which, consequently, the oscillations last longer before they get so weak as to be negligible. *See* Fig. 6 (*b*) and (*c*).

The word "persistency" is used to express the opposite of damping. A heavily damped circuit is said to have a small persistency, while persistent oscillations belong to the lightly damped circuit. Unless there be some source of continuous oscillations, all these currents must be damped more or less, and it will be seen that wherever there is a spark gap in a circuit there is bound to be damping, owing to the energy turned into heat at each oscillation.

At present undamped oscillations can be obtained only by the use of a high-frequency alternating dynamo, or else by one of the systems of arc-telegraphy now being developed. Fig. 6 (*a*).



Undamped. (*a*) *Strongly damped.* (*b*) *Feebly damped.* (*c*)

Fig. 6.

While a closed metallic circuit is necessary for the passage of a direct current, it will be seen that for oscillations even a straight wire will suffice. A condenser in a circuit will form a complete bar to the passage of a direct current, but has no effect on an alternating current other than to change its sign; but of this we shall see more later.

We are indeed justified in making a rather bold statement, as follows:—Every body has its own period of mechanical vibration, and can be made so to vibrate. Similarly every body will vibrate at its own period electrically, and these vibrations cause disturbances in the ether which travel at the speed of light and which can be detected by suitable means at great distances from their source.

In this statement is summed up the whole principle on which wireless telegraphy is based.

Now we have been talking about the current in these oscillating circuits being an alternating one. Further, reference was made just now to a body possessing its own electrical period of vibration. Vibration and oscillation are synonymous terms. Every alternating current has a time period of its own and consequently a frequency of its own.

Now, having a given oscillating circuit, what factors will determine the frequency of its current?

The circuit has three characteristics of its own—namely, resistance, inductance, and capacity. In the circuits used in wireless telegraphy for these oscillatory currents, the resistance is purposely made small so as to minimise as much as possible the damping due to this cause.

In circuits of this kind the effect of the resistance on the time period of the oscillations is inconsiderable and may be neglected.

Now to consider the inductance. A large inductance offers more opposition to the growth and decay of any current than does a small one, so we may easily see that it will take a longer time for a current to rise to a given value in a wire of large inductance than in one of small inductance. The time, however, does not increase uniformly with the inductance. If the inductance be increased four-fold the time will be increased two-fold, and an inductance altered to nine times its previous value will cause the time to increase to three times its value.

The time, therefore, increases proportionately to the square root of the inductance.

The capacity will have a very similar effect. To charge a condenser up to a given pressure, the time taken will depend on the capacity of the condenser. Obviously a large condenser will not be charged up to a given pressure so quickly as will a small one. The same sort of variation is to be expected as in the case of the inductance; that is to say, the time period will increase or decrease in proportion to the square root of the capacity according as to whether it increases or decreases.

In a circuit containing inductance and capacity, therefore, and whose resistance is small, we may say that the time period varies directly as the square root of the product of the inductance and capacity.

This expression "varies as" needs some explanation.

It will be best explained by an example.

A man wants to buy sheep. The amount of money he pays will depend upon two things, the price of each sheep, and the number of sheep bought. Stated mathematically, it would be said that the total cost "varies directly" with the price per sheep and with the number bought. Putting this into algebraical language, we say—

C varies as PN. Where C = total cost, P = price of a single sheep, and N = number of sheep purchased.

The sign "$\propto$" is used to denote the words "varies as."

Notice that a "direct" variation means that as one thing increases, so the other thing likewise increases. Notice also that this method of calculation does not tie us down to any particular system of units. The price of things might here be given in shillings, pence, pounds, or any foreign system of coinage, yet the statement would still hold good.

Similarly we might say that the distance we walk in a given time varies directly as our speed, or that the time taken to coal ship varied directly with the amount of coal we had to get in.

Variation may also be "inverse." The time taken to walk a given distance will vary inversely as our speed. This means that the higher our speed, the less will be the time.

Stated as above we should have,

T varies as $\frac{1}{S}$ where T = time, and S = speed. Notice that the S here goes into the denominator of the fraction, for, as the denominator gets larger, the whole expression will get smaller. Again, whether time be measured in seconds, hours or days, and whether speed be measured in miles per day, miles per hour, or feet per second are equally immaterial. The statement is still true.

Other examples of inverse variation may be helpful. The time taken to mow a field will vary directly as the area of the field and inversely as the number of mowers.

The resistance of a wire varies directly as its length and inversely as its cross section. This latter case is—

$$\text{Resistance varies as } \frac{\text{Length}}{\text{Cross section}}.$$

We have seen, then, that the time period of our oscillating current varies as the square root of inductance and capacity, that is—

$$\text{T varies as } \sqrt{LS} \quad \text{where } L = \text{inductance and } S = \text{capacity.}$$

We may now tie ourselves down to units. Expressing T in seconds, L in henries, and S in farads, the relationship that holds good is—

$$T = 2\pi\sqrt{LS}.$$ For "π" *see* Appendix.

Before we pass on to consider these units more fully, it may be well to remind ourselves that the time period is not affected by the voltage of the original charge, and that the frequency of discharge is similarly independent of this voltage.

The note given out by a ship's bell depends on the natural frequency at which it vibrates mechanically. This frequency depends upon the mass and elasticity of the bell.

The same note will be emitted whether the bell be struck violently or only a little, and similarly an electrical circuit will have a natural frequency independent of the violence of the original applied impulse. The inductance may roughly be called the electrical mass, and the capacity the elasticity of the circuit.

As you give a bigger charge for the condenser to set moving, so also do you increase the ability of the condenser to do this extra work, for the voltage will have to be correspondingly higher. The strength varies directly as the task demanded of it.

Returning now to the time-period formula, we may mention that this formula may be regarded as the fundamental wireless equation.

In its present form it is not much used, owing to the fact that an inductance as large as one henry is very seldom met with unless an iron core is being used, a thing which never happens in an oscillator. Again, the farad is an unwieldy unit to have, since even the largest condenser we shall meet with in practice is only a few millionths of a farad.

Considerable stress has been laid on the necessity of the resistance of the oscillator being low. So important is this, that if the resistance be increased above a certain limit the discharge of a condenser never oscillates at all, but gradually leaks across from one plate to the other, never "over-shooting the mark" and never reversing.

Such a discharge is called uni-directional.

The limiting factor which determines whether a circuit will oscillate or not, is as follows:—Provided the resistance be not greater than $2\sqrt{\frac{L}{S}}$, the discharge will be oscillatory. Here L and S will be in henries and farads, the resistance being, of course, in ohms.

We have been considering the discharge of a condenser without reference to any particular kind of condenser, that is to say, the action will take place whether the plates of the condenser be far apart or close together. If the former were the case, we should call the arrangement an "open oscillator," while a "closed" one has the condenser plates close together. To define one as opposed to the other is not easy, for, as in the case of high or low frequency currents, there is no hard-and-fast line of demarkation between the two.

However, for all practical purposes the open oscillator consists of the aerial wire, where the thickness of the air dielectric is perhaps many feet, while a closed oscillator has a condenser whose dielectric may be air, but is more likely to be glass, mica, oil, ebonite, or some such substance whose thickness would be measured in fractions of an inch or millimetre.

The difference, to the practical user, between the two types is very marked No less important is the difference between the natures of the disturbances sent out by the two kinds.

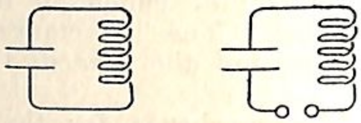


Fig. 7.

Closed Oscillator (Fig. 7).

The only energy other than heat that can be radiated by the closed type will be magnetic in its nature.

Closed loops of magnetic force will surround the wire, expanding, contracting, reversing, and again fluctuating, in sympathy with the current that causes them.

The electric lines of force, however, being confined to traversing the substance of the dielectric, never get a chance of being radiated out into their true vehicle, from a wireless point of view, the ether.

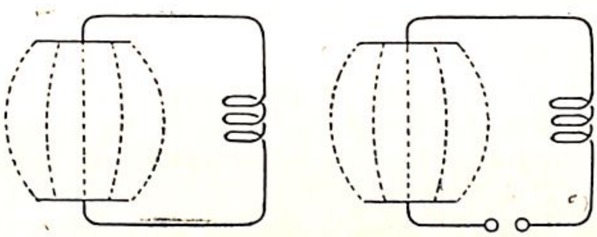


FIG. 8.

The open oscillator (Fig. 8), on the other hand, will radiate not only circular horizontal ripples of magnetic energy, but also closed or semi-closed loops of electric energy.

It will be seen that as the condenser part of the aerial becomes charged and discharged, the electric lines will expand, contract, and reverse in sympathy. As the current oscillates, we may picture these lines of force getting "cracked off" into space, like the loosely-tied end of a whip lash.

The aerial wire, therefore, possessing inductance and capacity, is a far more effective radiator than is the closed oscillator, mainly because it radiates electric as well as magnetic energy, instead of magnetic energy only.

The actions and reactions in and around an aerial wire are very complicated, and at present but little understood, but this subject will be dealt with in a later chapter.

So far so good. An aerial wire is necessary. Is it all that is required, or that can be desired? By no means.

At first sight the reader may fail to see how an aerial can be said to resemble the open oscillator just described. Where, for instance, does the condenser come in?

Aerial Wire (*see* Fig. 9).

Theory and experience have shown that the most efficient form of aerial is the well-known "roof" type. The bottom of the aerial is connected, generally, to the earth or surface of the sea. The earth forms one plate of a condenser, the wire, and especially the roof part, forms the other.

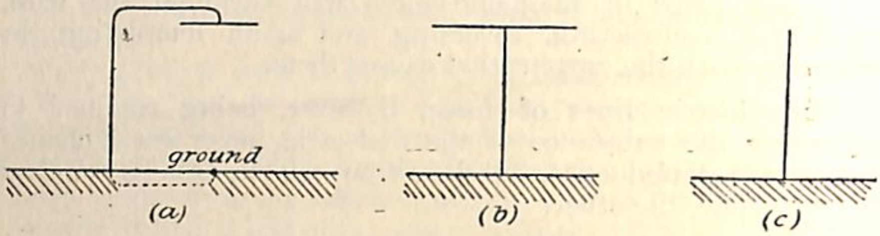


Fig. 9.

The dielectric consists of the intervening layer of air, although the actual seat of the lines of force is conceived to be the ether, and therefore to be independent of the presence of air.

Note that "sound" signals require air to carry them, hence the difficulty of hearing "up wind." Flashing and wireless do not depend on air for their transmission.

The inductance is furnished mainly by the "feeder," or wires leading down to the office. The actual calculation of the inductance and capacity of an aerial presents us with an exceedingly complex problem; suffice it to say for the present that the higher and larger the roof, or overhead part, the better is our aerial for radiating.

Now, since the height must be made as great as possible, and since the capacity of a condenser varies inversely as the thickness of the dielectric, the capacity will be small.

Again, the capacity varies directly as the area of the dielectric charged, that is, of the opposed plates.

The earth is big, but the overhead portion of an aerial is very limited, especially in a ship. Consequently this factor also goes to keep the condenser small.

It will be seen, therefore, that if we wish to charge up the aerial direct from the source of supply, the initial charge (coulombs) will be small unless we go in for an enormously high voltage. For many reasons this is inadvisable. The danger of shock is one, and another is that the "pull-off" of the trigger, or spark length, must be great. A long spark has a higher ohmic resistance than a short one. In consequence of this the damping due to resistance will be high.

Again, since the initial charge is small, this charge, when it gets in oscillation, will produce but a feeble current in the aerial, so that, although the electric lines of force may be strong enough, the magnetic ones will be weak.

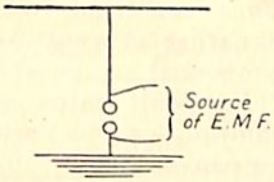


Fig 10.

This method of sending, that is, charging the aerial direct from the source, and having a spark gap in the aerial, is called "plain aerial," or, in America, the "whip-crack" method.

It is important to notice the following point.

An open oscillator parts with more energy at each swing than does a closed one, so that all other things being equal the damping due to radiation will be much more heavy in the open than in the closed type.

An efficient oscillator of the closed type will give a current time curve as in Fig. 6 (*c*). While that in an open oscillator, when charged direct, will be as in Fig. 6 (*b*). Hence the name used in America.

From receiving considerations it is important that the oscillations in the transmitting aerial should not die away too quickly, so that we must turn our attention to retaining the aerial on account of its good radiating properties giving it artificially a greater persistency than it would otherwise have.

This end is commonly attained by taking advantage of the phenomenon of *induction* between two circuits, generating the oscillations in a fairly persistent closed oscillator having a large condenser. This condenser can hold a large initial charge without an unduly long spark gap, and will part with its magnetic energy to the aerial, which thus has an oscillatory current induced in it.

To do this, a few turns of wire, called the "mutual coil" forming part of the aerial circuit, are placed in proximity to a few turns of wire forming part of the closed oscillator.

The latter now goes by the name of the "primary" and the whole aerial circuit is called the "secondary" of an "oscillation transformer."

It will be seen that the closer the mutual coil is to the primary the fewer lines of force will evade cutting the mutual coil. We thus get a high pressure induced in the aerial and a large amount of energy radiated at each oscillation. This means a few strong oscillations with heavy damping. On the other hand, if the mutual coil be rather remote from the primary, many lines of force will escape without cutting the mutual, and will, so to speak, "live to fight another day." The consequence will be that the aerial is charged to a comparatively low pressure, but that the damping of the waves is less and their life consequently longer.

The mutual coil can be regarded, from the point of view of the aerial, as an alternating current high-frequency dynamo whose terminals are connected to aerial and earth respectively, and which furnishes decadent trains of alternating voltage. This voltage and its damping can be varied at will within wide limits. This is a most convenient arrangement, for, by merely sliding the mutual coil nearer to or further from the primary, we can alter the nature of the outgoing oscillations, and thus, by experience, find that particular position of the coil which gives the best results at the receiving end with the particular detector or receiving circuit in use at the moment.

This system of sending, taking advantage as it does of the good generating properties of the closed oscillator, and of the good radiating properties of the open oscillator, while avoiding to a certain extent the bad qualities of both, is called the coupled system.

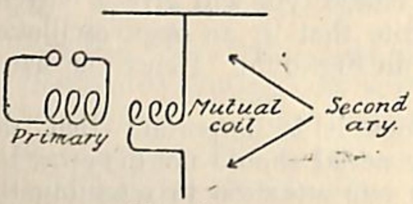


Fig. 11.

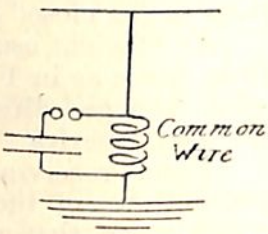


Fig. 12.

The aerial is here said to be *inductively* coupled to the primary (Fig. 11).

Another system of coupling is in use, but not in the modern Service spark-transmitting circuits, called "direct" coupling (Fig. 12).

In this type, a portion of the wire is common to both the primary and the aerial circuits. This piece of "common" wire takes the place of what is wrongly called the "mutual" in the inductive system.

Now when in the inductive (or electro-magnetic) system the mutual is close up to the primary, the two circuits are said to be "closely" or "tightly" coupled together, while the opposite state of affairs is called "light," or "loose" coupling. The latter terms are perhaps preferable in both cases, and will be used in future.

In the direct coupled type, the coupling will tighten with an increase, and loosen with a decrease, of the amount of common wire.

It now only remains to see to the adjustment of the two circuits, primary and secondary, so as to get the best results.

This process is called "tuning" or getting into "tune," and will be dealt with in a separate chapter.

CHAPTER III.

Units.

Before entering upon the subject of electrical units it will be well to get an idea of the fundamental units upon which they are based.

British Units.

These fundamental units are those by which we measure length, mass and time.

Length.

The British unit of length, the foot, is a purely arbitrary one, and consists of the distance between two marks on a certain bar of metal when at a certain temperature. This standard foot is kept at the Exchequer Office and several accurate copies are deposited in other places for safety.

It must be remembered that length, or space, is a primary conception and very difficult to define. It may, however, be said that it is "that which separates two non-coincident points."

Mass.

Again, "matter" cannot be defined, and so "mass" can only be said to be the amount of matter that a body contains.

The British unit of mass is the "pound," and consists of the amount of matter comprising a certain lump of platinum kept at the Exchequer Office.

The mass of a body is independent of its position on or off the earth, and of its temperature.

The reader must carefully distinguish between the mass and the "weight" of this lump of platinum.

The weight is merely the force with which the earth attracts a body, and this force varies at different places on the surface of the earth, being greater at the poles or at the bottom of a mine than at the equator or top of a mountain.

The process of "weighing" (except where a spring balance is used) is really comparing the mass of a certain body with known masses, since bodies of equal masses are attracted towards the earth by equal forces and are therefore said to "balance" one another.

Time.

The conception of time is inborn in man, as are those of space and of matter, so the units of time, the *second* or *minute*, may be described as being certain fractions of the mean solar day.

From these fundamental units other units are calculated, being called "derived" units. Such, for instance are those by which we measure the area of a field, the pressure in a boiler, the horse-power of an engine, or the speed of a ship.

C.G.S. System.

The French system of units has been adopted by the British Association for scientific purposes, and goes by the name of the "Centimetre-Gramme-Second" system, or, more shortly, the "C.G.S." system.

Length.

Here the unit of length is the centimetre, which is the hundredth part of a metre. The latter unit was understood to be a certain decimal fraction of the distance between the pole and the equator; but the original measurements were wrong, so the standard metre is an arbitrary length and is preserved in the French Archives.

Mass.

The gramme is the unit of mass and is defined to be the amount of matter composing a cubic centimetre of water when at its maximum density—that is, at 4° centigrade. The actual standard is not, of course, made of water, but is a small lump of platinum.

Time.

The unit of time is the same as our unit.

The relations between the two systems are given for reference:—

1 cm. = ·394 of an inch, or ·0328 of a foot.

1 inch = 2·54 cms. and 1 foot = 30·48 cms.

The pound weighs 453·6 grammes, and so contains 453·6 times more matter than does a gramme.

Derived Units.

Force.—Force may be said to be that which causes, or tends to cause, a body to alter its state of rest or of motion in a straight line.

A force may:—

(1) Cause a stationary object to get under way;
(2) Cause a moving object to stop; or
(3) Deflect a moving object into a new path;

Again, it may try, but fail, to do any of these things.

Forces have *magnitude* and *direction*. We measure their *magnitude* in pounds weight, but it must be remembered that the weight of the British pound (mass) varies with the locality. The force required to produce a certain definite slight extension of a steel spiral spring may, however, be assumed to be constant under all conditions.

A force has *direction*. That of gravity acts vertically downwards. The wind usually produces a horizontal pressure on any object exposed to its force.

Forces can therefore be represented by straight lines, whose length can represent, to some scale, pounds' weight, and whose direction, generally indicated by an arrow-head, shows the direction in which a body *would* move if it were solely under the influence of that force.

Thus :—

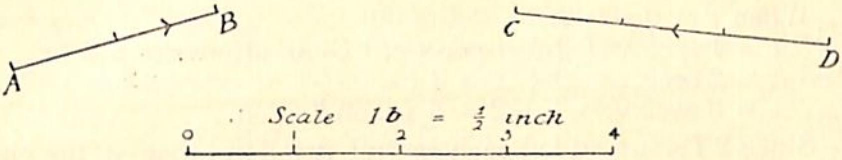


FIG. 13.

AB (Fig. 13) represents a force of 2 lbs. weight, which would move a body at A towards B. CD represents a force of 3 lbs. weight "acting" from D in the direction of C.

Velocity.—Velocity may be defined as the rate at which a body changes its position.

It is measured by the number of units of space passed over in unit time. Hence we talk of a velocity, or speed, of so many feet per second, miles per hour, or centimetres per second and so on.

When a body moves, the magnitude and direction of its velocity at any instant can be represented by a straight line.

In this case the length of the line shows to some scale, the number of units of velocity with which the body is moving, its direction, the direction of motion.

Velocity is said to be "uniform" when equal amounts of space are passed over in equal intervals of time. Thus, for uniform velocity we may say that :—

Space passed over $\propto$ velocity $\times$ time, or, where units are chosen,

$s = vt$, where s = feet passed over,
v = velocity in feet per second,
t = total time in seconds.

Consequently $v = \frac{s}{t}$, and $t = \frac{s}{v}$.

Now when a body starts, say from rest, and gradually increases speed, or when a moving body comes gradually to rest, its velocity is not uniform.

It is then said to move with "acceleration" or "retardation." The latter expression is sometimes called a "negative" acceleration, because in this case velocity is being subtracted all the time.

Acceleration, positive or negative, is measured by the number of units of velocity added to or substracted from the previous velocity of the body during each unit of time. Thus, we may have 2 feet-per-second velocity added every second.

This would be an acceleration (positive) of 2-feet-per-second *per second*. It will be noticed that acceleration is really "rate of change of velocity," while velocity was "rate of change of position."

Let us see how the velocity of an uniformly accelerated body alters from instant to instant.

Starting from rest, we say, taking the above value, that :—

When $t = 0$ $v = 0$,

$t = 1$ sec. $v = 2$ feet-per-sec. Generally written 2 f.s.

$t = 2$ sec. $v = 2 + 2 = 4$ f.s.

$t = 3$ sec. $v = 4 + 2 = 6$ f.s. and so on.

Since 2 f.s. are added each second, it follows that at the end of t seconds the velocity will be 2t f.s.

So for any acceleration of "a" feet-per-second-per-second (written f.s.s. or f.s.^{2}) we may say that the velocity (in f.s.) of a body after time = t seconds will be given by

$v = at$, provided that the body started from rest.

Again $a = \frac{v}{t}$

Acceleration is said to be "uniform" when equal increments (or decrements) of velocity are added (or subtracted) in equal time intervals.

Now what causes motion in matter? How is it produced or destroyed?

Due to the inertia (*see* page 7) of matter, no body possesses the *innate* property of altering its state—that is, it cannot get in motion from rest, or stop itself when moving, by its own agency. An *outside* force must be applied.

Let a stone drop from a height. The force of gravity, or, in other words, the weight of the stone, acts on the mass of the stone in a vertical direction downwards. The stone moves in the direction of the force. Notice that it moves faster and faster the further it falls. Its velocity is clearly not uniform. It is moving with acceleration.

This acceleration is uniform, but is found to have different values at different points on the earth's surface.

In London, a body falling freely moves with an acceleration of nearly

32·2 f.s.s., or

981 cms.-per-sec-per-sec.

We must be particular about saying falling "freely," because the air may seriously oppose the force of gravity by its resistance. If it were not for the air resistance a bullet and a feather, simultaneously let drop from the same height, would reach the ground at the same instant.

Hence the acceleration produced by the force of gravity is independent of the mass in question, but this must not be taken as the result of all forces.

We know that the weight of a mass varies with the size of the mass. Consequently in the case of gravity the bigger the mass we have to get under way, the bigger the force available to do the work.

Imagine any force not dependent on the mass on which it acts. If the mass be great it will *gradually* gather speed, and if the mass be small it will *rapidly* gather speed.

Hence we see that the acceleration produced varies directly with the force and inversely with the mass on which it acts, or

$$a \propto \frac{F}{m}, \text{ or } F \propto ma$$

We should like to choose our unit of force so that, acting on the mass of 1 lb. it produces an acceleration of 1 f.s.s. But we have seen that the weight of 1 lb., acting freely on the mass of 1 lb., produces 32·2 units of acceleration. The unit of force (weight of 1 lb.), is therefore 32·2 times too large, and the pound weight contains 32·2 absolute units of force in the British system.

This unit is occasionally used (though we shall continue with the pound weight), and it is called the "poundal."

Being equal to 1/32·2 of the force with which the earth attracts a mass of 1 lb., it is seen that the poundal is equivalent to the weight of about ½ an ounce.

In the C.G.S., system, the unit of force, sometimes called the absolute unit, is the "dyne." It is that force which, acting freely on the mass of 1 gramme, causes it to move with an acceleration of 1 cm. per-sec-per-sec.

The weight of a gramme is therefore 981 dynes.

Since 1 lb. weight = 453·6 grm. weight, the force of 1 lb. weight is equivalent to 981 × 453·6 = 445,000 dynes.

Work and Energy.

From these units of force, velocity, and acceleration we may now derive other units.

A force is said to do "work" when its point of application moves through space, be that space never so small.

Thus, a horse dragging a waggon does work, so does a man lifting a weight; but if the waggon were immovably stuck in a bog, or if the weight were too heavy for the man to lift, though the horse and man both put forth enormous exertions, neither would technically do "work."

The amount of work done is proportional to the force used and the distance through which it travels.

Thus, a man lifts a brick to the top of a wall. He does a certain amount of work. Lifting two bricks doubles the amount of work. Again, one brick lifted to the top of a wall twice as high entails twice the original amount.

The work therefore = lbs. × feet, and the unit of work is consequently called the "foot-pound." One foot-pound is expended in lifting 1 lb., weight through 1 foot, or ½ lb. through 2 feet, or 2 lbs. through 6 inches, and so on.

Work expended on a body is never thrown away. The body possesses, by virtue of the work expended on it, new properties.

It is now capable of giving up an equal amount of work when called upon to do so. This capability of doing work is called its "energy."

Energy may show itself in many different forms, and when a body gives up its energy, the consequent energy may be of one or several forms. Some of these forms may be useful to us and some useless, but the main points to notice are as follow.

No body can possess energy unless work has previously been expended on it.

Whenever work has been so expended, the body *must* possess a definite amount of energy.

Energy is indestructible. The energy imparted to a body may leave it again in many different ways, but the total amount that leaves it will be neither more nor less than that which was originally imparted.

Energy is consequently "uncreatable." Whatever energy there may be existed, perhaps in some other form, before. The supply of energy in the universe is believed to be fixed and unvariable and to have been so from all time.

Now since the energy a body contains is proportional to the work expended on the body we shall often find the words "energy" and "work" used indifferently, meaning the same thing.

Of the different forms that energy takes, we are chiefly concerned with a few broad headings:—

Energy of heat, or thermal energy.
Chemical energy.
Mechanical energy.
Electrical energy.

The light and heat of the sun, carried by the ether, probably in the form of electro-magnetic waves, arrives at the earth and is the source of all earthly energy.

Vegetation grows, and the vegetation of a few million years ago forms the coal of to-day. Animal life is supported by vegetation. Clouds are formed and the earth watered simply due to the energy emitted by the sun.

The subject is infinite in its vastness and we can but enter very briefly upon it here.

An instance may perhaps make things clearer.

Ages ago the sun gave certain units of work, in the form of light and heat, to a tree, which in process of time became a lump of coal. Stored up in this lump we have latent energy ready to be let loose at our convenience. This is called potential energy. We now allow chemical energy to appear.

The coal is ignited and its atoms of carbon, combining with oxygen from the air, give out heat. The coal being in the furnace of a boiler, heats the water therein, some of the heat being wasted up the funnel. The water boils and again we have potential energy in the pressure of the steam.

This steam is turned on to an engine. Its energy turns into energy of motion, or "kinetic" energy. Again some is wasted in heating the cylinder and bearings, in the latter case by friction. The twist of the engine is transmitted to the armature of a dynamo and is converted into electrical energy. The work thus done on the dynamo reappears in heating the conductors, as heat and light in lamps, as mechanical energy of motion in a motor, or as electro-magnetic energy radiated from our wireless set. The lamps heat the surrounding air and evaporate water, and so on. We could trace without ever ending the history of the energy originally imparted to that lump of coal.

This principle is called the law of the conservation of energy.

At present we are concerned with mechanical energy.

We have seen that work is measured in foot-pounds. Place a brick on the top of a wall. The work done = the weight of the brick in lbs. multiplied by the height of the wall in feet. The brick, due to its position above the surface of the earth, possesses potential energy, which is reckoned in foot-pounds—namely, the same number as were expended in lifting it. Allow the brick to fall to the ground. The potential energy now becomes kinetic, due to the motion of the brick.

Just before it strikes the earth, it possesses no potential but all its kinetic energy, which again is measured in foot-pounds.

To calculate potential energy, then, is easy. We have merely to see how many foot-pounds were expended in bringing about the potential state. Kinetic energy, however, presents greater difficulties.

Work done = force in lbs. × distance through which it has acted in feet, or

$$W = Fs, \text{ where } s = \text{feet of space passed over.}$$

Now to return to the brick. As it was falling, its potential energy was being replaced by kinetic. When it had fallen halfway, half its energy was kinetic and half still potential. When just about to strike ground we find its kinetic energy is greater than when halfway down. This is evidently due to its velocity being greater, for the further it falls, the faster it travels. Again, a large brick possesses more kinetic energy than does a small one falling with the same velocity.

Kinetic energy, then, depends upon the mass and velocity of a body, and we shall find that the work done to cause a body to move with a certain speed (which is the same as the energy stored in it) varies directly with the mass and directly with the *square* of the velocity generated.

Let a force F act on a mass m, causing it to move with acceleration a.

Now $F = ma$ (*see* p. 35).

Again, at the end of t seconds the velocity will be v, such that

$v = at$ (*see* p. 34).

Now, what about the space passed over?

Obviously as time goes on it will pass over greater and greater distances each second.

From the time when $t = 0$ to now, when it is t seconds, its velocity has been uniformly increasing from 0 to v.

Suppose its velocity had been *uniform* and equal to $\frac{v}{2}$, the *mean* velocity for the whole t seconds. It would then have passed over exactly the same distance. We can therefore say that the space passed over by the body in time t is given by

$$s = \frac{v}{2}t \text{ (see p. 33).}$$

$$\text{But } v = at \text{ (see above);}$$

$$\text{so } s = \frac{at}{2} \times t \text{ or } \tfrac{1}{2}at^2.$$

Now the total work done in producing velocity v must be

$$W = Fs \text{ (see p. 37),}$$

that is $\frac{1}{2}(Fat^2)$. Substituting ma for F, we have

$$W = \tfrac{1}{2}(ma^2t^2) \text{ or } \frac{m(at)^2}{2}$$

This is $\frac{1}{2}(mv^2)$ for $v = at$.

The energy stored up in a moving body, or the work it is capable of doing, is $= \frac{1}{2}mv^2$ foot-*poundals.*

Power.—Power is the rate at which work is done, and will therefore be measured by the number of foot-pounds expended every second.

For a man to walk to the top of a hill, a certain amount of work must be expended, depending upon the weight of the man and the height of the hill Whether the man runs, walks or drives up is immaterial to the work done.

The time taken cannot alter the work, but will have a great effect upon the power. The less the time taken, the greater the rate at which the work is performed.

Power therefore varies directly with the work done and inversely with the time taken to do it.

We have, then $P \propto \frac{W}{t}$

The practical unit of power has to be much larger than 1 foot-pound per second, so 550 ft. lbs. per second are chosen as the "horse-power."

550 ft. lbs per second $= 550 \times 60$, or 33,000 ft. lbs. per minute.

As an example, let a man weighing 10 stone walk up a hill 2,000 feet high in $1\frac{1}{4}$ hours. At what rate is he working?

He does $140 \times 2{,}000$ ft. lbs in all.

This is 280,000 ft. lbs.

The power, then, is 280,000 ft lbs in 75 minutes.

That is $\frac{280,000}{75}$ ft. lbs every minute, or

3737 ft. lbs per minute, or

$\frac{3737}{60} = 62 \cdot 3$ ft. lbs per sec. nearly.

His power is $\frac{62 \cdot 3}{550}$ or ·113 of a horse-power.

To return to the C.G.S. system, the unit of work is called the "erg," which is the work done by 1 dyne in moving through 1 cm.

The absolute unit of power would be a rate of 1 erg per sec.

The weight of 1 lb., which is 445,000 dynes, moving through 1 foot, or 30·48 cms., does $445,000 \times 30 \cdot 48$ dyne-cms. or ergs.

Hence 1 ft. lb. contains 13,570,000 ergs nearly.

The erg is therefore a very small unit.

Since 1 H.P. = 550 ft. lbs. per sec.

$\therefore$,, $= 550 \times 13,570,000$ ergs per sec.

$= 7,460,000,000$ ergs per sec.

The reader is now advised to refer to Appendix VI. of the Torpedo Manual, where these results are tabulated.

Electrical Units.

We now come to the electrical units, the theory governing the selection of which is a monument to the ingenuity of scientists, but a frequent source of irritation and despair to the student.

Happily, however, practical work can get on remarkably well without our being constantly on our guard as to whether a certain unit is in the electro-magnetic or the electro-static system, or what are the relative values of the different units expressed in the practical or absolute methods.

The electrical standards are those of current and resistance. From these all the others may be derived.

We shall be concerned with the practical units, which are based on the British units of length, mass, and time.

Most of them are calculated on the electro-magnetic basis, that is to say, with reference to the magnetic effects consequent on a current passing along a conductor. This corresponds to the study of motion (dynamics) in the mechanical world.

Such units are the

Ampère,	measuring	Current.
Volt,	,,	Pressure, D.P., or E.M.F.
Ohm,	,,	Resistance.

And the derived units—

Coulomb,	measuring	Quantity.
Henry,	,,	Inductance.
Joule,	,,	Work.
Watt,	,,	Power.

Potential energy, stored up in a condenser may not be accompanied by a current (or motion), so another system of units deals with the study of stationary charges and their mutual actions, being called the electro-static system.

The unit of capacity is the only one that concerns us: we have the

Farad, measuring Capacity.

It will perhaps enable us to grasp the *nature* of the electrical units better, if we draw comparisons between mechanical and electrical units.

Let— (1) Motion of matter			Be equivalent to— Electric flow in circuits.		
(2) Space - -	S	Feet	Quantity - -	Q	Coulombs.
(3) Velocity - - or Velocity - -	v $\frac{s}{t}$	F-sec "	Current - - Current - -	C $\frac{Q}{t}$	Ampères. Coulombs per sec.
Then— (4) Acceleration (Rate of change of velocity).	a $\frac{v}{t}$	F-s-s	Is equivalent to— Rate of change of current.	$\frac{c}{t}$	Amps. per sec.
(5) Mass - -	m	Lbs.	Inductance - -	L	Henries.
(6) Force (stationary).	F	lbs. wt.	Potential - -	E	Volts.
(7) Force (moving) $= m \times a$.	F	" or Poundals	E.M.F. [as that of Inductance $= L \times$ (Rate of change of current)] -	E or $L \times \frac{c}{t}$	Volts. "
(8) Momentum -	mv	No name	Electromagnetic momentum.	LC	No name.
(9) Energy of motion, Kinetic.	$\frac{1}{2}mv^2$	Ft. lbs.	E-M Energy of a circuit.	$\frac{1}{2}LC^2$	Joules.
(10) Work done in storing Potential Energy.	W or F.s	Ft. lbs.	Potential energy stored (as in condenser).	QE	Joules.
(11) Power (Rate of doing work).	P or $\frac{w}{t}$	Ft. lbs. per sec. horsepower.	Rate of change of Energy $= \frac{QE}{t}$. But $\frac{Q}{t} = C$ (*see* above).	EC	Joules per sec. = Watts.

Regarding (2) we may assume that electric charges, having no mass, can only be considered to possess dimensions.

Note also that we may regard a gallon of water as being a unit occupying a fixed space, and that a gallon and a coulomb may be compared. This is not, of course, true in many respects, so the comparison must be used with caution.

Regarding (3) we may say the strength of a current of water is "gallons per sec.," and of electricity "coulombs per sec."

Regarding (10) it will be noticed in the process of building a wall that the lower layers of bricks have to be lifted a small height only, so that to build a wall of height 10 feet, using 2 tons of bricks, we have to raise 2 tons through *5* feet.

$\frac{10}{2}$ or 5 feet is the average height to which we lifted bricks.

So also in charging a condenser we must take the *mean* value of E, E being the terminal voltage and starting from zero. The mean pressure was $\frac{E}{2}$, so we say that $\frac{QE}{2}$ joules are stored in the condenser.

Since Q = SE we have

Joules in a condenser of S farads charged to E volts are given by $J = \frac{1}{2} SE^2$.

Regarding the electrical units, the reader is already familiar with the practical units—the volt, the ampère and ohm.

The farad always, and the henry sometimes, are too large for practical use, and subdivisions of these units are employed.

Multiples and subdivisions of other units are often required, and certain prefixes are used, as follows:—

Prefix.	Language.	Meaning.	Or Shortly.
Meg- or Mega-	Greek	×1,000,000	$\times 10^6$
Kilo- - -	Greek	× 1,000	$\times 10^3$
*Hecto- - -	Greek	× 100	$\times 10^2$
*Deka- - -	Greek	× 10	×10
*Deci- - -	Latin	$\frac{1}{10}$	÷10
Centi- - -	Latin	$\frac{1}{100}$	$\div 10^2$
Milli- - -	Latin	$\frac{1}{1000}$	$\div 10^3$
Micro- - -	Greek	$\frac{1}{1,000,000}$	$\div 10^6$

* These are not often used.

Such applications as are in common use are:—

Megohm = 1,000,000 ohms.

Kilowatt = 1,000 watts.

Kilometre = 1,000 metres.

Centimetre = $\frac{1}{100}$ metre.

Millimetre $= \frac{1}{10}$ of a centimetre $= \frac{1}{1,000}$ metre.

Milliampère $= \frac{1}{1,000}$ ampère.

Millihenry $= \frac{1}{1,000}$ henry.

$$\left.\begin{array}{l}\text{Micro-henry}\\ \text{Micro-farad}\\ \text{Micro-second}\end{array}\right\} \frac{1}{1,000,000} \text{ of } \left\{\begin{array}{l}\text{a henry.}\\ \text{a farad.}\\ \text{a second.}\end{array}\right.$$

So also we can talk of a micro-millimetre. In general use among electricians we have the following units of length :—

"Mil" $= \frac{1}{1,000}$ inch.

"Micron" $= \frac{1}{1,000,000}$ inch.

Also "circular mil" being the area of the end of a wire called its "cross-section"—having a diameter of $\frac{1}{1000}$ inch. In future, to save writing long strings of cyphers, powers of 10 will be shewn thus :—

10^2 for 100
10^3 for 1,000 and so on.

The "index" number shows the total number of cyphers.

Again 4,500 may be written $4 \cdot 5 \times 10^3$ and $\cdot 00003$ would be $\frac{3}{10^5}$.

Multiplying

$10^2 \times 10^3$ we have $1,000 \times 100 = 100,000 = 10^5$.

Now $2 + 3 = 5$; so in multiplying *add* the indices.

Dividing $\frac{10^5}{10^2}$ we have $\frac{100,000}{100} = 1,000 = 10^3$.

Now $5 - 2 = 3$; so in dividing subtract the index of the denominator from that of the numerator.

For this reason $\frac{1}{10}$ is sometimes written 10^{-1}, for $1 = 10^0$,

and $\frac{1}{1,000,000}$ " " 10^{-6}

So that $\frac{100,000}{100} = \frac{10^5}{10^2} = 10^5 \times 10^{-2} = 10^{(5-2)} = 10^3$.

This method will simplify our calculations.

We have seen that

10^6 micro-henries = 1 henry.

Now the micro-henry is a very convenient unit in which to measure the inductance of our oscillators, so for shortness it is called the "mic."

Again, 10^6 micro-farads = 1 farad.

Even the micro-farad is too large for our purposes, although it is generally taken as the unit in books on wireless. This entails using small decimals in talking of W.T. circuits, so we in the Service use the "jar," being approximately the capacity of an ordinary pint-size Leyden iar.

900 jars = 1 micro-farad.

So 900×10^6 or 9×10^8 jars = 1 farad.

Now the absolute unit of inductance and capacity as given by the C.G.S. system work out as follow :—

1 henry contains 10^9 absolute units by the E.M. system.

These are called "centimetres of inductance."

Hence 1 mic. contains $10^9 \times 10^{-6} = 10^3$ centimetres.

Again,

1 farad contains 9×10^{11} absolute units by the E.S. system.

These again are called "centimetres of capacity."

$$\text{Hence 1 micro-farad} = \frac{9 \times 10^{11}}{10^6} = 9 \times 10^5 \text{ centimetres,}$$

$$\text{and 1 jar} = \frac{9 \times 10^5}{900} = 10^3 \text{ centimetres.}$$

Before the name "jar" was definitely adopted, reference will be found to capacity reckoned in "kilo-centimetres," or thousands of centimetres. It will be seen that a jar = a kilo-cm.

It is difficult at first sight to see how the absolute units of both L and S came to be of the same "dimensions," *i.e.*, a length.

The inductance of a wire varies as its *length*, and, if a straight wire have its size doubled all round (in length and thickness) its inductance is doubled.

Again, the capacity of a dielectric

$$\text{varies as } \frac{\text{Area}}{\text{Thickness}} = \frac{\text{Length} \times \text{Length}}{\text{Length}}$$

We see then, that it is of the nature of a length.

Straight wires are said to have distributed inductance and capacity, coiled wires have concentrated inductance and condensers concentrated capacity.

The relation between the joule and the foot-pound will prove useful, for then we can see what is the horse-power required to drive a dynamo giving so many watts output.

A joule = 10^7 ergs of work.

A foot-pound = $1 \cdot 357 \times 10^7$ ergs.

So that 1 foot-pound = $1 \cdot 357$ joules.

1 joule = $\cdot 737$ or nearly $\frac{3}{4}$ foot-pound.

Also :—

$$1 \text{ H.P.} = 550 \text{ foot-pounds per sec.}$$
$$= 550 \times 1{\cdot}357 \text{ joules per sec.}$$
$$= 746 \text{ joules per sec.}$$
$$= 746 \text{ watts, for } 1 \text{ watt} = 1 \text{ joule per sec.}$$

746 watts are sometimes called the "electrical horse-power." The latter part of Appendix VI. (T. Manual) above referred to should be carefully studied.

In the table given on p. 40 it will be seen that the energy stored up in a circuit of inductance L, having a current C flowing through it, is—

$$= \frac{1}{2} LC^2 \text{ joules.}$$

Here L is of course in henries and C in amps. The energy is in the form of a magnetic field. To take an example.

The shunt coils of a dynamo (iron core) of 100 henries have 10 amps. flowing. The energy expended in getting this current going, which is equal to the energy stored in the field, is—

$$\frac{1}{2} \times 100 \times 10^2 \text{ joules}$$
$$= 5{,}000 \text{ joules}$$
$$= 5{,}000 \times {\cdot}737 = 3{,}685 \text{ foot-pounds.}$$

No wonder, then, that the circuit gives a strong inductive "kick" when suddenly switched off. We have seen that a condenser of S farads, charged to a terminal potential of E volts, requires—

$$\frac{1}{2} SE^2 \text{ joules.}$$

In a W.T. circuit we might have 100 jars charged to 20,000 volts. Now 100 jars $= \frac{100}{9 \times 10^8}$ farads.

$$\text{Energy stored} = \frac{1}{2} \times \frac{100}{9 \times 10^8} \times (2 \times 10^4) \times (2 \times 10^4)$$
$$= 22{\cdot}\dot{2} \text{ joules.}$$
$$= 22{\cdot}\dot{2} \times {\cdot}737 \text{ foot-pounds.}$$
$$= 16{\cdot}4 \text{ foot-pounds.}$$

Hence each discharge starts with that much energy and probably does not turn much of it into electro-magnetic waves, owing to heat losses.

The *power* we shall radiate depends not only upon the energy per charge (or $\frac{1}{2}$ SE^2), but on the number of times per second we refill the condenser from the supply.

CHAPTER IV.

THE OSCILLATOR—*continued.*

Having now seen the system on which the "Service" units are calculated, we will now proceed to turn the fundamental wireless equation into a more workable form.

It has been shown that any circuit possessing inductance and capacity will, provided the resistance be low, oscillate with a time period given by

$T = 2\pi\sqrt{LS}$, where L is in henries and S is in farads.

We are now going to work in mics and jars, and, further, it will be useful to get rid of the expression 2π.

Now henries $= \frac{\text{mics}}{10^6}$ and farads $= \frac{\text{jars}}{9 \times 10^8}$.

So now we have, writing L as mics and S as jars,

$$T = 2\pi\sqrt{\left\{\frac{L}{10^6} \times \frac{S}{9 \times 10^8}\right\}}$$

That is $T = \frac{2\pi\sqrt{LS}}{\sqrt{9 \times 10^{14}}}$. But $10^7 \times 10^7 = 10^{14}$ and $9 = 3^2$.

$$\text{So } T = \frac{2\pi\sqrt{LS}}{3 \times 10^7}. \text{ Putting } 3{\cdot}1416 \text{ for } \pi.$$

$$T = \frac{\sqrt{LS}}{4{\cdot}8 \times 10^6} \text{ or } \frac{\sqrt{LS}}{4{,}800{,}000}.$$

So that a circuit having an inductance of 1 mic in series with a capacity of 1 jar will have a "natural" time-period of a little longer than half a millionth of a second or half a micro-second.

It will be seen that an increase of either L or S will produce an increase of T. Further, many different circuits might be made of large capacities and small inductances, or else of large inductances and small capacities, but all having the same "LS value" and consequently all the same time period.

Now we saw that the time period and frequency varied inversely as one another. As the time period got shorter, so the frequency got higher.

When the time period is expressed in seconds (or fractions of a second) and the frequency in cycles per second, we say—

$$T = \frac{1}{F} \text{ or } F = \frac{1}{T}.$$

Taking a circuit of 1 mic inductance and 1 jar capacity we see that its "natural" frequency is 4,800,000 cycles per second.

Now when we charge up the condenser and allow it to discharge itself across a gap in the form of an oscillatory spark, we know that after a few alternations, say 10 or 20, the oscillatory action ceases. It therefore lasts for but a very small fraction of a second.

Nevertheless, we are justified in talking of the frequency as being 4,800,000 cycles *per second*, because we mean that, *if* they lasted for *one complete second*, there would have been this large number of them.

In the same way we speak of a train travelling at a speed of 60 miles per hour. We do not mean that it has been 60 miles in the last hour, for it might have been stopped at a station 10 minutes ago, nor that it will go 60 miles in the ensuing hour, for it may be stopped in a collision within the next few seconds.

We merely mean that, at the instant we are talking about, the train is going at such a speed that would carry it 60 miles if that speed were maintained uniformly for an hour.

It will be seen, then, that the frequency formula may be obtained by merely turning the time period formula upside down.

We have then—

$$F = \frac{1}{2\pi\sqrt{LS}}, \text{ where L = henries and S = farads.}$$

or

$$F = \frac{4 \cdot 8 \times 10^3}{\sqrt{LS}}, \text{ where L = henries and S = jars.}$$

or

$$F = \frac{4 \cdot 8 \times 10^6}{\sqrt{LS}}, \text{ where L = mics and S = jars.}$$

All these three formulæ will be useful, but at present we are concerned with the last one only.

Now the electro-magnetic disturbances set up in the ether, henceforward to be called "waves," travel with the speed of light (*see* page 268), and we will assume that each complete cycle of alternating current in the aerial wire causes one wave to be emitted.

If the aerial be symmetrical these waves will spread out ringwise uniformly in all directions. Each new wave is born in the circular space just vacated by the outward passage of its predecessor.

Since they are all travelling at the same speed, one wave will not rush forward and "tread upon the heels" of its next ahead, nor will it lag behind and "tread upon the toes" of its next astern. They will all keep station on each other.

What will be their distance apart, and how shall we measure it?

The shortest distance between any two waves will be in a direction radial to the circle of which the aerial is the centre; that is to say, we must measure in a direction at right angles to the "front" of the wave. Fig. 14.

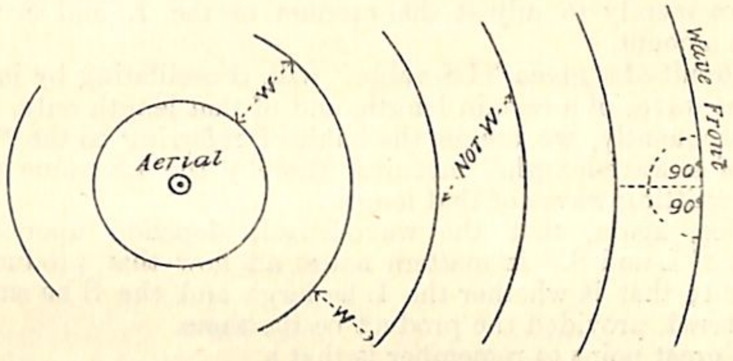


Fig. 14.

Suppose you were walking along a road counting the telegraph poles which you pass, and you notice that in two miles you pass fifty of them. To find the distance between any two poles you divide the total distance passed over by the total number of poles.

Here the distance in miles would be $\frac{2}{50}$ or ·04 mile.

Now imagine the oscillations in the aerial to continue without interruption for one complete second. By the time the last wave is formed the first one will be 186,000 miles away. Let there be F of them in all, then the distance between any pair, henceforward to be called the "wave-length," will be, *in miles*, $\frac{186{,}000}{F}$.

Now dividing by F is the same thing as multiplying by T. So we have—

$$W \text{ in miles} = 186{,}000 \times \frac{\sqrt{LS}}{4{\cdot}8 \times 10^6}, \text{ where } L = \text{mics and } S = \text{jars.}$$

It is more convenient to use feet, of which there are 5,280 in a mile, hence—

$$W \text{ in feet} = \frac{186 \times 10^3 \times 5{,}280 \times \sqrt{LS}}{4{\cdot}8 \times 10^6}$$

$$= \text{About } 206\sqrt{LS}.$$

This is the most generally useful formula in W.T. The reader should be able to extract the square root of any number.

It may be convenient, for reference, to give the wave-length formula in other units commonly met with outside the Service.

W in metres = $62 \cdot 8 \sqrt{LS}$, where L = mics and S = jars.

W in feet = $6{,}180 \sqrt{LS}$, where L = mics and S = microfarads.

From this we see that to send out a wave of definite length, we have merely to adjust the product of the L and S to a definite amount.

A circuit of a given "LS value" will, if oscillating by itself, send out waves of a certain length, and of that length only.

Consequently, we are in the habit of referring to the "LS value of a wave-length," meaning thereby the LS value of a circuit emitting waves of that length.

Notice, again, that the wave-length depends upon the product of L and S. It matters not at all how that product is composed; that is whether the L be large and the S be small, or *vice versâ*, provided the product be the same.

The great point to remember is that a

Large LS value means large period, low frequency, long wave;
and small ,, ,, short ,, high ,, short wave.

A few numerical examples may be of help here.

Example 1.

It is required to send a wave of 3,000 feet. Find the LS of the circuit.

$$W = 206 \sqrt{LS}.$$
$$\text{Here } 3{,}000 = 206 \sqrt{LS}.$$
$$\therefore \frac{3{,}000}{206} = \sqrt{LS}. \quad \text{Square both sides.}$$
$$\therefore LS = \left(\frac{3{,}000}{206}\right)^2$$
$$= (14 \cdot 56)^2$$
$$= 212 \text{ mic-jars.}$$

Example 2.

A circuit has an LS value of 27. Find the wave-length.

$$W \text{ in feet} = 206 \sqrt{LS}.$$
$$= 206 \sqrt{27}.$$
$$= 206 \times 5 \cdot 2. \quad \textit{See} \text{ Appendix for } \sqrt{27} = 5 \cdot 2.$$
$$= 1{,}070 \text{ feet.}$$

Example 3.

What is the frequency of the above circuit?

$$F = \frac{4 \cdot 8 \times 10^6}{\sqrt{LS}} \text{ cycles per second.}$$
$$= \frac{4 \cdot 8}{5 \cdot 2} \times 10^6$$
$$= \cdot 924 \times 10^6$$
$$= 924{,}000 \text{ cycles per second.}$$

Example 4.

A circuit has a time period of 1 micro-second. What is its LS value (*a*) and wave-length (*b*)?

$$T = \frac{\sqrt{LS}}{4 \cdot 8 \times 10^6}$$

$$\text{Here } T = \frac{1}{10^6} = \frac{\sqrt{LS}}{4 \cdot 8 \times 10^6}$$

$$\therefore \quad \sqrt{LS} = \frac{4 \cdot 8 \times 10^6}{10^6}$$ (For this operation *see* Appendix.)

(*a*) $\text{So } LS = (4 \cdot 8)^2.$
$= 23$ mic-jars.

(*b*) $W = 206 \sqrt{LS}.$
$= 206 \sqrt{23}$
$= 206 \times 4 \cdot 8$
$= 988$ feet.

The reader should make himself familiar with the method of working, especially that shown in examples (1) and (2). He can practice working with the service LS values of which he probably already knows the wave-lengths.

It will give the reader who makes his first acquaintance of wireless from this book an idea of the sort of thing to expect if we mention that a ship's aerial will have a virtual inductance (an expression to be explained later) of from 40 to 60 or 70 mics, while its capacity might be from $1\frac{1}{4}$ to $2\frac{1}{4}$ jars. These figures apply to aerials such as those fitted in battleships. A scout and a first class cruiser would have aerials whose values would fall short of, and exceed respectively, the above values.

The aerial in a destroyer would, of course, have small constants, such, for instance, as an inductance of, say, 15 mics and a capacity of the order of $\frac{3}{4}$ jar.

So much for the open oscillators. The closed oscillators now universally employed for the generation of the oscillations will naturally vary according to the wave-length to be emitted.

As a general rule we shall have a fairly large condenser and only so much inductance as is absolutely necessary.

The inductance is necessary in order to be able to have some lines of magnetic force wherewith to energise the mutual coil and so get the oscillations going in the aerial.

It therefore often happens that the condenser has two or even three adjustments, so that we can use the small, medium, or large values for the transmission of short, medium and long waves respectively. The fine adjustment necessary to bring the primary to the exact LS value required is most easily obtained on the inductance coil by means of a clip, whereby we can take the whole, or any less part of the total inductance available. In reducing the inductance to a minimum we must be careful to leave at least one complete turn of conductor, and that one turn should be at the end of the coil nearest to the mutual. Otherwise the mutual coil would be unable to get enough energy from the primary.

The primary, then, may have a condenser ranging from, say, 5 jars for very short waves, to 150 or so for long ones. The inductance might have a maximum value of about 20 mics, and when special precautions have been taken to cut it down to a minimum, might have as small a value as $\frac{3}{4}$ mic.

It must be remembered that the inductance of the leads to the spark gap have been included in these values.

In the same way that there is no hard-and-fast rule laid down as to what is an high and what a low frequency, so also there is no fixed dividing line between long and short waves.

A wave that is short from a battleship's point of view may be of a considerable length when about to be sent on a destroyer's aerial.

As a general rule, we speak with reference to a battleship. Now the "natural" wave-length of the aerial of such a ship would be about 1,700 to 1,800 feet, so anything longer than that would be called "long," and the other ones "short."

For the reasons explained in Chapter II., we saw that the best method of energising the aerial was to generate the oscillations in a closed circuit and then to transfer them to the open circuit by taking advantage of the phenomenon of the inductive actions of two adjacent circuits.

The whole apparatus may be called an "oscillation transformer," of which the closed oscillator coil forms the primary and the mutual coil the secondary.

Remember that the mutual coil applies a high-frequency alternating voltage to the aerial.

We now come to a point of extreme importance.

If an oscillatory circuit have an alternating E.M.F. set up in it, and if the frequency of this E.M.F. *agree with the natural frequency* of the circuit, then an immensely greater current will be produced than if the periods do not agree.

This exaltation of the alternating current, attained by "syntonising" the natural frequency of the circuit with that of the applied E.M.F., is said to be due to "electric resonance." This last word is one used in the study of sound.*

We are all familiar with the mechanical equivalent of this remarkable fact. Remembering that force corresponds to E.M.F., in the mechanical analogues given in the last chapter, and that motion corresponds to current, we will consider a few common examples, for the similarity is exact, and cannot be too fully realised.

First consider a pendulum. Even a very heavy bob may be set in violent oscillation by gentle taps, or even puffs of air,

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* The correct word to use should be "consonance," but the other is in such common use that we may adopt it permanently.

provided that they are administered at such instants as agree exactly with the natural period of the pendulum.

In other words, each tap must arrive just when the pendulum is ready to receive it, neither earlier nor later.

Another common example is in the case of a destroyer or any ship with rather light scantling. We know that these ships are liable to vibrate when under way very much more at some speeds than at others. The reason for this is that the ship, due to her mass (inductance) and elastic "compliance" (capacity), has a natural time period in which she will always try to vibrate when "whipping" in a fore and aft direction.

Should the comparatively feeble thumps of the engines have the *same* time period, the amount of swing will be vastly and most uncomfortably increased.

In some cases this resonance effect may be very dangerous.

A case has occurred of a factory building completely collapsing due to the engine picking up the natural frequency of the building. Again, a body of soldiers, when crossing a suspension or girder bridge, should always break step in order that their foot-beats may have no definite frequency (or periodicity) at all.

In the aerial wire, then, we have induced a series of impulses of alternating E.M.F., of a definite frequency, depending on the L.S., value of the *primary*. There will consequently be an alternating current due to this voltage.

This induced current can be enormously increased, greatly to the improvement of the signals, by so adjusting the natural frequency of the aerial circuit, that it is identical with that of the primary. In other words we have to make the aerial have the same LS value as has the primary.

This process of adjustment is called "tuning," and the two circuits when thus adjusted are said to be "syntonised," "in syntony," in "resonance," "in tune with each other," or, more shortly and commonly, simply "tuned."

For this reason any wave of a given length is often referred to as a "tune," generally preceded by a letter distinguishing it from other wave-lengths or tunes.

The principle, then, on which we are working is that of having two tuned, coupled oscillators, and it will be noticed that the tightness or looseness (*see* page 30) of the coupling is another important factor to be considered.

The tuning is effected by varying either the capacity or inductance, perhaps both, of either circuit until the resonance effect is obtained. There can be no mistake as to when the circuits are in syntony, since the rise in current in the aerial is most marked.

If oscillations are set up in a circuit which are in agreement with its natural frequency they are called "free oscillations." If, however, oscillations are maintained which have a frequency different from the natural frequency of the circuit, they are called "forced oscillations."

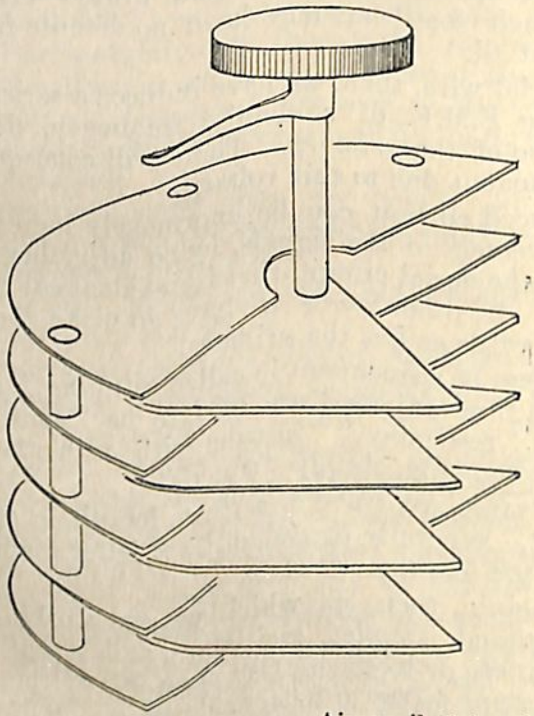
It may, perhaps, be remarked that it is not necessary that one of the circuits should be open and the other closed.

Any two oscillators whose natural frequencies are identical will exhibit this resonance effect when coupled together, either "directly" or by the "electro-magnetic" method. (*See* page 30.)

In the first case we have an oscillation transformer of the type known as an "auto transformer"; in the second case the two windings are separated by insulation and we have the ordinary type of transformer.

It will be seen, then, that a necessity at once arises for measuring accurately the LS value of any circuit, for thus shall we be able to construct a circuit to emit any desired wave-length. Not only that, but we can tune up two circuits separately to the same LS value, couple them together, and they will then be found to be in syntony.

This process is carried out by means of the wavemeter.



Variable Vane Condenser. Air or oil dielectric.
FIG. 15.

This instrument consists essentially of a closed oscillator whose LS value can be adjusted to any known amount within wide limits. The inductance is formed of a coil of wire, and several such coils of varying known inductances are supplied. One of these coils is selected and connected up to the terminals of a condenser whose capacity can be altered very gradually. This latter is effected by having an air or oil dielectric and a series of metal plates cut in the form of semi-circular segments. The odd-numbered ones are mounted one above the other at equal fixed intervals, attached to a rigid support, while the even numbered ones are mounted in a similar manner on a rotating pivot. (*See* Fig. 15.) These latter plates can then be introduced into the interstices between the fixed plates so as to overlap them more or less. The greater the overlap, the greater the capacity. The amount of overlap is measured by a pointer travelling over a scale of degrees.

The capacity of the condenser has been carefully measured for, say, every 10 degrees, by comparison with a standard condenser; the resultant capacities corresponding to any number of degrees of the pointer can then be read from a curve, which is supplied with every condenser.

Now, if this closed standard oscillator be brought into the proximity of any circuit in which oscillations are going on, and whose LS value it is desired to measure, an oscillating current will be induced in the wavemeter circuit having the same frequency as that in the circuit to be measured.

The current in the wavemeter circuit will therefore be in the form of "free" or "forced" oscillations, according as to whether the wavemeter circuit has or has not the same LS value as the circuit being measured.

By selecting a suitable inductance and then by varying the capacity in the wavemeter circuit we can bring the latter into resonance with the circuit being measured.

When this happens, and only then, the current in the wavemeter circuit will be at a maximum, for the oscillations will then be "free" ones.

It will be seen, then, that we must have some means of telling when the current in the wavemeter is at a maximum, for, after adjusting the latter circuit till this effect is attained, we can read off the curve the capacity at which the condenser happens to be standing, multiply it by the known inductance of the wavemeter circuit, and the product will be equal to the LS value of the circuit being measured.

Knowing this, we can tell what the length of the emitted wave will be.

Hence the wavemeter arrives at its measuring of waves in a rather roundabout manner.

The relative strength of the current in the wavemeter from instant to instant may be shown by several different methods. Notice that we are not concerned with the actual value of the current in ampères, but that we merely want to know when it is at a maximum, for at that instant the LS value of the wavemeter circuit will be that of the required circuit.

It is therefore not necessary to calibrate the current indicating device any more than it is necessary to calibrate a Menotti.

The type of current indicator used will have to be rather peculiar. Any device depending on the magnetic properties of a current will present great difficulties, because, as the current reverses, so the magnetisation reverses.

If any ordinary galvanometer were used, the needle would get a "kick" first in one direction and the next moment in the opposite direction. Consequently it would not move at all.

Now the heating effect of a current is independent of the direction in which the current is flowing. When the current is at a maximum the heating effect will be at a maximum.

The Service wavemeter takes advantage of this property of a current, and the deflections on the galvanometer supplied with the wavemeter are proportional to the heat developed at the moment by the current in the oscillatory part of the circuit flowing across a thermal junction, which acts as follows:—

The heating of the junction of two fine intertwined wires (of steel and eureka) by the passage of the oscillatory current, causes a *direct* D.P. to be formed at the outer ends of the wires, which, in turn, are connected to the terminals of a galvanometer. The swing in the latter depends on the D.P., the D.P. depends on the heat, the heat on the oscillatory current, and the current on the state of syntony of the wavemeter circuit with that which is to be measured.

Other wavemeters than those at present in the Service may make use of different methods of telling when the wavemeter circuit is in resonance with the circuit being measured. For instance, the maximum glow in a vacuum tube, noise in a pair of special telephones, swing of a hot-wire ammeter, glow of an incandescent lamp or temperature of an air thermometer can all be used to indicate the moment when the current is at a maximum.

It appears, then, that if we can set up oscillations in any circuit, we can measure the LS value of that circuit by placing the wavemeter near it and adjusting the latter until its own LS value is equal to that of the unknown circuit.

This state of affairs is made evident by the galvanometer or other detecting device, and the whole process hinges upon the fact that the induced current in the wavemeter circuit will be much larger when the two circuits are in resonance than at any other time.

There are a good many precautions to be observed in order to eliminate errors in reading. Since "personal" errors can never be entirely eliminated, the next best thing we can do is to make all the errors the same and as small as possible.

In the effort to attain this end, considerable care has to be exercised.

All wavemeters, before being issued to the fleet, are carefully calibrated by comparison with certain standard instruments which are kept in H.M.S. "Vernon" and which are so arranged as not to be affected by changes of temperature, atmospheric pressure, or other outside influences.

When we come to use a wavemeter we must try to get rid of disturbing influences as much as possible.

If the instrument be placed too near an iron bulkhead or safety screen the proximity of the iron will alter the value of the inductances.

Again, the proximity of your hand to the condenser will slightly alter its value from that shown on the curve.

It is very difficult to eliminate entirely this latter source of error, but we can at any rate keep the error constant by adopting a certain position for our hand, keeping it always in that position.

It goes almost without saying that, during the taking of a reading, no portion of either circuit must move, nor must the spark length or voltage be altered.

The ideal conditions for working will be realised when the spark in the circuit being measured is not spluttering or ragged, but is so steady that if the wavemeter be set to any reading and then left alone, the galvanometer reading stands firm, without jumping up or down.

When measuring an actual transmitting circuit, we cannot always afford to have a continuous torrent of sparks for fear of overloading our source of power. We have, therefore, to help ourselves to current in short bursts by making a succession of "shorts" on the signalling key.

This has, of course, to be performed by a second person, and the ease and accuracy of "tuning up" depends very largely on the way these shorts are made.

The first consideration is uniformity, both in duration and spacing. There is no need for extreme rapidity, which only tires the operator, so that he very soon begins to make irregularly. The "spaces" can be made shorter, and the actual shorts made longer, than in real signalling, with considerable advantage.

A minute description of the instrument would be out of place in a book of this nature, but a few general hints will be of universal application.

The wavemeter should be as far away as possible from the circuit being measured.

If the wavemeter circuit be too close to that being measured not only will the induced current stand a chance of damaging the instrument, but the "mutual induction" of the two circuits will come into play and vitiate the accuracy of our results. In other words, two circuits very closely coupled together react one upon the other and their several inductances will be different from what they were when separated.

Remember that the word "inductance," properly speaking, should be taken to include "self-induction" and "mutual induction" as well.

To have any "mutual induction" at all, it is presupposed that at least two circuits are being employed; but if they be some distance apart the amount of mutual action is very small.

The calculation of this quantity is very complicated, so, by putting our circuits as far apart as possible, we endeavour to make the mutual induction so small as to be negligible without affecting the correctness of our results.

Another point worth mentioning is that the spark in the circuit we are measuring need not be large.

In cases where the transmitting instruments are inside a safety screen made of an iron grid, it will not be possible for lines of force to reach the wavemeter if the latter be outside the screen, for they will be caught up by the screen, in which they will cause eddy-currents.

Now the wavemeter must be outside the screen, for the safety of the operator, so a loop of wire whose terminals are in series with the wavemeter circuit, is introduced through a hole in the screen and placed so that it will be threaded by some of the lines of force from the circuit we are measuring.

This loop of wire is called the "wavemeter mutual," for it performs the same office for the wavemeter as the mutual coil does for the aerial, that is, supplies it with an oscillating E.M.F.

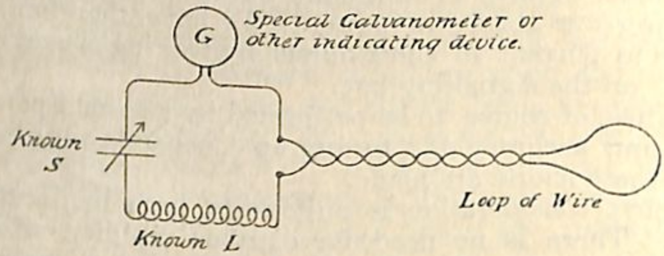


FIG. 16.

It is a good thing to make a wavemeter mutual in the form of a rigid insulated hoop of wire, whose inductance can be measured carefully, and to connect it up to the wavemeter by means of a long piece of flexible cabin-wire. The latter wire, whose two strands are laid up non-inductively, may be assumed to cause no difference to our readings, but the inductance of the loop part must be added to that of the particular coil of wavemeter inductance we happen to be using at the time. The smaller the loop the better, for then, if we do make an error in estimating its value, that error will not be large.

Placing this loop inside the screen so that its plane is parallel to that of the coil of wire forming part of the circuit to be measured, we find that if the two are close together we get a strong effect in the wavemeter. This effect may be weakened by moving the loop further away, or by *turning it round* so that its plane and that of the coil being measured are at an angle. This hint will be found of use when the space inside the screen is restricted, and we do not want to bring the loop too near the iron of the screen.

If the effect on the wavemeter be strong, the galvanometer needle will swing right across the scale directly anything near the point of resonance is reached. Whenever the needle is near this extreme position we must watch and see that sparking is not taking place between the plates of the wavemeter condenser. If this be allowed to happen, we shall get false readings, for the spark temporarily short-circuits a pair of condenser plates, thus altering the capacity of the condenser.

In all physical measurements, even if we are merely measuring off a yard of serge, exact measurements cannot primarily be expected. The efforts of the man are directed towards making the *difference* between the real lengths so small as to be negligible.

Should we want to find out the LS value of the open oscillator, or aerial, we may put a spark gap in the foot of it and make it oscillate at its natural frequency, as in Fig 17.

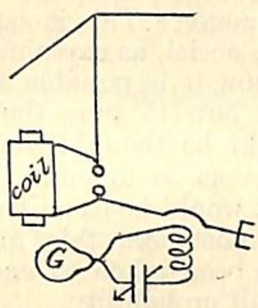


FIG. 17.

It will be noticed that we are thus sparking into the aerial and that the arrangement is now "plain aerial" (*see* p. 29).

A transformer must on no account be used for obtaining this spark, for a shock to anyone touching the aerial would then be fatal, the current output of a transformer being much greater than that of an induction coil.

If we want to know the value of the aerial, then, we must spark into it using a coil, preferably with hammer make and break.

In this case there will not be any dangerous pressure about, although a shock from the non-earthed side of the spark gap will be exceedingly unpleasant. We may therefore dispense with the wavemeter mutual, and place the instrument near the low-pressure side of the spark; that is, near the lead going to earth. Since the capacity of the aerial is small, the oscillating current in the aerial will not be very strong, and it may be necessary to bring the wavemeter inductance coil within an inch or so of this part of the aerial. It is for this reason that we avoid putting it near the high-voltage side of the spark gap.

Now in practice, the most frequent use of this instrument is not that of measuring an unknown LS value, but rather that of adjusting the transmitting gear so that it shall have certain fixed, known and pre-determined values.

Again, it is not necessary to adjust or "tune up" both the open and the closed oscillators separately to the same LS values and then to couple them together; although this process is quite correct. If carried out, it necessitates great alterations of the wiring and consequent waste of time.

Now the primary in an installation requires no alteration before we are able to spark into it, for the gap is already there, and the charging circuit complete.

Hence the practical method is to tune up the primary till it has the requisite LS value, and then to couple the aerial circuit to it. There will be, at first, forced oscillations produced in the aerial circuit, but we can adjust its LS value to equal that of the primary, and so turn the forced into free oscillations.

Under these conditions, the aerial will oscillate violently and the current in it will be at a maximum, a state of affairs that can be made visible or otherwise perceptible in various ways, without the use of the wavemeter. This is usually done by hanging a vacuum tube near the aerial, as explained later.

Having now seen how it is possible to adjust the primary to any LS value, and how to tune the aerial circuit to the same LS value, it might be thought that if two stations were tuned up in this manner so as to emit the same wave-lengths, then the waves sent out would be exactly similar in character.

Under certain circumstances this may be the case, but unless precautions have been taken to ensure this result, such will not be the case in all probability.

Two circuits which have been tuned to the same LS value and which are then "coupled" together exhibit a peculiar property for which we are at a loss to find a mechanical parallel.

By "coupled" circuits we mean that the two are under the mutual influence of each other's lines of force.

Coupling may be—

(*a*) "Inductive" or "electro-magnetic."

(*b*) "Conductive" or "direct" (*see* p. 30, Figs. 11 and 12).

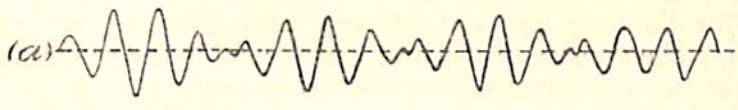
We are at present concerned with the first one only.

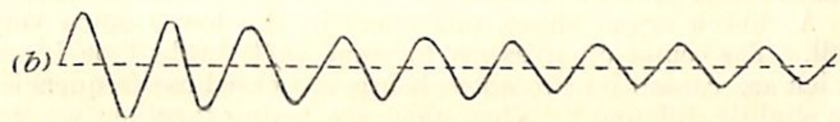
The interactions between two tuned circuits are very complicated, especially when the oscillations set up are such as those produced by a "spark" discharge, for the calculations are further involved by the respective "dampings" of the two circuits. Further, it may be said that the subject is not yet thoroughly investigated in all its details.

However, the net result may be expressed in a few words.

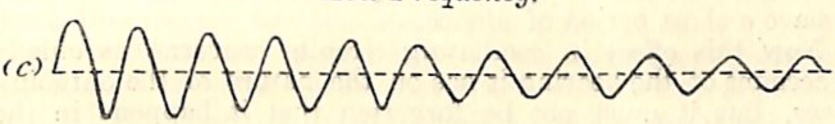
In a spark system of transmission, though the natural free frequencies of the two circuits may be the same, their mutual interaction may cause the energy to sway to and fro between them.

This surging of energy backwards and forwards between the primary and aerial causes the train of waves emitted from the latter to take the form of a series of "beats," as shown in Fig. 18 (*a*).

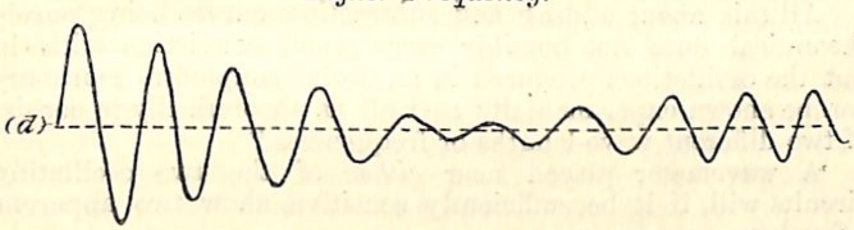




Low Frequency.



Higher Frequency.



Sum of (*b*) *and* (*c*).

FIG. 18.

This complicated-looking curve can be analysed into its constituent parts, which are two frequencies superimposed one upon the other as in (*b*), (*c*), and (*d*).

At first sight it looks improbable that two curves can be combined into one, but if the reader will draw two sine curves on the same piece of paper, giving them slightly differing time periods, he will find that at some points the curves are in step with each other and at others they get in opposition—that is, one is above and the other below the line. (Compare (*b*) and (*c*).)

If he now construct a third curve (Fig. 18 (*d*)) whose height at any place is equal to the algebraical sum of the two first curves at that place, he will find that the new curve will swell and die away, swell and die away again at regular intervals of time depending upon how close together he took his original frequencies.

By "algebraical sum" we mean adding the two when both are +ve or both −ve, but taking the difference, when one is +ve and the other −ve. In the latter case, should the +ve one be the larger, the resultant point will be above the horizontal line, while if the −ve one be the larger, the ordinate must be plotted below the line.

The nearer together the two frequencies the longer time it takes for them to get out of step, and also to get into step again. The number of "beats" per second is the difference between the two frequencies in cycles per second.

It will also be noticed that the resultant, or third, curve takes up a frequency of its own, which is not the same as that of either of the two other curves, but is between them.

A church organ shows this effect in the lower notes very well. The sound often seems to come in "throbs" or beats, which are caused by two notes being struck whose frequencies are slightly different. When they are acting together we get the sound; when in opposition they cancel each other out, and we have a short period of silence.

Now this effect in oscillating circuits concerns us chiefly on account of the bearing it has on the nature of the outgoing waves, but it must not be forgotten that it happens in the primary as well as in the aerial.

All this about adding and subtracting curves being purely theoretical does not possibly carry much conviction with it, but the oscillations produced in an aerial coupled to a primary can be shown experimentally as well as theoretically to consist of two different wave-lengths or frequencies.*

A wavemeter placed near *either* of the two oscillating circuits will, if it be sufficiently sensitive, show two apparent LS values.

Of this aspect of the affair we shall hear later. At present we may ask, what causes it and upon what does it depend?

The character of the "beats" depends mainly on the relative resistances, and consequently the damping, of the two circuits and also upon the degree of coupling—that is, whether the coupling be tight or loose (*see* p. 30).

Two sending stations, therefore, in order to emit exactly similar waves, must not only be tuned up to the same original LS value, but must have the same damping and the same degree of coupling.

Disregarding, for the present, the question of damping, we see that the character of the outgoing waves depends upon the distance apart of the two circuits.

If the coupling be tight, that is if the two circuits be close together, this double frequency effect will be more

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* This does not apply to the "quenched spark" system, which will be described later.

marked than with a loose coupling. By this we mean that the high frequency will be considerably higher, and the low one considerably lower, than the original frequency to which the circuits were separately tuned.

In other words, the wavemeter will give us two readings, showing two LS values, one bigger (the low frequency) and one less (the high frequency) than the original reading.

Also, the further apart these readings are, the tighter is the coupling.

The production of these two unequal readings is therefore due to the presence of "mutual induction" between the two circuits. Indeed, the whole action may be explained by imagining that the mutual induction affects the self-induction of the two circuits, thus altering their inductance and producing different LS values to what we had when the circuits were separate.

A mechanical analogy will possibly help to explain the matter, but it must not be carried too far, because the similarity is not quite exact.

Let a string be fastened loosely across a room, and from two points on it a few feet apart, attach two pendula of equal length. These two pendulums should have been previously adjusted to have the same time-period when tested separately. Now set one of them in vibration in a plane at right angles to the string. The other pendulum will at once begin to swing, because the first pendulum in its vibration imparts little jerks to the string, and so administers impulses which set the second pendulum in vibration. It will now be found that as the second pendulum begins to oscillate the first one comes to rest. When the latter is momentarily motionless the former is at full swing. The process then repeats itself, and the motion is gradually handed back from the second to the first.

Each pendulum when tested separately will vibrate with one frequency and with one only, just as any given oscillator has one definite "natural" frequency; but when two such pendula or oscillators are coupled together, whose separate natural time-periods are the same, then their mutual interactions are such that *both* pendula or oscillators vibrate, not alternately, but simultaneously, with a double frequency, one higher and the other lower than the natural frequency of each.

It will be seen, then, that a pendulum bob, even when momentarily at rest, may still be said to be vibrating with a double frequency—only, *at that instant*, the two swings are in opposition, producing rest. When, however, they are acting in unison, then the vibrations are at a maximum. What happens then, in the coupled transmitting circuit, is that the primary, starting with initial energy ($\frac{1}{2}$ SE^2 joules) hands this energy over to the aerial. The latter radiates some and hands the rest back to the primary, which again oscillates, giving its energy back to the aerial. This give-and-take may go on several times over during the life of one oscillatory discharge of the primary condenser.

The more nearly the aerial is in tune with the primary the more readily will the initial energy of the latter pass into the former, and the less will be the "quiescent" periods of the aerial, compared to its "active" periods.

Again, the tighter the coupling, the more often shall we have the give-and-take action going on in any one train of oscillations. This is because the beats get out of and into step with each other at shorter intervals of time, and the number of beats per second is increased.

Measurement of Couplings.

In most books on W.T., it will be found that coupling is expressed in the form of a "coupling coefficient" or "coupling factor," such that :—

$$K = \frac{M}{\sqrt{L_1 L_2}}$$

Where K = coupling factor.
M = mutual induction between the two circuits.
L_1 = self-induction of one circuit.
L_2 = self-induction of the other circuit.

Now the mutual induction may be taken as proportional to the lines of magnetic force linked between the two circuits.

Some of the lines of force produced by one circuit will not cut the other circuit, but *all* lines cut the circuit in which they originate (that is, their own circuit).

Hence M. must be smaller than $\sqrt{L_1 L_2}$.

Hence K must be less than 1.

It will be seen that in a "perfectly tightly" coupled circuit K would be 1.

In a "perfectly loosely" coupled circuit M = 0, and so K = 0. Here, since M = 0, there would be no transfer of energy to the second circuit at all.

Both these conditions are impossible in practice, so that we shall have K never as small as 0 and never as great as 1.

Now the two wave-lengths, although intermingled, are shown separately by the wavemeter unless the coupling be very loose.

Similarly we can give them separate formulæ.

Assuming that each circuit has been tuned up separately to emit a wave-length = W, then when coupled together there will be these two chief waves sent out. (There are others also with which we shall deal later.)

The long wave = $W_{Long} = W \times \sqrt{1 + K}$.

The short wave = $W_{Short} = W \times \sqrt{1 - K}$.

It may be thought, at first sight, that the mean of W_L and W_S would be = W, but this is not so.

This will be shown best by an example.

$$\text{Take } W = 2{,}000 \text{ feet and } K = \cdot 25.$$

$$\text{Now } W_L = 2{,}000 \times \sqrt{1 + \cdot 25}.$$
$$= 2{,}000 \times \sqrt{1 \cdot 25}.$$
$$= 2{,}000 \times 1 \cdot 12.$$
$$= 2{,}240 \text{ feet.}$$

$$\text{And } W_S = 2{,}000 \times \sqrt{1 - \cdot 25}.$$
$$= 2{,}000 \times \sqrt{\cdot 75}.$$
$$= 2{,}000 \times \cdot 867.$$
$$= 1{,}730 \text{ feet.}$$

$$\text{Now mean is } \frac{2{,}240 + 1{,}730}{2} = \frac{3970}{2}$$
$$= 1{,}985 \text{ feet.}$$

The long one is 240 feet longer than 2,000.
The short one is 270 feet shorter than 2,000.
Let us now turn to the LS values.

$$W_L = 2{,}240.$$
$$\text{So } 2240 = 206 \sqrt{LS}.$$
$$\therefore \sqrt{LS} = \frac{2240}{206}$$
$$= 10 \cdot 28.$$
$$LS = 118.$$

$$\text{And } W_S - 1{,}730.$$
$$1{,}730 = 206 \sqrt{LS}.$$
$$\sqrt{LS} = \frac{1{,}730}{206}$$
$$= 8 \cdot 42.$$
$$LS = 70 \cdot 7.$$

These are the values that the wavemeter gives.
Now take the mean of these two LS values.

$$\text{This} = \frac{118 + 70 \cdot 7}{2} = \frac{188 \cdot 7}{2} = 94 \cdot 35.$$

But, taking this again we have

$$W = 206 \sqrt{94 \cdot 35}.$$
$$= 206 \times 9 \cdot 72.$$
$$= 2{,}000 \text{ feet.}$$

So the mean of the two LS values as given by the wavemeter will be equal to the LS value to which the circuits were separately tuned.

Conversely, if we find these LS values have a mean equal to that to which we tuned our primary, we can say that the two circuits are *exactly* in resonance.

In tuning up the coupled oscillators we will bear in mind that we must so adjust them that the mean of the two LS values as given by the wavemeter must be made equal to the LS values to which we originally adjusted the primary circuit.

The tuning of the aerial till resonance is attained with the primary is carried out by means of some such device as a vacuum tube, and the result obtained in this way can only be considered approximately correct. When the wavemeter is applied and the two readings found, we can then see if. the two LS values have the correct mean. If they have, well and good, the two circuits are exactly in resonance.

If the mean of LS values, on the other hand, be larger than that to which we tuned the primary, then the secondary *cannot* be exactly of the same LS value as the primary.

It is too big, and must be reduced a little.

The process of getting into tune is completed when these LS values have the correct mean, that is, one which is equal to the LS to which we are tuning up.

Until we have attained this result it is no good thinking about measuring the coupling.

We will now assume that exact syntony has been obtained, and the next thing is to measure the coupling.

The method indicated above (using a "coupling factor") is very clumsy to use, because the mutual induction is a quantity which is very difficult to measure without a great deal of calculation.

We therefore make use of the difference between the waves emitted as a measure of the coupling, expressing it as a percentage of the wave-length to which we tuned the primary.

It will be seen that the tighter the coupling, the further apart will be the wave-lengths, and the bigger the percentage.

Finding the LS value of the two waves from the wavemeter, we work out their corresponding wave-lengths. We then subtract the shorter wave from the longer, and divide the result by the number of hundreds of feet in the original wave-length.

This method possesses the advantage that it does not matter whether the waves are given in feet or metres. If in the latter units, we take the difference in metres and divide by the number of hundreds of metres in the original wave-length.

In example previously worked out, where "K" was = ·25, we saw that the two waves were 2,240 and 1,730 feet respectively, while the original wave was 2,000 feet.

$$\text{Difference of waves} = 2{,}240 - 1{,}730.$$
$$= 510 \text{ feet.}$$

Now 2,000 contains 20 hundreds of feet.

$$\text{So coupling} = \frac{510}{20} \text{ or } 25\cdot 5 \text{ per cent.}$$

Similarly we can turn our method of measuring couplings into the theoretical method from which, if we know L_1 and L_2, we can deduce the value of M, the mutual induction.

The accompanying table gives the relationships between different values of "K" and the corresponding couplings per cent. It shows that the value of "K" can be found very nearly by dividing the percentage by 100.

Coupling factor or coefficient (K).	Corresponding percentage.
·05	5
·1	10·14
·2	20·1
·3	30·5

Henceforward we shall refer to couplings by their percentage values only.

There is no exact division line between what is a tight and what is a loose coupling. In the Service at the present moment we are tending towards looser and looser couplings owing to a loose coupling causing the waves to interfere less with waves of different lengths. Consequently people who are not in the Service talk of a coupling as being "loose," whereas we might possibly regard it as fairly tight.

As a rough guide, we may say that in the Service any coupling tighter than about 7 or 8 per cent. would be called tight, and that anything less than 3 or 4 per cent. would be loose. Commercially, 15 or 16 per cent. would perhaps not be thought too tight.

The bearing which the tightness or looseness of the coupling has upon the reception of the waves will be dealt with in a later chapter; for the present we will notice what effect it has on the nature of the outgoing waves.

A tight coupling will be the result of putting the mutual coil close up to the primary. In this case a large number of magnetic lines from the primary will cut the mutual at each alternation of current, and the voltage induced in the mutual coil will therefore be high. A tight coupling means a big pressure in the aerial.

Again, the interaction between the two circuits is strong, and the waves are far apart, thus giving a large percentage difference.

Further, since the frequencies of the two waves differ considerably, the "beats" of current will succeed each other at short intervals of time.

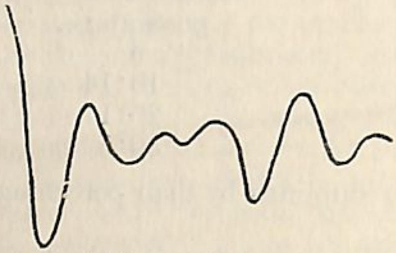
Not only this, but another important effect will be noticed.

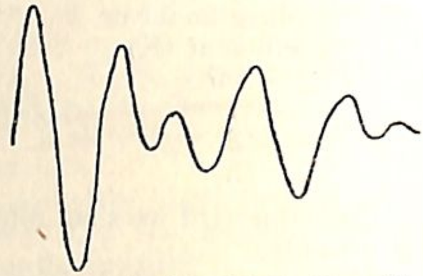
We saw that damping may be considered to be due to

(*a*) The ohmic resistance of a circuit.

(*b*) The amount of energy radiated at each swing.

Now the amount of magnetic field that cuts the mutual at each swing of current represents so much energy in a kinetic form. If we have the two circuits closely coupled together, the mutual coil helps itself to a large amount of energy from the primary at each oscillation, and there is therefore much less energy left in the primary for the next swing of current. Hence the oscillations in the primary will die away rapidly, the "radiation" damping being heavy.





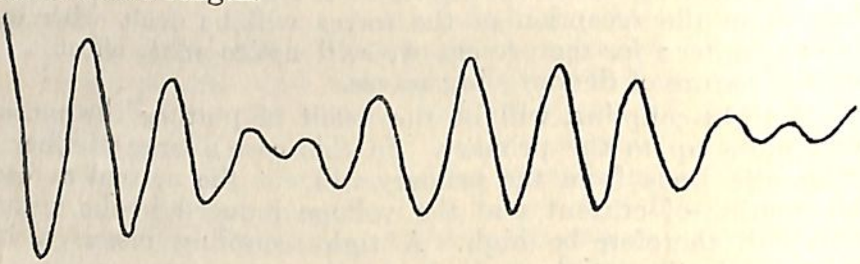
Volts in Primary. *Volts in Aerial, Tight Coupling.*

FIG. 19A (not to scale).

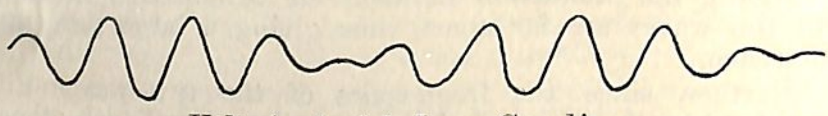
But it must now be remembered that the aerial depends upon the primary for the maintainance of its oscillations, for the aerial, due to its own good radiating properties, gets rid of its energy almost as fast as it receives it.

The result of all this is that waves from an aerial which is tightly coupled to its primary will be heavily damped, however low the resistance of either circuit may be.

By now, the reader will probably have anticipated the results consequent on loose coupling, so we will not deal with them at such length.



Volts in Primary.



Volts in Aerial, Loose Coupling.

FIG. 19B (not to scale).

Here the mutual is some distance from the primary, and so less voltage appears in the aerial, the surging of the energy backwards and forwards is not so marked, and so the two waves emitted have nearly the same frequency, and the "beats" succeed each other more slowly. Further, the oscillations die away more slowly, the damping due to radiation is less, and the train of waves is said to be "well sustained" or "persistent."

When loose coupling is used it becomes more important to keep down the damping due to resistance than when tight coupling is the method employed. In the former case the resistance losses in the leads and spark gap, also certain losses in the condenser, have a longer time to act and so become more harmful unless reduced to a minimum.

On the other hand, tight coupling throws a great strain upon the insulation of the aerial, owing to the great voltage developed, and the aerial may become overloaded.

In this event its dielectric, the air, begins to puncture, and this action is assisted by any sharp points that may be on the wires, so that energy is "squirted" off from the aerial in the form of "brushing."

Once an aerial begins to brush, it becomes useless to try to put a bigger pressure on it by tightening the coupling.

The tendency to brush is increased by the proximity of stays, &c., so that we can at any rate make one aerial less liable to brush than another. This will be treated more fully in the chapter on aerials.

To sum up the matter in a few words we may say that with tight coupling the primary hands over nearly all its energy to the aerial at once, and the aerial cannot radiate it quickly enough; hence the charges get piled up to a high pressure.

In a loosely coupled circuit, the primary doles out its energy to the aerial slowly, and the aerial "leaks" it away as soon as it arrives, and so the voltage rises but slowly and never rises to so large a value as in the other case.

In practice, we put on the tightest coupling which we intend to use when endeavouring to get the two readings on the wavemeter. This brings the two readings far apart and so makes them easily distinguishable. We now complete the tuning, getting the final adjustment of the aerial. Having done this, and *not* till now, we measure again and work out the percentage of this tightest coupling and note it down.

Then, having withdrawn the mutual an inch or so, we take two fresh readings. Due to the looser coupling, these two readings become closer together and less easy to read.

This new percentage, which will be less than the first one, is then worked out and logged down, together with the number of inches through which we withdrew the mutual coil.

This process is repeated and a still looser coupling measured. We should like to get three, and, if possible, four or five different adjustments.

The loosest coupling we can measure on the Service wavemeter will depend upon the skill of the operator and other considerations, but a smaller value than about 2·5 per cent. need not be expected. When the coupling is very loose the two waves become merged into one and no difference is distinguishable.

Now plot these results on a piece of squared paper and draw a fair curve running through, or as nearly through as may be, all these points, ignoring any point which lies any considerable distance outside (as in Fig. 20, 1 inch = 4·4 per cent.). The general "curliness" of this curve may then be continued on towards a still looser arrangement, and a good

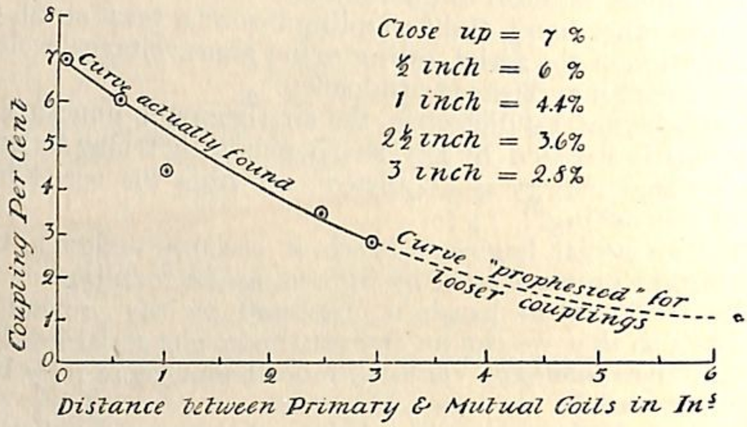


Fig. 20.

estimate made of the number of inches we must withdraw the mutual in order to bring the coupling percentage down to 2 or even 1 per cent.

The curve in Fig. 20 will show the sort of thing that may be expected.

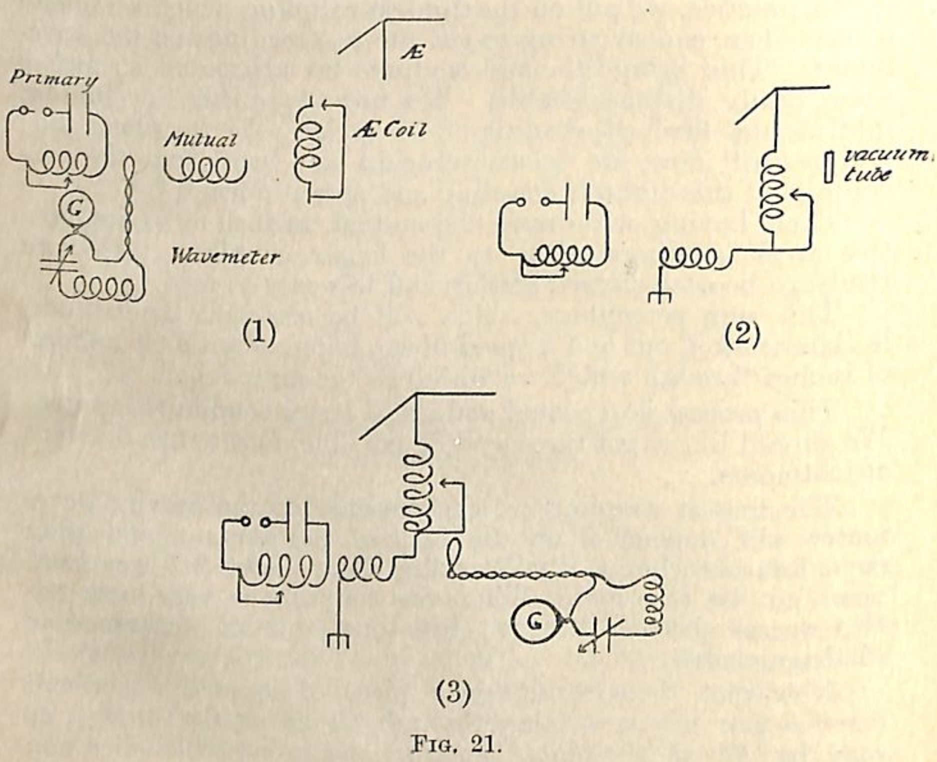


Fig. 21.

To sum up the process of tuning will possibly be of help. (*See* Fig. 21.)

(1) Disconnect and remove all wires connected to the aerial and tune the primary carefully to the required LS value.

(2) Connect up aerial and tune it to the primary, the point where resonance is obtained being shown by some indicating device, such as a vacuum tube hung near the aerial coil.

(3) Get the exact adjustment of the aerial by means of the wavemeter, putting on the tightest coupling.

(4) Work out this tightest coupling and measure other looser ones.

(5) Plot these results on a curve, and be careful to mark the final positions of the adjustable clips on the primary and aerial coils. The connection clips may be put on at leisure, but must make perfect contact with the turns of the coils.

The actual method of adjusting the circuits has not yet been investigated.

The primary usually has a rigid coil of copper tubing as its inductance, and some of this can be short-circuited at will by means of a movable clip.

The LS value of the aerial is generally less than that of the wave we want to transmit. In order to get into resonance, therefore, we have to increase its LS value artificially.

To do this we have an inductance-coil in addition to the mutual coil, placed in series with the aerial.

This is called the "aerial coil" or "tuner" and is made adjustable by means of a movable connection on the end of a flexible lead whose inductance is negligible. By means of this we can short-circuit any part of the coil that we do not require.

The fixed end of this wandering lead is generally attached to the bottom end of the aerial coil, and the coil itself hung up vertically with its axis at right angles to that of the primary coil, so that no energy from the primary will be conveyed to the aerial except by the medium of the mutual coil.

In the cases where we want to transmit a wave whose length is shorter than the "natural" wave-length of the aerial, we may either artificially reduce the LS value of the large aerial by putting a condenser in series therewith, or else we may put up a special small aerial, and get it into tune by means of a small amount of aerial coil.

In any case we must retain the mutual coil.

Sometimes the mutual coil is provided with a flexible lead by means of which any part of it may be thrown out by short circuiting those turns which are not required. These turns will of course be those which are most remote from the primary.

In this particular case, the adjustment of the coupling becomes slightly more complicated.

Suppose that at first we use all of the mutual coil and a certain amount of aerial coil to get in resonance for a certain wave.

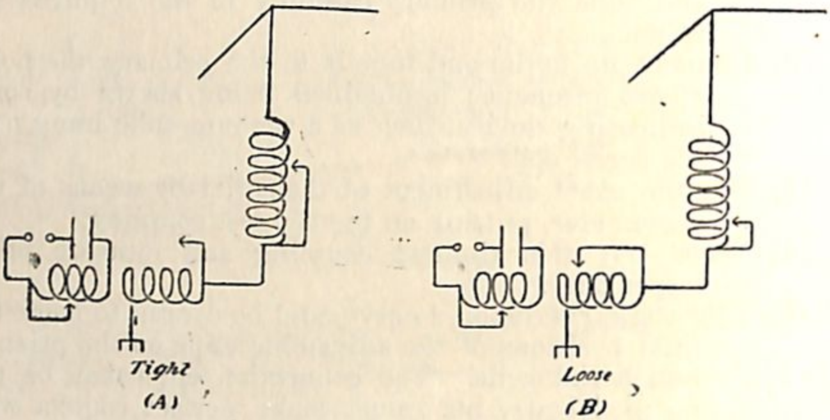


FIG. 22.

On measuring the coupling we may find that it is tighter than we shall ever want to use. Fig. 22 (*a*).

Now, without withdrawing the mutual coil, we short-circuit some of its turns, and put in a *corresponding* amount of inductance on the aerial coil(*b*). Thus the whole LS value remains unaltered, but there are now fewer effective turns on the mutual coil, and the coupling is consequently loosened.

We continue this process of transferring turns from the mutual on to the aerial coils until we get the coupling, when the mutual is in the "close up" position, *just so tight* as to be the tightest we want to use.

Then, when the mutual is withdrawn to its full extent we shall have a much looser coupling than would otherwise have been the case, thus gaining in non-interference at short ranges.

CHAPTER V.

ALTERNATING CURRENTS.

Hitherto we have been considering the effects of a single discharge of a condenser, assuming it to have been previously charged up by means of the application of some source of high voltage. Now in order to make intelligible signals we must be able to make a succession of discharges, so that the aerial will fire, as it were, a torrent of groups of waves like a maxim gun does its bullets, not merely single "shots" such as we get from a rifle.

To do this we must have at hand a source of pressure which can be applied at will by means of the operator's signalling key. This voltage must be high, of the order of 10,000 to 20,000 volts.

Some wireless stations employ a direct current machine for this purpose, but the design of high-pressure direct current dynamos presents considerable difficulties, and the large pressure is dangerous to handle. Consequently in most spark-installations of the present day alternating current is employed, because it can be generated at a low voltage, taken where necessary, and there transformed up into a high-pressure current suitable for charging the condenser of the closed oscillator.

The study of these currents takes us beyond the limits of Ohm's law, and is bound to entail considerable application on the part of the student for its proper comprehension. The Junior Ratings will probably do well to omit this chapter.

We will now proceed to study the general nature and mode of production of these currents before going into theoretical details.

The reader should refer back to page 17 for the definition of what constitutes an alternating as opposed to a direct current. We will now put that explanation into simpler language.

A direct current may be compared to the flow of water in a pipe, provided that the water always goes in the same direction.

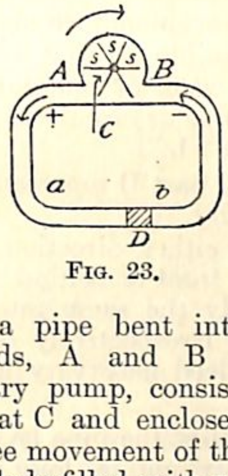


Fig. 23.

Suppose we have a pipe bent into the shape shown in the Fig. 23. Its ends, A and B are connected to the "terminals" of a rotary pump, consisting of a paddle-wheel arrangement, pivoted at C and enclosed in an iron case just big enough to allow free movement of the wheel.

Now imagine the whole filled with water. No movement of water will take place until we revolve the pump.

Assume it to revolve from left over to right as indicated.

The water at once begins to move round the circuit in a counter-clockwise direction. It flows round and round *passing through* the pump every time it gets round. Assume that no energy is wasted in forcing the water through the spaces S, S, S.

The faster we heave, the stronger will be the flow, or the more pints per second will pass through the pump.

The current strength is the same in all parts of the circuit. Notice that the "terminals" of the pump are at different potentials. There is a surplus of water at A and a deficit at B. Hence, when these points are connected by an outside circuit (the pipe) water flows from A round to B. We call A the + ve and B the — ve terminal.

So long as we turn the pump one way, the way shown above, A will *always* be + ve and B always — ve.

This action is analogous to that of a direct current dynamo where the rate of revolution, or rate of cutting lines of force, determines the difference of pressure in lbs. per sq. in. (or volts) between A and B. When the current flows its strength is measured in pints that pass per second (or coulombs that pass per second), and the current varies directly with the pressure and inversely as the friction or resistance of the water (or electricity) against the walls of the pipe (or conductor). Remember that ampères are coulombs per second. Here we arrive at the law for direct currents, namely, $C = \frac{E}{R}$.

Now consider the same circuit when we revolve the handle first in one direction and then in the other, changing the direction at regular intervals. We now have a representation of the action of an alternating dynamo, for there will be a flow of water in the pipe (current in the conductor) first in one direction and then in the other.

For the sake of this argument we may assume that electricity, like water, is incompressible, so that with a given flow (current) the number of pints of water or coulombs of electricity passing any point "a" in the pipe or circuit is the same as the number passing any other point "b."

Thus, let the shaded part D represent one pint of water or one coulomb of electricity.

When D moves in either direction, all the other units of water, or electricity, in front or behind it (that is, all round the circuit) move at exactly the same rate, measured in pints or coulombs per second, irrespectively of the size of the pipe or conductor, which indeed may vary at different parts of the circuit.

This will be true unless the pipe be made of elastic material (or has electrical capacity) and as long as it has no branches or alternative paths for the current.

Suppose, now, that the pump were hove round for half a minute right-handed and then left-handed for half a minute. The current will make two reversals every minute.

Again consider the pint at D. During the first half-minute it may travel, say, 10 times round the circuit, passing through the pump each time; while during the second half-minute it will do the same, but passing through the pump and circuit in the opposite direction.

Now imagine that the reversals of the pump are brought about more often, and the pump reversed every second.

Obviously the pint at D will not get so far as 10 times round the circuit in one direction before it is required to reverse and flow in the opposite direction.

Notice that as the reversals become more frequent, so the path of any one coulomb becomes more restricted. To get a definite number of coulombs past a given point in a second will be the same as getting a given strength of current. This may be attained either by using a low frequency reversal and a large displacement of coulombs, or else a rapid alternation with a small displacement for each coulomb.

The idea of regarding an alternating current as consisting of the alternate *displacements* of coulombs (pints) from their normal positions will be helpful when we come to consider the flow of these currents into condensers.

Hence a small charge moving to and fro through a small portion of the conductor at very short intervals of time may represent just as many "coulombs per second," or ampères, as will the flow of a large charge moving to and fro at longer intervals of time.

This is the reason why such very high frequencies are necessary in the aerial wire in order to get a sufficient current strength therein to make a good "magnetic disturbance" in the ether.

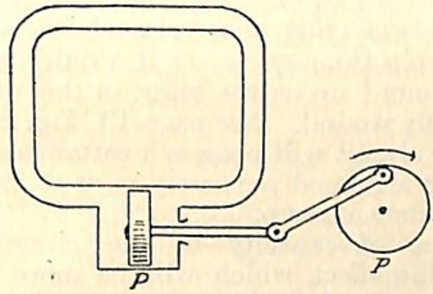


Fig. 24.

The hydraulic analogy of an alternating current circuit is often illustrated as in Fig. 24, the pulley p, representing the rotating part of the "alternator" or alternating dynamo, the force of the pump piston, P, the electro-motive force; and the to-and-fro movement of the piston, the reversals in the direction of the electro-motive force. Good as this analogy is in some respects, it is rather a faulty one, inasmuch as there is no actual passage of water through the pump, and from this the student might infer that there was no passage of electricity through the alternator, or dynamo, just as there is through the other parts of the circuit.

An alternating current may be described as a continual vibration of electricity in the circuit, just as the movement of the balance wheel of a watch is a continual vibration.

When we come to consider the introduction of self-induction into a circuit carrying alternating current, we can no longer deal with water in a pipe with any degree of similarity. We will, however, remember from previous chapters that an inductive circuit brings an opposing E.M.F. to bear against any alteration of the strength or direction of a current, so that these alterations are *delayed*.

We shall therefore have to keep in view the inductance all the time that alternating currents are in question, whereas in direct current practice we are concerned with it only at the moment of switching "on" or "off."

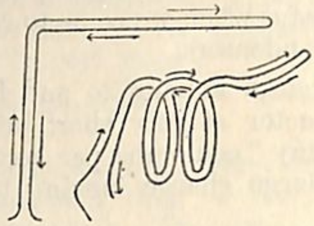


Fig. 25.

Although it is possible to arrange a simple circuit or wind a coil so that it shall have little or no inductance, as shown in Fig. 25., where each half of the circuit or coil neutralizes the magnetic effect of the other half, yet such a coil will be useless for solenoids or electromagnets, as it would have no magnetic field. A wire wound up on the bight in this manner is said to be non-inductively wound. *See* page 13, Fig. 2.

Again, every circuit will possess a certain amount of capacity and may even be arranged purposely so as to have concentrated capacity or inductance (*see* p. 43).

The presence of capacity in the circuit will produce another disturbing effect, which will be more fully explained later. The net result of all this is that *even if* the E.M.F. were to reverse instantaneously, the current will seldom do the same. *Time* is required to change, not only the direction, but also the strength of the current.

Further, as we shall see, even the voltage never varies in "jerks," but runs through a series of changes which we call a cycle, where each change is merged into the next ahead and next astern.

We must now proceed to see how these currents are generated in practice.

The Principles of the Alternating Dynamo.

The reader is referred to Chap. VI. in the Torpedo Manual, Vol. I.; but he must pay more attention to the actual rise and fall of the voltage than will be necessary for the comprehension of the matter therein contained.

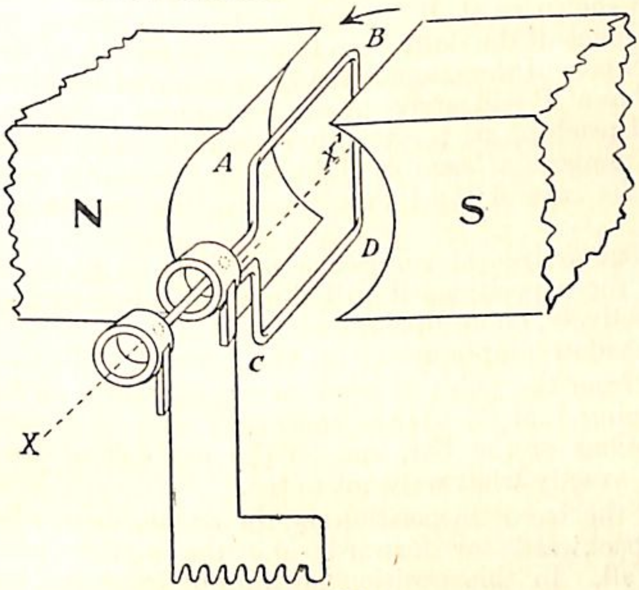


Fig. 26.

The principle of the alternator is shown in Fig. 26.

We will assume that the rectangle ABCD is being evenly revolved on its axle X X′ between the poles of an electro-magnet. The magnetic field occupying the space between the poles must be considered of uniform strength throughout.

We know that when the E.M.F. is tapped off by means of the slip rings, an alternating current is formed in the whole circuit.

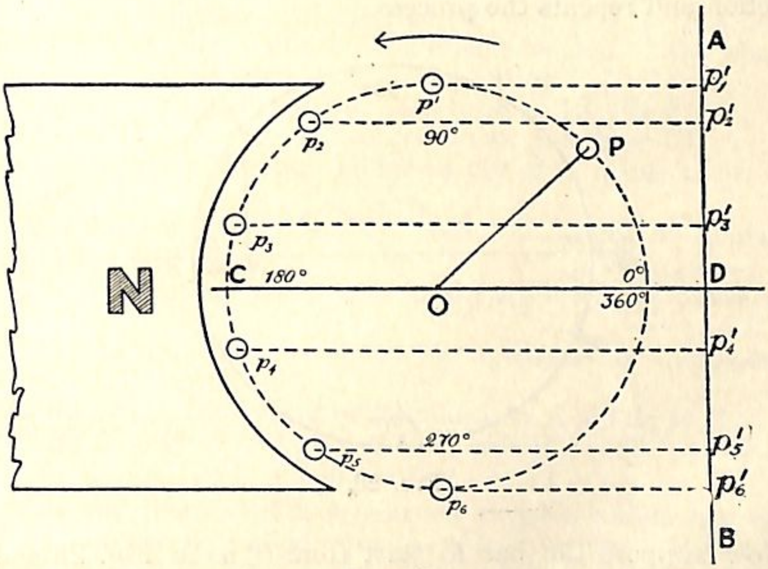


Fig. 27.

Now in Fig. 27 we have simply taken the one bar AB (*see* Fig. 26) and are looking at it endways from the front. It is therefore shown as at P. Consider P as it moves round the circumference of the dotted circle in the direction of the arrow.

The S pole of the magnet has been removed for clearness.

The bar at P will arrive at p_1, the highest point, and thereafter will reach p_2, p_3, p_4, &c., after equal intervals of time.

Now suppose a beam of light to be streaming across from N to S, the rays of light thus representing magnetic lines of force.

The bar arrives at successive positions p_2, p_3, p_4, &c., and when in those positions it will throw a shadow at p'_2, p'_3, p'_4, &c. respectively, on an upright screen at AB.

The shadow simply moves up and down.

Now, from the point of view of cutting lines of force and so producing E.M.F., we are concerned only with the *up and down* motions of the bar, and so the motions of its shadow represent exactly what we want to see.

When the bar is in position p_1, the rectangle may be moved slightly backwards or forwards and the shadow will hardly move at all. In this position no lines of force are being cut and so no E.M.F. is being generated.

When between p'_3 and p'_4, the shadow moves in response to the slightest movement of the rectangle. Hence many lines of force are being cut per second and a large E.M.F. generated.

Starting from the top of its travel at p', it will be noticed that the shadow moves downwards slowly at first and then gets up speed. On passing the line CD, which is the centre point of its travel, it is moving at its maximum speed. Thereafter it loses speed, comes momentarily to rest at p'_6, reverses its direction and repeats the process.

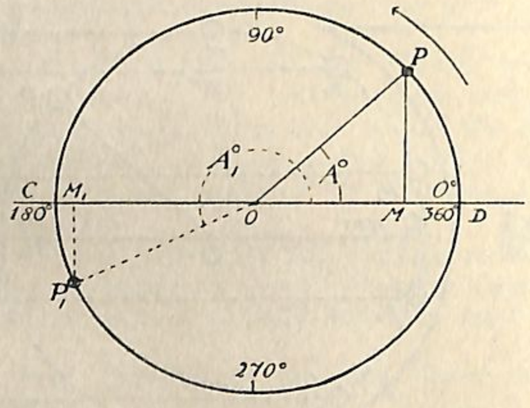


Fig. 28.

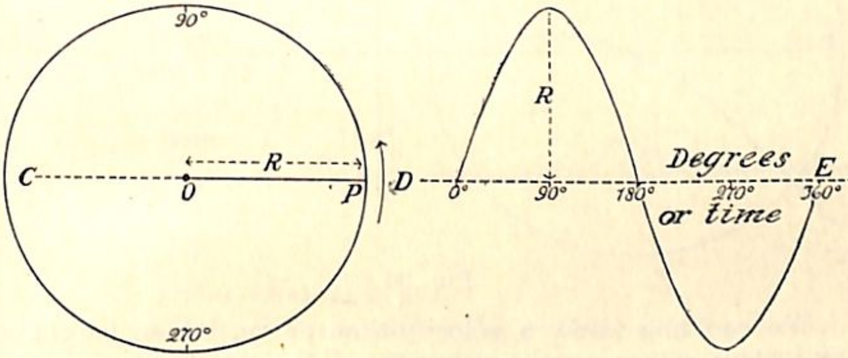
Now suppose the bar to start from 0° as in Fig. 28 and to travel round through 360°, from D round through C to D again.

At any point P, after the bar has swept out an angle of A degrees, PM represents the distance the shadow has moved from its zero line CD. Now $\frac{PM}{OP} = \text{Sin} A$. (*See* Appendix, p. 364.)

Hence at any position PM = OP × Sin A.
Here OP = radius of circle (or armature)

So the displacement of the shadow, after any angle A has been swept out = R sin A, where R is the maximum displacement in any one direction.

We may now take a horizontal line DE, Fig. 29, to represent degrees, and plot on it the various lengths and directions of the lines PM or P^1M^1 (as the case may be) in the last figure.



Position-time Curve.
Fig. 29.

On the left of this horizontal line it will be well to draw R in its initial position as at OP and to imagine the line to swing round, like the spoke of a wheel, on the centre O. Then the length of the "shadow" of the line OP will give us the height of the curve at any point, or the displacement of the shadow of the armature bar from its central position.

The curve is constructed as shown on p. 19, Fig 3.

When PM (*see* Fig. 28) comes above the line CD we call it +ve in sign. This will be for values of A lying between 0° and 180°.

For values of A between 180° and 360° P will be below the line and PM will be −ve.

After joining up the points found we have the curve as in Fig. 29.

The maximum height of the curve, called its "*amplitude*" will be = OP, which = R.

At all times, the height of the curve = R sin A, so that
When A = 0° or 180°, sin A = 0: when A = 90° or 270°, sin A = 1.

Now the distance DE represents degrees swept out by the bar. It might be called equally well, "radians* swept out,"

* *See* Appendix, p. 363.

"distance moved by the bar on its circular path," or "time from the beginning of measurement."

Let us now consider the abscissæ to be time while the ordinates are still the position of the bar's shadow.

Hence our curve is now a "position-time" curve.

Now the slope or steepness of this curve represents rate of change of position, or velocity, of the shadow.

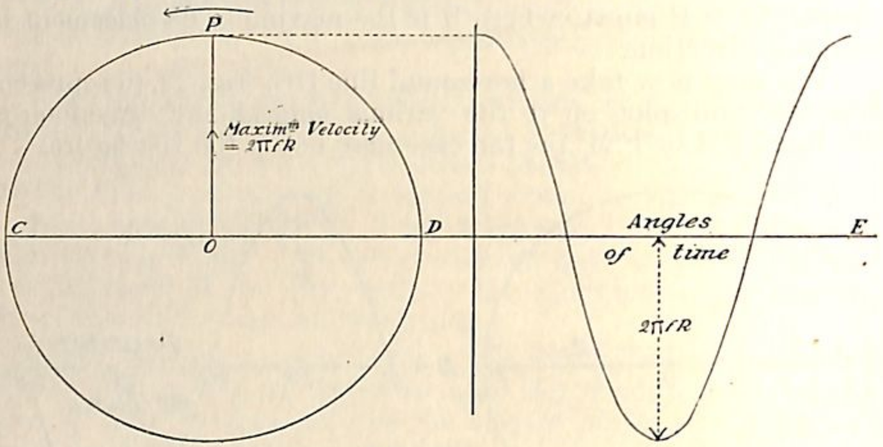


FIG. 30.

We can now draw a velocity-time curve, whose height at any instant represents the steepness of the position-time curve at that instant.

Thus we have* :—

Degrees swept through.	Fig. 29. Slope of Position-Time Curve.	Fig. 30, Height of Velocity-Time Curve.
0° and 360°	Maximum + ve, *i.e.*, up from Left to Right.	Max. + ve.
90°	Zero.	Zero.
180°	Maximum — ve, *i.e.*, Down from Left to Right.	Max. — ve.
270°	Zero.	Zero.

It will be noticed that the velocity curve is the same shape as the position curve, but is pushed 90 degrees ahead of it. *See* Fig. 30.

Now what will be the numerical value of the maximum velocity of the shadow? The shadow is at its greatest speed when crossing the line CD (Fig. 27), the bar being at 0° or 180°, and it will then *just keep pace* with the bar, which latter is travelling at a uniform speed on its circular path.

In 1 revolution it travels $2\pi R$ feet (*see* Appendix).

In f revolutions it travels $2\pi fR$ feet.

* For + ve and — ve slopes, *see* p. 9.

But if f be the frequency, the armature of a two-pole machine revolves f times a second.

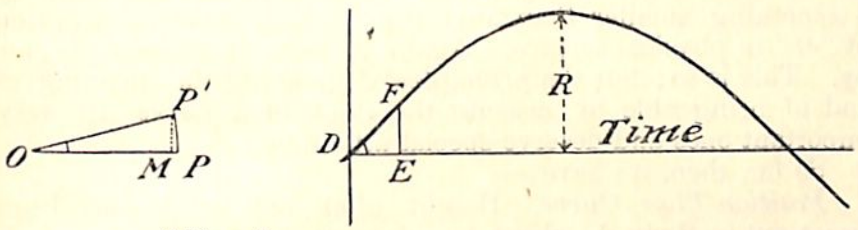
Hence the distance travelled per sec $= 2\pi fR$ feet.

So the maximum velocity of the shadow is $2\pi fR$ feet per second, since this is the uniform velocity of the bar on its circular path.

This will be the amplitude of the velocity curve. (Fig. 30.)

For those who have learnt a little simple trigonometry it will be instructive to get this result direct by measuring the maximum slope of the position curve.

Looking at all these curves, it is evident that the steepest part of the curve is where it crosses the horizontal line. In the case of the position-curve this happens at 0° and 180°.



$OP = R.$
$DE = small\ time = t.$
$FE = R\ Sin\ (small\ angle) = R\ Sin\ P\hat{O}P'.$

FIG. 31.

In Fig. 31 let the radius R move from zero through a very small angle $P\hat{O}P'$. The bar has now swept out a very small angle, and will have taken a small time "t" to do so.

On the curve itself, the line DE represents the very small time t, and the height EF is (by construction) $= R \sin P\hat{O}P'$.

Now it will be convenient to express the angle in circular measure. This is found as follows:—

In one second f revolutions take place, each of 360 deg.
" " " " " 2π radians.
" " $2\pi f$ radians are swept out in all.

So $2\pi f$ is the number of radians swept out per second.

This is sometimes called the "angular velocity" and, to save writing, will hereafter be denoted by "p", so that $p = 2\pi f$ radians per sec.

Now in 1 sec. p radians are swept out,
so, in t secs. pt radians are swept out.
So the circular measure of the angle $P\hat{O}P'$ is pt radians.
On our curve then we have $EF = R \sin P\hat{O}P' = R' \sin pt$.

But pt is a very small angle, so that we may say
$\sin pt = pt$ (*see* Appendix, p. 366).
So that $EF = R \sin pt = Rpt$.
and $DE = t$.

Now since we have taken a very small part of the curve DF, we may consider it to be a very short straight line. The steepness of a line is the amount it rises for unit progress, or the tangent of the angle of slope. (*See* note to p. 10, and Appendix.)

$$\text{Here steepness} = \tan E\hat{D}F = \frac{EF}{DE} = \frac{Rpt}{t} = pR = 2\pi fR,$$ and this is the maximum steepness.

If R is in feet and f is revolutions per second, then pR will be in feet per second.

It may be thought, first, that this result can be but approximately correct, but this is not so. It differs from the truth by "something smaller than anything," which is our conception of "0" in physical science. Again, it seems laborious to come by. This is so; but the principles of grasping the meaning of and of being able to measure the slope of a curve are very important ones and deserve special attention.

So far, then, we have:—

Position-Time Curve. Height after any angle has been swept out = R sin A, where A = degrees.

Height after any time t = R sin pt, where pt = radians.

Its maximum value = R feet, and happens when

$$pt = \frac{\pi}{2} \text{ or } 90°, \frac{3\pi}{2} \text{ or } 270°, \&c., \text{ for then } \sin pt = 1.$$

Velocity-Time Curve is the same shaped curve, only shifted $90°$ or $\frac{\pi}{2}$ ahead.

Its maximum value = pR feet per second, and happens at 0°, 180°, 360°, &c.

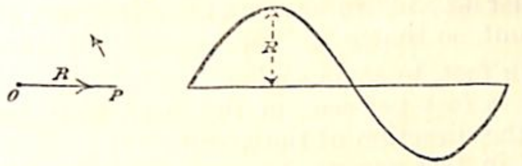
Now just as the slope of the position-time curve gave us "rate of change of position," or "velocity," so also does the *slope* of the velocity-time curve mean rate of change of velocity, or acceleration.

We notice that the second curve had a maximum value = p times that of the first curve. So again the maximum value of the acceleration curve will be p times pR, or p^2R.

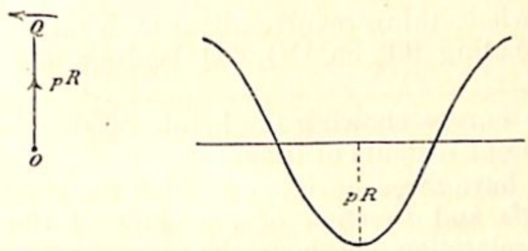
This is in feet per sec. per sec. (*see* p. 33).

Studying the velocity curve, its steepness and the consequent height of the next curve are as follow (*see* Fig. 32).

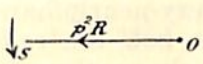
Degrees.	Slope of Velocity Curve (B).	Height of Acceleration Curve (C).
0° and 360°	Zero.	Zero.
90°	Maximum—ve. Down from left to right.	Maximum—ve.
180°	Zero.	Zero.
270°	Maximum + ve. Up from left to right.	Maximum + ve.



Position—time A.



Velocity—time B.



Acceleration—time C.

Fig. 32.

So the acceleration curve is the same shape as the velocity one, but again shifted 90° ahead of it. Further, its amplitude $= p^2R$.

The three curves are shown separately in Fig. 32 and combined in Fig. 33.

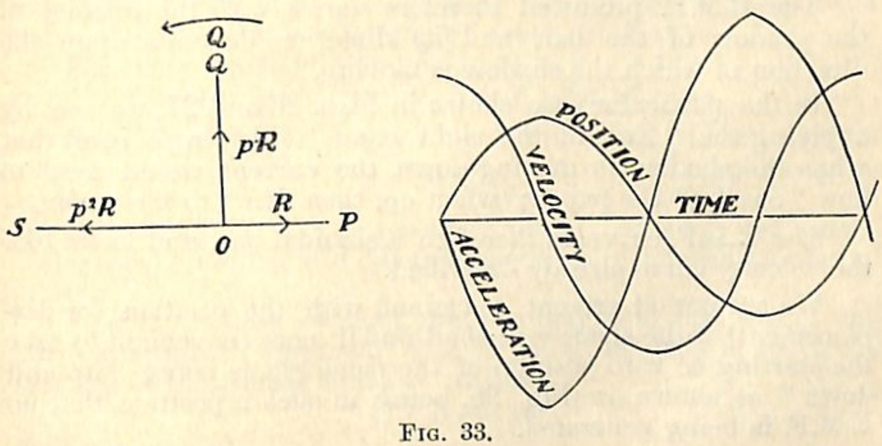


Fig. 33.

In this last fig., 33, we have on the left a sort of "key" to the curves laid out, so that—

OP = R in feet, to some scale.

OQ = pR in feet per sec., to the same scale, and 90° further on in the direction of the arrow.

OS = p^2R in feet per sec. per sec., to the same scale, and 90° further on still.

Let the whole thing revolve about O in the direction of the arrow, OS leading 90° on OQ, OQ leading 90° on OP *all the time.*

Plot the curves showing the height of the *shadows* of these lines at different instants of time.

Here we have three curves, of which the velocity one shows the *magnitude* and *direction* of the slope of the position one, while the acceleration one shows the same for the velocity one at any instant of time we like to take into consideration.

Now this to and fro movement, such as we have been studying in the shadow of the armature bar, is called "simple harmonic" or "sinoidal" motion. Such motion often occurs in mechanics.

If a steam engine have a very long connecting rod, then the reciprocating motion of the piston is very nearly harmonic: the motion of a gently-swinging pendulum bob, the *end-on* view of the feet of a man riding a bicycle, and the motion of the strings of musical instruments or prongs of a tuning fork are all examples of harmonic motion.

Notice that the masthead of a rolling ship moves with this motion. If the ship be under way also, then the truck traces out a *sine* curve in space.

So far we have merely dealt with the up and down motion of the armature bar, remembering that upon this motion will depend the strength and direction of the E.M.F. that will be induced.

Now for a given strength of magnetic field and number of bars on our armature, we know that the strength of the E.M.F. depends upon the number of lines of force cut per second.

The E.M.F. produced therefore varies with the velocity of the shadow of the bar, and its direction depends upon the direction in which the shadow is moving.

In the particular case shown in Figs. 26 and 27, we see, by applying the "Rule of the right hand" (Fleming's rule) that when the shadow is moving down, the current would tend to flow "out" of the paper; when up, then "in" to the paper.

The E.M.F. curve, is therefore a sinoidal one, and looks like the velocity curve already described.

We are not at present concerned with the position (or displacement) of the shadow, so shall find it more convenient to take the starting or zero position of the rectangle as being "up and down" as shown in Fig. 26, being in such a position that no E.M.F. is being generated.

Now if E is the maximum value of the E.M.F., then at any instant t, we have the voltage " e " given by

$$e = E \sin pt.$$

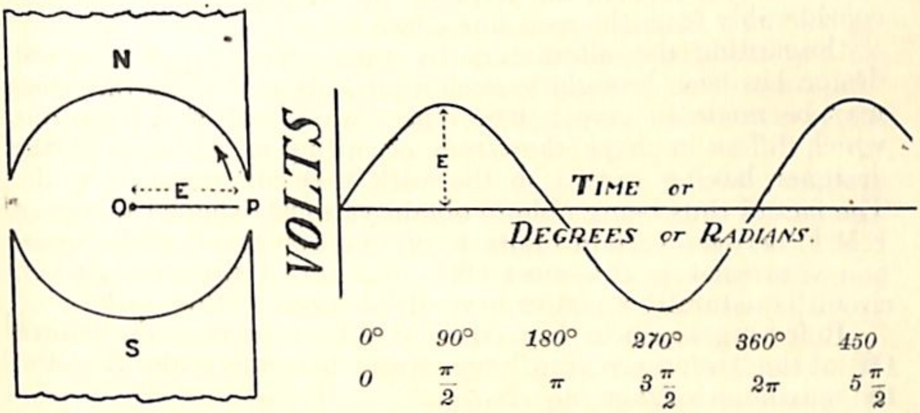


FIG. 34.

In Fig. 34 the voltage curve is shown. Above and below the reference line OP, the magnet poles N and S are put in to remind us how the voltage varies.

Here the line OP represents to scale the value of E, the maximum voltage.

It may again be mentioned that now when pt becomes $= \frac{\pi}{2}$ or $\frac{3\pi}{2}$ &c., then $\sin pt = 1$ and $e = E$.

The reader is probably very annoyed by the circular measurement pt being taken for his angle of A degrees, $\frac{\pi}{2}$ for 90° and so on. One of the reasons for the use of circular measure is in order to bring in the frequency f. We are then able to forget how many poles the dynamo has.

An armature revolving between one pair of poles generates one cycle of E.M.F. per revolution; if there are 4 poles, *i.e.*, 2 pairs, then 2 cycles are completed every revolution.

For every machine, then, we have

$$f = \text{revs. per second} \times \text{No. of pairs of poles.}$$

Now if two pairs of poles are fitted, although the armature sweeps out only 360 *actual* degrees, we have two complete cycles which require, on the curve, 720 " *electrical* " degrees.

By using p to represent angular velocity, we mean " electrical " angles, without reference to any definite number of poles.

Now it has been assumed that the magnetic field was of uniform strength throughout. If it be not so, the E.M.F. curve will not follow the simple sine law, so that

$$e = E \sin pt$$

will not be true.

In practice, owing to the non-uniformity of the fields of the alternators and to the various shapes of coils used for winding their armatures, not to mention the various kinds of "load" in the outside circuit, the form of the E.M.F. curve may vary considerably from the true sine curve.

Regarding the alternators by themselves, however, their design has been brought to such a pitch of perfection that they may be made to give a true sine "wave" of E.M.F., or one which differs in shape therefrom, according to the ideas of the designer, having regard to the work they are required to do. The fact of thus being able to obtain variously shaped waves of E.M.F. between certain limits is of importance; but the question as to what is the most efficient form of wave for a given circuit is naturally a matter beyond the scope of this book.

Referring again to Fig. 34, it will be seen that the length OP of the "reference line" represents, to some scale, E volts, the maximum voltage.

If we now suppose OP to be pivoted at O and revolve round in a "counter-clockwise" direction, at a uniform speed, we see that for any position of P there will be a corresponding value of PM (*see* Fig. 28). Now PM = OP sin A, where A is the angle swept out from the zero position or horizontal line.

So that PM = E sin A. PM consequently represents to the proper *scale* (*i.e.*, in *magnitude*) and in *direction* (above or below the horizontal line) the value of the E.M.F. at that instant, *provided* the E.M.F. follows the "sine law." The line PM would be the shadow of OP cast on an upright screen by a horizontal beam of light. OP is called a "revolving vector" and is a very valuable method of representing an alternating E.M.F., current or power. We shall use it constantly, and the reader should practice drawing vectors and their corresponding curves.

Let us now take the alternating E.M.F. of simple harmonic form, and apply it to the ends of a circuit, as shown in Fig. 23 at the beginning of this chapter.

Suppose at first, that the circuit contains resistance, but that it is non-inductively wound and has no capacity.

In any case a current will flow. In this particular case the alternating current will rise, fall and reverse in sympathy and in step with the voltage "impressed" on the ends of the circuit, and we can employ Ohm's law to find the strength of the current.

Hence, $C = \frac{E}{R}$.

Whatever the value of e may be at any moment, c will be equal to $\frac{e}{R}$ at that moment.

Also E = CR, which means that all the applied or "impressed" volts are employed in driving the current C through the resistance R.

We can therefore plot our volts and amps. on the same curve as shown in Fig. 35 (*a*).

The vertical scale will have to be graduated to read volts and amps. Of course C need not be less than E as in this case. In our example the resistance has been so chosen that C in amps is less than E in volts.

In this case it is to be noticed that the current and voltage are in step with each other, they reach their maxima and minima at the same instant, and, further, the applied or "impressed" volts have *nothing* to do but overcome the resistance of the circuit.

We have noticed that both E.M.F. and current undergo periodic changes of strength and direction; in other words, they pass through different *phases* or states.

We have been considering a case where the current rises, falls and reverses exactly at the same time as the E.M.F., it would then be said to be "in phase" or in step with the E.M.F. Now owing to the effects of inductance and capacity in the circuit, the current and voltage do not always rise and fall together. They reach their maxima and minima at different instants of time, the current either lagging behind or leading ahead of the E.M.F. (*see* Fig. 35 *b* and *c*). One of these effects happens more often than not, and the state of affairs is described by saying that the current is out of "phase" or out of step with the E.M.F.

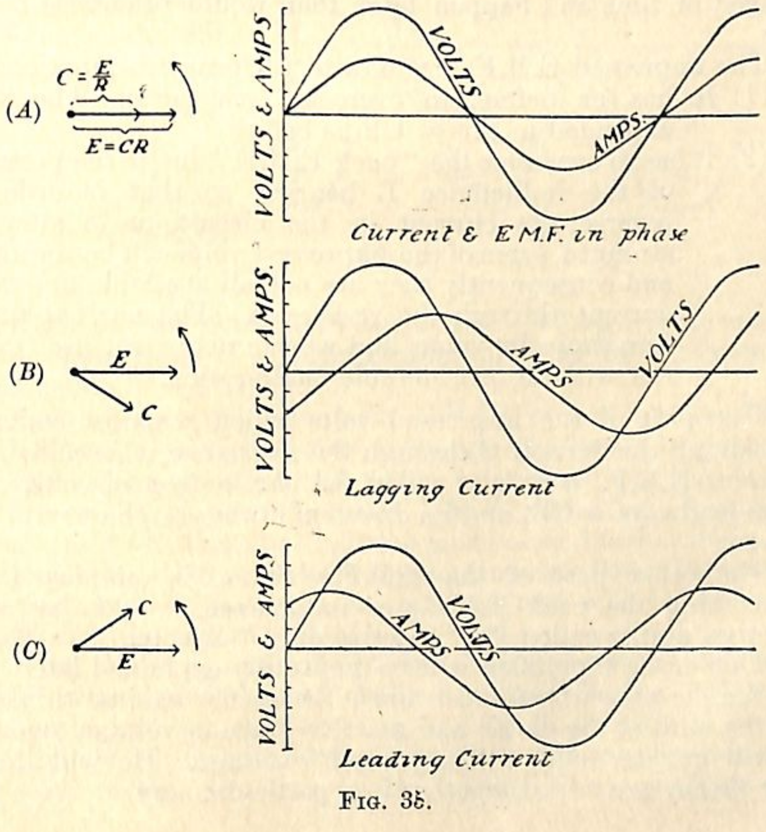


Fig. 35.

However much the current may be out of step with the E.M.F., it must be remembered that the *frequencies* of the two will be the same, for the current is the effect of the E.M.F., the latter being the cause of the former.

Now when the current is out of phase with the E.M.F. a "phase difference" is said to exist.

In our example we had no "phase difference" because there was no inductance or capacity present. Resistance pure and simple cannot affect the phase of the current, it will only alter its strength (or amplitude) according to Ohm's law.

Hence in the Fig. 35 (*a*) we have the line OP consisting really of two vectors superimposed one upon the other, the whole representing the maximum value of E and the part the maximum value of C, the "shadows"—or, as we shall now call them, "projections"—both being zero, maximum, zero, &c., at *coincident* instants of time.

Now let us insert an inductance of L henries in series with the resistance R ohms. Let the total resistance of the whole circuit remain as before.

Should we apply a direct E.M.F., to the terminals of this circuit, the current should be the same as before and be $= \frac{E}{R}$. With an alternating voltage applied to the circuit, however, a very different state of affairs arises. The changes in the current are delayed in time and happen later than would otherwise be the case.

The impressed E.M.F., has now to perform two functions.

(1) It has, as before, to overcome resistance. The volts expended in this = CR as before.

(2) It has to overcome the "back E.M.F." due to the presence of the inductance L henries, so that in order to reverse the current in the circuit, or to alter its strength, some of the impressed volts will be required, and consequently they are not all available to send a current through the resistance. The current therefore drops in value, and we can no longer use Ohm's law without considerable modification.

That part of the impressed volts which remains available for driving the current C through the resistance R is called the *effective* E.M.F., it is also called the *ohmic drop* of volts. Its *value* is always = CR, and its *direction* always in phase with the current.

The other part of the E.M.F., which is employed in overcoming the back E.M.F., or inductance, would be non-effective, and is called the "reactive drop" of volts.

This latter expression will be more fully explained later.

For the present we must warn the reader against thinking that by adding the ohmic and reactive drops of voltage together he will get the total or "impressed" voltage. He will do so only if they are added together in a particular way.

We must now see how the back E.M.F. of self-induction varies with the current.

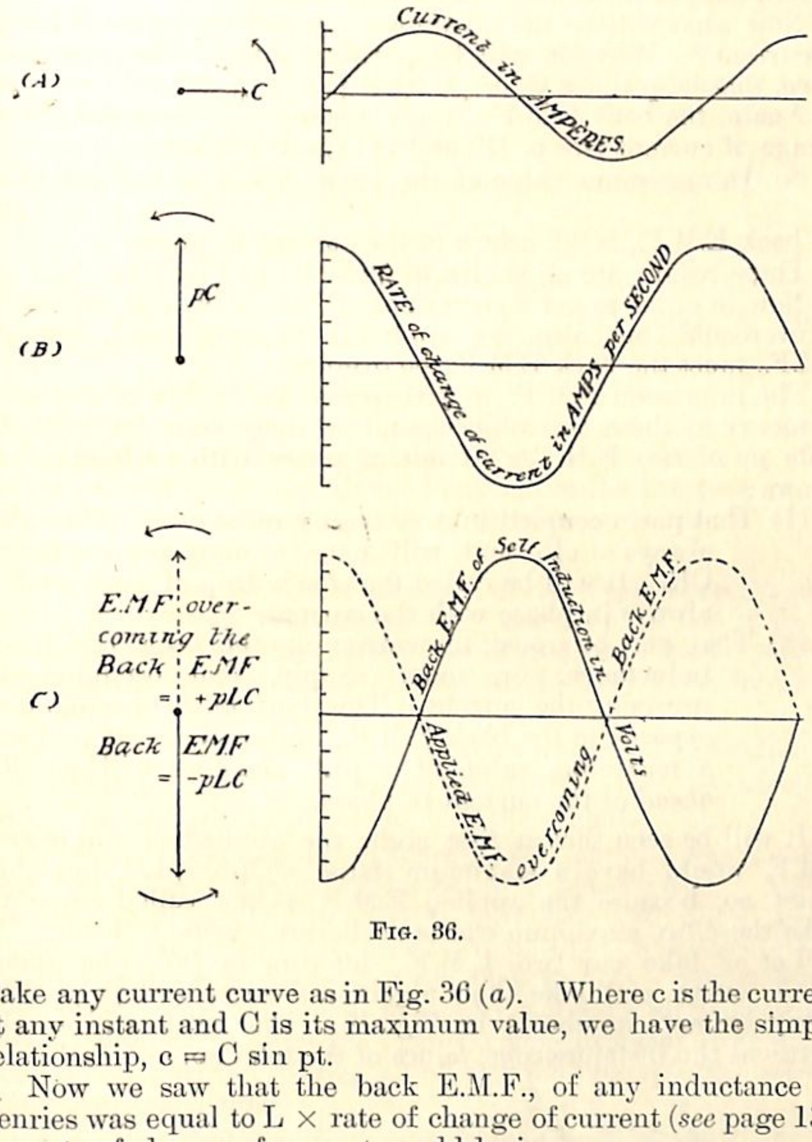


FIG. 36.

Take any current curve as in Fig. 36 (*a*). Where c is the current at any instant and C is its maximum value, we have the simple relationship, c = C sin pt.

Now we saw that the back E.M.F., of any inductance L henries was equal to L × rate of change of current (*see* page 13), the rate of change of current would be in amps. per sec.

We see, then, that the back E.M.F. varies from instant to instant and will therefore follow a sine curve, but it will be like the acceleration curve in the foregoing example (since "current" corresponds to "velocity"), *see* page 40, and will be 90° out of phase with the current.

From the foregoing example we should expect that the back E.M.F., would be 90° ahead of the current (as in Fig. 36(*b*)), but it must be remembered that it is trying all the time to *prevent* the change of current strength, whereas the acceleration was the *cause* of the alteration in the velocity (compare Chapter I.,

Fig. 1.) Hence the back E.M.F., must be in direct opposition to the acceleration, and be consequently 90° astern of the current (as shown by full line in Fig. 36(*c*)).

Now what will be the maximum value of the rate of change of current? Why, it will be p times that of the preceding curve, that is, p times C, or pC. (compare Fig. 32).

Again, the back E.M.F., at any instant = L times the rate of change of current (*see* p. 13) and is negative in sign.

So the maximum value of the back E.M.F. = L times pC.
= − pLC, and
the back E.M.F., is 90° *astern* of the current in phase.

These results are all shown graphically in Fig. 36 *a*, *b*, *c*.

Now in order to get a current at all, not only must resistance be overcome, but also, by applying an equal and opposite E.M.F., must the back E.M.F., be overcome.

The impressed E.M.F. may therefore be said to be devoting its energy to these two objects, and we may consider it to be made up of *two* E.M.F.'s 90° out of phase with each other, as follows:—

(1) That part occupied in overcoming resistance. This will always = cR, and will have a maximum value = CR. It will be called the *ohmic* drop of volts and is always in phase with the current.

(2) That part occupied in overcoming the back E.M.F. of inductance, or, more simply, that occupied in reversing the current. This part must be equal *and opposite* to the back E.M.F., and will therefore have a maximum value of + pLC and and will act 90° *ahead* of the current in phase.

It will be seen that at first sight the applied or impressed E.M.F. would have a maximum value = CR + pLC, but this is not so, because the applied E.M.F. is not called upon to make these *two* maximum efforts at the *same* instant of time.

Let us take our two E.M.F., differing by 90°, plot them on a curve and take their algebraical sums (*see* page 60), at any instants as shown in Fig. 18. The result will surely represent the instantaneous values of the total applied E.M.F.

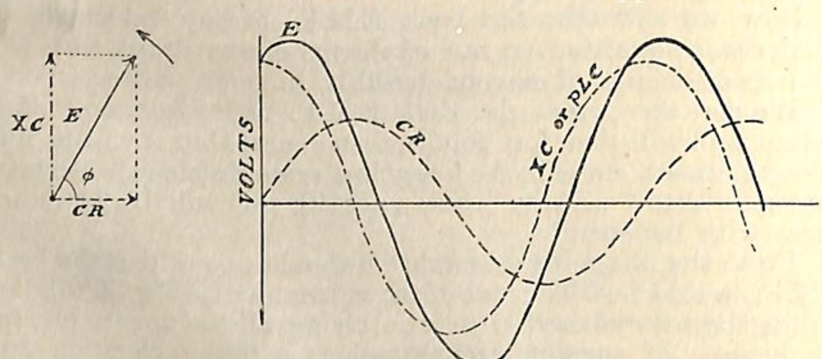


Fig. 37 (A).

If we join up the points so found by means of a (firm) line, we have the curve of impressed E.M.F. (Fig. (37 A.))

It is seen that its maximum value will always be greater than that of either of the other two curves, which is natural, for the impressed volts have to furnish those required both for the ohmic and for the reactive drops. Again, the maximum value of the impressed E.M.F. falls at a point on the curve which is between the maxima of the others.

Hence the *impressed* E.M.F., leads on the current, *but not* by as much as 90°.

This is generally expressed the other way round by saying that the current lags behind the voltage by a certain angle which can never be greater than 90°. This angle is called the "phase-difference angle," or "angle of lag."

Such is the effect of inductance on the circuit.

Some of the volts are required to make good the "reactive drop," and so less are available to make the current. The current, therefore, is less strong than before the insertion of the inductance, and it now lags by a certain angle astern of the impressed voltage.

It will be noticed this weakening of the current might have been equally well effected by the insertion of an artificial resistance, but then the current would not have been "pushed back" astern of the E.M.F., and it would have been in phase or in step with the E.M.F.

The effect of the inductance on the circuit may therefore be called that of a sort of "spurious resistance" and the effect is said to be due to the "reactance" of the circuit.

Now the resistance of the circuit is R ohms. The "ohmic drop" of volts = CR or RC volts, being in phase with C. Again, the reactive drop of volts is pLC volts, being 90° ahead of C. We can therefore call the quantity pL the "reactance," and consider it to be something of the nature of a "bogus ohmic resistance" which has not only the property of making the current weaker, as does an ordinary non-inductive resistance, but also of causing it to lag, a property not enjoyed by ordinary ohmic resistance alone.

The letter X is used for reactance, so that X = pL.

Now since all our curves (for the moment) show things of the same dimensions, volts, we must see what relationship exists between the total drop of volts and its subdivisions, the reactive and ohmic drops.

We have seen that *at any instant* the

Impressed volts = reactive drop + ohmic drop (algebraical sum).

Now, forces and velocities can be represented in magnitude and direction by vectors (*see* pp. 32 and 33).

In Fig. 37 (B) let OP represent in this particular way RC volts. Then the direction of OS, which represents pLC (or XC) will be 90° ahead of OP.

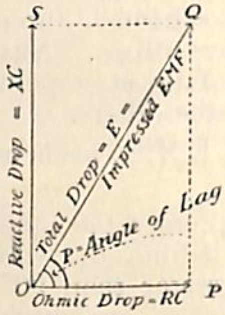


FIG. 37 (B).

Now OQ, the line forming the diagonal of the rectangle completed as shown, will represent in *magnitude* and *direction* the impressed E.M.F. Notice that the length OQ represents the maximum value of E, and its direction gives us an angle QÔP, with the CR line, and at this angle will the current lag behind the impressed E.M.F., for the current is in phase with CR.

This is a very important result, that of adding several forces together when represented by these "vectors" or lines such as OP, OS, &c. The rule is to complete the parallelogram and take the diagonal which lies between the sides representing the two forces. This diagonal represents in length and direction the resultant of the two.

Remember, we cannot add yards and gallons together, so we cannot find the resultant of a current and a pressure, or of any two quantities of different dimensions, but any number of currents or any number of voltages may be reduced down to one resultant current or voltage by successive applications of this principle. It is reasonable to apply it to currents as to voltages, for we saw that velocities, as well as forces, might be represented in magnitude and direction by straight lines. (Again note:—Currents are coulombs per second.)

Further it is not necessary that the two or more original vectors should be at right angles to start with. As long as they make an angle with each other we may complete the parallelogram and find the length of its diagonal. This figure will become a "rectangle" when the angle between the components is a right angle.

A parallelogram is a four-sided figure with its opposite sides parallel and its opposite angles equal, whereas a rectangle is the same, only all its interior angles are right angles.

The case of a wooden matchbox is always a parallelogram whether crushed or not. It ceases to be a rectangle when two opposite corners are crushed towards each other.

In Fig. 37(A) it is seen that the maximum height of the dotted curve is really equal to the length of the diagonal of the rectangle. The firm-line curve is then the true projection of the impressed volts vector.

When, as in this case, we have a rectangle, a very simple relationship connects the length of the diagonal with those of the sides.

In Fig. 37 (B) we have the rectangle OPQS of which the side OS = QP. Hence OPQ is a right-angled triangle whose hypotenuse (*see* Appendix, p. 364) is OQ representing E, and whose sides OP, PQ represent respectively RC and XC.

Now in any right-angled triangle the square on the hypotenuse is equal in area to the sum of the squares on the other two sides.

$$\text{Hence } (OQ)^2 = (OP)^2 + (QP)^2.$$
$$\text{That is } E^2 = (RC)^2 + (XC)^2.$$

Taking the square root of both sides we have

$$E = \sqrt{\{(RC)^2 + (XC)^2\}}$$

or in words:—The *impressed* E.M.F. is equal to the *square root* of the sum of the squares of the *ohmic* and *reactive* drops of E.M.F.

Since C^2 appears in each expression, we can write our formula

$$E = C\sqrt{R^2 + X^2}.$$

Or, most useful of all, $C = \dfrac{E}{\sqrt{R^2 + X^2}}$.

This is the new *Ohm's law* for alternating currents in circuits having negligible capacity.

Now in this last result, the denominator has been given the name of "impedence," so that impedence = $\sqrt{\{\text{resistance}^2 + \text{reactance}^2\}}$. Impedence is denoted by the letter "Z."

Our new Ohm's law now reads $C = \dfrac{E}{Z}$.

The impedence may be regarded as the combined effect of the true and the "spurious" resistances of the circuit. Both the impedence and reactance are consequently to be regarded as being expressed in *ohms*, but it will be noticed that the value depends on the frequency, among other things, so that if, for any reason, we insert an artificial inductance into a circuit, we may call it an impedence coil, but its own value will be measured in *henries*.

Not till its resistance and the frequency of the applied volts are determined can we say what the value of the impedence will be, and to find even the reactance we must know the frequency.

Now with regard to the angle of lag :—

We saw above that the angle of lag was the angle $Q\hat{O}P$.

Now the tangent of this angle is $\frac{QP}{OP}$

that is $\frac{XC}{RC}$

or $\frac{X}{R}$

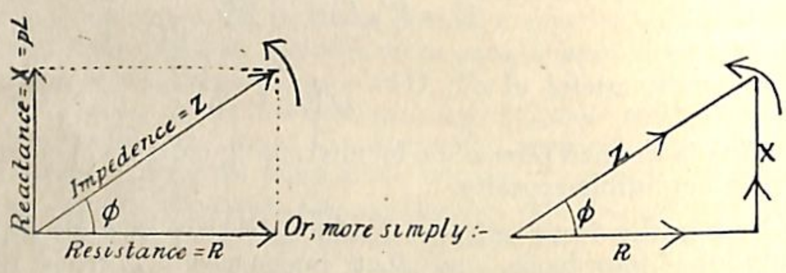
This angle is generally denoted by the Greek letter ϕ (phi) standing for the "phase difference angle," and it is such that its tangent is $= \frac{\text{Reactance}}{\text{Resistance}}$.

If we know the tangent of an angle, we can find its magnitude in degrees or radians straight from a table.

Impedence Triangles.

The easiest way of finding impedences and phase angles is to draw the resistances and reactances carefully to scale with lines drawn at right angles to each other, then the diagonal gives, to scale, the impedence in ohms, and the angle between it and the resistance line is ϕ. Z can then be measured with a linear scale, and ϕ with a protractor.

Thus :—



All measurements are in Ohms.

FIG. 38.

Example I.

Let an E.M.F. of 100 volts maximum at a frequency of 25~ be applied to a circuit of resistance $1{\cdot}5\ \omega$ and inductance $\cdot 01$ henry.

Here $p = 2\pi f = 2\pi \times 25 = 50\pi = 157$ radians per sec.

Reactance $= X = pL = 157 \times \cdot 01 = 1{\cdot}57$ ohms.

Resistance $= 1{\cdot}5$ ohms.

The current lags on the voltage by an angle ϕ.

Such that $\tan\phi = \frac{X}{R} = \frac{1{\cdot}57}{1{\cdot}5} = 1{\cdot}047$.

From the tables $\phi = 46° 19'$ nearly, or in circular measure $\phi = \cdot 80837$ radians

$$\begin{aligned} \text{Impedence } Z &= \sqrt{\{R^2 + X^2\}} \\ &= \sqrt{\{(1 \cdot 5)^2 + (1 \cdot 57)^2\}} \\ &= \sqrt{\{2 \cdot 25 + 2 \cdot 46\}} \\ &= \sqrt{4 \cdot 71} \\ &= 2 \cdot 17 \text{ ohms.} \end{aligned}$$

$$\text{Now } C = \frac{E}{Z}$$

$$\text{So } C = \frac{100}{2 \cdot 17}$$
$$= 46 \text{ amps.}$$

So we have a current of 46 amps. maximum value lagging 46° behind the E.M.F. of 100 volts maximum.

Plot these as vectors. It is no good taking a resultant because one is volts and the other amps.

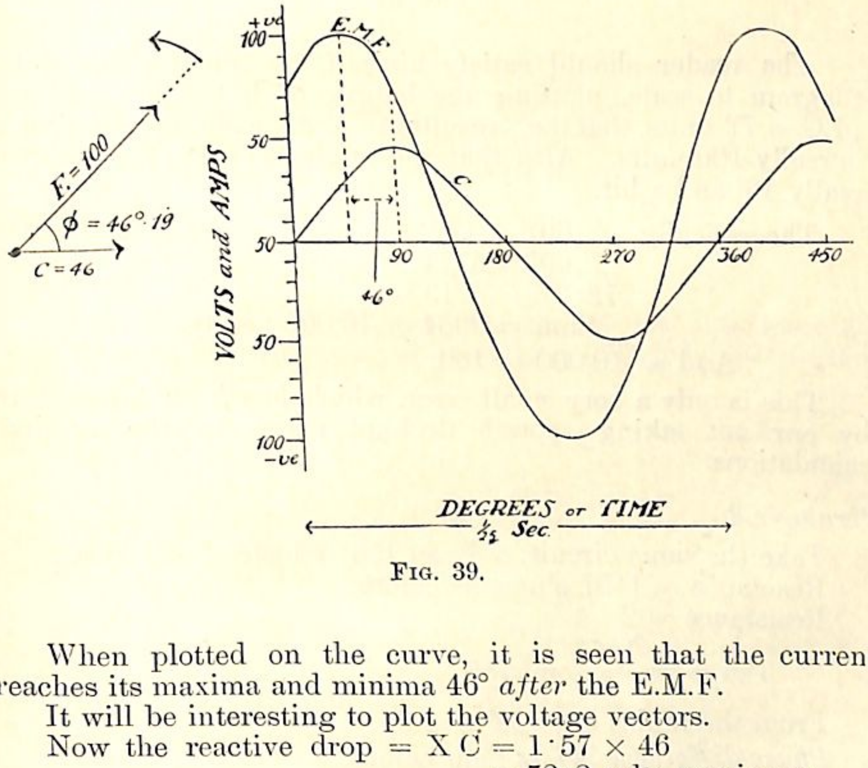


Fig. 39.

When plotted on the curve, it is seen that the current reaches its maxima and minima 46° *after* the E.M.F.

It will be interesting to plot the voltage vectors.

Now the reactive drop $= X C = 1 \cdot 57 \times 46$
$= 72 \cdot 2$ volts maximum.

The ohmic drop $= R.C. = 1 \cdot 5 \times 46$
$= 69$ volts maximum.

It looks impossible for the 100 impressed volts to supply both these values, but remember that the reactive and resistance drops have not got to have their maximum "wants" supplied simultaneously.

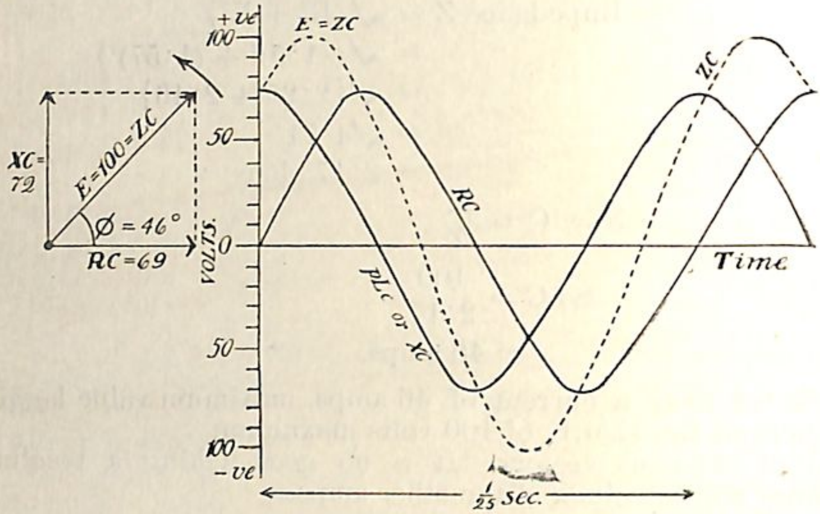


FIG. 40.

The reader should satisfy himself, by drawing the vector diagram to scale, plotting the lengths of RC = 69 units and pLC = 72 units, that the "resultant" or diagonal representing E is really 100 units. Also that the angle between E and CR is really 46° and a bit.

Theoretically $\sqrt{(69)^2 + (72 \cdot 2)^2}$ should = 100 or $\sqrt{10{,}000}$

$$69^2 = 4771$$
$$(72 \cdot 2)^2 = 5213$$
Sum = 9984 or 10,000 nearly.

And $\sqrt{10{,}000} = 100$.

This is only a very small error, which has been brought in by our not taking enough decimal places in the original calculations.

Example 2.

Take the same circuit, only let R = 2 instead of 1·5 ω.
Reactance = 1·57 ohms. as before.
Resistance = 2 ,, ,,

$$\text{Tan } \phi = \frac{1 \cdot 57}{2} = \cdot 785$$

From the tables $\phi = 38°.8'$ only.
Phase difference is *less* than before.
Also—

Impedence = $Z = \sqrt{\{2^2 + (1 \cdot 57)^2\}} = \sqrt{\{4 + 2 \cdot 46\}} = 2 \cdot 54$ ohms.

And $C = \frac{E}{Z} = \frac{100}{2 \cdot 54} = 39 \cdot 4$ amps. maximum value.

Current is *reduced*, as is natural, for R is greater and the impedence therefore has increased.

This result is shown graphically in Fig. 41.

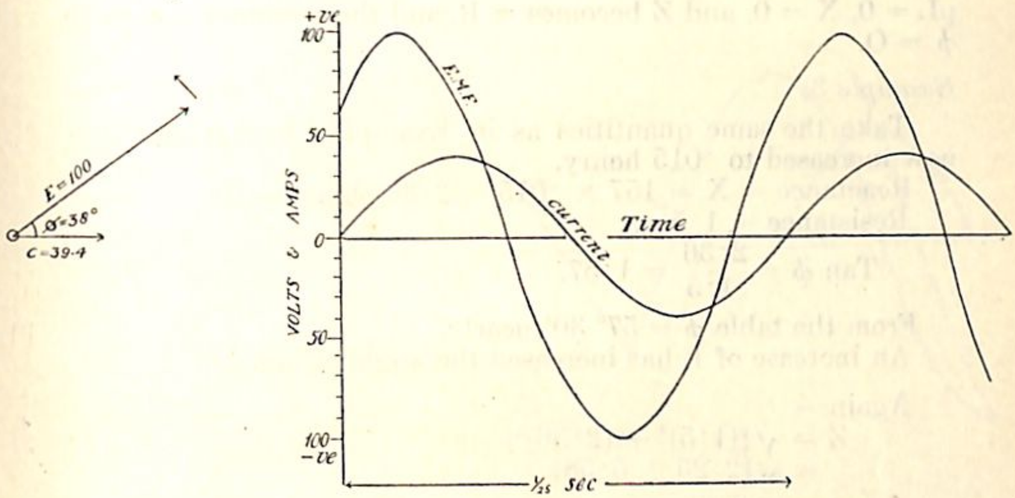


FIG. 41.

Again, the reactive drop = XC
= 1·57 × 39·4
= 62 volts maximum.

The ohmic drop = RC
= 2 × 39·4
= 78·8 volts maximum.

We notice, in Fig. 42, that the ohmic drop has increased and the reactive decreased, so that the angle of lag is less than before.

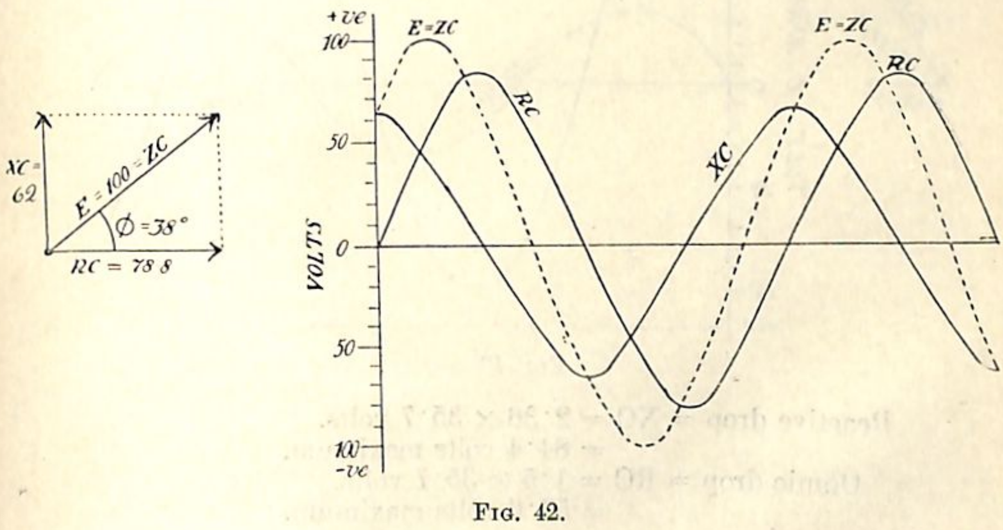


FIG. 42.

This process, carried to its logical conclusion, shows that a *perfectly* non-inductive circuit, whatever its resistance, will have the current $= \frac{E}{R}$ and in phase with the E.M.F., for if $L = 0$, $pL = 0$, $X = 0$, and Z becomes $= R$, and the reactance is zero, so $\phi = 0$.

Example 3.

Take the same quantities as in Example 1 except that L is now increased to ·015 henry.

Reactance $= X = 157 \times \cdot 015 = 2 \cdot 36$ ohms nearly.

Resistance $= 1 \cdot 5\ \omega$.

$$\text{Tan } \phi = \frac{2 \cdot 36}{1 \cdot 5} = 1 \cdot 57.$$

From the table $\phi = 57^\circ\ 30'$ nearly.

An increase of L has increased the angle of lag.

Again—

$$\begin{aligned} Z &= \sqrt{\{(1 \cdot 5)^2 + (2 \cdot 36)^2\}} \\ &= \sqrt{\{2 \cdot 25 + 5 \cdot 58\}} \\ &= \sqrt{7 \cdot 83} \\ &= 2 \cdot 8 \text{ ohms} \end{aligned}$$

$$\text{And } C = \frac{E}{Z} = \frac{100}{2.8} = 35 \cdot 7 \text{ amps.}$$

An increase of L has increased the impedence, so current is less than in Example 1. See Fig. 43.

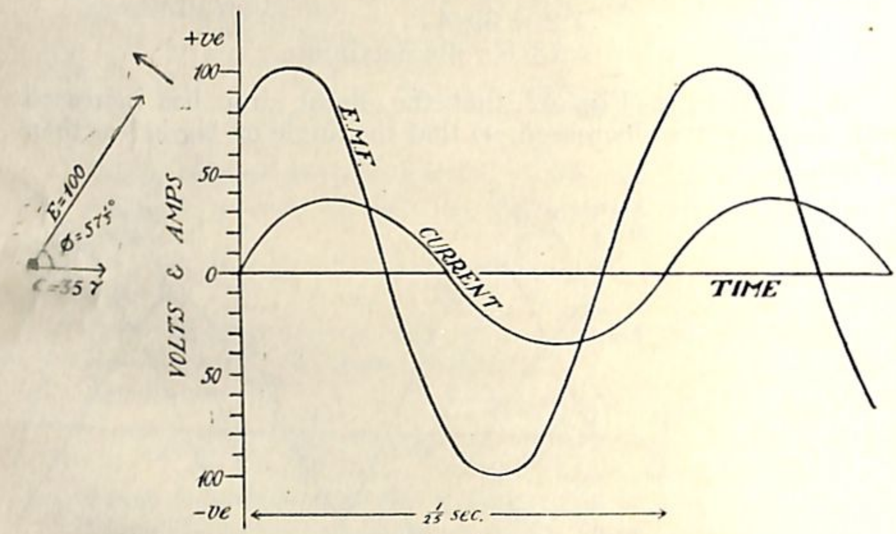


Fig. 43.

Reactive drop $= XC = 2 \cdot 36 \times 35 \cdot 7$ volts.
$= 84 \cdot 4$ volts maximum.

Ohmic drop $= RC = 1 \cdot 5 \times 35 \cdot 7$ volts.
$= 53 \cdot 6$ volts maximum.

From this it follows that a "perfectly inductive" circuit with no resistance at all would make the current lag 90°. For

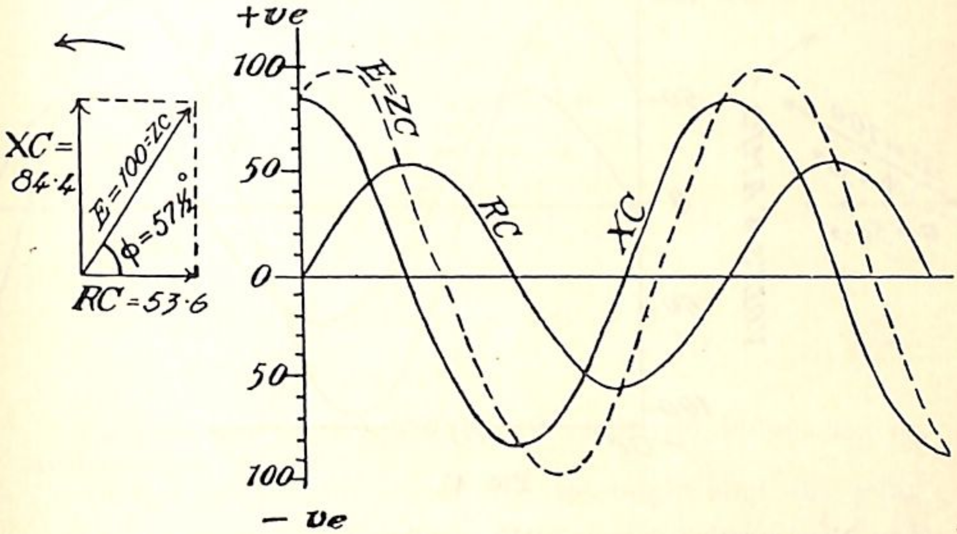


FIG. 44.

if R = 0, then Z becomes = X, and tan $\phi = \frac{X}{0} = \infty$ (*see* Appendix), so that $\phi = 90°$, and $C = \frac{E}{pX}$. In practice the lag can never be quite 90°, for R is never 0.

Example 4.

Take the same quantities as in Example 1, but let f drop from 25 ~ to 15 ~.

Here $p = 2\pi f = 2\pi 15 = 30\pi = 94 \cdot 5$.

Reactance $= X = 94 \cdot 5 \times \cdot 01 = \cdot 945$ ohms; this is less than in Example 1.

Resistance $= 1 \cdot 5$ ohms.

$$\text{Tan } \phi = \frac{X}{R} = \frac{\cdot 945}{1 \cdot 5} = \cdot 63.$$

$$\phi = 32° \ 13' \text{ only.}$$

Also—

$$Z = \sqrt{\{(1 \cdot 5)^2 + (\cdot 945)^2\}}$$
$$= \sqrt{\{2 \cdot 25 + \cdot 89\}}$$
$$= \sqrt{3 \cdot 14}$$
$$= 1 \cdot 77 \text{ ohms.}$$

$$\text{So } C = \frac{100}{1 \cdot 77}$$
$$= 56 \cdot 5 \text{ amps.}$$

Hence, the impedence dropping to 1·77 from 2·17 ohms causes the current to rise from 46 to 56 amps.

Current and voltage appear as in Fig. 45.

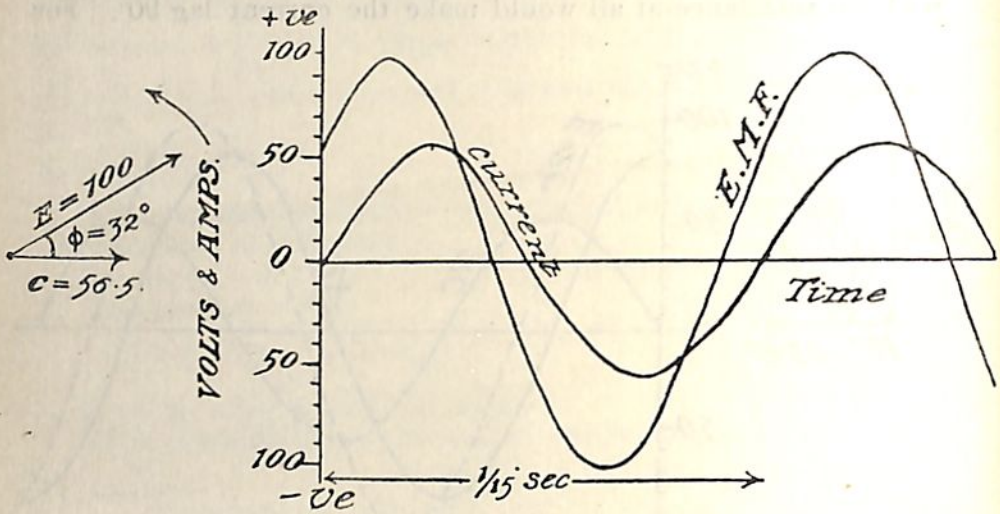


FIG. 45.

Now reactive drop = ·945 × 56 volts
= 53 volts. Less than in Example 1.
Ohmic drop = 1·5 × 56 volts
= 84 volts. More than in Example 1

Voltage vectors are shown in Fig. 46.

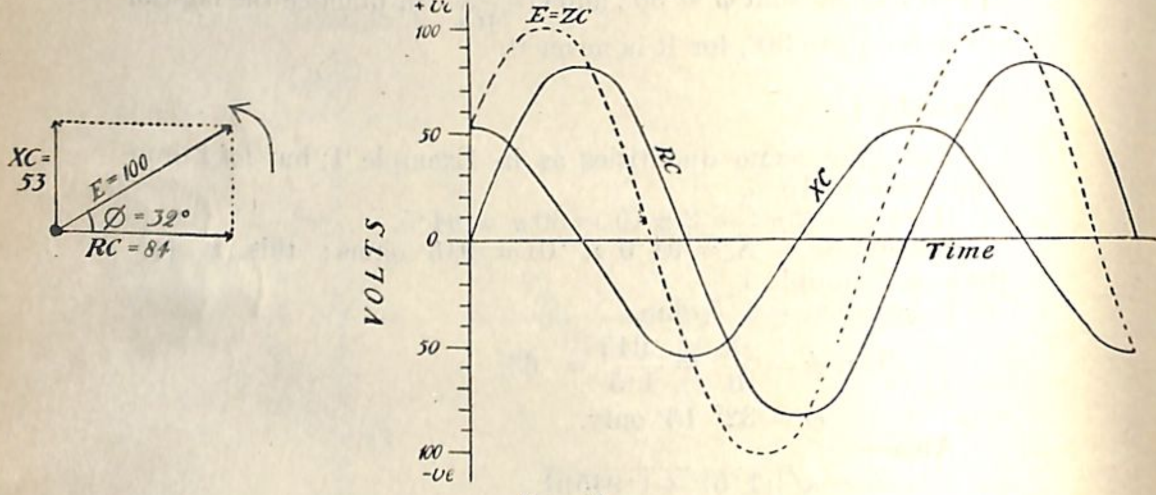


FIG. 46.

We see that the lower the frequency the greater the current, the less the reactance and the less the phase angle.

In a *direct* current the "frequency" of the voltage = 0 and p = 0, so that X = 0.

So we have $Z = \sqrt{\{R^2 + 0\}} = R$.

And $C = \frac{E}{Z} = \frac{E}{R}$ or Ohm's law.

In Example 1, the *direct* current would have been $= \frac{100}{1 \cdot 5}$ $= 66 \cdot 6$ amps.

We will now take an example of divided circuits.

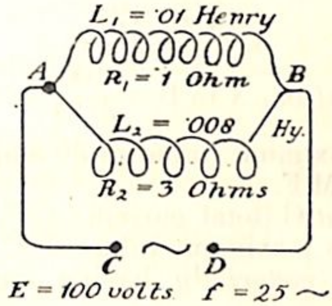


FIG. 47.

Suppose the leads AC and BD have no inductance or resistance.

In the case of direct currents we might find the joint resistance of R_1 and R_2 from the formula $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$, and then take $C = \frac{E}{R}$, or else we could find the value of C_1 (the current through upper half) $= \frac{E}{R_1}$ and C_2 (the current through the lower half) $= \frac{E}{R_2}$, and then $C_1 + C_2$ would $= C$, the current from C to D.

Turning to Alternating Current, we must use the latter method because the currents in the two halves may not be in phase with each other.

In both cases $p = 2\pi f = 2\pi\ 25 = 157$.

(1) *Upper half.*

Reactance $= X_1 = pL_1 = 157 \times \cdot 01 = 1 \cdot 57$ ohms.
Resistance $R_1 = 1\omega$.

$\text{Tan}\ \phi_1 = \frac{1 \cdot 57}{1} = 1 \cdot 57. \quad \phi_1 = 57\frac{1}{2}^\circ.$

$$\begin{aligned}\text{Again, } Z_1 &= \surd\{R_1^2 + X_1^2\} \\ &= \surd\{1 + 1 \cdot 57^2\} \\ &= 1 \cdot 86 \text{ ohms.}\end{aligned}$$

And so C_1 (from A to B) $= \frac{E}{Z_1} = \frac{100}{1 \cdot 86} = 53 \cdot 8$ amps.

Hence C_1 has maximum value $= 53 \cdot 8$ amps., which lags $57\frac{1}{2}^\circ$ behind the E.M.F.

(2) *The lower half.*

Reactance $= X_2 = pL_2 = 157 \times \cdot 008 = 1 \cdot 256$ ohms.
Resistance $R_2 = 3$ ohms.

$$\text{Tan } \phi_2 = \frac{1 \cdot 256}{3} = \cdot 4186. \qquad \phi_2 = 22^\circ\ 43'.$$

$$\begin{aligned}\text{Again, } Z_2 &= \sqrt{\{R^2_2 + X^2_2\}} \\ &= \sqrt{\{3^2 + (1 \cdot 256)^2\}} \\ &= \sqrt{10 \cdot 12} \\ &= 3 \cdot 34 \text{ ohms.}\end{aligned}$$

$$\text{And } C_2 \text{ (from A to B) : } \frac{100}{3 \cdot 34} = 30 \text{ amps.}$$

Here C_2 has a maximum value of 30 amps. and lags only 22° 43′ behind the E.M.F.

Now at *any instant* C (total current) = $C_1 + C_2$ (algebraical sum), but to find the maximum value of C we must add the values of C_1 and C_2 *vectorially*, having regard to the phase angle between them.

Now C_1 lags 57° 30′ on the E.M.F.

And C_2 lags 22° 43′ on the E.M.F.

So C_1 lags (57° 30°—22° 43′) or 34° 47′ on C_2.

The value of C is best found graphically as in Fig. 48.

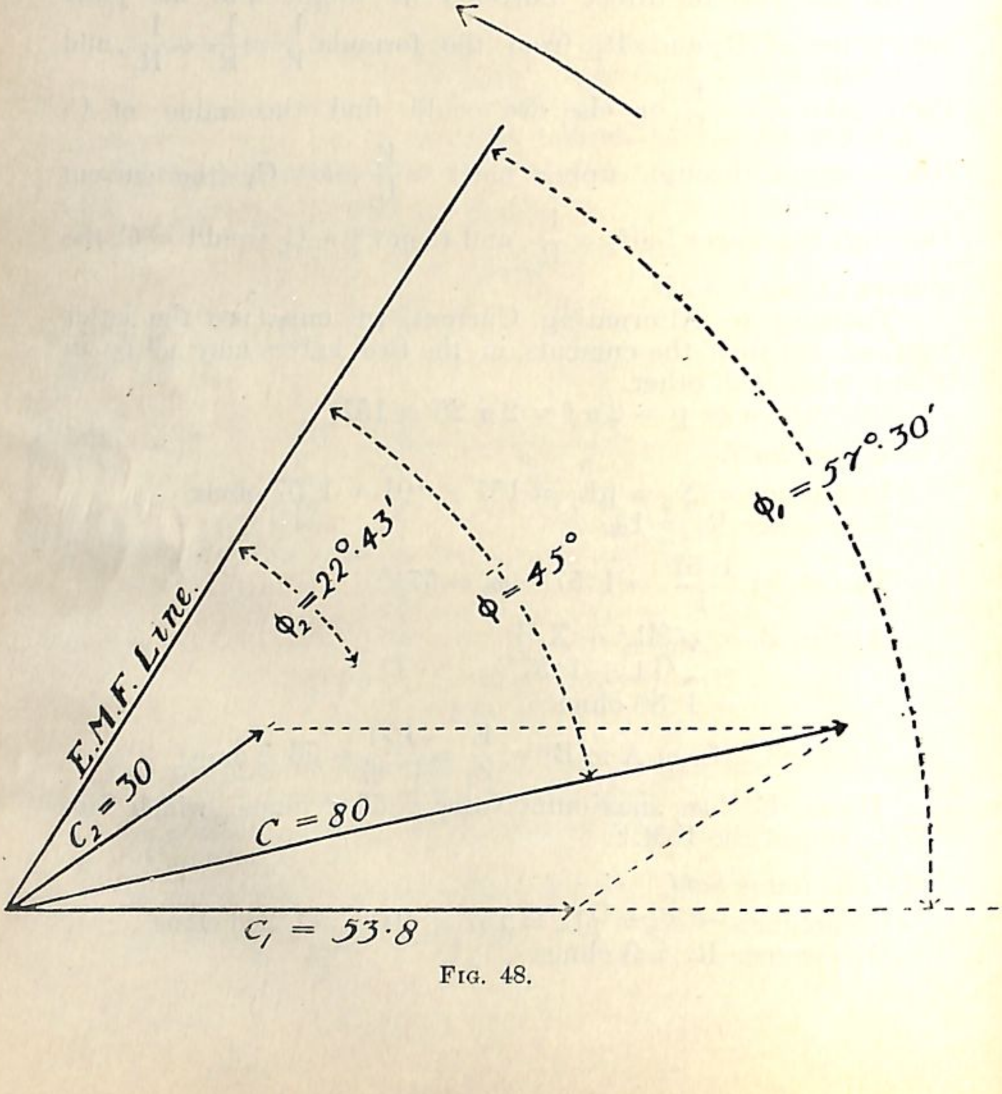


FIG. 48.

Drawing the vector diagram carefully—preferably on a large scale—we find that the resultant of C_1 and C_2 (the diagonal of the parallelogram) is 80 units long, representing 80 amps. as the maximum value of C, and this current lags about 45° astern of the E.M.F.

The reader should by now see clearly why C = 80 and not (54 + 30) or 84 amps.

In our W.T. circuits, dealing with currents of very high frequency, we have a special case.

Here $2\pi f$ or p is very large indeed.

Suppose $L = 200$ mics. $= \frac{200}{10^6}$ henries.

And $f = 10^6 \sim$. Then $p = 2\pi f = 2\pi 10^6$.

$$\text{Reactance} = X = pL = 2.\pi.10^6 \times \frac{200}{10^6} = 400\pi.$$
$$= 1{,}260 \text{ ohms.}$$

So that if the resistance be very low—say $\frac{1}{2}$ an ohm—we shall have several interesting effects :—

(1) $\text{Tan } \phi = \frac{X}{R} = \frac{1260}{\frac{1}{2}} = 2520.$ A very large number.

$\phi = 89° \, 58'$ nearly—or very nearly 90°.

(2) $Z = \sqrt{\{R^2 + X^2\}}$. Now X^2 is a very large number indeed, so that if we neglect R altogether, the answer will not be affected. We can then say Z = X and the circuit is almost "perfectly inductive" (*see* p. 97).

$$C = \frac{E}{X} = \frac{E}{pL}, \text{ or } E = pLC \text{ or } XC.$$

That is, the whole of the impressed E.M.F. is taken up in reversing and changing the current.

(3) Further, $C = \frac{E}{\text{A large number}}$

Unless E be very large, C will be very small.

Hence, even a *low resistance* coil of a few hundred mics inductance will form a complete bar to the passage of an oscillating current, whereas its opposition to that of a low frequency current is very small indeed. Notice that its reactance to a *direct* current is nil.

This phenomenon we shall find used in certain protective devices to be described later.

Arising out of this ability to neglect the resistance (provided it be low) of circuits carrying oscillatory currents, an important point arises. Take the circuit in Fig. 50 and let f be very large.

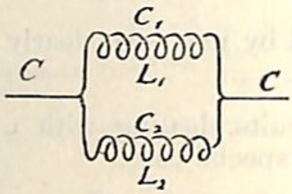


FIG. 50.

$$\text{Here } C_1 = \frac{E}{pL_1} \text{ and } C_2 = \frac{E}{pL_2}$$

Both these currents lag 90° on the E.M.F., and are therefore in phase.

$$\text{Hence } C = C_1 + C_2 = \frac{E}{pL_1} + \frac{E}{pL_2}$$

$$= \frac{E}{p} \times \left(\frac{1}{L_1} + \frac{1}{L_2}\right)$$

If L is the "joint inductance" of L_1 and L_2 or any more L_3, &c.

$$C = \frac{E}{pL} = \frac{E}{p} \times \frac{1}{L}$$

$$\text{Hence } \frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \ldots\ldots$$

This is similar to the ordinary law of resistances for direct currents.

In a circuit containing any number of resistances and inductances in *series*, such as resistances R_1, R_2, R_3 . . . . . and inductances L_1, L_2, L_3 and so on, *provided* there are no parallel or branched circuits, then the total resistance $R = R_1 + R_2 + R_3$ . . . . and the total inductance $L = L_1 + L_2 + \ldots.$

$$\begin{aligned} \text{Hence the joint reactance } X &= X_1 + X_2 + X_3 \\ &= pL_1 + pL_2 + \ldots\ldots \\ &= p\,(L_1 + L_2 + \ldots\ldots) \\ &= pL. \end{aligned}$$

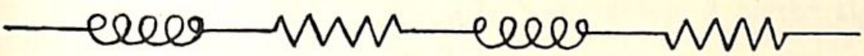
And the joint impedence $= \sqrt{\{R^2 + X^2\}}$ as before.

This may be found graphically by plotting the R_1, R_2, &c. horizontally and the X_1, X_2, &c. vertically. They may be taken in any order to find the final diagonal Z, but if Z_1, Z_2, Z_3, &c. be required, R_1 must be taken with X_1, R_2 with X_2, and so on.

This method is illustrated as follows :—

Example.—Let f = 50 ~. Find C if E = 100 v. $p = 50 \times 2\pi = 314$.

$R_1 = 2\omega$ $R_2 = 3\omega$ $R_3 = 4\omega$ $R_4 = 1\omega$



$L_1 = 0$ $L_2 = \cdot 0159$ $L_3 = 0$ $L_4 = \cdot 0222$

Fig. 51.

$$R = R_1 + R_2 + \ldots = 10\,\omega.$$
$$L = L_1 + L_2 + \ldots = \cdot 0381.$$
$$X_1 = 0. \quad X_2 = 5 \text{ ohms}. \quad X_3 = 0. \quad X_4 = 7 \text{ ohms}.$$
$$X = X_1 + X_2 + \ldots = 12 \text{ ohms}.$$

Or $X = pL = 314 \times \cdot 0381 = 12$ ohms.

Then $Z = \sqrt{\{R^2 + X^2\}} = \sqrt{\{100 + 144\}} = 15 \cdot 6$ ohms.

So that $C = \frac{E}{Z} = \frac{100}{15 \cdot 6} = 6 \cdot 4$ amps., lagging by an angle ϕ such that $\tan\phi = \frac{X}{R} = \frac{12}{10} = 1 \cdot 2$. $\phi = 50°$ nearly.

Further, Z_1 and Z_3 = QR_1 and R_3 respectively (since L_1 and L_3 are zero) and

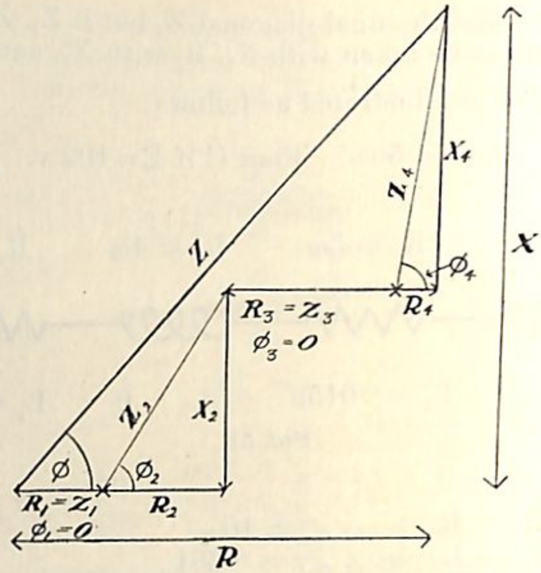
$$Z_2 = \sqrt{\{R_2^2 + X_2^2\}} \text{ and } Z_4 = \sqrt{\{R_4^2 + X_4^2\}}.$$

This could have been solved graphically, also giving ϕ_1, ϕ_2, &c., the latter being the angles by which the current lags on the "local" D.P.'s, that is, on the several E.M.F.'s across the portions of the circuit. Here $\phi_1 = \phi_3 = 0°$. *See* Fig. 52.

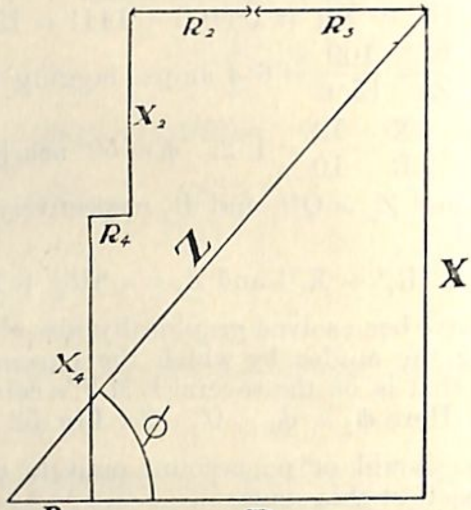
The reader should or no account omit to construct these figures for himself at this stage.

Now had any portion of this circuit been shunted, then this piece must first be dealt with by assuming some convenient voltage across it, finding C_1 and C_2 as in the preceding example, and from that deducing C graphically. This value C, divided into the assumed voltage, gives Z the joint impedence, for $Z = \frac{E}{C}$. Knowing Z and the angle at which the joint current lags on the local assumed voltage E, we can find X and R, the reactance and resistance, which would produce an *equivalent* effect in the circuit.

We can then proceed as above.



Taken in order, giving Z_1, Z_2, &c., and ϕ_1 ϕ_2 ϕ_3, &c.



Not taken in order, giving X, R, Z and φ, but not Z_1 Z_2 Z_3, &c., or ϕ_1 ϕ_2 ϕ_3, &c.

FIG. 52.

The reader should, in addition to arriving at his impedences and phase angles by calculation as shown above, also use the graphical method as shown in Figs. 38 and 51. He will at once appreciate the great utility of the "Impedence triangles" and will see what an enormous saving of arithmetical labour and of possible errors they effect.

Capacity.

Among the general considerations regarding condensers given in Chapter I., we observed that coulombs will flow into a condenser, gradually "charging it up" or raising its terminal pressure until this latter became equal to the applied pressure. At all times q = Se, where e is the pressure to which the condenser is charged at any instant (*see* p. 4).

We will now return to the hydraulic analogy given at the beginning of this chapter, but we now have introduced a flexible water-tight partition of india-rubber, stretching it across the pipe. (Fig. 23, p. 71.)

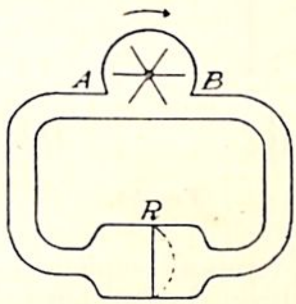


FIG. 53.

Suppose the pump handle be revolved *continuously* in the direction of the arrow. The water will try to flow in the outside circuit from A to B. (Fig. 53.)

The pump will, perhaps, deliver a few pints into the left-hand arm of the pipe, and the surplus of water here causes the rubber to bulge out to the right. This action will, of course, displace the water on the other side and allow a similar number of pints to flow up the right-hand arm of the circuit and into the —ve terminal of the pump at B.

This bulging of the rubber will continue till such time as the tension of the rubber (terminal voltage of the condenser) exactly balances the applied pressure at the pump (or applied E.M.F.) When this happens no further movement of water (current) takes place.

A direct current dynamo (or cell), therefore, can produce only a momentary current due to the "displacement" of the coulombs from their normal position of rest.

Consider now what happens when the rotary motion of the pump is alternating. Here the pints of water move backwards and forwards, the rubber bulging first one way and then the other. Consequently we get an alternating current in the pipe, and since the action of the rubber diaphragm corresponds to that of the charged dielectric, we can get an alternating electric current in a circuit containing a condenser.

In a circuit in Fig. 54 (*a*) it would be possible to light the lamp with an alternating, but not with a direct current.

Again, suppose the pipe were further subdivided by a number of elastic discs placed at intervals round the circuit and the spaces filled with water when at rest, we should still get an alternating movement of water which would be the same in all portions of the pipe.

Consequently we could light the lamp as in Fig. 54 (*b*).

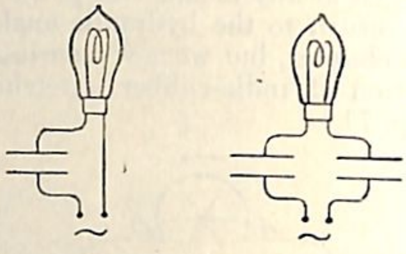


FIG. 54.

A condenser, then, forms a complete bar to the passage of a continuous sustained direct current, but it allows an alternating current to flow.

It may be well to notice that no water actually flows *through* the substance of the rubber, and likewise the coulombs do not penetrate the dielectric.

We shall often speak of an alternating current flowing "through" a condenser, but shall always remember that this implies that the dielectric is distorted but not penetrated, and that the current moves "into and out of" the condenser, not "through" it in the ordinary sense of the word.

We must now consider more closely what effect the presence or absence of the rubber diaphragm will have upon the alternating current of water.

The presence of the rubber is shown by its opposition to any *continued* flow of water. In other words, while it is being expanded it exerts a "back pressure" tending to make it more difficult for each succeeding pint of water to get past a given point in any one direction, provided that the pint be moving so as to tend to stretch it still more. It therefore tends to restrict the movement of the water within narrower limits than would otherwise be the case.

We see at once that the "stretchiness" (the proper expression being "compliance") of the rubber will affect our calculations.

The smaller and thicker the rubber disc the less will it stretch and the sooner will movement be "brought up," that is, the fewer pints of water will suffice to raise the tension of the rubber to equal the applied pressure, this being the point at which all further movement ceases. In other words, the larger and thinner the rubber, the greater its "stretchiness" or "capacity" for water and the *less difference* will its presence make to the passage of water or current strength.

So also, a condenser of large capacity will allow a large number of coulombs to flow into it before its terminal pressure equals the applied pressure, and the larger the capacity of the condenser the less is its presence felt in the circuit. We can carry the analogue still further and say that the larger the area and the less the thickness of the dielectric (or rubber disc) the greater is its capacity and the less its disturbing effect.

Again, one sample of rubber may be more elastic than another, so also some dielectrics have a greater capacity than others of the same size and thickness.

The opposition to the continued flow of a current will take the form of a back E.M.F. which tends to keep the condenser empty, and we have already seen that the larger the capacity the less the opposition, and so the less the back E.M.F.

The back E.M.F. of any condenser will therefore vary inversely as its capacity

$$\text{or back E.M.F.} \propto \frac{1}{S}.$$

We may follow this result to its logical conclusion. A condenser of *infinitely* large capacity will allow an enormous number of coulombs to flow into it without being charged up to any pressure at all. Such a condenser would even allow a direct current to pass on for ever, for it would never get charged up. Hence an infinitely large condenser is the same thing as a *dead short circuit* of conducting material.

Again, an infinitely small condenser would consist of a complete *break* in a circuit, where the two ends of the broken wire, like pin-points, are opposed to each other, have a minute area and practically no capacity. Such a condenser at *once* gets charged up to the applied pressure and allows no current to pass at all, for no coulombs can flow into the dielectric.

Between these limits all practical examples will fall.

We have now considered the effect of the size of the condenser. We have now to consider the *frequency* of the alternating current flowing.

We saw at the beginning of the chapter that in the case of a low frequency current we might conveniently suppose that the coulombs went several times round the circuit in each direction, while with a high frequency they only travelled a little distance in the conductor before reversing. Stated more exactly, the coulombs have a greater *amplitude* of movement in the case of the low frequency than in that of the high one.

Now the rubber diaphragm, unless it be ruptured, *will not allow* any complete circulation of the water round the circuit, and the shorter the range of movement of the water in the neighbourhood of the disc, the better the disc will be pleased, since it does not have to stretch so much.

So also with electric currents. A low frequency will fully charge the condenser each time, while a high one may but partially charge it at each swing of current.

Consequently the back E.M.F. of a condenser will be less as the frequency of the current (and therefore of the applied E.M.F.) increases.

We have, then,

$$\text{Back E.M.F.} \propto \frac{1}{f}.$$

Combining this with the above result

$$\text{Back E.M.F.} \propto \frac{1}{fS}.$$

Now to consider the effect of the current strength. The more coulombs we try to force into a condenser in any one second, the greater, obviously, will be the pressure to which the condenser is charged during that second. So the stronger the current the larger the back pressure.

Hence back E.M.F. $\propto$ current.

To combine all three

$$\text{Back E.M.F.} \propto \frac{C}{fS}.$$

This does not tie us down to units of any sort.

We shall find later that

$$E = \frac{C}{2\pi fS} \text{ or } \frac{C}{pS}$$

Where E = back E.M.F. (or terminal P.D.) in volts.
C = current in amps.
f = frequency in ~.
S = capacity in farads.
p = $2\pi f$ (as before).

To prove this last result and to get a more thorough insight into the action we will trace out the cycle of changes which take place. Keeping in mind our analogue, we see :—

When the dielectric (diaphragm) is charged (bulges) to its full extent, then the maximum number of coulombs (pints) have passed into the condenser (bag). Also, *no* coulombs (pints) are now moving.

Hence the current is zero, while the dielectric (rubber) is charged (distended) up to a pressure equal to that applied.

Further, the back E.M.F. of the condenser (tension of the rubber) is in such a direction as to *assist* in the reversal of the current.

Let the current now reverse.

Coulombs (pints) flow out of the condenser (bag).

The back E.M.F. of the condenser (tension of rubber) falls while the new current increases in strength.

When the condenser (bag) is completely emptied the back E.M.F. (tension) is zero and the current is at a maximum.

Due to the applied E.M.F. the current goes on flowing.

Coulombs (pints) flow into the condenser (bag) and the dielectric (rubber) develops a tension in the reverse direction (the bag being now inside out) opposing the continual flow of current and assisting it to reverse.

The current gets weaker and finally stops.

At this instant the dielectric (rubber) is fully charged (distended) once more to a pressure equal to that applied, for the full number of coulombs (pints) are now in the condenser (bag) and no more current can flow without reversing.

Consider a point in the circuit, which we will call A. Now when a current flows the coulombs will move to and fro passing the point A as they do so. Let A be the centre point of the travel of a certain number of coulombs Q.

Consider those situated to the right of A to be +vely, and those to the left of A to be −vely situated.

Let all the coulombs be pushed away to the left of A, and to be just about to come back from left to right.

Here coulombs are maximum −ve (Q of them in all).

Current is zero, but about to become +ve (moving to right).

Now as the coulombs start moving, the current grows.

When half the coulombs have passed A, they will be evenly balanced and the "displacement of coulombs or charges" will be zero. The current, however, is maximum +ve, for it is flowing from left to right.

Tabulating the results for the whole cycle, we have—

Displacement of Coulombs.	*Current.*
Maximum −ve.	Zero, changing from −ve to +ve
Zero, changing from −ve to +ve.	Maximum, +ve.
Maximum +ve.	Zero, changing from +ve to −ve.
Zero, changing from +ve to −ve.	Maximum −ve.
Maximum −ve.	As before.

Remember, the maximum displacement was Q coulombs. Draw a displacement curve for coulombs and a current curve, both having the same time units as abscissæ. (Fig. 55.)

We see at once that the current curve is a curve of "slopes" of the coulomb curve. The latter is a position-time curve, while the former is a velocity-time one. This must be so, since amps. are essentially "rate of change of coulombs" or "coulombs per second."

Now the maximum value of the first curve is Q coulombs, so that of the second curve will be pQ ampères, where $p = 2\pi f$, as

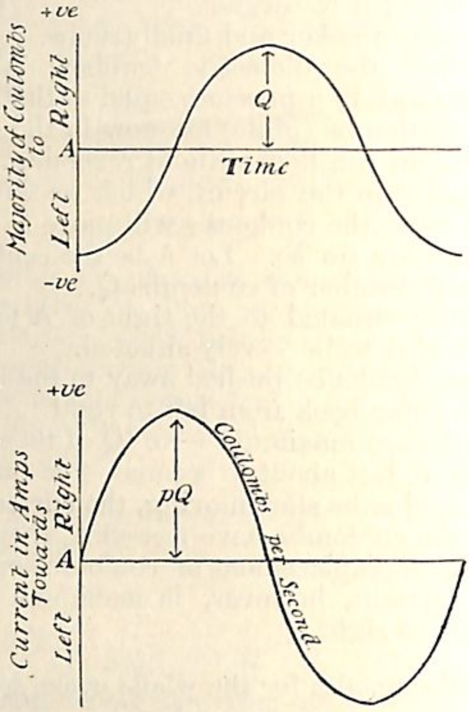


FIG. 55.

before. (*See* Fig. 32.) Further, the current curve leads by 90° on the coulomb displacement curve, so that the vectors are shown as in Fig. 56.

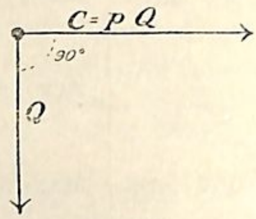


FIG. 56.

Now to observe the back E.M.F. again.

The fuller the condenser the greater the strain on the dielectric, so the bigger the displacement of Q the bigger the back E.M.F.

Hence the Q curve and the back E.M.F. curve will rise and fall together, but will be in direct *opposition*.

Remember that the condenser *opposes* the movement of coulombs into it. When the displacement is to the left (−ve), the tension of the rubber is pulling towards the right (+ve).

So, if the current leads on the displacement by 90°, the back E.M.F. leads on the current by 90°.

Now the max. $C = pQ$ amps. But $Q = SE$.

So max. $C = pSE$, where E = max. back E.M.F.

Or max. $E = \frac{C}{pS}$, where C = max. Current.

Hence the terminal voltage of a condenser leads by 90° on the current and has a maximum value $= \frac{C}{pS}$, where C is the maximum current.

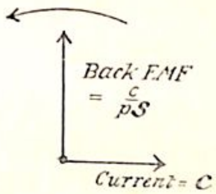


Fig. 57.

Now consider the applied E.M.F. As before, part of it will be employed in overcoming resistance, being in phase with the current and having a maximum value = CR.

The other part must overcome the back E.M.F. of the condenser, being employed in charging and discharging it.

This part must be equal and opposite to the back E.M.F.

So we have Fig. 58.

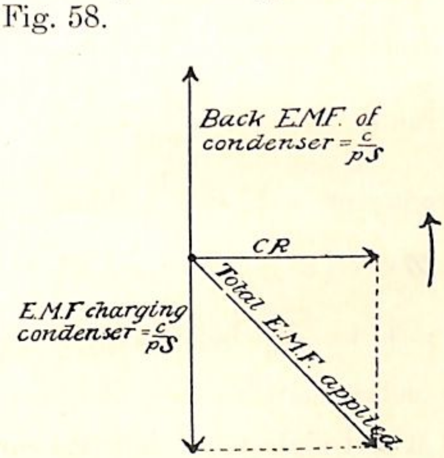


Fig. 58.

This "reactive" drop of volts due to a condenser must therefore be 90° *astern* of the current in phase, and have a maximum value $= \frac{C}{pS}$.

Further, the reactance of the condenser is $\frac{1}{pS}$ ohms.

Now to restrict ourselves to the applied E.M.F. and its component parts, we can draw our E.M.F. vectors as in Fig. 59.

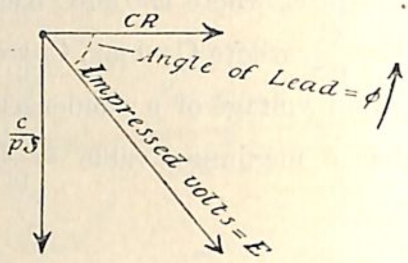


FIG. 59.

Now the net result of all this is that the presence of a condenser means that some of the E.M.F. is absorbed in storing static energy in the condenser, and is therefore not available for producing current through the resistance.

Consequently the current is not so strong as it was before the introduction of the condenser, and further, it now jumps ahead of the voltage, "leading" by an angle whose tangent is given by $\frac{\text{Reactance}}{\text{Resistance}} = \frac{1}{\text{p S}} \div \text{R} = \frac{1}{\text{pSR}}$.

Tabulating our results—

$$\text{Ohmic drop} = \text{CR volts.}$$

$$\text{Reactive drop} = \frac{\text{C}}{\text{pS}} \text{ volts.}$$

$$\text{Tan } \phi = \frac{1}{\text{pSR}}.$$

The Reactance is now $= \text{X} = \frac{1}{\text{pS}}$ ohms.

$$\text{Impedence} = \text{Z} = \sqrt{\{\text{R}^2 + \text{X}^2\}} = \sqrt{\left\{ \text{R}^2 + \left(\frac{1}{\text{pS}}\right)^2 \right\}}$$

And current $= \text{C} = \frac{\text{E}}{\text{Z}}$ as before, only Z here is impedence due to resistance and capacity.

It is difficult at first sight to see how the current can jump ahead of the voltage which causes it. It must be remembered that it cannot do so at the instant of switching on. A few alternations will take place during which the current is gradually increasing its phase angle; very soon it will pick up its proper value.

Both in inductive and condenser circuits the current is momentarily greater during the first swing or two than that given in the above formulæ. These latter give its value after having got "into its stride."

It will possibly be helpful to regard the inductance as being an inveterate "obstructionist" to all changes. "What does this current mean by changing? Let it wait awhile," may be taken as the views of the inductance.

On the other hand, a condenser is very discontented with its present lot. Eager for any change, it readily accepts current when empty, then tries to disgorge as quickly as possible the coulombs it has just accepted. Being always looking ahead for "some new thing" it seems to suck the current ahead of the E.M.F. in sympathy with its aspirations.

Example 1.

Let —

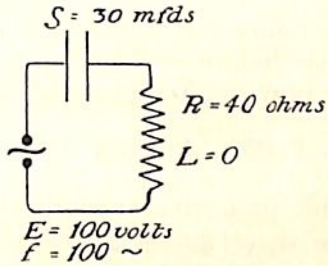


FIG. 60.

$$p = 2\pi f. = 2\pi 100 = 628. \qquad S = 30 \text{ microfarads.}$$

$$\text{Reactance} = X = \frac{1}{pS} \qquad = \frac{30}{10^6} \text{ or } \frac{3}{10^5} \text{ farads}$$

$$= \frac{10^5}{3 \times 628} \text{ ohms.}$$

$$= 53 \text{ ohms.}$$

Resistance = 40 ohms.

$$\text{Tan } \phi = \frac{\text{Reactance}}{\text{Resistance}} = \frac{X}{R} = \frac{53}{40} = 1 \cdot 325.$$

$\phi = 53°$ nearly.

Also—

$$Z = \sqrt{\{40^2 + 53^2\}}$$

$$= 66 \cdot 4 \text{ ohms.}$$

$$\text{So } C = \frac{E}{Z} = \frac{100}{66 \cdot 4} = 1 \cdot 51 \text{ amps. maximum value.}$$

So we have $C = 1 \cdot 51$ amps *leading* 53° on the volts.

Now the ohmic drop = $CR = 1 \cdot 51 \times 40 = 60 \cdot 4$ volts.

Reactive drop = $XC = 1 \cdot 51 \times 53 = 80$ volts.

The E.M.F. vector diagram is as in Fig. 61.

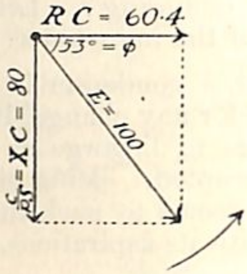


FIG. 61.

Example 2.

Now let the resistance fall to 20 ohms.
Here reactance as before = 53 ohms.
,, resistance now = 20 ohms.

$$\text{Tan } \phi = \frac{53}{20} = 2 \cdot 65. \quad \phi = 69^\circ \, 40' = 70^\circ \text{ nearly.}$$

The current leads by a greater angle than before.

Here impedence $= \sqrt{\{20^2 + 53^2\}}$.
$= 56 \cdot 7$ ohms.

$$C = \frac{100}{56 \cdot 7} = 1 \cdot 77 \text{ amps.}$$

Hence the current is increased, but leads more.
The E.M.F. divides its duties as shown in Fig. 62.
Reactive drop $= 53 \times 1 \cdot 77 = 93 \cdot 6$ volts.
Ohmic $= 20 \times 1 \cdot 77 = 35 \cdot 4$ volts.

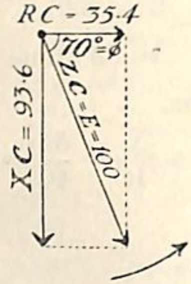


FIG. 62.

Example 3.

Follow this to its natural conclusion and let R become zero.

$$\text{Here tan } \phi = \frac{X}{R} = \frac{53}{0} = \infty \text{ (\textit{see} Appendix).}$$

Hence $\phi = 90^\circ$.
The current is 90° ahead of volts.

Also since Z = X,

$$C = \frac{E}{X} = \frac{EpS}{1} = pSE,$$
$$= \frac{100}{53} = 1 \cdot 89 \text{ amps.}$$

So that if the resistance of the circuit be very low, the current will have a maximum value of pSE, and will lead 90° on the E.M.F.

Example 4.

Let S increase to 40 mfds., keep the rest as in Example 1.

Here reactance $= X = \frac{1}{pS} = \frac{10^5}{628 \times 4}$ ohms.

$\therefore X = 40$ ohms, nearly.

Notice X is less than in Example 1.

$\text{Tan } \phi = \frac{40}{40} = 1. \quad \phi = 45°.$

The current does not lag so much.

Also—

Impedence $= Z = \sqrt{\{40^2 + 40^2\}}$.
$= 56 \cdot 6$ ohms.

$C = \frac{E}{Z} = \frac{100}{56} = 1 \cdot 78$ amps., larger than in Example 1.

Example 5.

Carry this to its natural conclusion and let S become *infinitely large*. Reactance = X = 0, for if $S = \infty$

Then $\frac{1}{S} = 0$

and $X = \frac{1}{pS}$.

So $\tan \phi = \frac{X}{R} = 0. \quad \phi = 0°$ and current and volts are in phase.

Also, since X = 0, Z = R.

Hence $C = \frac{E}{R}$. Ohm's law.

The case of the "infinitely small" capacity is left to the reader (*see* p. 107).

Example 6.

Let f now = 300. All the rest as in Example 1.

Here $p = 2\pi 300 = 1880$.

Reactance $= \frac{10^5}{3 \times 1880} = 17 \cdot 7$ ohms.

Resistance = 40 ohms.

$\text{Tan } \phi = \frac{\text{Reactance}}{\text{Resistance}} = \frac{17 \cdot 7}{40} = \cdot 443.$

$\phi = 24°$ nearly.

The angle of lead is lessened.

Also—

Impedence $= \sqrt{\{40^2 + (17 \cdot 7)^2\}}$
$= 43 \cdot 7$ ohms.

So $C = \frac{100}{43 \cdot 7} = 2 \cdot 3$ amps., a larger current than before.

So the higher the frequency the less the reactance, the less the impedence, and the smaller the angle of lead.

The reader should draw the curves and vector diagrams for himself. The E.M.F. being 100 volts and the current about 2 amps., he will have to make special scales in the case of E.M.F. and current curves.

However, where the E.M.F.'s are all on the same vector diagram he *must* keep to the same scale throughout.

Now in W.T. oscillating circuits we have very high frequencies and low resistances. Further, the capacities are small compared to a farad.

Looking at the equation—

$$\text{Tan } \phi = \frac{1}{pSR},$$

we see that if any one of them—p, S, or R—become zero, ϕ becomes 90°.

In a *direct current* circuit $p = 0$, so reactance (with a condenser) $= \frac{1}{0 \times S} = \infty$. Hence no current *flows*.

In W.T. oscillators p is very large, S very small, so pS may be considered a moderate value. R may be made small. If this happens we have $C = pSE$ and leading 90° on the volts.

In a circuit containing condensers in series we add their reactances together, so that—

$$\begin{aligned} \text{Joint reactance } X &= X_1 + X_2 + X_3 + \ldots\ldots \\ &= \frac{1}{pS_1} + \frac{1}{pS_2} + \frac{1}{pS_3} + \ldots\ldots \\ &= \frac{1}{p}\left(\frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3} + \ldots\ldots\right) \end{aligned}$$

Hence the joint capacity is given by—

$$\frac{1}{S} = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3} + \ldots\ldots$$

Let us now take the case of a circuit containing resistance, inductance, and capacity.

Here the applied E.M.F. has to supply the ohmic and two reactive drops of voltage at different instants of time.

The maximum E.M.F. values to be overcome will of course be—

(1) Ohmic = CR in phase with current.

(2) Reactive due to inductance = pLC 90° ahead.

(3) „ „ „ capacity $= \frac{C}{pS}$ 90° astern.

It is seen at once that (2) and (3) are directly opposed to each other in phase. This means in ordinary language that the back E.M.F. of inductance assists in the charging of the condenser whose own back E.M.F. in turn assists in the changing of current in the inductance. Hence the joint effect of L and S is to neutralise each other's reactances, thereby reducing the total reactance of the circuit.

Now the inductive reactance = pL, we will call this X_L, and the "condensive" (or "captive") $= \frac{1}{pS}$, we will call this X_s.

In a circuit containing both L and S in series we have the joint reactance = difference between pL and $\frac{1}{pS}$.

Now if pL be larger than $\frac{1}{pS}$ the inductive reactance wins the day and current lags on the E.M.F. If, on the other hand, $\frac{I}{pS}$ preponderates over pL, the current leads on the E.M.F.

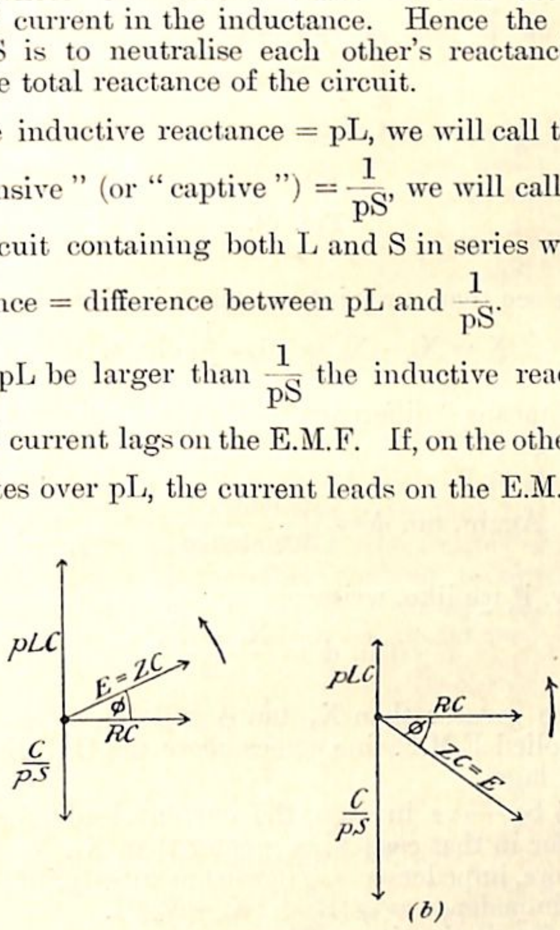


Fig. 63.

Our voltage vectors will appear as in Fig. 63 (*a*) and (*b*). The reactances and impedences are shown in Fig. 64, both in the form of parallelograms and triangles.

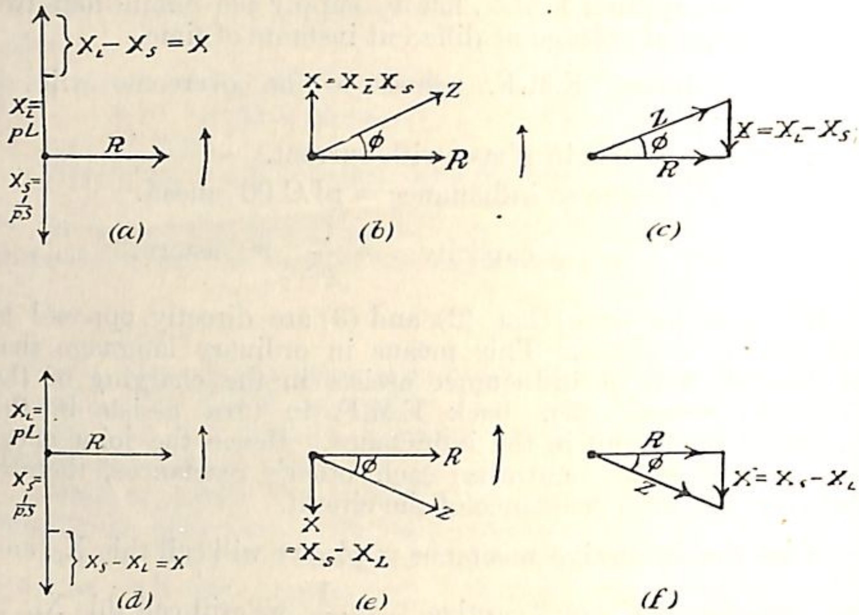


FIG. 64.

Here we see that our joint reactance is given by

$$X = X_L \sim X_s = pL \sim \frac{1}{pS} \text{ ohms,}$$

where "$\sim$" means "difference"—that is, "subtract the smaller from the larger."

$$\text{Again, } \tan\phi = \frac{\text{Reactance}}{\text{Resistance}} = \frac{pL \sim \frac{1}{pS}}{R}.$$

We may, if we like, write—

$$\text{Tan } \phi = \frac{X_L - X_s}{R}$$

If X_L be greater than X_s tan ϕ will be + ve, showing us that the applied E.M.F. line comes *above* the C.R. line and that the current lags.

If tan ϕ be — ve in sign, the current leads, for E will be *below* CR, for in that case X_s is greater than X_L.

Once more, impedence = $\sqrt{\{(\text{resistance})^2 + (\text{joint reactance})^2\}}$.

Hence, impedence = $\sqrt{\{R^2 + (X_L \sim X_s)^2\}}$.

So that for all circuits we have—

$$C = \frac{E}{\sqrt{\{R^2 + \left(pL \sim \frac{1}{pS}\right)^2\}}}$$

$$\text{or } C = \frac{E}{\sqrt{\{R^2 + (X_L \sim X_s)^2\}}}, \text{ or } C = \frac{E}{Z}$$

which is the complete Ohm's law for alternating or direct currents *in a single circuit.*

$$Z = \sqrt{\{R^2 + X^2\}}$$
$$\text{Where } X = X_L \sim X_S.$$

Looking at these equations it will be well for the student to consider what happens to C and ϕ in the following cases.

(A) In direct currents (where $p = 0$)—
 (1) If S be a moderate size.
 (2) If S be infinitely large (*see* page 107).

(B) In alternating currents (where p is a finite number)—
 (1) If L be large.
 (2) If S be small.
 (3) If p becomes very large.

This is a very instructive process and should be followed invariably whenever any equation is met with which seems complicated at first sight.

It has probably already occurred to the reader that since we have two opposing reactances, can we not make them equal? We may purposely do so by so adjusting L, S, and p so that

$$pL = \frac{1}{pS}. \quad \text{For then } X = pL - \frac{1}{pS} = 0.$$

We have at once $Z = R$, for $X = 0$.

So that $C = \frac{E}{Z} = \frac{E}{R}$. Ohm's law.

$\text{Tan } \phi = \frac{0}{R} = 0. \quad \phi = 0°.$ The current and E.M.F. are in phase with each other and it would seem that the inductance and capacity had disappeard. Not quite that, but their mutual interaction saves the applied E.M.F. the trouble of looking after their wants, and it is therefore enabled to devote its whole energies to driving a larger current C through the resistance R.

This condition is called "electrical resonance," and in order to obtain it we must have

$$pL = \frac{1}{pS}$$
$$\text{or } p^2 = \frac{1}{LS}$$

Taking square root of both sides we have

$$p = \frac{1}{\sqrt{LS}} \quad \text{or}$$

$$2\pi f = \frac{1}{\sqrt{LS}} \quad \text{which becomes}$$

$$f = \frac{1}{2\pi\sqrt{LS}}, \text{ where } L = \text{henries}. \quad S = \text{farads}.$$

(*See* page 46.)

Assume, now, that we have a certain circuit of fixed L and S and a frequency f such that

$$f = \frac{1}{2\pi\sqrt{LS}}.$$

Then, whatever may be the resistance R, we know that $C = \frac{E}{R}$ and ϕ = zero.

(A) Now increase the frequency, keeping LS and R, the same,

we no longer have $pL = \frac{1}{pS}$.

As f increases pL gets larger and $\frac{1}{pS}$ smaller.

The current therefore gets weaker and begins to *lag* on the voltage

(B) Decrease the frequency.

$\frac{1}{pS}$ gets larger and pL smaller.

The current gets weaker and begins to *lead* on the voltage. It may be well to take some examples.

Example 1.

Take conditions of Example 4 (capacity examples) above. Here we have f = 100 ~ p = 625 $S = \frac{40}{10^6}$ farads

E = 100 volts, R = 40 ω.

The result was a current of 1·78 amps leading 45° on E.M.F. Now introduce L = ·05 henry of negligible resistance.

We have inductive reactance $X_L = pL = 628 \times \cdot 05 =$ 31·4 ohms.

We have capacity reactance $X_S = \frac{1}{pS} = 40$ ohms.

The capacity reactance preponderates.

Joint reactance = 40 − 31·4 = 8·6 ohms, this is X.

$$\text{Tan}\,\phi = \frac{\text{Reactance}}{\text{Resistance}} = \frac{8\cdot 6}{40} = \cdot 215.$$

$$\phi = 12^\circ\ 8' \text{ only.}$$

Current *leads* by 12° 8′.

Further

$$C = \frac{E}{\sqrt{\{R^2 + X^2\}}}$$

$$= \frac{100}{\sqrt{\{40^2 + (8\cdot 6)^2\}}}$$

$$= \frac{100}{40\cdot 9}$$

$$= 2\cdot 43 \text{ amps. nearly.}$$

We have therefore increased the current from 1·78 to 2·4 amps and reduced lag from 45° to 12° merely by the introduction of the inductance L.

This effect have been still more marked had we taken a lower value for R.

It will be well to draw again our voltage vectors to scale.

Inductive reactance drop $= X_L C.$
$= 31·4 \times 2·43.$
$= 76·5$ volts.

Condensive reactance drop $= X_S C.$
$= 40 \times 2·43.$
$= 97·4$ volts.

Ohmic drop $= CR.$
$= 40 \times 2·43.$
$= 97·4$ volts.

These are shown in Fig. 65 (*a*) and (*b*).

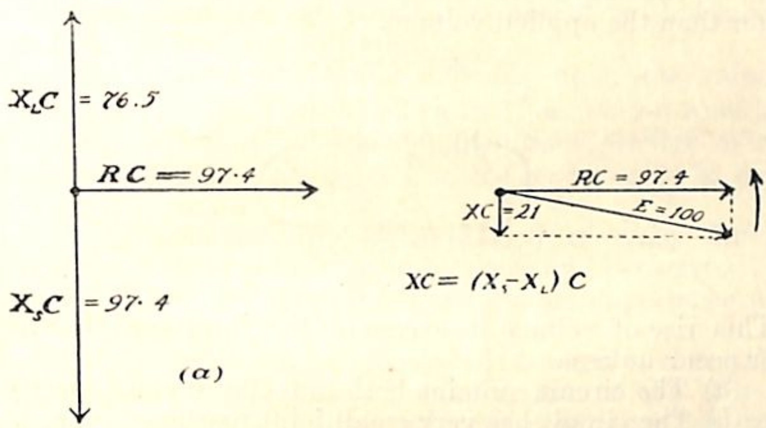


FIG. 65.

The reader should also use the Impedence Triangle method as in Fig. 52.

Example 2.

In the last example, what inductance is necessary to get "resonance" and what will be the current so obtained?

For resonance we must have $pL = \frac{1}{pS}.$

But $\frac{1}{pS} = 40$ ohms.

pL must $= 40.$

L must $= \frac{40}{p} = \frac{40}{628} = ·064$ henries nearly.

Now when $pL = \frac{1}{pS}$, $C = \frac{E}{R}.$

$= \frac{100}{40}.$

$= 2·5$ amps.

Also $\tan \phi = 0$, so that C and E are in phase.

The resistance is the only factor to be considered.

A most interesting effect is to be noticed here.

Our E.M.F. vector will show—

Ohmic drop = CR = $2 \cdot 5 \times 40 = 100$ volts.

Inductance reactance drop = $X_L C = 40 \times 2 \cdot 5 = 100$ volts.

Capacity reactance drop = $X_s C = 40 \times 2 \cdot 5 = 100$ volts.

Remember this, and now let R fall to 20 ohms.

Example 3.

Still having "resonance" we shall have a larger current, for $C = \frac{E}{R} = \frac{100}{20} = 5$ amps.

Ohmic drop = CR = $20 \times 5 = 100$ volts.

Inductive reactance drop = $X_L C = 40 \times 5 = 200$ volts.

Capacity reactance drop = $X_S C = 40 \times 5 = 200$ volts.

We have then an applied E.M.F. of 100 volts at A and B (Fig. 66), causing local voltages across portions of the circuit greater than the applied voltage.

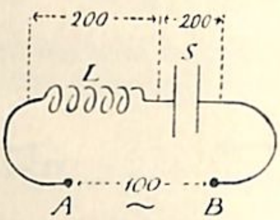


Fig. 66.

This rise of voltage in excess of the impressed E.M.F. can never occur unless—

(*a*) The circuit contains both inductance and capacity.

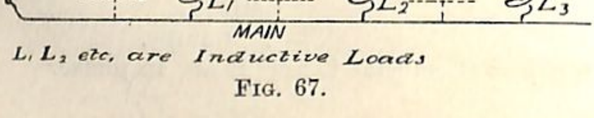
(*b*) The circuit has very small joint reactance indeed.

(*c*) The resistance is less than either of the two reactances.

It is a phenomenon which is very convenient in wireless telegraphy where we want to get a high voltage, either in a low-frequency or oscillating circuit, but in commercial work it is avoided owing to the high voltage being liable to strain the insulation of cables and to do other damage.

Condensers might be used to reduce the angle of lag, but owing to the great expense of manufacture, they are rarely used commercially. It must, however, be remembered that cables, especially concentric ones where one conductor envelopes the other, always possess capacity. This condenser action may be due to the opposing mains being separated by the insulation, or else by each main having a definite capacity to earth.

Diagrammatically a commercial inductive load will contain "distributed" capacity thus :—



L₁ L₂ etc. are Inductive Loads

Fig. 67.

This type of circuit will present a difficult problem, but we are concerned with cases where the capacity is concentrated and the inductance generally is fairly concentrated also (*see* p. 43).

The reader should make himself thoroughly familiar with this "resonance effect," for upon it depend not only the whole principles of his low-frequency alternating mains, but also the effects produced in his high-frequency or oscillating circuits, both for sending and receiving.

We see that a voltage E of frequency f applied to a circuit containing L and S, such that

$$f = \frac{1}{2\pi\sqrt{LS}},$$

will "find everything ready" for its reception with no reactance to be overcome. It is therefore a common practice to call $\frac{1}{2\pi\sqrt{LS}}$ the "natural frequency" of the circuit.

It is that frequency at which the circuit will *naturally oscillate* if set in electrical vibration.

Since the natural frequency depends upon the value of $\sqrt{LS}$, the product LS is often called the "oscillation constant" or "resonance constant" of the circuit. Some writers refer to this quantity meaning $\sqrt{LS}$ not LS, so the reader must be on his guard against an error.

Again, the constant may be expressed in many different combinations of diverse units of inductance and capacity.

This consideration becomes one of supreme importance when dealing with oscillatory currents.

Referring now to the process of tuning the aerial or secondary circuit to the same LS value as that of the primary, the reader is now in a position to see that what we are really doing is adjusting the oscillation constant of the aerial circuit to such a value that the current induced in the aerial shall be in phase with the E.M.F. transferred thereto from the primary. Remembering that the mutual coil may be considered to be an high-frequency alternating dynamo whose frequency coincides with that of the primary, this dynamo has its terminals connected up to an inductance and capacity in series with each other (that is, the inductance and capacity of the aerial).

If the L and S of the aerial be such that

$$f = \frac{1}{2\pi\sqrt{LS}}$$

where L is in henries and S is in farads, and where f is the natural frequency of the primary, then the current in the aerial will be in phase with the E.M.F., it will equal $\frac{E}{R}$, and may possibly reach great momentary values.

Further, seeing that the resistance of the aerial is small, we shall get this "resonance effect" showing itself in a very great voltage across the terminals of the L and the S, that is, between the top of the aerial and earth. This voltage will exceed many times that induced at the terminals of the mutual coil.

By getting this large current we have strong magnetic lines of force, while the high voltage across the "plates" of our aerial condenser will give us a strong electric field, both these effects resulting in an increase in the strength of the radiation.

It may be borne in mind that all the above calculations will be incorrect unless—

(1) The E.M.F. curve be a true sine curve.

(2) The amplitude be constant.

The conditions in (1) may be nearly fulfilled, those in (2) will be fulfilled in alternating current practice.

In dealing with oscillations given out by a spark system we know that the damping causes the voltage to decay. The general principles of A.C. theory hold good for damped trains of high-frequency oscillations, but undue reliance must not be placed on the above formulæ. They *can* be altered to give the theory for decadent currents, but this would involve complications which are unnecessary in this book.

One other type of circuit may be examined, since it produces an apparently paradoxical result which is interesting academically.

Take an alternating current circuit with L, S and R as before, but place the L and S in parallel with each other as in Fig 68.

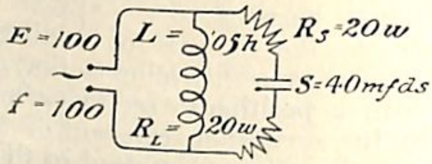


Fig. 68.

With these circuits in series we got a current of 2·43 amps. leading 12° on the E.M.F. (*See* Example 1, p. 120.)

It would seem at first sight that now the current would be greater, for the joint resistance is now only 10 ohms.

Let C_L be the current through L.
And C_S " " S.

Now C_L will *lag* on the E.M.F. by an angle ϕ_L such that

$$\text{Tan } \phi_L = \frac{pL}{R_L} = \frac{628 \times \cdot 05}{20} = 1 \cdot 59.$$

$\phi_L = 57° \, 49'$.

Reactance $= 31 \cdot 9$ ohms $= X_L$
Resistance $= 20$ ohms $= R_L$
Impedence $= 37 \cdot 7$ ohms $= Z_L$

$$C_L = \frac{E}{Z_L} = \frac{100}{37 \cdot 7} = 2 \cdot 66 \text{ amps.}$$

Now C_s will *lead* on the E.M.F. by an angle ϕ such that

$$\text{Tan } \phi_s = \frac{1}{pSR} = \frac{10^6}{628 \times 40 \times 20} = 2.$$

$$\phi = 63\tfrac{1}{2}^\circ.$$

Reactance $\left(= \frac{1}{pS}\right) = 40$ ohms $= X_s$

Resistance $= 20$ ohms $= R_s$

Impedence $= 44 \cdot 7$ ohms $= Z_s$

$$C_s = \frac{100}{44 \cdot 7} = 2 \cdot 24 \text{ amps.}$$

If we now add these currents vectorially we shall obtain C, the resulant current flowing through the whole circuit. (*See* Fig. 69 (A).)

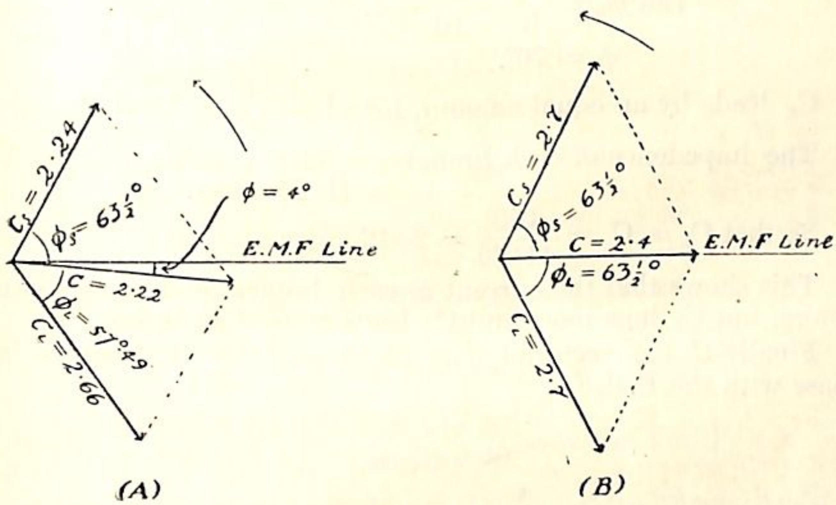


Fig. 69.

Taking this resultant to scale, we find that it is $2 \cdot 22$ amps. lagging 4° on the E.M.F.

So that we have actually *reduced* the total current flowing. Now if the L and S were so adjusted that $pL = \frac{1}{pS}$ and the resistances of both circuits were the same, then C_L would lag and C would lead by an equal amount. Further, the impedences would be the same, so that C_L would $=$ C and the resultant current would lie on the E.M.F. line and be in phase with the E.M.F. (See Fig. 69 (*b*).)

Example 2.

To illustrate this, let $pL = \frac{1}{pS}$ so that $L = \cdot 064$ henries as before. (See Example 2, p. 121.)

The resistance of each arm is still 20 ohms.

Now $pL = \frac{1}{pS}$ = reactances = 40 ohms each, impedences 44·7 ohms each.

So that C_L will = 2·24 amps. lagging $63\frac{1}{2}$ degrees.
C ,, ,, leading ,,

C, the vectorial sum = 2·4 amps. in phase with E.M.F.

This result is even less than the 2·5 amps. obtained when L and S were in series, although the resistance is lower.

Now comes the peculiar part of the phenomenon.

Example 3.

Let the resistances drop to 10ω. each arm.

We then have C_L lagging by ϕ_L such that

$$\text{Tan } \phi_L = \frac{X_L}{R} = \frac{40}{10} = 4.$$
$$\phi = 76°.$$

C_s leads by an equal amount, for $pL = \frac{1}{pS}$ so $X_L = X_s$.

The impedence of each branch $= \sqrt{\{10^2 + 40^2\}}$
$= 41·25$ ohms.

So that $C_L = C = \frac{100}{41·25} = 2·42$ amps.

This shows that the current in each branch is stronger than before, but C_L lags more and C leads more than before.

Finally C, the vectorial sum of C_L and C_s = 1·2 amps. in phase with the E.M.F.

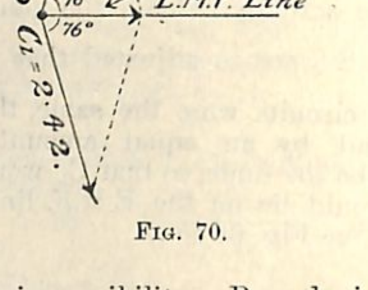


FIG. 70.

This seems an impossibility. By reducing the resistances from 20 to 10ω. each, we have reduced the resultant current from 2·8 to 1·2 amps.

Note that the *local* currents increased as the resistance dropped, but they got more and more out of phase with the

E.M.F. and with each other, consequently the diagonal of their parallelogram (the resultant current) got shorter and shorter.

Following this to its natural conclusion, we see that if a circuit containing L and S in parallel had no resistance at all we might arrange L and S so that no current would flow through the whole circuit.

Example 4.

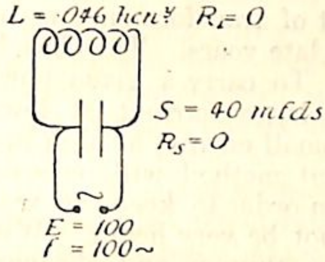


FIG. 71.

In this case reactance $= \text{pL} = \dfrac{1}{\text{pS}} = 40\omega$,

And resistance = 0

So $Z_L = Z_S = 40\omega$.

$\text{Tan } \phi_L = \text{Tan } \phi_S = \dfrac{40}{0} = \infty. \quad \phi_L = \phi_S = 90°.$

$C_L = C_S = \dfrac{E}{Z} = \dfrac{100}{40} = 2 \cdot 5$ amps.

C_L then $= 2 \cdot 5$ amps. lagging 90° } on the E.M.F.
C_S $= 2 \cdot 5$,, leading 90° }

Hence the two currents are 180° apart in phase, being in direct opposition to each other. Their resultant is zero, so that under these conditions no current flows from the alternator terminals through the circuit, or through the alternator itself.

As long as the frequency of the machine remains the same, this low-resistance outside circuit behaves like a complete insulator, although the local currents in the branched circuit may be large.

In practice, if this circuit were used, it would never quite produce this effect because the resistance would never be zero.

Notice that the circuit behaves as a complete insulator to any voltage, but to *one* frequency *only*.

CHAPTER VI.

TRANSFORMERS.

The development of transformers has been carried forward to a great extent of late years. This has been largely due to the cost of copper. To carry a given power (watts) from one place to another a large current at low pressure may be employed, or else a small current at high pressure.

The large current method will necessitate conductors of large cross-section in order to keep the resistance down, while the insulation need not be very heavy. With the small current it is possible to use a thinner and cheaper copper conductor, but the insulation must be very good to prevent leakage.

As it happens, it is cheaper to get the extra insulation than to get the large conductors and, consequently, the high-pressure-small-current method of transmission is much more economical commercially, the economy being very marked in cases where the generators have to be some distance from the consumers, as, for instance, where water power is employed to drive the dynamos.

Now this power may take the form of a direct or an alternating current at high pressure. Up till quite lately direct currents of this nature have been very little used, on account of difficulties in constructing a dynamo having an armature sufficiently well insulated and for other reasons connected with the distribution at the consumer's end of the line.

Alternating currents of high voltage can, however, be generated in a stationary armature inside which the field magnets revolve. Hence the insulation difficulty at the generator end does not appear.

In any case, the power will be produced at a pressure of the order of 2,000 volts and so carried across country.

This voltage would be dangerous to human life, so that high pressure mains have to be carried in heavily insulated cables, paper being in common use in England for the insulation, these cables being frequently laid in underground conduits.

On arriving at the consumer's end of the power line the volts have to be reduced to some safe value, such as 100 volts, for use in houses. To effect this reduction by inserting resistances in series with the mains would, of course, be very wasteful, so that other means are devised.

The problem is to transform the energy so that as little as possible is wasted. If the volts are to be reduced in some proportion, the amps. must be increased in the same proportion and *vice versâ*.

To alter the voltage of a direct current circuit recourse has to be taken to a "motor generator," which consists of a motor running on the "old" voltage driving a dynamo giving out an entirely separate current at the "new" voltage.

This system is used in ships to generate the low-pressure currents used for communications and gun circuits.

It entails having practically two machines, each with its bearings and commutators to be looked after.

Now the voltage of alternating current circuits can be raised or lowered as desired, with very little loss of power indeed, by means of a device called a "transformer," which is much cheaper than a motor generator, simpler, has no moving part or parts requiring replacement, and when once set up requires no attention at all, except in the larger sizes.

On shore, where alternating current is used at high pressure, transformers are inserted across the mains where required, producing in their "secondary" circuits any particular voltage that may be necessary. These secondary circuits are entirely separate from the mains which are connected to the primary of the transformer.

It will be seen that commercially transformers are mainly used to give a reduced voltage with a large current. Such are called "step-down" transformers. In wireless circuits we are trying to get a very high pressure wherewith to charge up the condenser, so that "step-up" transformers are employed to deliver this small current at high tension. "Tension" and "pressure" are used indiscriminately to indicate voltage.

It must be distinctly understood that there is no creation of energy in a transformer. The whole device may be regarded as a tackle. Consider a boat's falls. We obtain a very great tension on the boat's slings in return for a moderate tension applied on the fall, but this is at the expense of speed (current). Further, energy is lost in friction in the sheaves of the blocks. This form of tackle is evidently a "step-up" transformer from the pressure point of view, but the speed (or current) is "stepped down" in the same ratio. Transformers are rated as being step up or step down according to the change which takes place in the voltage.

An example of a step-down tackle is that of an overhauling whip as used in hydraulic lifts. Here a very small motion (current) under enormous pressure delivers a very large movement at less pressure.

Now any tackle, if suitably arranged, can be made to give a step up or a step down of pressure. So also every transformer can be used for either purpose by being suitably connected. The step up or down is measured as follows :—

A transformer takes current at 2,000 volts and delivers a new current at 100 volts.

For every 2,000 volts put in, 100 appear in the secondary.

For every 20 volts put in, 1 appears in secondary. This transformer would be called a step-down transformer, having a "transformation ratio" of 20 to 1.

Similarly, a transformer having a step up of 70 to 1 would, if supplied with primary current at 100 volts, deliver a secondary current at 7,000 volts, but the secondary current would be but 1/70th the strength of the primary current.

To alter the voltage of direct current mains, then, we have a "rotary transformer" or motor generator, generally consisting of two machines on the same shaft. Sometimes the two armatures and field magnets are united, when we have a "booster."

To alter the voltage of an alternating current system we have a "stationary transformer."

To alter direct into alternating current we have a "converter," which may take the form of two machines, a D.C. motor driving an A.C. dynamo, in which case we have a "motor alternator," or else one machine may do both duties, being called a "rotary converter" proper.

To alter A.C. into D.C. we must have a different kind of converter. A D.C. dynamo is driven by an A.C. motor. With this type of conversion we are not at present concerned in the Service, except in the generation of a small quantity of direct current in the large power shore stations.

The type of transformer with which we are concerned is called the "constant-pressure" form. It is designed to give a secondary voltage, which with a constant primary voltage remains very nearly fixed for all loads, the current increasing as the load incraeses. This corresponds to the motor generator in direct currents.

Another and more complicated form of transformer is the "constant-current" type, in which the secondary voltage increases with an increase of load, so that the current is thereby kept fixed. There is no exact direct-current equivalent of this instrument. The action of a series-wound dynamo is somewhat similar, since the voltage increases as the load increases.

Commercially these constant current transformers are used for burning arc lamps in series.

We are now merely concerned with constant-pressure stationary transformers.

The conditions which constitute a transformer are that we have two conducting circuits insulated from each other, but linked together by a third or magnetic circuit.

The conducting circuits are, of course, made of copper. The magnetic circuit may be completed, as follows :—

(1) Entirely through material having unit permeability, that is, through air. In this case we might wind the conducting circuits on wooden, ebonite, paper, or other such substance, having no iron near at all. Or

again, the coils might be made of a rigid material, such as copper tube, and stand up of themselves without any supporting core.

A transformer of this type, where the permeability of the core is unity, is called an "air-core" transformer. The reader is already familar with this type of transformer used for high frequency currents, as exemplified in the action of the primary coil of the closed oscillator upon the adjacent mutual coil.

(2) The core may be partly of iron (or other material having large permeability) and partly of air. Such a transformer is the induction coil, where the core inside the windings is of iron and the return path for the lines of force is *outside* the coil, being completed through the air, or (more properly) through the ether. This is called an "open circuit" transformer.

(3) Where the core forms a complete ring of iron we have the "closed-circuit" type. Since in this case the iron forms a complete and easy path for the lines of force, there is much less energy lost for currents of low frequency than in the preceding forms, so that all commercial transformers have closed magnetic circuits.

We will now study the action of this last type before investigating the details of construction.

A transformer may be defined as—

"A device in which the inductive action of one circuit upon another is employed. A fluctuating current in the primary produces a fluctuating flux (magnetisation) in the iron core, which, penetrating the secondary, causes an E.M.F. in the secondary winding proportional to the number of turns contained upon it."

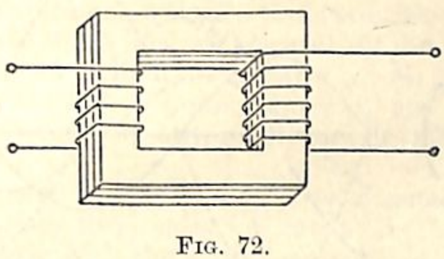


FIG. 72.

Take a simple transformer as shown in Fig. 72.

(1) Leave the secondary terminals not connected to anything so that the winding is on "open circuit." Apply an alternating E.M.F. to the primary terminals. An alternating current will flow.

Now although there may be but a few turns of wire in the primary, and these turns of very low resistance, the winding will not get burnt out, because these few ampère-turns will produce a very strong flux in the core, owing to the magnetic path being so easy for the lines of force.

Any circuit which produces a strong magnetic field must have a large self-induction. Hence the primary is a very heavily inductive circuit.

The reactance is therefore large and the resistance small.

Very little current flows, and such as does flow will lag nearly 90° astern of the E.M.F. The current that flows when the secondary is on open circuit is called the "magnetising current." The more efficient the core the less will be the strength of the magnetising current. It will be noticed that the back E.M.F. of self-induction in the primary is very nearly equal to the applied E.M.F.

The reader should compare the effect with that of a motor running "light." Very little current is taken, for the only work that has to be done is to overcome the friction of bearings and brushes. The back E.M.F. of the motor equals the applied E.M.F. very nearly.

Now regarding the secondary, which is still on open circuit. The primary current lags nearly 90° behind the primary E.M.F.

The magnetisation or flux lags *slightly* behind the current, for the iron cannot immediately take up or give up its magnetism as ordered to do by the current. This effect is said to be due to the magnetic "hysteresis" of the iron.

The effect of this is that the flux lags practically exactly 90° behind the primary E.M.F.

Now this flux on its passage round the iron ring threads through the secondary turns, inducing therein an inducting E.M.F. which will be opposed to the direction of the flux.

Again, the induced secondary voltage will depend upon the rate of change of flux at any instant.

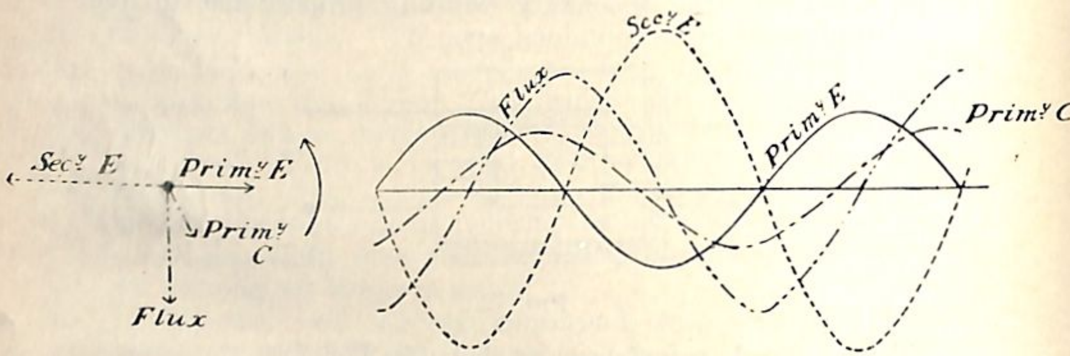


Fig. 73

We have seen that if one simple periodic vibration causes another, and if the amplitude of the second depends upon the rate of change of the first, then the second one is 90° out of phase with the first.

Now the rate of change of flux would be 90° ahead of the flux itself. But the induced secondary volts are in direct opposition to the rate of change of flux. Hence the induced volts are 90° astern of the flux, a little more than 90° astern of the primary current, and consequently 180° astern of the applied primary E.M.F. In other words, the applied and induced E.M.F.s rise and fall in exact opposition of phase.

Now let E_1 be the maximum E.M.F. applied to the primary, E_2 being the maximum E.M.F. induced in the secondary. If N_1 = number of turns in the primary winding, we shall be applying $\frac{E_1}{N_1}$ volts to each turn of primary.

This voltage, neglecting losses, will reappear in each turn of the secondary. Now the secondary has N_2 turns, so that the total secondary voltage will be N_2 times that induced in each turn.

Hence $E_2 = N_2 \times \frac{E_1}{N_1}$ or $= E_1 \times \frac{N_2}{N_1}$.

That is

$$\text{Sec. volts} = \text{prim. volts} \times \frac{\text{turns on secondary}}{\text{turns on primary}}$$
$$= \text{prim. volts} \times \text{step up (or down).}$$

It will be seen that E_2 will be larger or smaller than E_1 according as to whether the secondary turns are more or less in number than the primary turns.

A step-up transformer has few primary and many secondary turns. By simply reversing the windings and applying the E.M.F. to the winding having many turns we have a reduced secondary voltage and the device becomes a step-down transformer at once.

The ratio $\frac{N_2}{N_1}$ is called the "transformation ratio" which is fixed for any transformer; whether this ratio becomes step-up or step-down depends upon how we connect up the windings.

We will call the primary current C_1. So far this current has been small. C_2, the secondary current, has been zero, for the resistance between the terminals outside the machine has been "infinity."

(2) Now connect up a *non-inductive* resistance of R ohms across the secondary terminals. A secondary current C_2 will flow, being in phase with the secondary voltage.

Neglecting the resistance of the secondary winding this current will $= \frac{E_2}{R}$.

Now C_2 at each alternation flows through the secondary winding and will therefore cause a magnetic flux due to N_2C_2 ampère-turns in the iron core. This secondary flux is in opposition to the flux due to the primary, and therefore "cancels out" some of the primary lines of force.

The result of this is that these latter lines, instead of having an easy path throughout the core, now have to fight their way round the core. The same thing happens as if the iron had suddenly become less permeable (*see* p. 12). The inductance of the primary drops, its back E.M.F. is reduced, the reactance is lessened, and consequently C_1 increases and comes a little more into step with the E.M.F., E_1.

Notice that the current increases automatically to the right amount.

(3) Now increase the secondary load by reducing R. More secondary current is taken, the primary back E.M.F. again drops, and more primary current flows.

This increase of primary current tends to cause a stronger flux, but this tendency is counteracted by the fact that the secondary current is tending to produce a flux in the opposite direction. The result is that the flux actually produced remains practically constant whatever current is being taken from the transformer provided that the voltage supplied to the primary winding remains constant.

Hence the total flux is very little more on "full load" than on "no load." If, however, a very large current be taken from the secondary, by practically short-circuiting its terminals, the secondary voltage will not remain constant, as it is intended to do. It will fall off owing (1) to the large amount of energy expended in heating the wires (*see* "Copper Losses" later) and (2) to the "magnetic leakage" of flux which occurs under this condition. Normally the flux is confined to the path of laminated iron, but when the currents in the primary and secondary are very large the opposite magnetising tendencies mentioned above cause some of the flux to leak out into the space surrounding the transformer. Thus some of the flux which is developed by the primary winding fails to pass through the secondary winding and this portion of the flux is known as "magnetic leakage."

The question as to whether the iron core gets "saturated" or not depends upon the amount of iron in the core, the number of turns of primary, and upon the voltage and frequency of the energy supplied. Since all these factors except the voltage and occasionally the frequency will be fixed, we note that any increase of the primary volts will cause an increase of flux in the core. Should, however, the primary volts increase abnormally, the core will become incapable of taking any more flux, that is, it becomes "saturated." When this takes place the primary winding fails to produce enough back E.M.F. to keep the primary current in check, so that a very large primary current will flow.

Since, however large the magnetising current may be, the iron cannot hold more than a certain amount of flux, and since it is to the flux that the secondary voltage is proportional, we see that this abnormal increase of primary current will not do any good, because the secondary volts will not rise with the primary volts.

Hence, if a much higher voltage be employed than that for which the transformer was designed, considerable loss of power will ensue and there is a danger of burning out the transformer windings.

Reducing the frequency of the voltage supplied to the primary has the same effect as regards saturating the iron and overloading the transformer as is caused by raising the primary voltage.

Transformers are designed so that the core is *not* saturated at a given primary voltage and frequency.

Notice that at all loads E_2 remains nearly $= \frac{N_2}{N_1} \times E_1$, and that current is transformed in the inverse ratio to the transformation of voltage.

The output in watts = the input in watts, neglecting losses, which may be made very small. So with a step-up transformer of 20 to 1 ratio, for every volt put in to the primary we have 20 volts available for the secondary, while for every ampère employed in the primary we have $\frac{1}{20}$th of an ampère in the secondary.

Further, a transformer having a non-inductive secondary load will cause the primary current to get nearly and more nearly in step with the primary voltage as the load increases.

On full load, and sometimes long before this point is reached, the primary current and E.M.F. will be in phase with each other, and the transformer will behave as though it had practically no *inductance* at all.

We notice here that the inductance of a winding having an iron core is *not constant*, but alters according to the state of saturation of the iron. An air-core transformer will therefore not follow the same laws as an iron-cored one.

The reader will do well to compare, step by step, the action of a transformer with that of a shunt motor on various loads.

Currents for Transformers.

Closed circuit transformers are worked from alternating current mains only, since there is no outside magnetism to operate a hammer make-and-break.

Open circuit transformers (induction coils) may be used either with alternating or direct current, provided that in the latter case the direct current is made intermittent or pulsating in its nature by means of some make-and-break.

This intermittent current may be convenient where an alternating source of E.M.F. is not available, but better results will be obtained, even with induction coils, if alternating current be used. Induction coils are used only as step-up transformers.

Remember that the secondary E.M.F. will not appear unless the primary E.M.F. is continually varying in strength from instant to instant.

It will be seen that an alternating current applied to the primary need not necessarily follow the exact sine law, but may, and often does, vary therefrom to a considerable extent. All alternating currents and E.M.F.s will follow some periodic law more or less complex, and can be delineated by some shape of curve, which, whatever its shape, will repeat itself at regular intervals of time.

We shall not attempt to enter into the theory of this subject, but will remain content with a few generalisations on the effects produced by different shaped "waves" of E.M.F. and current.

Efficiency of Transformers.

No machine yet invented can deliver as much useful energy as it receives. Losses are bound to occur, and we can only hope to reduce these losses as much as possible.

The *efficiency* of any machine may be described as a percentage. If we apply 100 watts to the primary of a transformer and take out 97 watts from the secondary we should say that the output was 97 per cent. of the input. In other words, 3 per cent. of the input is lost. Properly speaking, no energy is lost at all, it merely appears as heat or possibly in some other form which we are not prepared to turn to useful ends.

It appears, then, that input = output + losses.

$$\text{So that efficiency} = \frac{\text{output}}{\text{input}} \times 100$$

$$\textit{or } \frac{\text{output}}{\text{output} + \text{losses}} \times 100.$$

It will be convenient to regard these losses as being in watts.

The losses in a transformer may be divided into (1) The copper loss, in the form of *heat*, due to the current in the conductors, both primary and secondary, flowing against ohmic resistance ; (2) The iron or core loss, due to the *heating* of the iron caused by eddy-currents induced therein, and also by the hysteresis of the iron.

Now the total losses can be measured at any load by means of a watt-meter. Here input watts − output watts = total losses.

To investigate the losses separately :—

(1) *The Copper Loss.*

In a step-up transformer we have a large primary current and a small secondary current. The rate at which heat is being developed in any wire = C^2R watts.

In the primary, then, we have $C_1^2 R_1$ watts lost ; and in the secondary, $C_2^2 R_2$ watts lost.

The loss in the conductors, then, = $C_1^2 R_1 + C_2^2 R_2$. The primary is made of thick wire or even ribbon, and the secondary of as thick wire as is compatible with getting the correct number of turns on the winding.

Again, if this heat be allowed to accumulate, the wires themselves will get hot, and since the resistance of copper increases with the temperature, the loss will get bigger.

Cooling arrangements are therefore important.

As the load increases, the current in both windings also increases, so we must be prepared to find that the copper loss will increase with the load.

Since the primary at any rate is made of stout wire, there is a danger of eddy currents being induced in the copper itself, unless the conductor be wound of stranded wire.

This loss, however, is very small in practice and may be neglected.

(2) *The Iron Loss.*

It has been mentioned that the magnetic field in a piece of iron lags a little behind the magnetising force (or current) which produces it. This is due to the "hysteresis" of the iron. It may be defined as a property of iron by which energy is dissipated in the form of heat when the magnetism is being reversed.

We may conceive a lump of iron to be made up of innumerable minute particles called "molecules." Imagine that these molecules are slightly egg-shaped. It is supposed that before the iron is magnetised these egg-chaped molecules are lying jumbled up "anyhow" in the fibre of the iron, but that when magnetised a certain number of them (probably the outer ones first) get turned round so that their "heads" point one way and their "tails" the other way. A long thin bar of iron gets very slightly longer when magnetised. The number of directed molecules may be taken as varying with the strength of the flux. When the bar is "saturated" with flux we may say that all the molecules are directed one way, like a crowd of people watching a speaker on a platform.

When, however, the polarity of the magnetism changes, the molecules turn round and "look" the other way, just as the crowd will do if something at the back of the room interests them. In turning round, each member of the densely packed throng rubs shoulders with his neighbour.

This rubbing action between the molecules of iron which happens as the magnetism alters in strength or direction must cause friction and consequently heat in the fibre of the iron, the heat requiring a definite expenditure of energy for its production.

We may look upon the phenomenon from another point of view. It is reasonable to suppose that the molecules possess mass, since the whole mass of iron is but the combined effect of the masses of the molecules. They therefore possess inertia, which means that the molecule will not move instantaneously when commanded to do so by the magnetising force. The iron will not at once become a magnet on the application of the ampère-turns, and after the latter have been removed it retains a certain amount of magnetism.

This quality is described as the "reluctance" of the iron to take up or give up its impressed magnetic lines (*see* page 12).

Notice that, like inductance, the reluctance effect and the loss of energy due to hysteresis do not affect us where direct currents are concerned.

Now a piece of hard steel makes a good "permanent" magnet. This is on account of the great "magnetic reluctance" of steel.

The molecules, being firmly bound together by the hardness of the steel, are reluctant to move. Having once been set in one direction, there they stay.

A piece of soft iron allows the molecules to reverse with but little internal friction, and so cannot be used for a permanent magnet.

In order to ensure the hysteresis losses being as small as possible, transformer iron is made of the best, purest and softest Swedish iron, or sometimes of mild steel.

We may mention that iron seems to "age" with prolonged use in transformers. The fibre of the metal appears to get tired of having its magnetisation continually reversed and a greater reluctance is consequently developed. Hence the hysteresis loss increases slightly with time.

Neglecting this ageing effect, it is found that the true hysteresis loss per half-period is constant, and depends chiefly upon the amount and quality of the iron, being practically independent of the frequency.

The hysteresis loss of any transformer is constant for all loads, provided the primary voltage remains constant, whereas the copper loss increases with the load.

When on no load, there is no copper loss since the current is so small, so that the only power supplied to the transformer is that necessary to overcome the hysteresis and eddy-current losses. Hence a wattmeter reading of the true power supplied to the primary when the secondary is on open circuit will give us these losses, which are frequently referred to as the "iron losses." It is for this reason that the primary current which flows under these conditions is called the "magnetising current."

It will be noticed that a commercial transformer is generally left with its primary permanently connected up to the mains, lamps being switched on or off in the secondary circuit as required. The iron losses go on all day, while the copper loss comes in only for a few hours in the twenty-four when the consumer turns on his lights. The "all-day efficiency" is an expression used to denote the efficiency of a transformer from the point of view of an electrical supply company.

The company is more concerned with keeping down the iron losses than with reducing the copper loss, because the consumer does not pay for the magnetising current, since his meter is fed from the secondary mains.

Large transformers are capable of being made much more efficient than are small ones, so that in towns, where consumers live close together, it is usual to have large transformers in several sub-stations, each sub-station supplying current at low pressure to a number of houses. In scattered districts, on the other hand, it may be more economical to let each house have its own small transformer, placed, of course, in such a position that the inhabitants cannot touch any of the high-tension mains.

It has been stated that the iron losses are made up of the hysteresis and the eddy-current loss. The latter is the same sort of loss that would occur in the armature of a dynamo were it not built up of thin sheets or "laminations" insulated from each other.

If the iron were solid throughout, local currents would be induced, which, though of low voltage, would rise to very large values owing to the very low internal resistance of the iron. For this reason the cores of transformers are laminated.

The stampings actually employed may be complete rectangles in one piece or else built up of several pieces.

The latter method is used in all large transformers on account of the ease of winding coils on separate formers and then building up the iron core inside them.

The stampings are frequently L-shaped, being pushed into the hollow interiors of the coils from alternate ends.

The idea is to get as good a magnetic circuit as possible (with no air gaps) round the core, but to make a path of high resistance transversely through the core.

The insulation used between laminations may consist of paper, varnish, or even the layer of rust and mill-scale which covers the sheet of iron.

In well-designed transformers the eddy-current loss is very small indeed when used on ordinary commercial frequencies such as 50 cycles per second. This loss, however, increases as the square of the frequency so that at frequencies of 400 cycles per second it is often greater than the hysteresis loss, which latter only increases in direct proportion to the frequency.

If the transformer be enclosed in an iron case it may be that eddy-currents will be induced in the case itself. Since, however, the magnetic circuit is already completely of iron, the lines of force will not be likely to stray out so far as to induce currents of any strength in the casing.

Although several of these causes do not singly make an appreciable loss, yet it must be remembered that heat produced by any cause whatever, if not immediately radiated away, will raise the temperature of the copper wires and so increase the copper loss.

It becomes imperative, then, to have cooling arrangements which will keep even the centre of the iron core from getting too hot when the transformer is working continuously on full load.

In large transformers this cooling is a very serious consideration and necessitates the employment of air fans, circulation of water or oil, or sometimes a combination of all these devices.

In the small transformers used for wireless either air or oil is used for cooling.

Air cooling is cheap and clean, but the transformer must not be allowed to get damp, or the insulation of the high-tension winding will suffer, nor must it be put away in a corner or covered up where no air will reach it or circulate round it.

Oil cooling necessitates a tank which increases weight. It possesses the advantage of protecting the instrument, and, moreover, the oil protects the windings against damp, and the insulation of the windings is further materially assisted by the presence of the oil.

In large transformers the oil is caused to circulate through ducts in the cores, but this method is not necessary in transformers used for wireless purposes.

It must be borne in mind that if a transformer which has not been in continuous use is not, or has not been for some time immersed in oil, it is risky to apply full voltage to it straightaway. It is safer to short-circuit the secondary winding and apply a very small voltage to the primary for several hours in order to "dry it out" before using it under ordinary conditions. An air-cooled transformer in a ship where wireless is not much used is bound to absorb moisture, so that it must be thoroughly dried out before being used. This applies especially to ships undergoing refit, &c.

The core and cooling arrangements, then, are as above indicated. A short description of the way in which the windings are made will, perhaps, impress upon the reader that the transformer deserves all the attention that it will get.

If oil cooling is to be used india-rubber must not be employed for insulating the windings, for oil attacks this material and rots it.

Both windings are generally wound with double cotton-covered wire. They are wound in thin flat coils which are afterwards dried in a vacuum oven at high temperature. They are then treated with a compound which prevents the re-absorption of moisture and adds greatly to their mechanical strength.

The treating process is repeated many times to ensure a heavy, uniform waterproof coating, and after this treatment the coils are wrapped with insulating tape and assembled with suitable ventilating ducts and insulating barriers between them.

The coils are subdivided either so that parts of the primary and secondary are interlaced (placed alternately on the core) or else so that the secondary is wound over the top of the primary.

Having now investigated the losses and how they are reduced we must return to the efficiency.

The total loss in watts will be :—

Copper loss = $C_1^2R_1$ in primary.
Copper loss = $C_2^2R_2$ in secondary.
Iron loss = W watts, measured with a wattmeter when secondary is on open circuit.

Now when the load is small, the copper loss will be negligible, but the core loss is large in proportion to the load. Hence the efficiency or $\frac{\text{output}}{\text{input}}$ will not be great.

As the load increases the copper loss increases, but the iron loss remains the same as before, being constant for all loads. Hence the total loss at full load is a smaller proportion of the total power than it was when the load was small.

As full load is reached the efficiency should rise to its maximum.

The small transformers used in wireless have efficiencies varying from 94 to 97 per cent. Large transformers may have more than 98 per cent. efficiency.

Notice that these measurements must all be taken with a non-inductive load upon the secondary, otherwise extra complications will arise owing to the secondary current being out of phase with the secondary volts.

One other cause of loss remains ; it is a loss in volts. Take a transformer and apply a fixed R.M.S. primary voltage and alter the load on the secondary, reading the secondary volts after each alteration.

As the load increases, the volts will fall off just as would happen in a shunt wound dynamo run at a constant speed. This drop of voltage is, of course, partly due to the resistances of the two windings and will equal C_1R_1 and C_2R_2 for the primary and secondary respectively. There is also another contributory cause, viz., the magnetic leakage, the action of which has already been referred to.

It is avoided as much as possible by winding one coil on top of the other, or else by placing them in sections alternately disposed around the limbs of the core, thus compelling all lines of force produced by any one winding to cut the opposite winding.

Now the shape of the E.M.F. curve is very seldom that of a true sine wave. One alternator will give a different shaped curve from another. This has been previously explained.

Again, for a given alternator the E.M.F. curve will vary according to the extent to which the machine is loaded and the nature of the load, *i.e.*, whether re-active or not.

When the load consists of transformers working incandescent lamps the load will be fairly non-inductive. If, however, they are lighting arc lamps, driving motors or doing any other inductive work, then the E.M.F. curve will take a different shape.

Again, the make of transformer will affect the E.M.F. curve applied to the primary.

Suppose, then, we have an E.M.F. of definite wave-form applied to the transformer.

Then the magnetising current will take up some shape, not necessarily resembling that of the E.M.F.

The shape of this primary no-load current curve will depend upon

(1) The shape of the E.M.F. curve.
(2) The nature of the iron used in the core.
(3) The general construction of the transformer.

The secondary E.M.F. curve will be an *exact* copy of the primary E.M.F. curve to an altered scale according to the step up or down and lagging 180° on it. This is an important point.

When the transformer is loaded up with a non-inductive load the secondary E.M.F. lags a little more than 180° behind the primary E.M.F., this being due to magnetic leakage, which is not felt on no load.

Again, on load, the primary current curve gets more in phase with the E.M.F., so that on full load the primary current and E.M.F. are in phase, but the primary current is nearly 180° out of phase with the secondary E.M.F.

The curve of magnetic induction, magnetisation, or flux, lags behind the current as before explained. It is always 90° out of phase with the primary E.M.F. As a rule it is more nearly a true sine curve than is the E.M.F. curve, the irregularities being smoothed out as it were. The flux is not the same strength in all parts of the core, nor quite the same on open circuit as on full load.

The flux due to the primary current compared to that due to the secondary is constant at all loads, except where an open magnetic circuit is employed.

The Loss of Secondary Volts.

We saw that the drop of voltage was primarily due to copper loss and magnetic leakage, and that it increased with the load. It is also affected by

(1) The construction of the transformer.
(2) The shape of the primary E.M.F. curve.

These four causes combine together to produce a certain drop in the secondary voltage. This may become a nuisance if the load consist of incandescent lamps. It is not entirely avoidable, and in order to prevent lamps burning dimly when the transformer is on full load, the secondary is generally wound to give a slightly higher no-load pressure than is required. For example, suppose the drop is 2 volts in a secondary giving 100 volts. On full load the lamps will get 98 volts and will burn dimly. If, however, the no-load pressure be 101 volts, the full-load pressure would be 99 volts and the change in brilliancy would not be noticed.

It will be seen that the general effect of the shape of the primary E.M.F. curve is very complicated. Speaking broadly, it may be stated that a sharply peaked E.M.F. curve will give a smaller current to a given circuit than will a rounded one of the same R.M.S. value. (For " R.M.S. value," *see* later.)

A peaked curve reduces hysteresis loss, but causes greater magnetic leakage in the core. Taking the core losses all together, a peaked curve gives more total core loss than does a rounded or flat-topped one of the same R.M.S. value and frequency.

Auto-Transformers.

Whereas the ordinary transformer is an inductively coupled device, we remember that an oscillation transformer (*see* p. 30) may be "directly" or "conductively" coupled. This type of transformer, whether having an iron or air core, is called an "auto-transformer."

The ordinary auto-transformer is a transformer having but one winding. It is commonly used for small steps-down of voltage. In such a case the primary voltage would be applied across the total winding, or, in other words, across the total number of turns, and the secondary circuit is connected between two taps taken off from the same winding, the voltage being changed in the ratio of the number of turns.

It is possible, by having a number of leads tapped in at suitable places, to provide ourselves with a wide range of voltages which may be applied to the secondary outside circuit.

Further, an ordinary transformer may be connected up as an auto-transformer in several different ways.

It will be seen that their chief use lies in regulating pressure compensating for ohmic drop &c., and we are not much concerned with them, except perhaps, from the point of view of their possible use for power-regulators.

For a given transformation of energy, an auto-transformer may be made considerably smaller than an ordinary transformer, and consequently its losses will be less and its efficiency higher. This is because the total watts delivered to the secondary circuit is in excess of that actually transformed. The power *actually* transformed = *difference* between primary and secondary volts multiplied by total current delivered.

Example.—The voltage of a long-distance transmission line is to be raised from 40,000 to 45,000 volts, and the maximum current to be handled is 750 ampères. What is the rating of the auto-transformer required for this service?

And what will be the actual power delivered over the line?

Actual rating of the auto-transformer will be—

$$5{,}000 \times 750 = 3{,}750{,}000 \text{ watts.}$$
$$= 3{,}750 \text{ kilowatts.}$$

The total power delivered to the line will be—

$$45{,}000 \times 750 = 33{,}750{,}000 \text{ watts.}$$
$$= 33{,}750 \text{ kilo-watts.}$$

It should be noticed that as in an ordinary transformer, the primary and secondary currents are in opposition, so that the common portion of an auto-transformer's winding carries only the difference between the primary and secondary currents.

Effect of different circuits on transformers.

To save writing, let $\frac{n_2}{n_1}$, the transformation ratio of voltage, be denoted by T, neglecting losses—

We remember $E_2 = T.E_1$ (*see* p. 133).

$$\text{and } C_2 = \frac{C_1}{T} \text{ or } C_1 = T.C_2.$$

(1) *Non-inductive.*

Suppose resistance R_1 be placed in series with primary.

Volts lost in primary $= C_1R_1$, so that the volts across primary are reduced by this amount.

Hence reduction of sec. volts $= T \times$ reduction of P volts.
$= T.C_1R_1$.

But $C_1 = T.C_2$.

Hence sec. volts are reduced by $C_2(T^2R_1)$.

Hence we could have equally well reduced our secondary volts by this amount by inserting a resistance R_2 such that

$$R_2 = T^2R_1, \text{ and } \frac{R_2}{T^2} = R_1.$$

Any resistance inserted in the primary may be considered to act in the secondary circuit provided we multiply it by the *square of the step up.*

(2) *Inductive.*

Place L_1 in series with primary.

Here we have E.M.F. overcoming reactance $= pL_1C_1$ volts $90°$ ahead of C_1.

This voltage will be transformed and reappear as $T \times pL_1C_1$ volts in the secondary 180° ahead of pL_1C_1.

$$\begin{aligned} &\text{Now } C_2 \text{ is } 180^\circ \text{ ahead of } C_1, \\ &\text{So if } pL_1C_1 \text{ is } 90^\circ \text{ ahead of } C_1, \\ &TpL_1C_1 \text{ is } 90^\circ \text{ ahead of } C_2. \\ &\text{But } C_1 = T.C_2, \\ &\text{So } TpL_1C_1 = T^2pL_1C_2. \end{aligned}$$

So we have $T^2pL_1C_2$ in secondary 90° ahead of C_2. This effect would have been produced had the inductance been inserted in the secondary originally as L_2, such that

$$L_2 = T^2 \times L_1 \text{ or } L_1 = \frac{L_2}{T^2}.$$

The same result as for resistances.

It will be seen that a transformer supplying a secondary *inductive* load appears to have inductance itself, although we say that a fully loaded transformer on non-inductive load had a negligible inductance itself.

(3) *Condenser action.*

Place condenser S_1 in series with primary.

E.M.F. charging $S_1 = \dfrac{C_1}{pS_1}$ volts, 90° astern of C_1.

This reappears in secondary as

$$\frac{T \times C_1}{pS_1} \text{ volts } 90^\circ \text{ astern of } C_2.$$

But $C_1 = T.C_2$.

We have then

$$\frac{T^2.C_2}{pS_1} \text{ volts } 90^\circ \text{ astern of } C_2.$$

This effect would be produced by S_2 in the secondary, such that

$$\frac{1}{S_2} = \frac{T^2}{S_1},$$

$$\text{or } S_2 = \frac{S_1}{T^2} \text{ or } S_1 = S_2T^2.$$

Which is the other way about to the results for L and R.

CHAPTER VII.

Alternating Current Measurements.

As in continuous current practice, the rate of flow of an alternating current is expressed and measured in ampères.

Alternating pressure is expressed and measured in volts and alternating power in watts. Unlike continuous current and voltage, alternating current and voltage present for measurement quantities which are continually varying not only in strength but also in direction from instant to instant.

Such quantities are conveniently measured by taking an average of the entire value existing through the interval of time elapsing between the moments when they are at zero. This is done in the practical measurements of alternating current and voltage. As electrical power is the product of current and pressure, it also is measured as an average.

An alternating current ampère is not considered to be the strength of the current when at its highest instantaneous value, that is, at the top of its wave, nor is an alternating volt to be considered to be the pressure attained at the top of the voltage wave. If they were taken to be this value, it would be necessary to make the measurements at that particular moment. It is this matter of instantaneous values which somewhat complicates questions in alternating current work.

The basis of comparison is taken from the steady values of the continuous current volt, ampère, and watt. The corresponding alternating units are considered to be values which will produce *equal effects*. The alternating current ampère is taken to be that average flow which will produce the same heating effect in a wire as that which a continuous current of one ampère will produce under precisely similar circumstances. The alternating volt is taken to be that average pressure, or difference of potential, which is equal to one volt of steady (continuous volt) pressure. That is, either pressure would produce an equal flow of current if applied in turn to the ends of a non-inductive circuit.

For example, 100 alternating volts would send as great a flow of current through an incandescent lamp as would 100 steady volts; but it would be an average value actually, the voltage reached at the maximum being considerably greater than 100 volts. An alternating watt is the product of one alternating ampère into one alternating volt, and is therefore an average value which is an equal amount of power to one watt obtained by multiplying one steady ampère into one steady volt, *provided* the alternating current and voltage are in step with each other. For example, an incandescent lamp takes two ampères when supplied with 100 alternating or steady volts. The rate at which the lamp is consuming energy is 200 watts in each instance. But the alternating watts are an average value and do not represent the product of the alternating volts and amps. when at their maximum values, though it is quite correct to multiply them together, since the lamp is a non-inductive circuit. It might appear at first sight that a lamp burnt by alternating current would flicker owing to the ever-varying current. This flicker does exist, of course, but will be imperceptible to the eye if the alterations are sufficiently rapid, say, anything from 20 or 30 cycles upwards.

If an alternating ampère or volt be measured by an average value it must rise to a value above this because it falls to zero periodically. This is the case, in fact.

An alternating ampère or volt, measured by this average value, is approximately only ·7 of its maximum instantaneous value. An alternating current of 70 ampères, as measured by a properly calibrated ammeter, therefore really rises to a maximum value of 100 ampères at the top of each wave, but as it only attains this value for an instant and then falls to zero, the effect produced by the current in the circuit to which it is supplied is equal to that produced by only 70 ampères continuous current. In fact the ammeter gives a measurement which is of practical use to an electrical engineer and enables him to reduce his quantities to a comparable basis. In like manner an alternating voltage is approximately ·7 of its maximum instantaneous value. A pressure of 70 alternating volts, as measured by a suitable voltmeter, means that at the top of the wave of voltage the instantaneous value is 100 volts; but the voltmeter does not show it, because it is measuring the pressure as an average value, to bring it to a level with a continuous voltage. This is a very important matter in alternating current practice; thus the supposed voltage which is held by the insulation of a cable, transformer, or other piece of apparatus may be very much less than the actual pressure which is straining it.

When designing alternating current apparatus according to the reading of a voltmeter or ammeter measuring the average pressure or current, a margin may have to be allowed in the strength of insulation employed for this maximum instantaneous E.M.F. to which the voltage really rises in practice; but no margin need be allowed in the size of cable employed to carry the current, for the heating of the cable is the result of the average current, not of its maximum value.

This average value, which is measured practically by voltmeters and ammeters, is *not* the arithmetical mean of all the instantaneous voltages and current throughout the cycle.

The heating effect of a current passing through a wire varies as the square of the current, and not directly as its strength. If the arithmetical mean be taken we shall find the average value to be ·64 of the maximum value, a result which is too low. Measuring instruments do not measure this value, although it sometimes has to be calculated when dealing with E.M.F.s or currents which do not follow the simple sine law. The instruments measure a mean which is somewhat higher than the true arithmetic mean, whether they depend for their action upon the heating effect produced by the current flowing through a wire (hot-wire ammeters and voltmeters), or upon the magnetic effect of repulsion and attraction between coils of wire through which the current flows (electro-dynamometers), or upon the attraction between a current-carrying coil and a piece of soft iron (electro-magnetic ammeters and voltmeters) or attraction and repulsion between charged metal plates (electric-static voltmeters.) The average value of current or voltage which these instruments measure is called the "root mean square" value.

This latter is written R.M.S., and is a mean value of the current or voltage obtained taking a number of instantaneous values of E.M.F. or current at equal short intervals of time, squaring each one, taking their mean or average, and then finding the square root of the answer. This sounds rather a formidable process, but really presents few difficulties if taken graphically.

Assume an alternating current whose maximum value is 3 ampères. What is it worth as direct current? In other words, find its R.M.S. value.

Draw the current curve on squared paper, taking, say 18 small squares for the half-cycle as abscissæ, and two small squares per ampère as ordinates. The maximum ordinate will take six squares.

Remember that $c = C \sin A$, here we have

$$c = 3 \sin A.$$

Take values of A for every 10 degrees (represented by one small square) and look out the sines from a table. Multiply these sines by three, and plot the results on the paper.

We shall, of course, get a sine curve whose amplitude is 3 ampères. Draw a complete cycle of this curve.

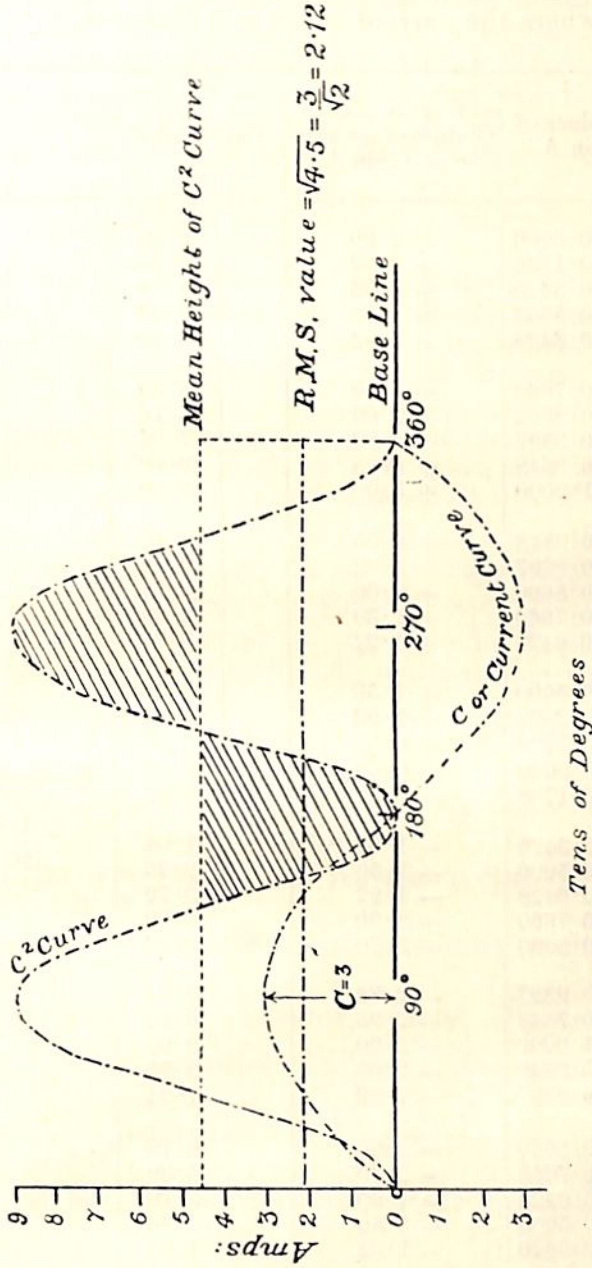


FIG. 74.

Now take the values found for each 10°, square them separately and put them on the same piece of paper.

Remember that it does not matter in which direction the current is flowing, the heating effect will go on just the same.

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For example, 100 alternating volts would send as great a flow of current through an incandescent lamp as would 100 steady volts; but it would be an average value actually, the voltage reached at the maximum being considerably greater than 100 volts. An alternating watt is the product of one alternating ampère into one alternating volt, and is therefore an average value which is an equal amount of power to one watt obtained by multiplying one steady ampère into one steady volt, *provided* the alternating current and voltage are in step with each other. For example, an incandescent lamp takes two ampères when supplied with 100 alternating or steady volts. The rate at which the lamp is consuming energy is 200 watts in each instance. But the alternating watts are an average value and do not represent the product of the alternating volts and amps. when at their maximum values, though it is quite correct to multiply them together, since the lamp is a non-inductive circuit. It might appear at first sight that a lamp burnt by alternating current would flicker owing to the ever-varying current. This flicker does exist, of course, but will be imperceptible to the eye if the alterations are sufficiently rapid, say, anything from 20 or 30 cycles upwards.

If an alternating ampère or volt be measured by an average value it must rise to a value above this because it falls to zero periodically. This is the case, in fact.

An alternating ampère or volt, measured by this average value, is approximately only ·7 of its maximum instantaneous value. An alternating current of 70 ampères, as measured by a properly calibrated ammeter, therefore really rises to a maximum value of 100 ampères at the top of each wave, but as it only attains this value for an instant and then falls to zero, the effect produced by the current in the circuit to which it is supplied is equal to that produced by only 70 ampères continuous current. In fact the ammeter gives a measurement which is of practical use to an electrical engineer and enables him to reduce his quantities to a comparable basis. In like manner an alternating voltage is approximately ·7 of its maximum instantaneous value. A pressure of 70 alternating volts, as measured by a suitable voltmeter, means that at the top of the wave of voltage the instantaneous value is 100 volts; but the voltmeter does not show it, because it is measuring the pressure as an average value, to bring it to a level with a continuous voltage. This is a very important matter in alternating current practice; thus the supposed voltage which is held by the insulation of a cable, transformer, or other piece of apparatus may be very much less than the actual pressure which is straining it.

When designing alternating current apparatus according to the reading of a voltmeter or ammeter measuring the average pressure or current, a margin may have to be allowed in the strength of insulation employed for this maximum instantaneous E.M.F. to which the voltage really rises in practice; but no margin need be allowed in the size of cable employed to carry the current, for the heating of the cable is the result of the average current, not of its maximum value.

This average value, which is measured practically by voltmeters and ammeters, is *not* the arithmetical mean of all the instantaneous voltages and current throughout the cycle.

The heating effect of a current passing through a wire varies as the square of the current, and not directly as its strength. If the arithmetical mean be taken we shall find the average value to be ·64 of the maximum value, a result which is too low. Measuring instruments do not measure this value, although it sometimes has to be calculated when dealing with E.M.F.s or currents which do not follow the simple sine law. The instruments measure a mean which is somewhat higher than the true arithmetic mean, whether they depend for their action upon the heating effect produced by the current flowing through a wire (hot-wire ammeters and voltmeters), or upon the magnetic effect of repulsion and attraction between coils of wire through which the current flows (electro-dynamometers), or upon the attraction between a current-carrying coil and a piece of soft iron (electro-magnetic ammeters and voltmeters) or attraction and repulsion between charged metal plates (electric-static voltmeters.) The average value of current or voltage which these instruments measure is called the "root mean square" value.

This latter is written R.M.S., and is a mean value of the current or voltage obtained taking a number of instantaneous values of E.M.F. or current at equal short intervals of time, squaring each one, taking their mean or average, and then finding the square root of the answer. This sounds rather a formidable process, but really presents few difficulties if taken graphically.

Assume an alternating current whose maximum value is 3 ampères. What is it worth as direct current? In other words, find its R.M.S. value.

Draw the current curve on squared paper, taking, say 18 small squares for the half-cycle as abscissæ, and two small squares per ampère as ordinates. The maximum ordinate will take six squares.

Remember that $c = C \sin A$, here we have
$$c = 3 \sin A.$$

Take values of A for every 10 degrees (represented by one small square) and look out the sines from a table. Multiply these sines by three, and plot the results on the paper.

We shall, of course, get a sine curve whose amplitude is 3 ampères. Draw a complete cycle of this curve.

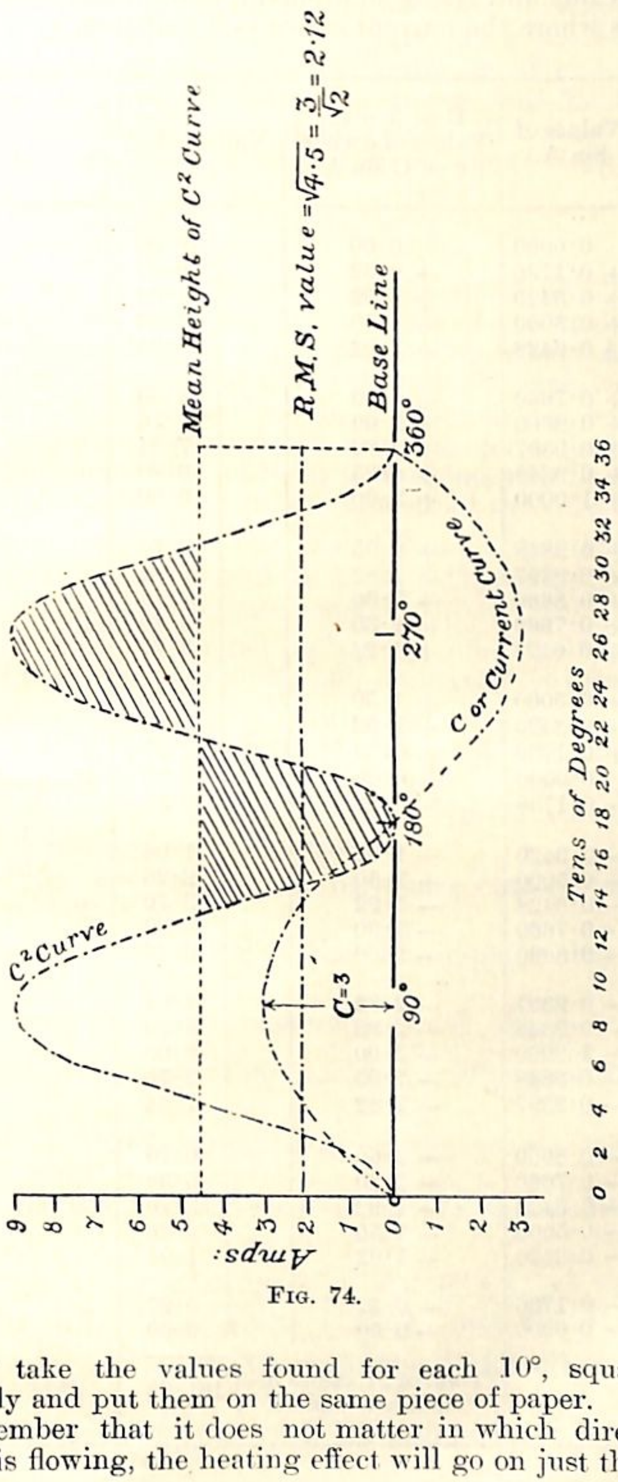


Fig. 74.

Now take the values found for each 10°, square them separately and put them on the same piece of paper.

Remember that it does not matter in which direction the current is flowing, the heating effect will go on just the same.

The square of any number, whether + ve or − ve, is always + ve. We shall get another sine curve standing up on the horizontal line and rising to a maximum of 9 ampères opposite the points where the current curve is 3 ampères.

Degrees.	Values of Sin A.	C = 3 max. Values of c where c = C sin A.	Values of c^2.	
0	0·0000	0·00	0·00	
10	+ 0·1736	+ 0·52	0·27	
20	+ 0·3420	+ 1·02	1·04	
30	+ 0·5000	+ 1·50	2·26	
40	+ 0·6428	+ 1·92	3·70	
50	+ 0·7660	+ 2·30	5·30	
60	+ 0·8660	+ 2·60	6·76	
70	+ 0·9397	+ 2·82	7·94	
80	+ 0·9848	+ 2·95	8·70	
90	+ 1·0000	+ 3·00	9·00	
100	+ 0·9848	+ 2·95	8·70	
110	+ 0·9397	+ 2·82	7·94	
120	+ 0·8660	+ 2·60	6·76	
130	+ 0·7660	+ 2·30	5·30	
140	+ 0·6428	+ 1·92	3·70	
150	+ 0·5000	+ 1·50	2·26	
160	+ 0·3420	+ 1·02	1·04	
170	+ 0·1736	+ 0·52	0·27	
180	0·0000	0·00	0·00	Mean value of c^2 =
190	− 0·1736	− 0·52	All positive 0·27	
200	− 0·3420	− 1·02	1·04	$\frac{161 \cdot 88}{36} = 4 \cdot 5.$
210	− 0·5000	− 1·50	2·26	
220	− 0·6428	− 1·92	3·70	
230	− 0·7660	− 2·30	5·30	
240	− 0·8660	− 2·60	6·76	
250	− 0·9397	− 2·82	7·94	
260	− 0·9848	− 2·95	8·70	
270	− 1·0000	− 3·00	9·00	
280	− 0·9848	− 2·95	8·70	
290	− 0·9397	− 2·82	7·94	
300	− 0·8660	− 2·60	6·76	
310	− 0·7660	− 2·30	5·30	
320	− 0·6428	− 1·92	3·70	
330	− 0·5000	− 1·50	2·26	
340	− 0·3420	− 1·02	1·04	
350	− 0·1736	− 0·52	0·27	
360	− 0·0000	− 0·00	0·00	
		Total of 37 values including 0° and 360°	161·88	

Call this second curve the c^2 or heating effect curve.

Now the average of all the values of c^2 which we have found and plotted can be found by adding them together (there will be 36 of them throughout the cycle, since the first and last are zero and must not be counted twice, for 0° and 360° are the same) and dividing by 36. The answer will be 4·5, that is, half the value of 9 the maximum value. The mean value of all such things as c^2 is equal to half its maximum value, that is—

$$\text{Mean value of } c^2 = \frac{C^2}{2}.$$

Now this mean value of c^2 is the thing which causes the deflection of an ammeter. If the scale of the instrument were graduated according to the *deflections* we should have squares of amps. (or volts) to deal with. In order to save us taking the square root of the deflections the graduations on the face of the instruments are proportional, not to the deflections themselves but to the square roots of those deflections, that is, proportional to the square root of the mean value of all the values of c^2.

Now the mean value of c^2 was 4·5 amps.^{2}, so that the R.M.S. value would be $\sqrt{4\cdot 5}$ or 2·12 amps. This is the actual reading that would be given by an ammeter.

The reader is advised to satisfy himself that the mean value of the c^2 curve is really half its maximum value.

This may be done by cutting off with a pair of scissors the top half of each "hump" of the curve, these humps being found to fit exactly into the hollows left. One such hump and one such hollow are shown shaded in Fig. 74, which illustrates the whole series of measurements.

Now we saw that in our particular case the R.M.S. value came out to 2·12 amps.

Suppose, however, that the maximum value were any number, say C, amps.

In that case, the maximum value of the current^2 is C^2 amps. The mean value of C^2 is $\frac{C^2}{2}$. The square root of this is $\sqrt{\frac{C^2}{2}}$ or $\frac{C}{\sqrt{2}}$ which is the R.M.S. value.

To get the R.M.S. value we divide the maximum value by $\sqrt{2}$.

To get the maximum from the R.M.S. we multiply the latter by $\sqrt{2}$. Now $\sqrt{2} = 1\cdot 4142...$ and the R.M.S. value being $\frac{1}{1\cdot 4142}$ of the maximum value, is therefore ·707 of the maximum, for $\frac{1}{1\cdot 4142} = \cdot 707$. Notice that $3 \times \cdot 707 = 2\cdot 12$.

A simple rule will convert one into the other.

R.M.S. = 70 per cent. of maximum.
Maximum = 140 per cent. of R.M.S.

All this argument applies to currents and voltages equally.

Remember that for power calculations and for finding the sizes of cables necessary to carry currents we are concerned with R.M.S. values of current and voltage, while for determining the thickness of insulation necessary, the strength of a dielectric or the instant at which a spark gap breaks down, we are concerned with maximum values of voltage.

It is seen then that an ammeter or voltmeter gives a kind of false reading when measuring alternating current. On this account the readings are called "virtual." An ammeter thus does not show actual ampères but "virtual ampères" and a voltmeter "virtual volts" as they are termed. The scales are frequently marked to this effect.

It may bring the matter home to the student if we mention that the scale readings are fixed (a process called "calibration") by the passage of known *direct* currents and applications of known *direct* volts, comparison being made with carefully standardised direct current measuring instruments. What these instruments really do is to reduce the alternating measurements to a basis of comparison with steady current or voltage measurement. This is quite correct, for after all the engineer requires to do certain work with electricity, and provided that work be satisfactorily done it does not matter what kind of current is used.

We shall keep to the following letters:—

c, e, and v for instantaneous values of current, E.M.F. and D.P.

C, E, and V for maximum values of current, E.M.F. and D.P.

C.E.V. for R.M.S. (or virtual) values of current, E.M.F. and D.P. respectively.

To measure power in a direct current circuit, all we have to do is to multiply the volts and amps. together, the result being in watts. In an alternating current circuit the volts and amps. are continually varying, and so must the watts vary.

It is therefore permissible to say that at any instant of time the product of the volts and amps. will give us the power, or rate, at which energy is being absorbed at that instant. This seems at first a simple affair to multiply the volts and amps. together, but in doing so we must have due regard to the phases of the two components.

Take the case of a non-inductive circuit, where the current is in phase with the E.M.F. Here the two curves lie one upon the other, crossing the base line simultaneously. At any instant $c = \frac{e}{R}$, and wherever there is a D.P., there also is a current in the *same* direction. Consequently when c is + ve e will be + ve; when c is − ve, e is also − ve.

In every case, therefore, the value of ec will be + ve (*see* Appendix).

Let us draw a current and an E.M.F. curve upon the same piece of paper and then put their product down for several values, thus obtaining a power, or watt curve.

Let C (max.) = 3 amps. and E (max.) = 2 volts.

Then the values of c, e, and ec for every 10° will be as in the table.

Degrees.	Values of c.	Values of e.	Values of ec.
0, 180, 360	0·00	0·00	0·00
10, 170, 190, 350	0·52	0·35	0·16
20, 160, 200, 340	1·02	0·68	0·69
30, 150, 210, 330	1·50	1·00	1·50
40, 140, 220, 320	1·92	1·28	2·46
50, 130, 230, 310	2·30	1·54	3·54
60, 120, 240, 300	2·60	1·74	4·54
70, 110, 250, 290	2·82	1·88	5·30
80, 100, 260, 280	2·95	1·97	5·82
90, 270	3·00	2·00	6·00

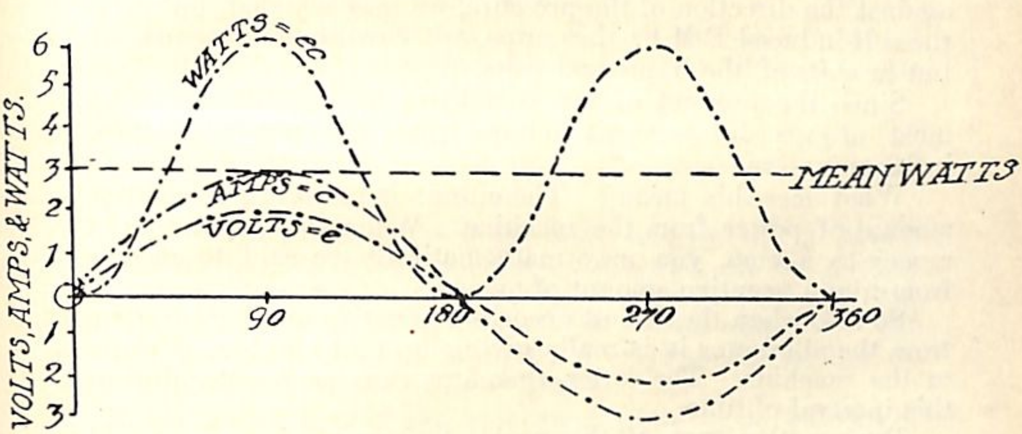


Fig. 75.

When these curves are plotted as in Fig. 75, we see at once that the mean height of the watt curve is equal to half its maximum height—that is, the mean rate of production of energy throughout the cycle is $\frac{6}{2}$ or 3 watts. This is the reading that would be given by a wattmeter placed in the circuit.

Now the maximum value of ec was EC, and the mean watts always = $\frac{1}{2}$ EC, provided that the current and voltage are in phase with each other.

We may write this result $\frac{E}{\sqrt{2}} \times \frac{C}{\sqrt{2}}$. Since $2 = \sqrt{2} \times \sqrt{2}$.

That is to say, the R.M.S. amps. and R.M.S. volts multiplied together give us the watts.

Now draw the same curves of current and voltage, putting the current lagging 60° on the voltage.

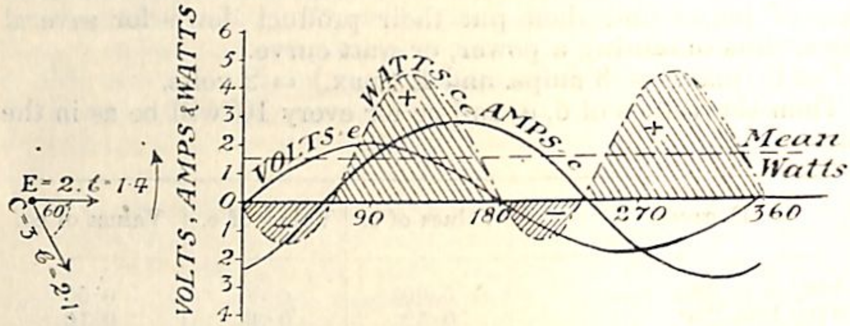


Fig. 76.

Here we notice that sometimes we have current but no voltage, voltage without current, and sometimes also current flowing in opposition to the voltage.

Any finite number multiplied by 0 must be zero, so that in the first two cases the power at those instants will be zero. With regard to the intervals during which the current flows against the direction of the pressure, we may say that, owing to the self-induced E.M.F., the amps. are flowing not because of, but in *spite* of, the impressed volts.

Since the product of two quantities having different signs must always be −ve, it follows that the power at these instants is −ve.

What does this mean? The circuit is receiving a negative amount of power from the machine. When you pay a sum of money to a man, you may mathematically be said to receive from him a negative amount of money.

So also when the circuit absorbs a negative number of watts from the alternator it is really giving up that number of watts to the machine. The latter, therefore, runs as a *motor* during this interval of time.

During the part of the cycle during which current and pressure are working in the same direction the machine may be said to be doing two things. It is doing useful work against resistance and also storing up magnetic energy in the inductive circuit (or else electric energy in a condenser).

Twice every cycle the machine has a treat, running on the watts it has saved up and thus *sparing* the steam or other engine the trouble of twisting it round.

This evidently means that less steam is required from the boiler and less coal on the furnace.

Now all energy originally comes from the coal, so that if the current be not in phase with the E.M.F. we are not really developing the power that we think.

The ammeter measures current without reference to whether it be out of phase with the E.M.F. or not.

In this case, if we multiplied the R.M.S. ammeter and voltmeter readings together we should obtain 3 watts as before, for the ammeter gives ·7 of 3 = 2·1 amps., and the voltmeter ·7 of 2 = 1·4 volts, and 2·1 × 1·4 = 3 watts very nearly (·7 is a rough value). This result is called the "apparent watts."

But we have seen that we shall not really be developing this amount of power, because some of those watts are "ear-marked" for use at the time when the machine is going to enjoy a little of its own saved-up power.

The true watts will be less than the apparent watts by an amount which depends upon the phase difference angle.

A wattmeter placed in the circuit will measure the true watts. If the wattmeter reading be equal to the product of the voltmeter and ammeter readings, we may say at once that there is no phase difference, no reactance, and $C = \frac{E}{R}$. If, however, the true watts come out less (they can never be more) than the apparent watts we know at once that the current is not in phase with the E.M.F., but whether it lags or leads we cannot say unless the inductive reactance be known to be greater or less than the capacity reactance.

Having drawn the current and E.M.F. curves 60° out of phase with each other, now find values for ec at different points and plot the watt curve. This is shown in Fig. 76.

We must be careful to take the correct numbers and to call the products +ve when e and c are in the same direction and −ve when they are in opposition.

The resulting watt curve is the same shape and total height as the other one, but it dips below the horizontal line twice every cycle. At these points the circuit is giving power *to* the machine, the power given *by* the machine being negative. The rest of the cycle is spent in doing useful work *and* in saving up some watts to supply the negative parts.

Now the total area of the watt curve gives us the amount of work (joules) expended in the circuit during the complete cycle. The average watts produced by the machine is 3 as before, this being the "apparent" watts. But of these the machine receives back some, so that the true watts available in the circuit for actual work will be the average height of the curve *above* the zero line. Referring to Fig. 76, this height is seen to be only 1·5 watts. A wattmeter would show this value of 1·5, which are the "true" watts.

The greater the angle of lag or lead, the less do the true watts become, even if the apparent watts remain the same.

When the phase difference is 90° the machine develops *no power at all.* In this case the watt curve dips as much below the line as it rises above it, and the machine runs twice as a dynamo and twice as a motor each cycle, using up as a motor all the energy it produced when running as a dynamo.

The result of dividing the true by the apparent watts is called the "power factor."

When $\phi = 0°$, the power factor = 1.
When $\phi = 60°$, the power factor = $\frac{1}{2}$ (as in this case).
When $\phi = 90°$, the power factor = 0.

We shall see that the power factor is the cosine of the phase difference angle.

From this we see that

True watts = R.M.S. volts × amps. × cos ϕ.

This result is arrived at as follows:—

Vector diagrams may be used for maximum or R.M.S. values with equal truth. Let us therefore take an R.M.S. value of E.M.F. represented by the line OP in Fig 77.

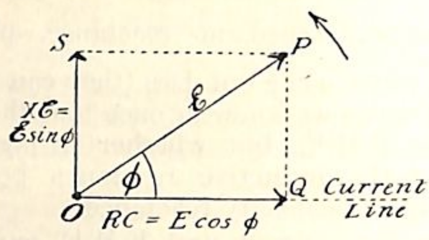


Fig. 77

Let the current lag by an angle ϕ on the E.M.F. In phase with the current we have an *effective* E.M.F., whose R.M.S. value is R times the R.M.S. current. 90° out of phase with the current we have a non-effective part whose R.M.S. value = reactance multiplied by R.M.S. current. Let these lines be represented by OQ and OS respectively, completing the rectangle OQPS. Now the voltmeter reads the total R.M.S. volts E = OP. The ammeter reads the R.M.S. current. But of the whole E.M.F. E, only a part = RC is in phase with the current. The other part is 90° out of phase therewith and therefore develops no watts. The watts (true) will consist of the product of the R.M.S. current with the R.M.S. *effective* E.M.F. OQ. Now $\frac{OQ}{OP} = \cos\phi$, so that OQ = OP × cos ϕ = E cos ϕ.

Hence effective E.M.F. = cos ϕ times the R.M.S. volts as given by the voltmeter.

Hence the true power = C^2R = (R.M.S. current) × (R.M.S. volts × cos ϕ) = CE cos ϕ.

It will be noticed that the non-effective E.M.F. has a R.M.S. value = E sin ϕ, for OS = PQ, and $\frac{PQ}{OP} = \sin\phi$.

This result might equally well have been obtained by considering the current to consist of two components as shown in Fig. 78. One part, the useful component, is in phase with the

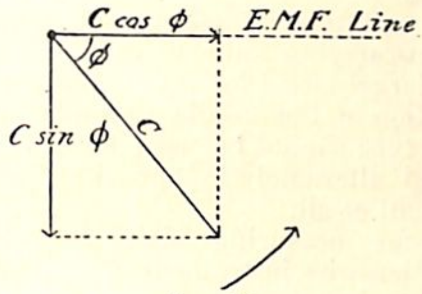


FIG. 78.

E.M.F. and has an R.M.S. value = $C \cos \phi$, and the other or "wattless" component = $C \sin \phi$ and is 90° out of phase with the E.M.F., developing no power.

The same result is obtained, namely, the

True watts = apparent watts × cos ϕ.

= apparent watts × power factor.

Hence cos ϕ is the power factor.

This method of looking at the problem often results in great confusion in the mind of the student. How can a current be wattless? What becomes of it? Where does it go?

Remember that it is that portion of the current which flows either when no volts exist, or else when the volts are in opposition to it. The wattless current is not available for doing any magnetic work, such as operating a transformer or energising a magnet, but circulates idly, heating the conductors in which it flows, and therefore making it necessary to use a larger machine as a dynamo than would otherwise be the case. Alternating dynamos have to be installed sufficiently large to supply the full number of apparent watts to the circuit without overheating, whereas the steam-engine driving the dynamo need be only sufficiently large to produce the true watts.

For this reason alternators are rated, not as being capable of giving an output of so many K.W. or kilo-watts, but one of so so many K.V.A. or kilo-volt-ampères.

This is because the maker of the dynamo does not know whether you are going to use his machine on a reactive or non-reactive load. In other words, he does not know what your phase difference angle or power factor will be.

What he guarantees is, that *if* there be no phase difference (so that the power factor is unity), then his machine will develop so many K.W., but in any case it will *apparently* develop that number of volt-ampères when you multiply R.M.S. volts by R.M.S. ampères. To get K.V.A. you must, of course, divide the result by 1,000.

Measuring Instruments.

Without going into minute mechanical detail, we may now investigate the principles on which alternating current measuring instruments work.

The moving coil type of instrument, where the magnetic effect of a current-carrying coil acts on the field of a permanent magnet, is very largely used for D.C. ammeters and voltmeters. Since the deflection of the needle depends on the *direction* of the current, this type cannot be used for A.C., since the needle would be pushed alternately in opposite directions, the result being no movement at all.

Instruments for measuring alternating currents can be divided into (1) hot-wire instruments; (2) dynamometer instruments, and (3) iron-core instruments.

(1) *Hot Wire Instruments.*

The principle on which the hot-wire instruments work is very simple. The current to be measured, or a part of it taken off a suitable shunt, flows through a fine wire, heats it and causes it to expand, the amount of expansion is magnified on the scale, and is a measure of the current strength. When the current is a large one a shunt is used in parallel with the wire, so that only a small fraction of the total current passes through it. It is important to remember that the fraction of the total current flowing through the hot wire is not a constant quantity, unless the shunt and the wire both heat up to the same temperature and are of the same material. In most cases the shunt is arranged so as to become less heated than the wire, so that with the materials employed a smaller fraction of the total current flows through the wire for large currents than for small.

Such an instrument is therefore accurate only if used with the particular shunt for which it is calibrated. This is important when the shunt is supplied and mounted up separately from the ammeter, which is generally the case when the current to be measured exceeds 100 ampères. A hot-wire instrument cannot safely be shunted to decrease its sensibility, nor can the shunt be removed to increase its sensibility, and the instrument thus used for measurement, unless a fresh calibration be performed throughout the *whole scale.*

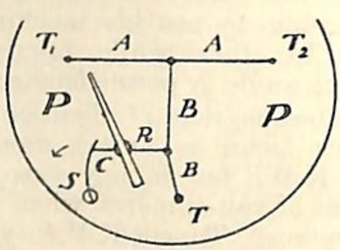


FIG. 79.

A common type of hot-wire instrument is shown diagrammatically in Fig. 79. In this a platinum-silver wire AA is stretched between two blocks T_1 T_2, one of which is adjustable. To the centre of the platinum-silver wire is attached a much thinner one BB, of phosphor-bronze, which is fixed at its other end to a terminal T; to the phosphor-bronze wire is attached a piece of cocoon fibre C, which is wrapped round a grooved metal roller R, to which the pointer is fixed, the other end of the fibre terminating in an eyelet attachment to a flat steel spring S.

When the current flows through the wire its sag increases, thus enabling the phosphor-bronze wire to be more deflected.

The increased deflection of the latter is measured by the movement of the thin cocoon fibre, which turns the pointer.

The whole of the hot-wire movement is mounted on a compensation plate PP, which expands and contracts with heat and cold at the same rate as does the wire.

The wire is protected from draughts of air which might cause false readings.

The shunts used for ammeters measuring large currents are made of "constantin," a metal whose resistance does not vary with the temperature, so that the indications of the instrument are equally accurate in hot or cold weather.

The instrument comes to its proper reading somewhat slowly, owing to the time taken by the wire to attain a steady temperature; for many purposes this is rather an advantage than otherwise, and for measuring steady alternating currents considerable accuracy can be attained, for the inductance of the instrument is negligible. A damping device is attached to the spindle of the needle, generally consisting of a thin aluminium disc moving between the poles of a small strong permanent horse-shoe magnet. On motion taking place the current induced in the disc produces a magnetic field opposing the motion and thus delaying it. This is said to produce better results, but probably its effect is not very great, since the motion of the needle is normally fairly slow. When the current is suddenly switched off, however, the damping prevents the needle from swinging back too quickly, thus counteracting the tendency of the pulley, to which the pointer is attached, to slip.

(2) *Dynamometer Instruments.*

These depend for their action on the magnetic properties of the current. Briefly we have two coils of wire joined in series with each other, one of them being fixed and the other capable of rotating on a vertical axis. In the zero position the planes of the coils are at right angles to each other. On a current being passed the moving coil will tend to set its plane parallel with that of the fixed coil so that it encloses as many lines of force as possible, turning in the same direction irrespective of the direction of the current, for the current is reversed in both coils simultaneously. The "pull" of the moving coil is proportional to the product of the currents in the two coils, but since they are in series, this current is the same in both coils, hence the twisting force or "torque" depends on the square of the current.

If alternating current be applied to this instrument, the torque indicates the mean square of the current, the former being measured by the amount of tension which has to be put on a spiral spring in order to bring the moving coil back to the zero position against the torque of the current. The results obtained will show the mean square of current and consequently the instrument does not show R.M.S. values directly, unless the graduations be spaced unequally. These instruments are not used much in practice, but are useful as laboratory standards owing to their having no iron in their composition.

(3) *Iron-core or Moving Iron Instruments.*

These instruments are coming largely into use owing to their simplicity and consequent cheapness. The principle is that of a solenoid carrying the current into which is sucked a thin iron wire or cam-shaped disc. For direct currents iron discs are generally used, taking up certain positions inside the coil of the solenoid against the action of gravity or a spring. For alternating currents the eddy current induced in the iron plate would vitiate the readings, so that a single thin wire is more common. Being of soft iron it will, of course, be attracted towards the centre of the coil whatever the direction of the current in the solenoid. The attraction of the wire being the deflecting force, the "control" is usually gravity, the motion of the pointer causing a want of balance in the rotating system. These instruments must be protected from stray magnetic lines by means of an iron screen; they further possess the disadvantage that since the wire is subjected to an alternating magnetisation, eddy currents are induced in it. The magnitude of these currents will vary with the square of the frequency. Moving-iron ammeters are usually made to register currents of a definite frequency.

If the iron wire be made sufficiently thin, this eddy current error becomes very small in practice.

Voltmeters.

The instruments used for measuring alternating P.D.'s are very similar to those used for measuring currents, the essential difference being that their resistance is high whereas that of an ammeter is low. They are always connected *across* the mains. In addition to the above classes of instruments used as ammeters we have the electrostatic voltmeter.

(1) *Hot-wire* voltmeters are used for low voltages up to about 600 or 700 volts. They require from $\frac{1}{8}$ to $\frac{1}{4}$ ampère to cause sufficient heat to give a reading. Hence if they were

used for high voltages the watts consumed by the instrument would be considerable. For example, an instrument measuring 2,000 volts, would, if working on $\frac{1}{4}$ ampère, consume 500 watts, or $\frac{1}{2}$ a K.W. The original hot-wire voltmeter is the Cardew type, of which a few are still used in the Service for measuring steady voltages. In this instrument the wire is about 12 feet long, rove four times up and down a long tube over pulleys. One of these pulleys is arranged to take up the slack of the wire on its expansion, the amount of expansion being measured in the same way as before (*see* Hot-wire ammeter).

Modern hot-wire voltmeters are constructed like ammeters, having a thinner wire, whose sag is measured in exactly the the same way. In series with the wire is a suitable non-inductive resistance generally mounted at the back of the instrument.

(2) *Special modifications* of the dynamometer type of instrument, notably Kelvin's ampère balance, may be used as voltmeters, but their use is restricted to the laboratory.

(3) *Moving iron* voltmeters differ but little from ammeters of the same type, having, however, solenoids wound of many turns of fine wire instead of a few turns of thick wire.

In these last two types where coils of wire are used, it is important that the resistance of the wire should be very large compared to its inductance. The deflection of the instrument is caused by the current in the coils, so that if that current be cut down at all by reactance, it will be cut down more at high frequencies than at low. Hence the readings will be too small for high frequencies. It is also necessary, as in D.C. instruments of these types, to use wire for the coils whose resistance does not alter materially with the temperature.

(4) *Electrostatic* voltmeters are far the best for high pressures. They waste no energy, are free from temperature variations, are not affected by stray magnetic lines, they can be used for steady or alternating pressures, giving in the latter case accurate R.M.S. values direct without errors due to alteration of frequency or distortion of the shape of the E.M.F. curve from the true sine form.

Against these advantages must be weighed the fact that they will not read very low voltages, but are eminently suitable for reading the high voltages commonly used in alternating current power transmission lines.

These voltmeters depend for their action upon the principle that two oppositely charged bodies will attract one another. In general design they are similar to the variable condenser whose principle is shown in Fig. 15 (p. 52).

If the fixed vanes and the moving vanes be joined respectively to the terminals of any dynamo, the fixed and moving members become oppositely charged. There is therefore a tendency for the moving vanes to enter the interstices between the fixed vanes, thus rotating the pivot and carrying the needle across the scale.

The pivot is, of course, arranged to offer very little frictional resistance.

In some cases the pivot is horizontal and the vanes set in a vertical plane. Here we should have the moving vane balanced on knife-edges and revolving thereon against the attraction of gravity. This type, having but two fixed vanes embracing a single moving one, is generally used for high voltages of the order of 10,000 volts or more.

To measure smaller voltages ranging from 40 to 1,600 volts it is necessary to multiply the attractive force by using many fixed and many moving vanes. In this type, called the "multi-cellular" voltmeter, we generally have a vertical pivot, the twisting effect being controlled by a torsion spring.

In both types a damping arrangement will be found, consisting either of a light friction clutch which can be applied to the moving member by hand, or else of an oil dash-pot, the idea being in both cases to reduce the oscillation of the instrument and render it "dead-beat."

Wattmeters.

To get an accurate measure of the true power being expended in an A.C. circuit we have seen that we cannot multiply the volts and ampères together unless the current and E.M.F. be in phase with each other. Since this state of affairs seldom exists in practice it becomes necessary either to measure the angle of lag and so to calculate the power factor, or else to measure the true watts direct, from which we may then deduce the power factor.

"Power factor indicators" are made, but are in general suitable for but one particular frequency, so that a good wattmeter is far more useful for practical experimental work.

The simplest form of wattmetter resembles the dynamometer form of ammeter and voltmeter. In those instruments we had the fixed and moving coils in series. In the wattmeter, however, we have the moving coil wound of many turns of fine wire and joined across the mains as if it were a moving coil voltmeter, while the fixed coil, wound of thicker wire, carries the main current. The moving coil may be mounted on a fixed jewelled pivot, its motion being controlled by two spiral springs, which serve to feed the small current to the moving coil.

As in the dynamometer voltmeter it is important the resistance of the moving coil should be large compared with its inductance, otherwise the current therein will lag on the voltage, and it is the effect of the voltage that we wish to represent by the current in this coil; further, this error, if any, would increase with the frequency.

In order to effect this it is the practice to insert a large non-inductive resistance in series with the moving coil.

The reader has probably noticed that a wattmeter is essentially a combination of a volt and an ammeter.

The high resistance winding represents the voltmeter part, and the low resistance coil corresponds to the ammeter part. Four terminals are frequently provided, one pair to each winding; in some cases, however, there are only three terminals (one small, and two large), one of them corresponding to the junction of the two windings (Fig. 80 shows one with three terminals).

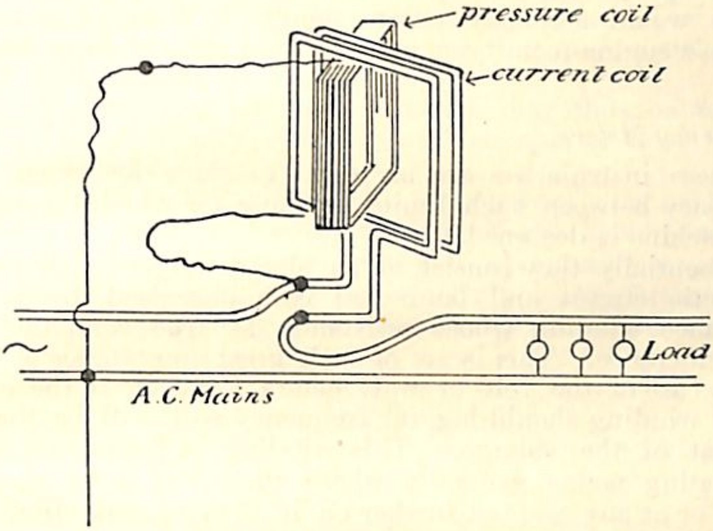


FIG. 80.

The high-resistance winding is often spoken of as the "pressure coil," and the low-resistance one as the "current coil," of the instrument. As in the case of voltmeters, the high resistance winding is not contained all on one coil, by far the larger portion of it being a separate non-inductive fixed resistance coil.

The action of the instrument is as follows:—

The thick wire, or current coil, is fixed and produces a field proportional to the current whether that current be in phase with the E.M.F. or not. In this field is placed the pressure coil which carries a current, and therefore produces a field, proportional to the P.D. at its terminals.

The two coils, each producing a field, tend to set themselves so that each embraces as many as possible of the other lines of force. Since one cannot move, the other does, and for any given relative position of the two coils, the torque on the movable coil is proportional to the product of the current and P.D. at that instant—that is, to the instantaneous power. If the power fluctuates rapidly as in alternating currents, the mean torque acting on the moving coil represents the mean true power, which is what we are trying to measure.

The instrument may be made to read directly in watts, or the moving coil may be brought back to its zero positions by means of a handle whose revolution puts tension on a torsion spring.

This type of wattmeter will read steady current power as well as alternating, but if an instrument be required for the latter, care must be taken to see that its case and internal fittings, excusive of the coils themselves, are not made of metal. The cases are made of mahogany and ebonite, the reason being that eddy-currents set up in the metal would produce fields which would seriously vitiate results. Wattmeters (except Kelvin's engine-room type) must be kept clear of stray magnetic fields.

Frequency Meters.

These instruments are arranged to show the variations in frequency between such limits as those for which the speed of the machine is designed.

Essentially they consist of an electro-magnet with an open magnetic circuit and laminated core energised by a high-resistance winding whose resistance is large compared with its inductance. This is not of such great importance as it was in the case of the volt- or watt-meters, for even if the current in the winding should lag, its frequency will still be the same as that of the voltage. This winding is joined across the alternating mains generally where they first enter the W.T. office, or at any rate not further on in the charging circuit than just bejond the cut-outs.

The core of this magnet becomes magnetised twice every cycle and these magnetic pulls are felt by every one of a row of small steel tongues.

These latter are fixed at their inner ends and free to vibrate in a vertical direction at their other ends, each tongue having been "tuned" like a tuning fork, to vibrate at such a frequency as is marked against it.

The particular frequency at which any tongue will oscillate depends on its mass and springiness (*see* p. 51).

Since all the tongues are pulled equally, one of them will find itself pulled at intervals corresponding to its own time period. It will therefore oscillate violently, so much so that its end, which is turned up and painted white, appears, not as a white dot, but as a grey band against the black interior of the instrument.

It should be noted that if the instrument shows a complete octave of frequencies—that is, if it run from, say, 50 to 100 inclusive—we shall find both of these extreme numbers vibrating when the real frequency is really one or the other. This is because the one which does not represent the real frequency finds itself pulled either twice too often or else once in every two swings, but the pulls will coincide more with its period than with the periods of the others except the one which shows the real frequency.

Some of the older meters in the Service are fitted with two D.C. terminals at the top, the bottom ones being for A.C.

The D.C. terminals carry direct current round another winding on the same magnet core, which has the effect of causing the core to pull all the tongues equally, with a steady strain, until the A.C. is applied.

When the alternating magnetism is superimposed upon the steady magnetism, its effect is merely to strengthen and weaken the latter at regular intervals of time. Accordingly the pull on the reeds never falls to zero, but gives a strong pull to the reeds *once* in every cycle.

Their rate of mechanical vibration may thus be adjusted truly to that frequency which is marked against them, instead of to twice that frequency.

Another advantage of the "non-reversing" flux is that less energy is expended in heating the iron, due to hysteresis.

All new frequency meters have a permanently magnetised core, in order to avoid the D.C. supply. The latter, if left switched on for a long time, causes the instrument to get unduly hot.

CHAPTER VIII.

Production of Alternating Currents.

We have seen that the elementary alternating dynamo works on the same principles as does the direct current machine, the only difference being that slip-rings take the place of the commutator. Any direct-current dynamo, if fitted with slip-rings having suitable connections made to the armature windings, may be made to give an alternating current instead of, and even as well as, a direct current. This latter can be effected by placing the slip-rings on the armature shaft preferably at the end remote from the commutator.

This method of generating alternating current for the use of wireless sets in ships is not convenient; for one thing, it would mean that all the dynamos in the ship would have to be fitted, and further, the voltage of the alternating mains would never exceed that of the ship's direct current mains, being therefore unsuitable for high-power sets.

For the latter purpose electrically driven alternating dynamos or "alternators" are in common use. The whole machine comprising a D.C. motor driving an A.C. dynamo is called a "motor alternator," as opposed to an alternator driven by steam, water, or other "prime mover." We have already seen that the frequency of an alternating current depends on the number of pairs of poles in the field of the machine and upon the speed at which the armature revolves.

It is therefore necessary that the D.C. motor driving an A.C. dynamo should revolve at a constant speed under all conditions. A shunt motor (with slight modifications) can be relied upon to give a constant speed at all loads, whereas a series motor will race when the load is taken off and slow up when it is applied.

The load in a wireless set is applied to the alternator, but when the alternator is giving out current it becomes more difficult for the driving force to twist the armature round. As far as the motor is concerned, the load might be the task of lifting projectiles or doing any other mechanical work, but the nature of the load is an important consideration.

The load is applied and removed by means of the operator's signalling key. Its application is very sudden, as also is its removal. While on, the load is great, too great for the machine to supply continuously without overheating.

Both the A.C. dynamo and the D.C. motor which drives it are subjected to a succession of temporary overloads.

In such a set as above described, the alternator may be designed to give, within wide limits, any voltage or frequency required, while the alternating mains would be entirely separate and distinct from the ship's D.C. supply, the only part played by direct current being the energising or "excitation" of the field magnets between whose poles the A.C. armature revolves.

It will be remembered that in the case of the elementary dynamo we assumed the presence of these poles, and that their polarity was not changed from instant to instant. Alternating current cannot be used for their excitation, so that we must either use permanent magnets of steel or else electro-magnets whose coils carry direct current from some other source.

In commercial alternating current generating stations separate direct-current dynamos are generally installed whose sole duty is the provision of a suitable strength of field for the large machines; this method is used in the Naval high-power stations. Sometimes the shaft of the alternator itself drives a small self-exciting shunt dynamo providing current for this purpose. In either case the D.C. machine is called the "exciter."

This exciter is, of course, not necessary in ships, where plenty of D.C. supply is available, but, since we do not require the field of the alternator excited unless the motor be revolving the armature, the direct current is switched on to the field of the alternator only when the motor is started up; suitable connections are made on the starter of the motor to effect this purpose.

It will be seen that the motor alternator might be correctly described as a "rotary converter." because it converts, by rotation, direct into alternating current, but this word is generally restricted to another type of machine in which the motor and alternator are combined.

In a "rotary converter" one set of field magnets and one armature suffice for both duties, the armature having a commutator at one end and slip-rings at the other end of its shaft.

Such a machine possesses the undoubted advantages of small size, lightness, and cheapness over the motor alternator; but its alternating voltage has a maximum value which never exceeds that of the ship's mains, a fact which would make an enormous current necessary for a high-power set.

Again, the slip-rings are not insulated from the direct current mains of ship.

Due to this last imperfection, it is possible, by a combination of unfortunate and unlikely circumstances, to get direct current through the primary of the transformer. In this event the back E.M.F. of the transformer would be zero and a burn-out might ensue.

This is not a very important consideration, for the likelihood of the occurrence is very remote, but an inconvenience arises when the machine is stopped owing to the armature being in connection with one of the D.C. mains. This has the effect of allowing both A.C. mains to be "alive" with direct current, although they will both be at the same potential.

If any repairs have to be effected to the A.C. circuit, even with the rotary stopped, it will be well to disconnect both alternating mains between the place of repair and the machine, or to take the machine off the D.C. switchboard. This precaution is not necessary where a motor alternator is fitted, unless it be running.

Now as to the principles of construction and action of the machines.

The reader will do well to read Chapter VI. of the Torpedo Manual, Vol. I, if he have no knowledge of the action of an ordinary D.C. dynamo. To sum up the matter therein contained, we may say that all machines for generating current by means of the inductive action between a coil and a magnet depend for their action upon the relative motion of the two. There may be a single coil of wire moving past a single magnet pole, or there may be many coils of wire and several magnets. In ordinary direct-current machines, the coils, called the armature windings, are driven across the pole face of the magnet, but this is on account of the necessity of using a commutator.

When alternating currents are to be generated and no commutator necessary, the same method may be employed or else the magnets may be moved so that their pole faces sweep across the edge or face of the coil or coils. Provided that a relative motion is given, so that the magnetism cuts across the turns of the coil, it does not matter which part has motion; both coil and magnet may be made to move in opposite directions if a convenient practical construction be thus attained. The essential condition is that the amount of magnetism embraced by the coil should be a continually varying quantity.

The voltage generated will invariably depend upon the number of magnetic lines of force cut per second, or (in other words) the rate at which the flux embraced by the armature coils varies. It therefore follows that:—

(1) The more turns of wire on the coil or armature the greater will be the voltage, and *vice versâ*.

(2) The higher the speed of the moving part the greater the voltage, and *vice versâ*.

(3) The stronger the magnetic field the higher the voltage, and *vice versâ*.

Now in any motor alternator we shall have an alternator having an armature of a definite number of turns and a field magnet of a definite number of poles. The speed of the moving part and the strength of the field may be made variable by means of suitable field regulators.

Resistance put into the field of the *motor* will cause it to speed up and drive the dynamo faster.

Resistance *taken out* of the field of the alternator will provide a stronger magnetic field for the alternator.

An increase of speed will have two effects. It will increase the alternating voltage and also the frequency. An increase of the strength of field of the alternator will, on the other hand, cause an increase of the alternating volts alone, without affecting the frequency.

In order to increase the density of the magnetic flux which is to be cut by the coils of the armature, the armature itself is built up on a soft iron laminated core, a practice which is common to direct and alternating current dynamos.

Whichever part of the machine is moving will require slip-rings and brushes bearing thereon in order to enable the direct current to energise the field if the latter be moving or else to allow the alternating current to reach the outside circuit if the armature be moving.

In order to avoid confusion as to which is the armature and which the field magnet, the moving part is called the "rotor" and the stationary part the "stator" both in alternators and A.C. motors. It will be seen that direct-current dynamos have stator field magnets and rotor armatures.

Simple types of alternators are shown in Fig. 81. Here the field is assumed to consist of a permanent magnet.

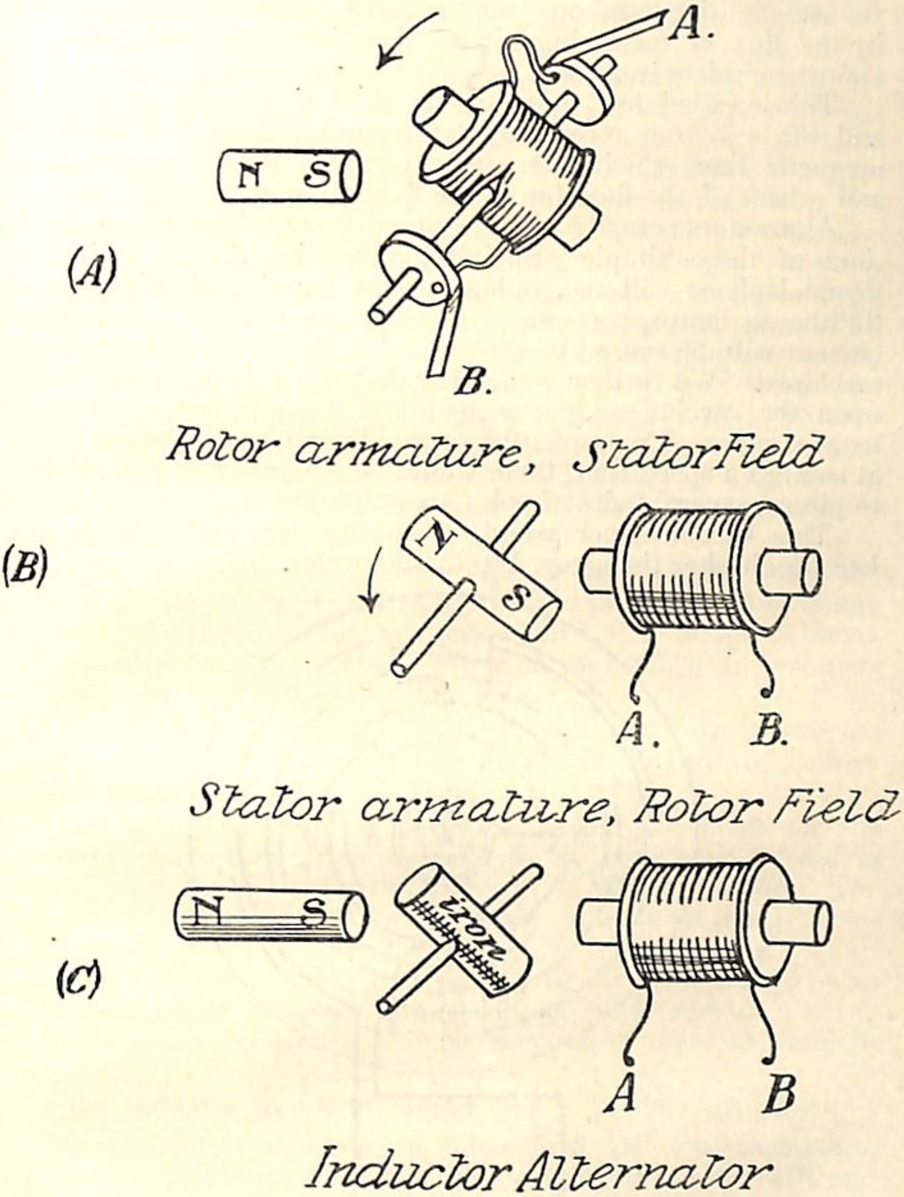


Fig. 81.

Notice that all slip-rings are insulated from the shaft and from each other.

In Fig. 81 (*a*) and (*b*) we have the ordinary type of alternator, in (*c*) it is seen that both armature and field are stationary, being "stator" in form. The rotor consists of a piece of soft iron with pole pieces, the bar of iron coming into line with both magnet and armature twice every revolution. The "Mordey" alternator is of this type, and it is seen that no slip-rings or correcting arrangements of any kind are necessary. Its action depends on the relative difficulty experienced by the flux of traversing air to that felt when traversing an almost complete iron path.

This is called the "inductor" method of generating currents, and the soft iron rotor may be regarded as a "carrier" of magnetic lines which alternately furnishes the armature with, and robs it of, the flux due to the field magnet.

Alternators actually used in practice are, of course, elaborations of these simple principles, and, with the exception of toys, telephone call-ups, and machines for the illumination of lighthouse lamps, permanent magnets are not used, but direct current will be caused to flow round coils as in direct-current machines. We further remember that the frequency depended upon the revolutions per second and the number of pairs of magnet poles. Consequently, to avoid running large machines at so high a speed that there would be a danger of their flying to pieces, several pairs of poles are employed.

This becomes increasingly necessary when the frequency becomes higher than, say, 100 to 150 cycles.

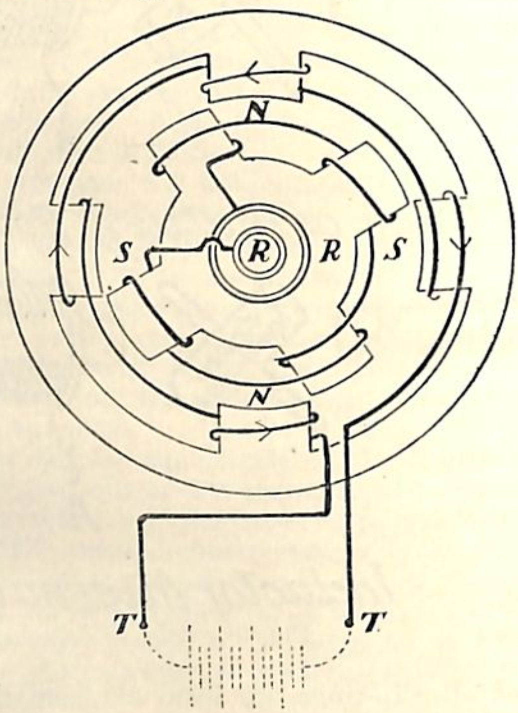


Fig. 82.

Fig. 82 is a diagram showing the arrangement of magnets and coils in a simple alternator. Instead of a single bar magnet, two horse-shoe pattern electro magnets are combined to form a four-pole stator field magnet. The poles are spaced alternately north and south as indicated by the letters N S. These poles are covered with suitable coils joined in series with each other and the terminals TT are connected to those of a continuous current exciter or battery.

For the rotor armature four coils are wound upon an iron core, which is provided with projections to receive this winding, the ends of which are connected to two slip-rings RR. Brushes of carbon or copper gauze rub upon these rings and collect the current. The flow of magnetism is as shown in Fig. 64, p. 80, Torpedo Manual, Vol. I. The principle is simply an extension of the arrangement shown in Fig. 31 (*a*). As the coils are symmetrically disposed upon the core, the armature is in balance and can be rotated without setting up vibration. The four coils can be connected up as shown in the diagram to add their voltages together, and thus produce four times the voltage of a single coil. They may be connected all in parallel to give the same voltage as one coil with four times the flow of current, or, again, we might have two in parallel and two in series, giving half the voltage and twice the current given by the first arrangement.

When the coils are exactly opposite the magnet poles the rate of change of flux penetrating the coil is zero, so the voltage is zero. In this position we may regard the voltage induced in one edge (say, the leading edge of the coil) to be counterbalanced by that induced in the other edge.

When the coils are midway between the pole pieces the rate of change of flux is at a maximum and the induced voltage is at a maximum.

One complete cycle is performed when the poles on the armature have been from one pole to its next *similar* pole in order, say from poles N, past poles S, to poles N again. The frequency here will be twice as great as if a single pair of poles and a single armature coil were used.

The number of coils and poles will be arranged so as to meet the speed, frequency and voltage requirements. Large slow-speed machines may have as many as 72 poles in the field magnet.

The inductor type is no longer used in modern machines.

In Fig. 82, representing a stator field and rotor armature, the reader will notice that by interchanging the letters RR and TT the machine becomes one having stator armature and rotor field, by far the commoner type in large machines.

This conversion from one to the other must never be attempted in practice, for although the windings are correct either way as regards direction yet their relative resistances and ampère turns are different. The armature, being of low resistance wire, will burn out if coupled up to the exciter in the event of its being used as a field.

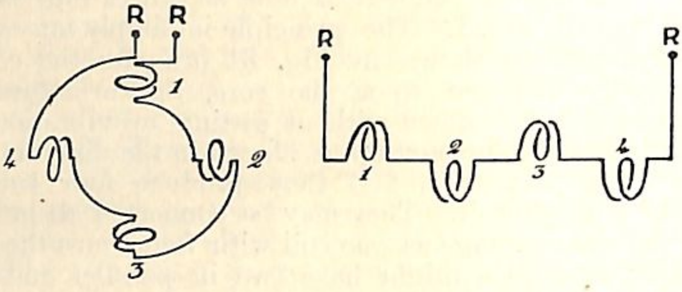
The armature winding of the machine as shown in Fig. 82 and as subsequently discussed, may be represented diagrammatically as in Fig. 83 (*a*), (*b*), (*c*).

Windings are shown in their proper position and also laid out between the terminals RR.

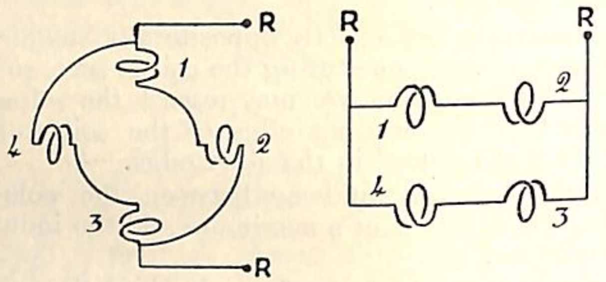
(*a*) All in series, high voltage, small current.

(*b*) Two in parallel and two in series, medium voltage and current.

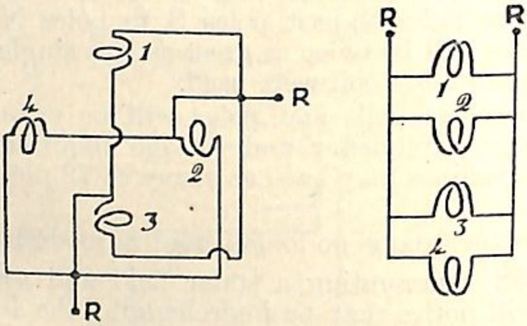
(*c*) All four in parallel, low voltage, large current.



(*a*).



(*b*).



(*c*).

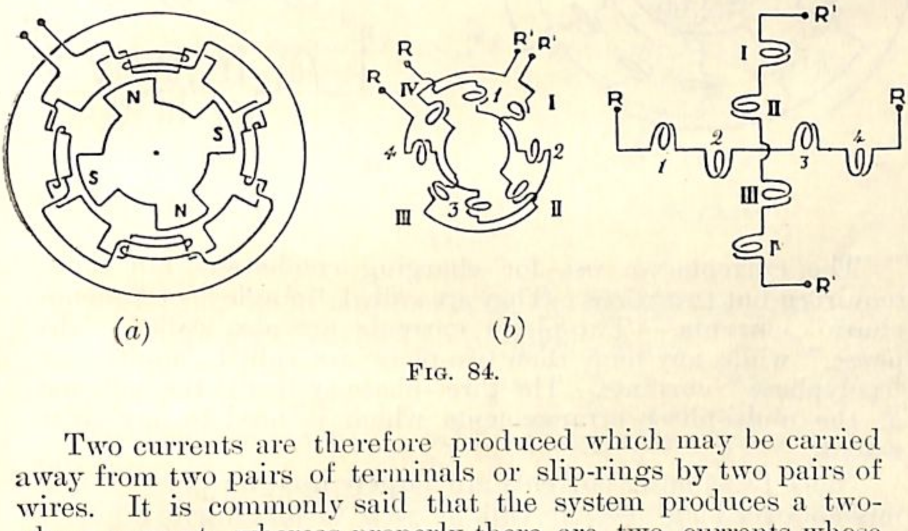
Fig. 83

Whatever the type of machine used the field magnets will always consist of an even number of pole pieces, alternately north and south, symmetrically disposed round the periphery of the circle. If a field be the stator, the poles project inwards; if rotor, they project outwards. In the latter case the field forms a flywheel for the engine; indeed, the rim of the engine flywheel actually is the bed or "yoke" on which the magnet poles are mounted. This is the invariable practice in all large modern alternators. The poles are fixed at intervals round the rim, the spaces being about the same width as the poles themselves.

The armature, whether stator or rotor, is usually "tunnel wound"—that is, the conductors are pushed through holes in the iron, not dropped into slots therein. By burying the conductor within the substance of the armature stampings, eddy currents and certain other harmful armature reactions are minimised.

In the machine shown in Fig. 82, we see that there are as many armature coils as there are field coils, and that they are wound alternately right- and left-handed.

We see, further, that there are spaces between the armature coils which are inoperative. Suppose an entirely separate armature winding introduced so as to occupy these spaces. At its terminals we should have another alternating current exactly like the old one, but differing from it in phase by 90°. When the old winding gives maximum volts, the new one gives zero pressure.



(a) (b)

FIG. 84.

Two currents are therefore produced which may be carried away from two pairs of terminals or slip-rings by two pairs of wires. It is commonly said that the system produces a two-phase current, whereas properly there are two currents whose phases differ by 90°, a state of affairs which is called being "in quadrature."

Fig. 84 represents a four-pole two-phase machine (*a*) showing the arrangement of pole pieces, one armature winding being omitted for clearness, and (*b*) the diagrammatic representation. The coils may be connected in series or parallel as before, provided we do the same to each set of windings.

Notice that the practice of connecting coils in series or parallel corresponds with that of having a "wave" or "lap" wound armature in D.C. practice.

By extending this principle still further, placing two intermediate coils between each of the old coils, we may obtain three separate alternating currents, 120° out of phase with each other, provided that no two adjacent coils are wound in the same direction. Every third coil connected up forms one circuit. The three circuits may send off energy by means of three pairs of leads (six wires). *See* Fig. 85 (*a*).

This is called a "three-phase" current, and an armature generating such a current is shown diagrammatically in Fig. 85 (*b*).

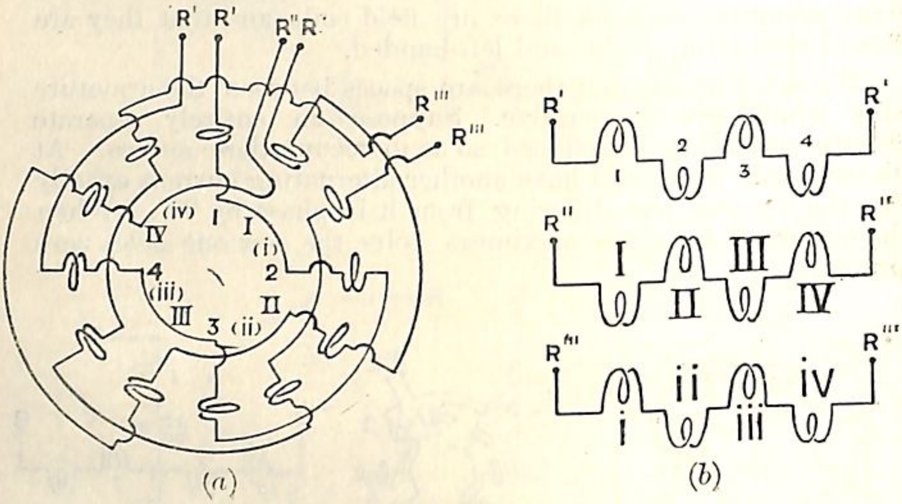


Fig. 85.

The currents we use for charging condensers are those requiring but two wires. They are called "single" or "monophase" currents. Two-phase currents are also called "diphase," while any more than two-phase are called "multi" or "polyphase" currents. The three-phase system is the only one of the multi-phase arrangements which is used to any great extent.

Since these latter currents are largely used for power transmission over long lines, it will be well to investigate a few of their peculiar properties.

Any direct-current dynamo may be made to produce any kind of alternating current, by connecting slip-rings to suitable points on the armature.

Take a two-pole machine.

A single-phase current may be obtained by connecting two opposite points on the armature (180° apart) to each of the two slip-rings.

A two-phase current will be generated if we take four points 90° apart on the armature and connect opposite pairs to each of two pairs of slip-rings.

A three-phase current will flow if we take three points 120° apart, connecting them to one each of three slip-rings.

A single-phase alternator may be represented thus :—

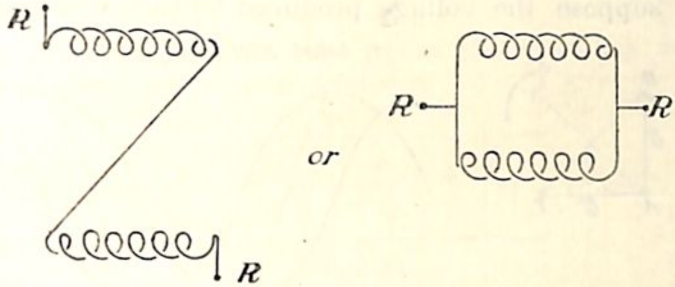
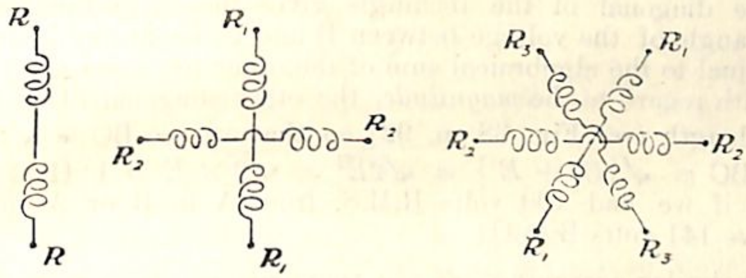


Fig. 86.

according as we have the coils in series or parallel. Diagrams will be simplified if we take series arrangements only. Thus we have :—



Single Phase. Two Phase. Three Phase.

Fig. 87.

Under present arrangements for the outside circuit :—

A single-phase current requires 2 wires.
A two-phase ,, ,, 4 ,,
A three-phase ,, ,, 6 ,,

The common practice is to use three wires only for the last two cases.

A two-phase machine has a common terminal for one end of both windings. We have then (Fig. 88) two thin wires and one thick one. The latter forms the common return.

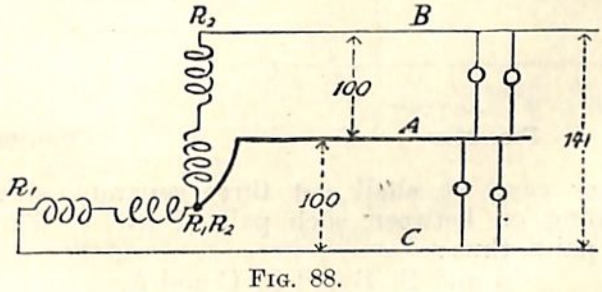


Fig. 88.

If we call the thick wire A and the others B and C, we have a single-phase current in A and B, and another single-phase current in A and C in quadrature with the first.

Now suppose the voltage produced by each winding $= E$,

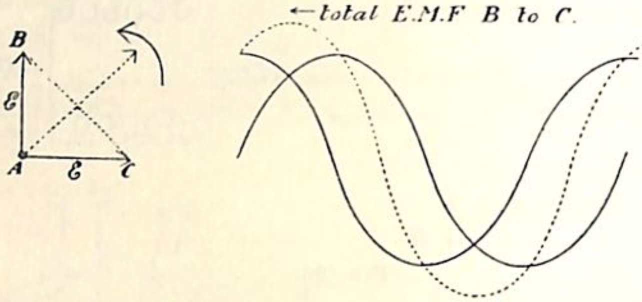


FIG. 89.

we have a vector diagram showing a voltage E (R.M.S.) across AC and AB. What voltage have we across BC?

The diagonal of the rectangle gives the magnitude and phase angle of the voltage between B and C, for at any instant it is equal to the algebraical sum of the other two voltages.

With regard to the *magnitude*, the other diagonal BC is the same length (*see* Fig. 38, p. 92), so that we see BC $= \sqrt{2}E$, for BC $= \sqrt{\{E^2 + E^2\}} = \sqrt{2E^2} = \sqrt{2} \times E = 1{\cdot}41 \times E$. Hence if we had 100 volts R.M.S. from A to B or A to C, we have 141 volts B to C.

By similar reasoning we see that current in A $= \sqrt{2} \times$ currents in B or C, so that A is made of thicker wire.

Coming now to three-phase machines, we wish to avoid having six wires, so can connect up either as in Fig. 90 (*a*) or (*b*).

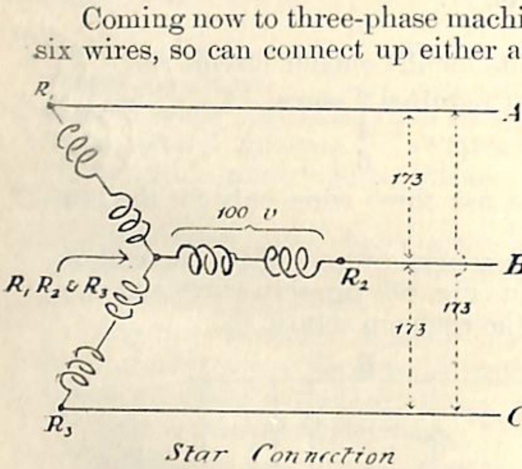


FIG. 90*a*.

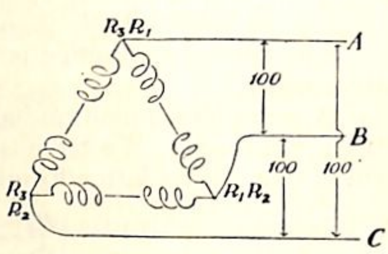


FIG. 90*b*.

In either case we shall get three separate single-phase currents going on between each pair of wires. Three wires form three pairs, thus:—

A and B, B and C, C and A.

Whichever way we connect up the windings the voltages in all three pairs will have the same R.M.S. values, and all wires will be the same thickness for they carry the same current. Each wire in turn becomes the common return for the other two.

Loads should be connected up as shown in Fig. 91, so that all three phases are equally loaded.

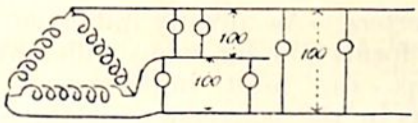


Fig. 91.

If the star system be used we sometimes (but not necessarily) have a fourth wire led to the point of junction, as in Fig. 92.

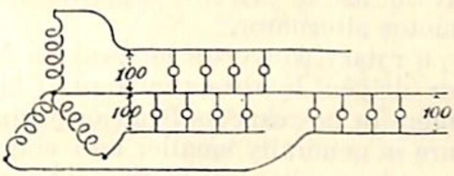


Fig. 92.

Now regarding the voltages, we have :—

Mesh System.—Pressure between any pair of leads = pressure produced by any winding.

Star System.—Pressure between any pair = $\sqrt{3}\times$ pressure produced by any winding, unless circuit in Fig. 92 be used.

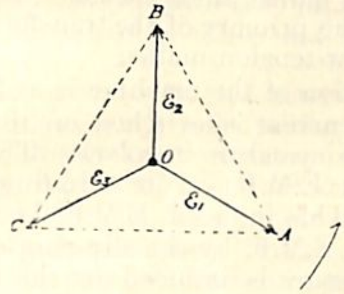


Fig. 93.

If OA, OB, OC (Fig. 93) all = E, pressure at ends of any winding, AB = BC = CA = $\sqrt{3}\times E$.

Now $\sqrt{3} = 1\cdot732$.

So that if we had the circuit in Fig. 90 (a), we should have 173 volts between the "phases" if each winding gave 100 volts.

By a similar reasoning for currents we have :—

Star System.—Current in mains = current in any one winding.

Mesh System.—Current in mains = 1·73 times that in any one winding, for the current divides in the armature.

The *Star* system gives a high voltage and small current.

The *Mesh* system gives a low voltage and large current.

Rotary Converters.—As already indicated, rotary converters may be of many forms and for many different purposes. Commercially perhaps the most important application of these machines consists in the conversion of three-phase alternating current, which has come at high voltage over long-distance transmission lines, into direct current for use at or near the place where the converter is situated. In wireless telegraphy as installed in ships, however, we are merely concerned with machines designed to convert a direct into an alternating current without the use of the two separate machines which are required in a motor alternator.

Essentially, a rotary convertor as used for W.T. consists of a four-pole motor driven by direct current. The motor is shunt wound, and differs in no respects from an ordinary motor except that its armature is generally smaller and shorter than that of a motor doing merely mechanical work. The cores of the field poles also are smaller and the commutator larger.

Attached to two points 90° apart on the armature are two conductors, which are connected one to each of two slip-rings mounted on the shaft of the armature at the end remote from the commutator. The two slip-rings are, of course, insulated from each other and from the shaft. On the slip-rings bear brushes made of soft carbon or, in the older-pattern machines, of copper or brass gauze, these brushes being connected to the leads supplying the primary of the transformer, commonly called the alternating low-tension mains.

Briefly the action of the machine is as follows :—

When direct current is switched on to the motor the field is energised and the armature revolves. The revolving armature generates a back E.M.F. in its windings which opposes the applied E.M.F. This induced E.M.F. is tapped off as a single-phase alternating E.M.F. by the slip-ring connections.

Whatever pressure is induced in the armature owing to its dynamo action is bound to be alternating, from the elementary theory of the dynamo. At the commutator end we convert it into a direct E.M.F., which opposes the direct E.M.F. applied to the motor, while at the slip-ring end we have it plain and uncommutated as an alternating single-phase E.M.F.

Notice that the two connections for the slip-rings are made to two points on the armature which are 90 actual degrees apart, but which, since the machine has four poles, are really 180 electrical degrees apart (*see* p. 83).

Though not quite theoretically true, it is very convenient to consider the alternating E.M.F. to be actually the counter E.M.F. of the motor tapped off in an alternating way.

The reader is probably ready by now to accept the statement that the E.M.F. will be alternating, and further, that its maximum value can never exceed the voltage of the ship's D.C. mains, but it will be well to investigate more thoroughly the actions which take place in the armature and which are produced at the slip-ring terminals.

Take a two-pole motor and assume its field magnets to be energised with direct current. Neglecting the shifting of the brushes necessary to give the "angle of trail" (*see* p. 139, Torpedo Manual, Vol. I.) we see that the brushes would be midway between the pole pieces so as to be on the "neutral line."

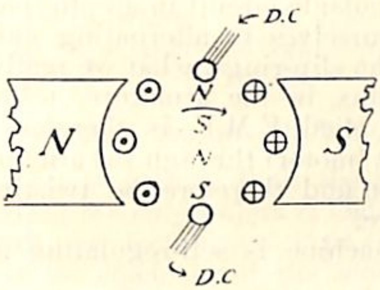


Fig. 94

A simple armature winding is shown in Fig. 94.

The D.C. entering the armature at the upper brush there divides, flowing in the armature circuit so that it enters the paper (shown by a cross) in all the right-hand conductors, and emerges from the paper (shown by a dot) in all the conductors on the left. Finally the currents unite and leave the armature by the lower brush.

The effect of the current is to cause the armature to become magnetised with a north pole at the top and a south at the bottom. The mutual attraction between unlike and repulsion between like poles causes the armature to revolve in a clockwise direction. In the effort to satisfy these mutual attractions and repulsions the armature moves round a little, but in doing so brings a fresh pair of commutator strips under the brushes, the effect being that the magnetism of the armature is shifted back into its old position and the attractions are still unsatisfied. It is due to this continual slight movement and immediate shifting back of the magnetism of the armature that the machine manages to retain its continuous rotary motion. The action may be likened to that of an animal running after its own tail.

Now, remembering that the armature is revolving over to the right, we may consider it as a dynamo.

Since we have a properly wound armature revolving in a magnetic field we may apply "Fleming's rule" to find the direction of the currents induced by this action. (*See* p. 73, Torpedo Manual.)

We see at once that those in the right-hand armature bars are "out of" while those in the left-hand ones are "into" the paper, the exact opposite of the currents causing revolution. These currents are of course the result of the back or counter E.M.F. of the motor and do not normally flow in the outside circuit, the only effect of the back E.M.F. being to reduce the strength of the current supplied to the motor. Their effect will be to cause south polarity at the top, and north at the bottom of the armature (shown dotted), weakening the effect of the original flux.

Now these induced "dynamo" currents can be caused to flow in another outside circuit in an alternating way.

If we help ourselves to alternating current by applying a "load" across the slip-rings, what we really do is to strengthen this secondary flux in the armature, robbing it of some back E.M.F. The applied E.M.F. is therefore enabled to urge a stronger current (motor) through the armature, thus bringing up its magnetisation and therefore the twisting effort to the same amount as before.

Hence the machine is self-regulating and acts rather like a transformer.

When no alternating current is flowing the back E.M.F. is very nearly equal to the applied E.M.F., and very little direct current is taken. When, however, alternating current flows, the back E.M.F. drops and the applied direct current gets stronger, the motor revolving at the same speed as before.

Now regarding the voltage of the alternating current.

Firstly it is clear that (in a two-pole machine) the two connections to the slip-rings must be at points opposite to one another on the armature (*see* p. 174), and since the brushes on the commutator end are also at opposite points there will come an instant twice in every complete revolution when the armature bars to which the slip-rings are connected are immediately connected, through the commutator brushes, with the ship's mains.

At these instants the alternating E.M.F. will be at its maximum value, which will be that of the ship's direct E.M.F., in one direction or the other. Hence we see that the maximum value of the alternating E.M.F. can *never*, whatever the speed of revolution, exceed that of the ship's D.C. mains.

In other words, a rotary running on 100 volts direct generates an R.M.S. alternating voltage of 70 volts, neglecting ohmic losses in the armature and assuming the E.M.F. to be of the true sine wave.

We must remember if the speed of the machine be doubled the armature does not cut more lines of force per second, because the increase of speed is obtained by weakening the field (inserting resistance therein) to half its previous strength.

Consequently, though we may vary the frequency we cannot vary the voltage in the alternating mains.

It has been said that the R.M.S. voltage at the slip-ring terminals will be but 70 per cent. of the applied direct pressure, but this will be more like 65 or 60 per cent. in actual practice, owing not only to the ohmic drop due to the brush and armature resistances, but also owing to the reactive drop due to the inductance of the iron-cored armature. To this reactance of the armature we shall return later.

Now if there were no losses in the machine the alternating output would equal the direct current input (in watts).

Assume, for the sake of argument, such a perfectly efficient machine running at 15 ampères on 100 volts direct. The input is 1,500 watts or 1·5 kilo-watts. The alternating volts are 70 R.M.S., so that 70 × R.M.S. current = output in watts = input = 1,500.

The alternating current has an R.M.S. value = $\frac{1,500}{70}$ = 21·43 ampères. This is greater than the direct current, a result which at first sight seems peculiar. The excess of output current over input will not be quite so marked as is shown in this example, owing to the efficiency of the machine not being 100 per cent., but it is at any rate a factor which may have to be taken into account.

As has been indicated, the armature reactions are really very complicated owing to the machine doing the double duty of motor and generator. To discuss fully the phenomena taking place will not be possible in this book, but certain reactions are important and must be investigated.

Keeping the same distinctions as were drawn above between the motor current and the alternating dynamo current in the armature, we will consider three cases.

(1) When the alternating current and E.M.F. are in phase.

(2) When the alternating current lags behind its E.M.F.

(3) When it leads on its E.M.F.

Under any conditions we will assume that the strength of the flux in the armature due to dynamo current is, at any instant, proportional to the alternating current at that instant.

(1) When the current and E.M.F. are in phase with each other we shall have the armature flux due to that current following exactly the same variations as the voltage. It will be at a maximum when the voltage is at a maximum, and so on. The magnetisation or flux in the armature will of course shift about and vary in strength as the armature revolves, but it may be considered to take up a mean position nearly equivalent to its position when at its maximum strength.

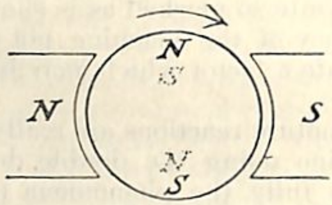
This is obviously in the "up and down" position, as shown in the dotted lines in Fig. 95 (*a*).

These induced poles may be considered to act either as those induced in an ordinary dynamo, where the polarity of the armature is always in such a direction as to tend to oppose motion, or we may consider them as weakening, by cancelling out some of the strength of the poles caused by the motor current, thus robbing the armature of some of its torque.

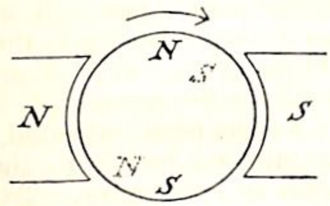
In either case, when alternating current flows it becomes more difficult for the armature to revolve, so that its speed momentarily tends to drop, its back E.M.F. drops, and more motor current flows so as to restore the lost torque to its original value.

The chief thing to notice is that the "dynamo" polarity of the armature consists of poles which are equidistant from the pole pieces of the field magnets, so that they can (unless the field be distorted) in no wise alter the strength of the latter. The speed of the machine will remain unaltered when alternating current is taken from it, *provided* that the current be in phase with the E.M.F.

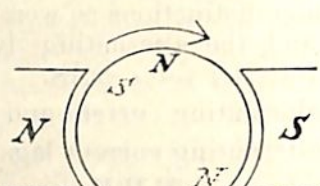
(2) Now in the case where the current lags behind the E.M.F., we still have the armature motor polarity in the same place, as shown by the full lines in the last figure (*see* Fig. 95 (*a*).



(*a*) *In Phase.*



(*b*) *Current Lagging.*



(*c*) *Current Leading.*

FIG. 95.

The alternating current, however, will not reach its maximum value till after the E.M.F. has passed through its maximum value and has begun to decrease. Hence, the mean position of the dynamo polarity in the armature will not be in that occupied by the maximum voltage as in the last case, but will be further on in the direction of revolution as shown in the dotted lines in Fig. 95 (*b*). Notice that this is caused by the armature moving round a little while the current is "making up its mind" to increase to its maximum value.

Now the effect of this shifting of the magnetism forward is two-fold. Although the current in the alternating mains may be made to be of the same strength as before (when it was in phase), so that the apparent watts are not diminished, yet the weakening effect of the dotted dynamo poles on the firm-line motor poles is now *not so great*. Hence the back E.M.F. will not fall to so low a value, the D.C. will increase by a less amount, and the *true* watts applied to the motor will not be so great as when that current was in phase with the E.M.F.

This might be, and possibly may be, made a very convenient method of reducing the power for transmitting over short distances, if it were not for another effect of this lagging current.

It is seen that the dotted dynamo poles are now nearer to one side than to the other. They will therefore have a reactive effect upon the strength of the field magnets. The south pole of the field will be weakened by the close proximity of the south dotted pole more than it is strengthened by the less close proximity of the north dotted pole. The same remarks apply to the north field magnet pole.

Since the field is weakened the motor speeds up. (*See* p. 137, Torpedo Manual.)

(3) When the current leads on the E.M.F. the opposite effect obtains. The poles due to the dynamo current have a mean position which occurs earlier in the revolution, the dotted poles taking up some such position as shown in Fig. 95 (*c*). The effect of this is that the field pole N is strengthened by the adjacent S (dotted) pole of the armature, while the field pole S is strengthened by the adjacent N armature pole. This has as its result the slowing down of the armature.

As results then, we have :—

A current in phase with the E.M.F. will not cause any appreciable alteration in the speed of the machine.

A lagging current causes the rotary to speed up, while a leading current causes it to slow down.

Under certain conditions this surging effect may be very marked and result in serious sparking at the commutator; so that, apart from the point of view of avoiding a wattless current, it becomes advisable to get the current and E.M.F. in phase with each other to reduce the surging of speed.

Note that this effect does not occur in a motor alternator, for the motor revolves the alternator armature "blindly," being ignorant (as it were) of whether the alternating current is in phase with the E.M.F. or not.

As a general rule a current which lags or leads but slightly will cause worse surging than one which differs in phase from the E.M.F. by a very considerable extent. For this reason :—

A current will not lag *very much* unless the reactance be large compared with the resistance of the circuit. If the reactance be large, the current will thereby be cut down to a small value. Hence the magnetising effect of the dynamo current in the armature will be small. Consequently, although the dynamo magnetism in the armature is shifted round by a very considerable angle, yet its strengthening or weakening effect on the field magnets will be inconsiderable.

If, on the other hand, the reactance be not very great, but still perceptible, the current will still be fairly strong and consequently the armature dynamo flux will be shifted, albeit by a slight amount, yet will be shifted round enough, and will be strong enough, to alter the strength of the field magnets to a considerable extent, and so cause an alteration of speed which may become harmful.

This may throw light on what would at first sight appear a contradictory state of affairs.

Suppose the rotary to speed up slightly every time the key is pressed. This shows a lagging current and we reduce the inductance in the circuit accordingly. After this alteration, it may happen that the machine speeds up to a greater extent than before. Unless we have altered the step-up of the transformer, an occurrence of this kind is due, in all probability, to the reason explained above.

To sum up, then, we have the following characteristics of motor alternators and rotary converters.

The motor alternator is bulky, heavy, more expensive, has several bearings and generally demands more attention than the rotary. It can, however, be made to give an alternating voltage of high value, thus enabling the current to be kept within convenient limits in high-powered sets; moreover the voltage may be varied.

The rotary converter, on the other hand, is small, light, cheap and simple. It has but two bearings, one armature and one set of field magnets. It has, however, a limited and unvariable voltage. It is a very suitable machine indeed for use in small ships where it would be difficult, and indeed inadvisable, to instal a high-powered set.

It has been seen that the harmful reactions in the rotary converter are due to the armature magnetisation altering the strength of the field. This effect may obviously be minimised by making the field relatively much stronger than the flux in the armature. Not only in rotary converters does this hold good, but also in the case of the alternator and the motor in the case of the larger machine.

In all alternating current generators the shape of the E.M.F. curve is found to depend chiefly upon the design of the pole pieces of the field. For this reason much attention has been paid to the effect of different shapes for the faces of the magnet poles. As a general rule they have their corners slightly chamfered off, this having the effect of smoothing off the sharp peak which otherwise occurs in the E.M.F. curve.

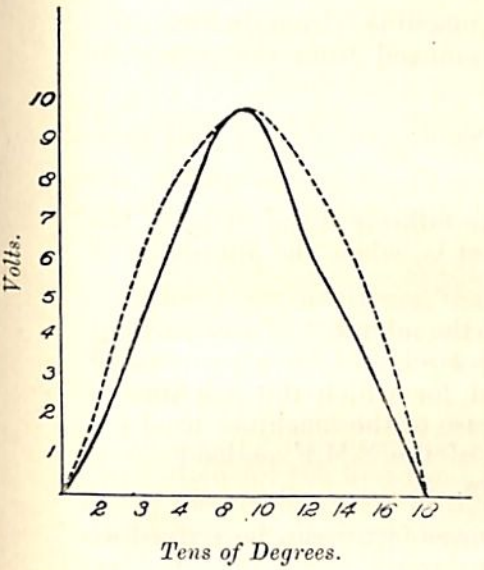


FIG. 96 (*a*).

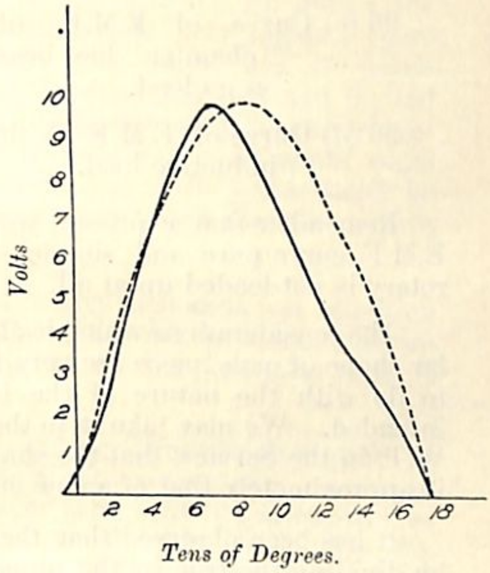


FIG. 96 (*b*).

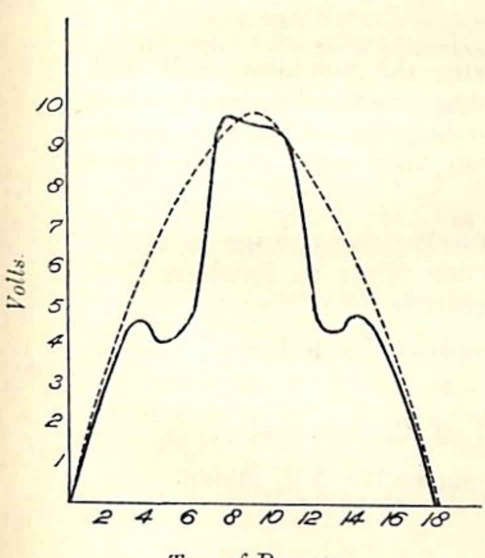


FIG. 96 (*c*).

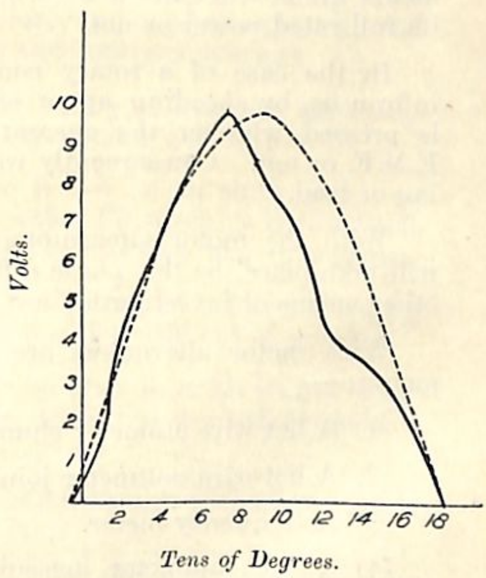


FIG. 96 (*d*).

Figures 96 (*a*), (*b*), (*c*), and (*d*) are curves of voltage, given by an alternating current dynamo under the following conditions :—

96 (*a*) Curve of E.M.F. of machine with chamfered pole ends on no load.

96 (*b*) Curve of E.M.F. of the same machine on full non-inductive load.

96 (*c*) Curve of E.M.F. of machine from which the "chamfer" has been removed from the pole ends on no load.

96 (*d*) Curve of E.M.F. of the same machine on full non-inductive load.

Remember that at present we are talking of the shape of the E.M.F. curve pure and simple—that is, when the alternator or rotary is not loaded up at all.

The considerations which lead to the adoption of any particular shape of pole piece are very involved, and have principally to do with the nature of the load for which the machine is intended. We may take it, in the case of the machines used for W.T. in the Service, that the shape of the E.M.F. no-load curve is approximately that of a sine curve.

It has been observed that the power factor can be arrived at by dividing the true by the apparent watts. Now in a ship we are not at present provided with a wattmeter or a power factor indicator, so that we cannot obtain any very reliable measurements which will inform us whether the machine is developing its full rated power or not.

In the case of a rotary converter the machine itself will inform us, by speeding up or slowing down whenever the key is pressed, whether the current be lagging or leading on the E.M.F. or not. Consequently we can take steps to reduce the lag or lead.

With the motor alternators, however, no change in speed will take place, be the phase difference never so much, so that other means of investigation are required.

With motor alternators are supplied the following instruments :—

(1) A hot-wire ammeter shunted off the A.C. mains.

(2) A hot-wire voltmeter joined across the A.C. mains.

(3) A frequency meter.

(4) A D.C. ammeter measuring the current supplying the motor which revolves the alternator.

Now (1) and (2) multiplied together will give the apparent watts developed. When no alternating current is flowing the A.C. ammeter will show zero, but the D.C. ammeter will show a certain small current, which, multiplied by the D.C. voltage of the ship's mains will give the watts necessary to run the machine on no load—that is, to overcome friction.

When the key is pressed the A.C. ammeter will spring to life, so that from it and the A.C. voltmeter we obtain the apparent watts. The D.C. ammeter will also register more current than it did before. The true watts will be given roughly by taking the difference between the new and the old D.C. ammeter readings and multiplying the result by the voltage of the ship's mains. Dividing the true by the apparent watts will, of course, give the power factor, but if the power factor be less than unity we are still ignorant as to whether the current lags or leads.

It has been mentioned that a rotary demands less attention than does a motor alternator. This must not be taken to mean that the machine will not require all the attention that it will get.

Regarding the erecting and testing of motor alternators in ships fitted for the first time, it is of *vital* importance, especially where the machines are of the older type with two armatures on the same shaft, that the directions contained in W.T. appendix to Annual Report of Torpedo School, 1909, should be carried out absolutely to the letter.

Once the machine is installed and has been running satisfactorily, the same remarks, or nearly so, apply to the care and maintenance of motor alternators and rotary converters.

The A.C. generators, whether rotary converters or motor alternators, are always placed below armour in a ship.

In cases where the W.T. office is not on the same deck, but on a higher level, it often happens that the machine is forgotten, or at any rate does not receive all the attention that it requires.

This is especially the case in destroyers where the rotary is often placed in a very cramped position difficult of access.

Again, when at sea, it may be that in order to get to the machine, certain "C" doors have to be opened and permission requested before opening them.

These considerations only too often are apt to lead to damage to the machines.

As a general rule two machines are supplied having but one starter in the W.T. office. This means that a pair of two-way switches, one for D.C. and the other for A.C., called "change-over switches," are necessary to enable one or other, but not both simultaneously, of the machines to be started up by means of the starter in the office.

The machines are duplicated with the idea that they will both be subjected to an equal amount of wear, not that one will be worked till it fails and then the other used as a "stand-by."

It is intended that if continuous signalling be necessary, the machines should be changed, say every hour, so that each machine will get a rest in turn.

It will be remembered that the nature of the wireless load is a very trying one to any machine, whether human or mechanical.

A succession of temporary herculean efforts will cause more depreciation than will a steady moderate load.

Starters and Field Regulators.

These are of different designs in the case of different machines, but in general outlines follow the ordinary design of starter for shunt-wound motors shown on p. 246 of Torpedo Drill Book, 1908. The field regulators consist of adjustable rheostats placed in series with the field winding.

They may be combined with or separate from the main starter. In the latter case, where the armature is very heavy, the ajustment of the resistance may be effected by a worm-wheel arrangement so designed that any sudden alteration of the resistance by any considerable amount is impossible.

Regarding starters, the precautions for their use laid down on p. 247, Torpedo Drill Book, 1908, must be carefully followed.

In the case of some of the starters for small rotary converters, no overload coil is fitted, but in its place we have a single-pole cut-out in one of the mains leading to the starter, which is easily accessible, being placed on the instrument board inside the W.T. office. In addition to this cut-out, a pair of double-pole cut-outs are fitted in the D.C. mains down below. The one inside the office is arranged to blow before the pair down below.

One special source of danger applies to ships fitted with two machines. The D.C. change-over switch, referred to above, is below armour, preferably as near to the rotaries or motor alternators as possible. They are, therefore, out of sight and not under the immediate control of the W.T. staff at all times.

Now if this switch be broken when one machine is running the no-volt release of the starter should at once let go the starter arm, which causes the latter to fly back to the "off" position.

It may happen that someone might throw the change-over switch right across to the other machine while the first was running.

Under these circumstances the no-volt release might not let the switch arm go sufficiently promptly to prevent the stationary motor being switched on with the arm of the starter to the full-on position. A burn-out of cut-outs and damage to the switch contacts would certainly ensue.

This hanging-on effect of the demagnetised no-volt release coil is due to the "residual magnetism" of the core of the latter, and the residual magnetism is increased if the iron armature which is attached to the switch arm be allowed to come actually into contact with the pole pieces forming the ends of the no-volt coil. It is well, therefore, to glue a thin sheet of paper to the faces of the latter pole pieces, so that a minute air-gap will be formed and the no-volt release will be far more prompt in its action.

Regarding the care and maintenance of motors and dynamos generally, the reader is referred to pp. 251–6, Torpedo Drill Book, 1908.

In addition to the above, the following points should be borne in mind.

The lubrication of all A.C. machines in the Service is on the loose ring principle. Too much attention cannot be given to this important point, not only as to the filling of the oil wells but also, especially in the case of the large high-speed motor alternators, as regards the periodical replacement of old oil by a fresh supply.

It is well to institute a routine for inspecting these lubricating fittings, say once a day for rotary converters and every time the machine is started up in the case of motor alternators. The replacement of the oil might be carried out weekly at the same time as the lubrication of the commutators and slip-rings with paraffin wax, as laid down for motor alternators.

Regarding the care of the brushes, commutators, &c., the instructions given in T.D.B. must be followed to the letter.

Where soft carbons are supplied for the slip-rings and hard ones for the commutator, care will be exercised to avoid confusion between the two. If not marked in any special way the soft carbons have a shiny blacklead-like appearance when scraped, whereas the hard ones feel gritty and crystalline.

In the older rotaries it will be remembered that the A.C. brushes are of copper or brass gauze and that they bear upon a corrugated slip-ring. If the pressure of these brushes be excessive the slip-rings will become deeply grooved and rapidly worn away. To such an extent has this scoring been carried that a case has occurred of the brush on the inner ring actually biting down so deep as to make contact on the lead running to the outside slip-ring, thus shorting the rings and burning out the armature.

In all cases, then, we want to get the pressure only just enough to collect current without sparking or making bad contact.

Certain maximum pressures are laid down on the basis of so much pressure per square inch of brush surface, but these standards are difficult to follow in small machines as a practical method of adjusting pressure.

The best way of adjusting the brushes of a rotary is to do so while the machine is running and while someone is pressing the key (making some V's, say) in the office up above.

The spark should be the maximum ordinary signalling spark, so that the machine will be giving its normal maximum load.

Now to adjust the brushes on either commutator or slip-rings, take one brush at a time and gradually reduce the pressure till sparking just begins to take place. Thereafter increase the pressure till sparking *just ceases.*

This same method can be used for adjusting the D.C. brushes of the motor alternator, but must on no account be adopted for the A.C. brushes because the voltage at the slip-rings is enough to give a very nasty and perhaps dangerous shock.

The cover fitted over the A.C. end of the machine must not be lifted unless the machine be stopped, so that the process of adjusting would necessitate the stoppage of the machine between tests so that different pressures might be tried.

In any case it is no good inspecting the brushes of a machine of either kind when it is running "light," still less so when it is stationary. The machine must be supplying a wireless load—that is, an intermittent one—and the W.T. staff must not rest content until they eliminate absolutely all traces of sparking either at the D.C. or A.C. brushes of a motor alternator; from a rotary, all traces at the A.C. brushes and, at the D.C. end, all but the merest glow, which can only be seen by peering down the slit between the brush and the commutator.

The motor alternator is provided with a self-regulating angle of "trail." As the current in the armature increases with the load the "interpoles" which carry a series winding become energised and tend to shift the motor field round in the direction of revolution. This alteration of the resultant field magnetism of the motor is exactly the same as the increase in the angle of "trail" by which it would otherwise have been necessary to move the brushes back against the direction of revolution.

In this way sparkless commutation of the motor is assured at all loads. The interpoles also have other beneficial effects, such as keeping the speed of the machine nearly constant even under a considerable fluctuation of the D.C. supply voltage, but into the causes which lead to this result we need not enter here.

In the rotary converter no such interpoles are fitted, but the brushes are fitted on a rocker, which, by the way, should hardly ever want alteration, and also, due to the relatively great strength of the field compared to that of the armature, the distortion of the field on load is but small, and the increase in the angle of trail when the machine is loaded is consequently very little indeed.

It must not be forgotten, however, that theoretically the brushes of a rotary should be moved back a little every time the key is pressed. As this is obviously impracticable, it will not be surprising if sparkless commutation of a rotary be not quite within our reach. There is therefore all the more reason of constant cleansing of the commutator strips.

These few short notes on the care of W.T. A.C. generators are inserted with the idea of showing the special points which are more or less peculiar to this type of machine, and which are not already insisted upon in the directions for care and maintenance above quoted.

CHAPTER IX.

The Charging Circuit.

It has already been seen that a transmitting circuit consists essentially of a coupled system in which two syntonised oscillators are employed. The aerial circuit or open oscillator is excited by the inductive action of the primary circuit or closed oscillator, the latter in turn deriving its energy from some source of high E.M.F. which is so arranged as to charge up the condenser at definite intervals of time to such a pressure that the insulation of the spark gap will be broken down. The condenser thereupon discharges itself in an oscillatory manner. It must be borne in mind that the result of charging the condenser *once* is the production of one "jig" * in the closed oscillator and that, while the jig continues, the charging circuit (or source of high E.M.F.) is more or less quiescent, whereas on the cessation of the jig the insulation of the spark gap is once more restored and the condenser will once again commence to be charged up.

The method in which energy is applied to the condenser during this "loading" process will now be investigated, the

* The word "jig" will now be used to mean "a damped train of electric oscillations (or waves) of high frequency," *i.e.*, of such frequency as is used in W.T.

phenomena consequent on the "firing" action having already been dealt with generally.

In the early stages of the application of electro-magnetic radiation to the practice of signalling without wires the source of pressure was invariably the induction coil.

Although this instrument has now been superseded in all modern Service sets by the transformer used with alternating current, yet there are still some installations in the Service and a very large number of commercial ones in which the coil is used.

The principal advantage of the coil is that it does not necessitate having a source of alternating current, a consideration which may, under certain circumstances, make its use imperative.

Commercially these instruments are often supplied with D.C. from a battery of secondary cells, or accumulators, which will have to be recharged periodically from a dynamo or even, as in the case of lightships, from a battery of primary cells

The advantage of using a secondary battery is that the set is, for a time at least, independent of the running of the ship's dynamo, an advantage which has already resulted in the saving of many lives.

If the dynamo room or stokehold of a ship be flooded through collision, and the dynamo be consequently stopped, signalling for assistance is at once rendered impossible unless cells be employed. However, the coil requires a voltage of less than 40 volts, whereas the ship will be lit with current at, say, 100 volts. Reducing this voltage by means of resistances is not commercially economical, but of course this drawback does not affect us in the Service.

Hence where coils are employed with direct current two adjustable resistances are used in series with the dynamo mains, and the Service dynamos, being duplicated and carefully protected by armour, are fairly immune from damage.

General Construction of Coils.

For the purposes of wireless telegraphy the type of induction coil most frequently employed is one called a 10-inch coil, meaning an induction coil which can produce a spark 10 inches long between points or small balls attached to the ends of its secondary circuit.

Such a coil consists of a primary circuit of thick wire generally of No. 12 S.W.G. in size, wound in 300 or 400 turns on an iron core composed of a bundle of well-annealed soft Swedish iron wires, each not more than No. 22 S.W.G. in thickness, the bundle being 2 inches in diameter and about 18 inches long. The coils now supplied to the Service have their primary winding arranged in four layers, and all coils returned for survey are to have four-layer primaries before re-issue. If two coils are to have their primaries connected in parallel for any reason, it is important that they should consist of the same number of layers.

The resistance of the primary may be taken as being about 0·3 of an ohm, and its inductance as 0·02 of a henry.

This primary coil is enclosed in an ebonite tube, into which it should slide easily, the tube having very thick walls, at least ¼ of an inch thick; it must be very carefully made and be perfectly free from flaws. The tube projects slightly beyond the end of the core, which latter is kept in place by two semi-circular distance pieces at each end, the distance pieces being held up to their work by two discs screwed into the extremities of the tube. The ends of the primary winding are brought out through a hole or holes in these discs.

A three-layer coil may be recognised by the two ends of the winding coming out of opposite ends of the core, whereas those of a four-layer coil come out both at the same end, generally that next to the hammer make-and-break.

Outside the ebonite tube we have two thick ebonite cheeks between which the secondary winding is secured, the winding being compressed between the cheeks by the standards supporting the coil itself being screwed hard up against washers which bear against them. The standards engage in threads formed upon the outside of the ebonite tube.

The secondary coil consists of from 10 to 17 miles of fine double silk-covered copper wire of No. 34 or 36 S.W.G.

The circuit consists of a very large number of flat coils or sections, several hundred such coils being sometimes employed. These are prepared by winding the wire between paper discs in a flat spiral, as a rope is coiled down upon the deck.

The coils are then slipped on to the ebonite tube enclosing the primary coil, and the ends of the coils are then jointed together. To enable this to be done, the coil sections are wound in double flat layers with a disc of paraffined paper between, the beginning and end of the wire being thus at the outside, and the two layers so wound that the windings follow on in the same direction. There is then no difficulty in making the connections between the various flat coils composing the secondary circuit.

When the whole number of flat coils has been assembled in this way, the coil so formed is compressed between the ebonite cheeks and the whole immersed in paraffin-wax to exclude moisture. The wax, being finished off into a cylindrical form, is covered with a thin jacket of ebonite, whose edges fall into annular grooves cut in the inner faces of the cheeks.

In re-assembling a coil which has been parted it is important to see that both edges of the ebonite sheath engage these grooves before the coil supports are screwed home.

The two ends of the secondary are brought out to terminals mounted near the tops of the cheeks.

Two other adjuncts are then necessary. In the first place some means have to be provided whereby the primary current may be caused to vary in strength from instant to instant, because, without such variation, no E.M.F. can be induced in the secondary circuit. This appliance is called an "interruptor," and may take several different forms. The principle underlying all these forms is, however, the same.

They convert what would otherwise be a steady flow of direct current of constant strength into an intermittent pulsating current which alternately grows and dies away, without, however, changing its direction.

We may therefore speak of the "number of interruptions per second," but we must not speak of the "frequency" of the current, because the current does not change its direction, and is therefore not alternating but "uni-directional."

In addition to the interruptor it is necessary to have a condenser of a certain capacity placed across the points between which the interruptions of the primary circuit occur.

This is called the primary condenser, and is made of a number of sheets of tinfoil separated by sheets of paper soaked in paraffin wax. Odd-numbered sheets of foil are connected to one terminal and even-numbered ones to the other terminal.

In reference to the construction of induction coils for wireless telegraphy, it should be noticed that the value of a coil must not be judged simply by the length of spark it can give between the ends of the secondary wire when the primary circuit is interrupted, but by the spark length which can be obtained when a condenser of a certain capacity, say 50 jars, is connected across the ends of the secondary circuit; that is, across the testing spark-gap.

Assuming we have, for the moment, some means of interrupting the primary circuit, we will now see what happens when the primary current is started and stopped.

Action of an Induction Coil.

When the interruptor "makes" contact for the first time a direct current will commence to flow in the primary circuit.

Since the resistance of the primary is small this current would tend to grow to a large value. Opposing the rapid growth of this current, however, we have the self-induction of the coil. The current grows slowly on this account, and before it reaches a dangerously high value it is automatically broken by the interruptor.

Owing to the growth of the current in the primary, an E.M.F. will be set up in the secondary in an opposite direction to that of the current in the primary, for the flux due to the primary current is cutting the turns of the secondary.

Now although there are very many turns of secondary, the E.M.F. induced therein at this stage will be very small and may be neglected. The strength of the induced E.M.F. will depend, of course, upon the rate at which lines of force are cut, or (in other words) upon the rate at which the current in the primary is changing its strength.

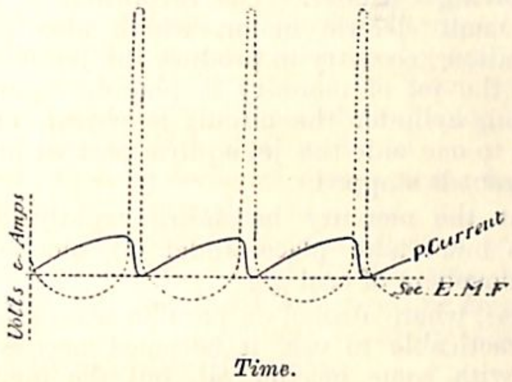


FIG. 98.

In Fig. 98 the first part of the primary current curve is shown rather flat, this flatness illustrating the slow growth of the primary current.

From the instant at which the interruptor breaks the primary circuit (and the more sudden the break the better) the current in the primary begins to die away.

Owing to the enormous resistance suddenly introduced into the primary circuit by the action of the "break" forming in the interruptor, the current dies away to zero very rapidly, and it is to the rapidity of fall of current that the very large secondary induced voltage is due.

This large voltage is, of course, in the same direction as was the current in the primary originally.

The rapid fall in the primary current is shown in Fig. 98 by the steepness of the curve as it drops from maximum to zero.

Notice that as the current curve gets steeper the secondary voltage increases, whereas as soon as the current curve begins to get less steep the secondary voltage curve begins to drop, reaching zero as soon as the current curve becomes horizontal.

The curves are not drawn to any particular scale.

We see, then, that the secondary terminals present us with a voltage which actually is alternately of opposite polarity, but that the voltage in one direction is so feeble as to be negligible compared with that in the opposite direction.

This latter rises suddenly to an enormous value and as suddenly dies away, its whole "life" being but a small fraction of a second.

Regarding the "make-and-break" or interruptor for the primary circuit we are chiefly concerned with the "hammer" type. The other types in general use are the mercury jet and the Wehnelt electrolytic cell.

To dispose first of these two latter, the mercury interruptor consists essentially of a jet of mercury which is caused to impinge upon a series of metal tongues projecting from the rim of a revolving cylinder. The revolution is produced by means of a small electric motor, which also performs the pumping operation necessary to produce the jet of mercury.

Whenever the jet of mercury is playing upon the tongue of the revolving cylinder the circuit is closed, but when the tongue moves to one side the jet squirts past without touching it and the current is stopped.

To prevent the mercury becoming rapidly oxidised, the whole process must take place under oil, alcohol, or, better still, in an atmosphere of coal gas.

For ship use, where alcohol or paraffin would be dangerous, and gas impracticable to use, it becomes necessary to cover the mercury with some heavier oil, but the mercury after a time develops a tendency, under these conditions, to mix with the oil and form a kind of homogeneous black sludge.

The process of cleaning the mercury is tedious and the metal is expensive to replace, so that the use of this form of interruptor, although it gives beautifully uniform results if in proper order, has now been discontinued in the Service.

The electrolytic break was invented by Dr. Wehnelt in 1899 and is often called by his name. Its principle is as follows:—

If a large lead plate be immersed in dilute sulphuric acid containing 20 per cent. of acid (*i.e.*, one. part acid to four parts water) and if a second electrode of very small surface be immersed, consisting of a short length of platinum wire, projecting for about $\frac{1}{8}$ of an inch out of the end of a tight-fitting glass or porcelain tube, then such an electrolytic cell placed in series with the primary circuit of an induction coil will interrupt the current, provided that the current enter the cell by the platinum electrode. Under these conditions the +ve terminal of the dynamo must be connected to the terminal of the platinum point, which is then called the "positive electrode" or "anode," while the lead electrode is the "negative" or "cathode."

If a continuous E.M.F. be applied to such an electrolytic cell in series with an inductive wire, the current is found to be non-continuous or intermittent. Several hundred interruptions occur every second. The action essentially depends upon the presence of inductance in the circuit, and if the inductance of the coil primary alone be insufficient, an extra inductance coil must be added in series with it.

The spark given at the secondary terminals of the coil when working with an electrolytic break is different in character from that obtained with a hammer or mercury break.

Whereas the spark in the two latter cases is thin, irregular and lightning-like, we have a shorter and more flame-like spark, somewhat resembling an alternating current arc. This is due to the large number of interruptions per second.

For wireless purposes this very large number of sparks per second makes it difficult to avoid arcing between the spark balls of the primary oscillator, so that better results are obtained by using the electrolytic in series with the hammer break.

Under these conditions we may, if we have two coils, join their primaries in parallel, the electrolytic break being placed in the mains before they fork off to each coil.

Each coil will then be using its own hammer break, and the secondaries will be best, probably, in series.

Otherwise, when hammer or mercury breaks are in use, the coil primaries must not be joined in this way, but in series with each other, so that one break only need be employed.

The electrolytic will not work well on an 80-volt circuit, but requires a pressure of nearly 100 volts.

When mixing up the acid and water, the acid must always be added to the water in small quantities, the mixture being stirred continuously all the time. On no account must the water be poured on the strong acid. The density of the mixture should be 1,200 by hydrometer.

To adjust for a spark, the following procedure should be adopted. When first trying for a spark the platinum point should always be raised. Gradually lower the point and at the same time adjust hammer make-and-break in the usual way (as hereinafter explained) until a good steady spark is obtained, but never lower the point more than is necessary.

It should not be necessary to refill or clean the jar until the sediment which forms at the bottom nearly touches the platinum or lead electrode.

The commonest form of break is the hammer. Its action is precisely similar to that of an electric bell.

A soft iron armature, which should be very securely screwed on to its platinum contact, is secured to the top end of a flat steel spring whose tension can be adjusted by means of an ebonite wheel. This armature is in juxtaposition to the one end of the iron core of the coil, the play between the two being anything up to about $\frac{1}{16}$ or $\frac{1}{20}$ of an inch.

The natural "set" of the steel spring, when no tension is on the adjusting screw, should be to cause the armature to set up gently against the core. The tension screw will then enable us to cause the armature to set away from the core by a force which can be as small as we like.

Behind the vibrating armature we have a fixed standard carrying an adjustable "back contact," whose end is also covered with platinum. The fixed and moving contact are in series, through the medium of their respective supports, with the rest of the primary circuit, the current being able to be reversed from time to time by means of a commutating switch, which is mounted on the wooden base of the coil. When working the coil with the hammer make-and-break and direct current, it is advantageous to change the direction of the primary current from time to time, as by this means the wear of the platinum contacts is rendered more uniform. Usually a coil works slightly better with the commutating switch in one position than in the other.

To explain the action of the coil we need not take this switch into account, and the diagram in Fig. 99 shows all that is necessary.

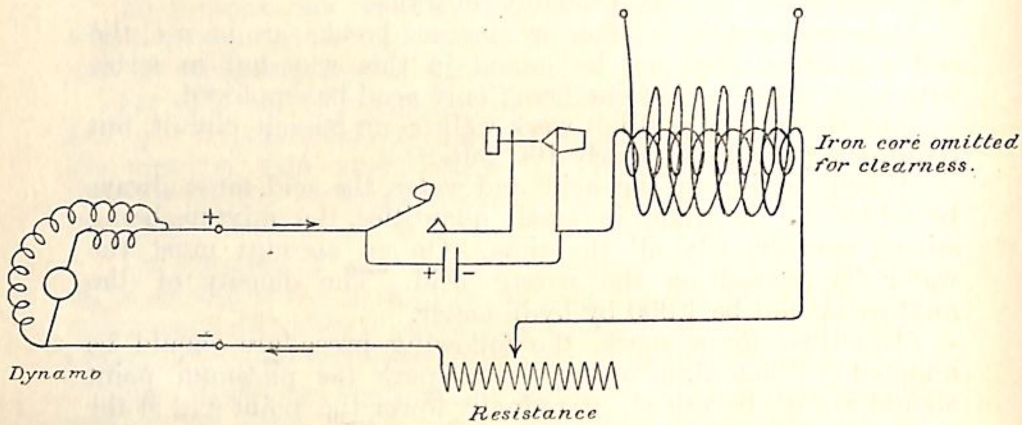


Fig. 99.

On the signalling key or other switch being closed the direct current will flow across the two contacts and round the primary winding, thereby magnetising the iron core.

Sufficient tension must have been previously put upon the spring to cause the normal position of the hammer or armature to be set away from the core, a small clearance to allow of its movement having been left.

When the core is energised in this way, the hammer, being made of soft iron, is attracted over, thus breaking the circuit.

Since the core is a magnet *only* when the current is flowing round it, the cessation of the current allows the hammer to fly back again to its original position, thus closing the circuit once more. The number of interruptions per second will depend upon the mass of the moving part, the springiness and tension of the spring, and also upon the amount of play allowed to the hammer, but may be taken as being of the order of 100.

In this way the current in the primary is caused to be intermittent, and the use of a hammer make-and-break, unless separately operated, at once precludes the use of a closed magnetic circuit for the coil. (*See* p. 135.)

Now unless proper precautions are taken, it is found that the flaming and sparking at the contact pieces will be excessive.

To mitigate this evil, for great heat is evolved and the platinum rapidly burnt away, a large condenser is shunted across the make-and-break.

This condenser is built up of tinfoil separated by waxed paper, and has a capacity of about 1 mfd., or 900 jars.

Its functions are twofold :—

(1) To absorb the sparking which would otherwise occur at the contacts, not only of the coil itself but also at those of the signalling key.

(2) To cause the primary current, when the circuit is broken, to die away to zero in a much smaller time than would otherwise be the case, thus giving a much higher secondary voltage.

These two functions are explained as follows :—

When the hammer first begins to move over towards the core, a minute gap will appear between the two contacts. Due to the "inductive kick" (*see* p. 13) of the primary, the current will tend to go on flowing across the gap. Instead of that happening, the condenser, which had previously been shorted by the make-and-break, accepts the moving charges for the moment, being charged up to a fairly high pressure (that of the back D.P. of inductance) in the process.

This is shown in Fig. 99 by the signs + and −.

By the time the condenser is charged, the gap between the contacts will be large enough to make a spark across it impossible. The condenser, therefore, finds itself with no way of getting rid of its charge except by giving a momentary backward current right through the whole circuit, through the dynamo and backwards through the primary. This momentary rush of current through the primary will effectively kill the last remains of the old direct current which may not by then have disappeared.

In this manner the condenser is a very valuable attachment to the coil, owing to the great increase of secondary voltage attained. It is of vital importance that the leads to the terminals of the condenser should be making very good contact inside the French terminals which take them.

If the condenser be disconnected the hammer at once begins to splutter and flame, and the spark at the spark-gap falls off.

Undue sparking at the hammer contacts may also be due to the condenser being punctured. If this happens the condenser must be parted, examined, repaired and thoroughly dried before use. Again, the contacts must be kept filed up true, square and bright, or flaming will take place.

When using a single coil with hammer make-and-break for charging a transmitting condenser, great attention must be paid to getting the correct adjustment of the make-and-break and also of the series resistances.

These latter have a value of about 5·7 ohms each, and are used to reduce the voltage across the terminals of the coil.

Always start with all the resistance in, taking it out gradually, so that no more current is used than is just necessary to make a spark of the required length.

Similarly, as little tension on the spring as possible should be used, and further, up to a certain limit, the less the play of the hammer when using a small spark the better.

If the spark be fairly large, less resistance, more tension, and more play will be required.

If too much tension be used with too little play the contacts will get very hot.

We therefore find that for any given spark there is a certain adjustment of resistance, play of make-and-break, and tension on the spring which will give the best results, but this can only be found by trial.

Flaming or sticking of the contacts, when the condenser is known to be all right, generally means too much power, so that resistance must be increased or tension reduced.

Time spent on getting the make-and-break and resistance into proper adjustment for your spark is never time wasted.

When two coils have to be joined in series for use with D.C. one hammer make-and-break alone is necessary.

It is then often convenient to keep the two condensers separate, so that one is put across the sending key and the other looks after its own hammer contacts, the key terminals of this coil being short circuited.

Otherwise the two condensers may be put in parallel and the key terminals on the "acting" coil be employed.

The secondaries may be connected in series or parallel, but *not* in parallel unless the two are of the same pattern.

The hammer make-and-break of the so-called "idle" coil should be screwed up taut or else removed, to prevent rattling.

To obtain any spark at all, whether the secondaries be in series or parallel, the current in the two primaries must be in the same direction, otherwise the secondary voltages will be in opposition. This can at once be verified by fixing the position of one of the reversing switches and switching the other first one way and then the other.

Supplied with each coil is a fine cut file whose purpose is to keep the contacts filed up square and true. It should be used with economy but always when necessary.

Ships having modern installations are supplied with transformers and A.C. circuits, but one coil is issued to all ships except destroyers, which may be used for tuning purposes, fitting up temporary or alternative sets on board, or even temporary stations ashore.

We have seen that the "rating" of the coils used in the Service is indicated as 10 inches. Now the voltage required to produce such a spark between sharp points or small metal balls is of the order of 150,000 volts. If a Leyden jar be connected across the spark-gap, it would inevitably puncture if its terminal voltage actually reached this value.

Such, however, is not the case in practice. The time taken to charge up any condenser to a given pressure varies directly as SR, the product of its capacity into the resistance through which it is charged. In this case the charging current has to flow through the secondary of the coil which, owing to the thin wire employed, will be of high resistance (of the order of 10,000 ohms).

The time taken to charge up a condenser of S farads so that its terminal P.D. equals the steady applied voltage is given by:—T in seconds = 5 SR, where R is the resistance of the charging circuit in ohms.

Hence a condenser of 20 jars, charged through a resistance of 10,000 ohms, would take

$$5 \times \frac{20}{9 \times 10^8} \times 10^5 \text{ seconds.}$$

$$= \frac{1}{90}\text{th of a second to reach the full P.D.}$$

Now assuming a rate of interruption of 100 per second we see that the condenser could never be charged up to the full voltage because a very large portion of the $\frac{1}{100}$th of the second intervening between successive breaks is taken up by the slow growth of current in the primary.

It is due to the exceeding shortness of the "life" of the secondary voltage that we cannot charge up the condenser to the same P.D. as we actually have ready at the secondary terminals.

For wireless purposes, then, it is not quite a fair method of comparing two coils, to measure the spark given between two sharp points, unless the gap be bridged by a condenser, say of 10 jars or so.

The larger the condenser we put across the gap the smaller will be the longest spark we can get, for, although the total voltage is enough to give a 10-inch spark, yet only a small portion of that voltage is available in the very short time at our disposal.

The larger the condenser which we wish to charge up, the more important it becomes to reduce the secondary resistance. This can be done by winding the secondary of fewer turns of stouter wire. But fewer turns mean a smaller voltage. This is so, naturally, but, owing to the lower resistance, more of that voltage is available, and so the coil may actually give a longer spark across a condenser than will its rival of many turns of fine wire.

Coils of this nature are commercial articles now that W.T. has created a demand for a different coil to what is commonly used for Röntgen Ray work. They are called "intensified" or "heavy discharge" coils. The secondary would be wound of

No. 30 gauge instead of No. 36; about the same total weight of wire being employed.

Having a pair of *similar* coils given us, we may join the secondary coils either in series or parallel.

The series arrangement will give the largest voltage, but a high resistance, whereas the parallel arrangement will give a voltage equal to that of one coil, but the resistance of the combined arrangement will be less than that of one coil.

Which of the two will give the best results will depend chiefly upon the size of the condenser to be charged.

A capacity of 20 jars might be charged better by the series than by the parallel arrangement, while one of 40 jars would almost certainly do better with the parallel arrangement, for as the capacity increases so also is there an increased necessity of keeping down the resistance.

Regarding the design of the "coil condenser" (that is the one across the other make-and-break), two antagonistic considerations determine its value.

If the condenser be large there will be no danger of flaming at the contacts, but the suddenness of the break will not be very great. A small condenser makes for a very sudden break, but, on the other hand, there will be danger of sparking. Normally its value would be about one m.fd. as before mentioned.

Use of Coils with Alternating Current.

We may either altogether discard or short-circuit the hammer make-and-break, or else screw the contacts up taut, when coils are to be employed as transformers supplied with A.C. from a rotary. Under such conditions their action resembles that of a transformer and they may be grouped in series or parallel so as to give large or small steps up and current outputs.

It must be remembered that the coil is essentially a transformer with an open iron circuit, and it will therefore give an alternating secondary voltage when supplied with an alternating primary current.

We may, and generally do, find that the spark that can be obtained with A.C. is larger than that obtained with D.C. and hammer make-and-break.

This is partly due to the fact that the voltage at the secondary, although lower than with D.C., lasts longer and so charges the condenser better.

The considerations which will determine whether we should join the coils in series or parallel, and whether high or low frequency A.C. should be used to charge up a given condenser, will be understood better when we have seen the principles of the application of A.C. to the charging of condensers through transformers.

We may mention here a point which is often overlooked because it has no direct bearing upon the wireless efficiency of the set. Whenever two coils have their primaries connected up in series or parallel, whether on an A.C. or a D.C. circuit, they should be so arranged as to have opposite polarity at their adjacent ends, as shown in Fig. 100 (*a*). If, on the other hand, the two north or two south poles at any instant are at the same end as in Fig. 100 (*b*), then the lines of force, mutually repelling each other, will wander off into space, producing possibly very disturbing effects on the standard compass, should it be anywhere in the vicinity of the office.

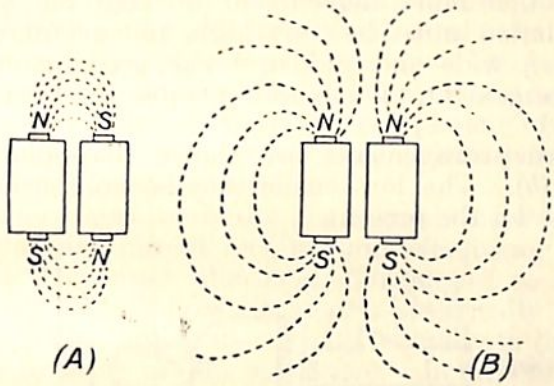


Fig. 100.

Whenever possible, an office near the standard compass should never be built of wood, but iron. The stray lines will then be caught up by the iron and very little external field from the coils will exist outside the office, and hardly any from transformers; the compass is said to be "screened" by the iron.

Use of A.C. for Charging Condensers.

With coils using hammer make-and-break the amount of current in the primary when at its maximum strength is relatively small, since an increase thereof would cause flaming and sticking of the contacts. Hence the stiffness of the spring carrying the moving contact is such that when at its stiffest a current of about seven ampères in the primary will provide enough ampère-turns to overcome the spring and break the circuit.

Since the voltage will be of the order of 30 or 40 volts will be seen that the mean power developed will be but small.

Consequently coils using direct current will be useful only for sets using ½ K.W. or less.

In all high-power sets we are therefore compelled, and in all sets we prefer, to use alternating current supplied to a step-up transformer. We shall now consider such an arrangement used for W.T. purposes.

The signalling key is usually in series with one of the low-tension mains, but this is merely for convenience. It will be remembered that the primary windings of commercial transformers are often connected up permanently to the supply mains, and that but little current flows until the secondary load is applied. We may therefore (if we prefer it) place the signalling key so as to form either a single or double pole break in the high-tension side of the transformer.

In the first arrangement the current broken will be large and its voltage low. The chief enemy will be "sticking" of the key contacts owing to the heating up of the metal. In the latter case, on the other hand, the current through the key is small, but the insulation must be very high, and arrangements must be made for a wide and sudden break, accompanied by some blow-out arrangement, to stop arcing across the break due to the high voltage.

These two arrangements are shown diagrammatically in Fig. 101 (*a*) (*b*). The low-tension key is more usual, and will be considered for the present.

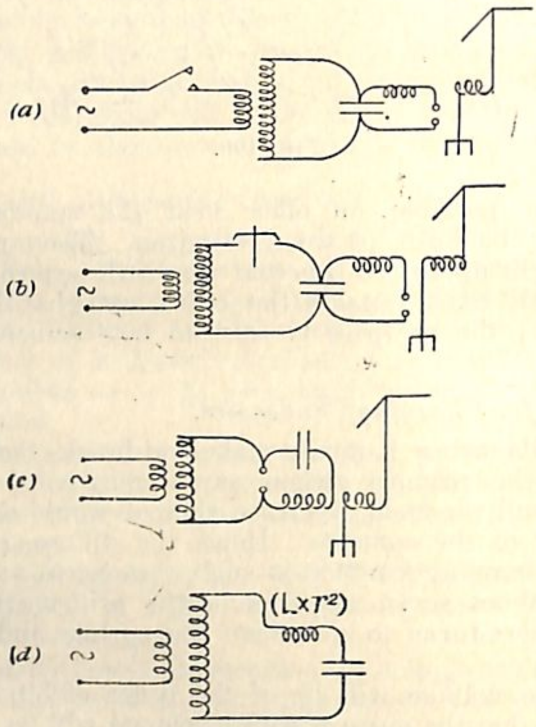


Fig. 101.

Looking at the last figures we see that the circuit consists of:—

(1) An alternator armature giving us a single-phase current at a certain voltage and frequency. This armature will have a certain amount of self-induction which will not be quite constant for all loads.

(2) The low-tension alternating mains leading from the machine to the office. These will possibly be of considerable length, but we may give them a very small self-induction by using concentric cable.

(3) The transformer will step-up the voltage in a fixed ratio which we call T (*see* p. 144). On full load its self-induction will be small.

(4) Connected to the secondary we have the condenser of certain fixed capacity. It is this condenser which we are to charge up, and which represents the "load." When the charge reaches a certain value, the condenser terminals will be at such a pressure that the spark-gap breaks down and the stored energy disposed of as a "jig." After the completion of the jig the condenser will once more commence to receive energy from the machine.

The reader must carefully distinguish between the low-frequency charging circuit and the high-frequency discharging circuit. The condenser alternately "belongs" to each circuit. Notice further that it does not matter electrically whether the high-tension mains are connected up actually to the condenser terminals or to those of the spark-gap. In either case it is the condenser, not the gap, which is being charged, and the few extra mics in the high-tension mains which are introduced in the latter case (*see* Fig. 101 (*c*)) will make no difference to the charging circuit.

Now in order to investigate what happens when the key is pressed and the circuit completed it will be well to consider the high-tension mains only.

We will regard the secondary of the transformer as a high-voltage alternator, whose armature, the secondary winding, has negligible inductance. This we may assume, since it is when on full load that we wish to obtain the best results.

We must not forget to make allowances for the self-induction of these parts of the low-tension circuit to which reference has already been made, viz., that of the alternator armature and the alternating mains.

Referring to page 145, we see that we may consider this self-induction to be in series with the secondary winding, provided we multiply its value by the square of the step-up.

We have, then, a high alternating voltage of frequency f applied to the ends of a circuit containing inductance L and capacity S, as shown in Fig. 101 (*d*).

Now since our object is to charge up the condenser to a certain high pressure with as little delay as possible, it follows that this will best be realised when electrical "resonance" has been attained. We must therefore so adjust L and f, since S is fixed for the moment, that the resonance equation holds good

$$f = \frac{1}{2\pi\sqrt{LS}} \quad (\textit{see } \text{p. } 46).$$

Under these conditions the secondary current will be in phase with the E.M.F., the primary will imagine it is supplying a non-reactive load, the true and apparent watts will be equal, the phase difference zero, and, most important of all, we shall obtain that peculiar rise of voltage across portions of the circuit, —that is, notably across the terminals of the condenser.

Hence in such a circuit, if it be properly adjusted, we may actually find ourselves getting good fat sparks of such a length that a voltage would be required to break them down, even three times as much as we should expect to get from the secondary of the transformer of given step-up.

Now since f is comparatively small, being a few hundred cycles at most, and since S is but a fraction of a mfd., it follows that L must be considerably large.

For example:—It is required to charge 100 jars at a frequency of 50 cycles. What must be the inductance L to produce resonance in the charging circuit?

The formula $f = \frac{1}{2\pi\sqrt{LS}}$ may be turned into a more convenient form as given on page 46, where we use jars and henries.

In this case

$$f = \frac{4{\cdot}8 \times 10^3}{\sqrt{LS}}$$

$$50 = \frac{4{\cdot}8 \times 10^3}{\sqrt{100 \cdot L}}$$

$$\therefore \sqrt{L} = \frac{4{\cdot}8 \times 10^3}{50 \times 10}$$

$$\sqrt{L} = 9{\cdot}6 \text{; square both sides.}$$

$$L = 92 \text{ henries.}$$

Now the self-induction of the armature of the machine plus that of the alternating mains would, even when multiplied by T^2, never be as much as 92 henries. Consequently inductance has to be added to the charging circuit artificially.

It may be placed either wholly or partly in either the low or high tension mains. Again, it may be wholly in one main or partly in each. These arrangements are shown in Fig. 102. (The key and discharging circuit are omitted.)

It has become the custom in the Service to give the coils different names according as to what place they occupy in the circuit. In either case they might be called "resonance coils," but their names bring out another function which they perform and which will be dealt with later.

When placed in series with the secondary, as in Fig. 102, (*a*) and (*b*), they are called "choking coils." When they are in the low-tension side, as in (*c*) and (*d*) (*d* is not used), they go by the name of "impedence coils."

In the latter case it will be seen that their reactive effect in the secondary winding is that of their actual value multiplied by the square of the step-up.

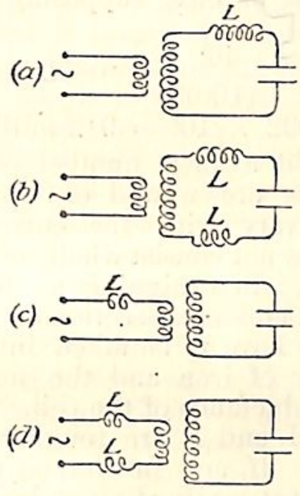


FIG. 102.

Hence a choking coil must consist of very many turns of fine wire, carefully insulated and wound on an iron core.

An impedence coil, on the other hand, need not be so carefully insulated, but must consist of thick wire to carry a large current. It need not consist of many turns because its actual self-induction need be but small.

The circuit containing the impedence coil looks rather puzzling owing to the L and the S apparently having no connection with each other. They are, however, very intimately connected by the magnetic "grip" of the transformer, and we may suppose that the condenser tends to make the secondary current lead on the E.M.F., whereas the impedence coil tends to make the primary current lag on the primary E.M.F. If the two tendencies counterbalance each other there will not be any internal reaction in the transformer, but the current and E.M.F. will be in phase with each other.

Owing to the ease and cheapness of manufacture, no less than to the ease of repair, impedence coils have now superseded choking coils in the Service. To find roughly the inductance required for an impedence coil, calculate as if for a choking coil, as in the example given above, afterwards dividing the answer by the square of the step-up of the transformer. The result will be the self-induction of the impedence coil required to get resonance in theory; but this will not be borne out in practice, because we have neglected the self-induction of the armature of the machine, &c., and also because absolutely complete resonance is not required, for reasons to be explained later.

The result will be a small decimal of an henry, so that to avoid this it is usual to express the value of an impedence coil in millihenries.

In the example given above we might either employ a choker of 92 henries or else, supposing T to be 100 to 1, an impedence coil of

$$\frac{92}{(100)^2} = \cdot 0092 \text{ henries,}$$

$$\text{or } \cdot 0092 \times 10^3 = 9 \cdot 2 \text{ millihenries.}$$

In order to avoid a large number of turns of wire these artificial inductances are wound on iron cores, but lest the inductance should vary with the current in the wire, the magnetic circuit does not consist wholly of iron but is completed through an air-gap. In designing an impedence or choking coil, both the length and cross-section of the iron core and also those of the air-gap have to be taken into consideration. The greater the quantity of iron and the smaller the air-gap the larger will be the inductance of the coil.

In practice, the L and S are roughly arranged to counterbalance each other. If any further adjustment be needed, it will generally be most easily effected by a slight alteration of the frequency.

It will be seen, then, that the charging circuit possesses an "LS value" and a "natural frequency" no less than do the two parts of the discharging circuit, but whereas the latter have but a few "mic-jars" LS and a very high frequency, the former has a very large LS, so as to put it in resonance with the low frequency of the alternating supply voltage.

We now come to another and very important function of the choking or impedence coil. We have seen that its presence enables the machine to charge up the condenser to the best advantage; that is to say, the "loading" of our electrical gun is materially assisted by its presence. Now we must consider what happens to the charging circuit, or loading mechanism, while the condenser is being discharged—that is, while the gun is actually firing.

Remembering that the spark itself has a resistance of but a few ohms, while the inductance of the oscillator primary is a negligible quantity, we see that the terminals of the transformer secondary are practically put in a dead non-inductive short circuit during the passage of a spark. At first sight, therefore, we should expect that a large secondary current would flow, in the form of an alternating metallic arc across the spark-gap, thus wasting much primary energy and melting the spark balls.

If it were not for the impedence or choking coil this action would doubtless take place, greatly to the detriment of the signals and damage to the gear. When the spark passes it short-circuits the terminals of the condenser, so that the latter is momentarily cut out of the charging circuit. The charging circuit at once becomes heavily reactive, for the inductance therein is now no longer counterbalanced by the capacity. Hence any *sudden* rush of current in the A.C. circuit is held in check by the back E.M.F. of self-induction for long enough for the "opportunity" to pass away. It must be remembered that the whole jig lasts but a very small fraction of a second, so that if an arc is to form it must seize its opportunity quickly. If the arc be delayed in its formation for a minute instant, this instant will suffice for the jig to finish and the insulation of the spark-gap to be restored once more.

In this way the artificial inductance, whether it be as a choker or as an impedence coil, will help the machine while the spark is not passing and will hold the machine in check while the spark is passing.

Herein lies the reason why such a coil may truly be said to "impede" or "choke back" the rise of A.C. which would otherwise form an arc across the gap.

There is no doubt that even under the most perfect conditions of resonance a certain amount of arcing does go on, the A.C. arc being blended with the spark. This results in the rapid burning away of the spark balls and in hissing and irregularities in the sound in the receiving telephones.

We shall find this effect very marked when a high spark frequency is aimed at with the idea of producing a musical note at the receiving end. The jigs succeeding each other at very short intervals of time cause the air between the balls to become very hot and semi-conducting. Under these conditions the insulation of the spark-gap is never fully restored between the jigs, so that a large leakage current which does not charge up the condenser will be continually flowing in the form of a low-frequency A.C. arc across the gap. Consequently an impedence coil which is too large for correct resonance will be of advantage owing to its action in cutting down the arcing.

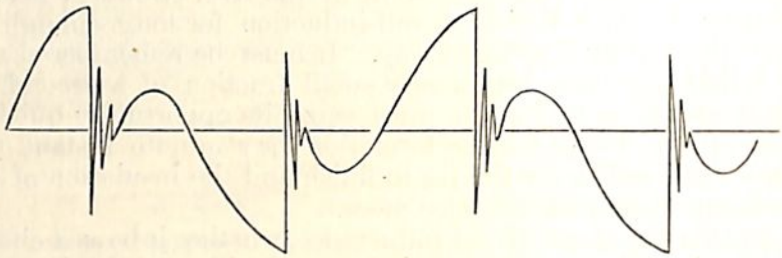
It is with this question of the spark frequency that we now have to deal.

First let us assume a machine of a given frequency supplying current to a circuit having a properly adjusted impedence coil, a transformer of given step-up and a fixed condenser. Suppose the transformer step-up is such that we get 7,000 volts R.M.S. at its secondary terminals. Now the spark-gap will break down first when the *maximum* pressure is just enough to cause it to do so. We shall have 10,000 as the maximum voltage.

If we have spark balls 2 cms. in diameter and set them 2·5 mms. apart, the gap would just break down at 10,000 volts.

Now the terminal voltage of the condenser will rise to this value twice in every cycle with alternately opposite polarity. Hence in such a circuit we should get the gap breaking down twice in every cycle. Each time it breaks down a jig is formed, the condenser getting rid of its energy in a very short space of time indeed. Directly the jig is over, the condenser begins to receive energy from the transformer.

The circumstances here discussed are shown graphically in Fig. 103.



One Spark per ½ Cycle.

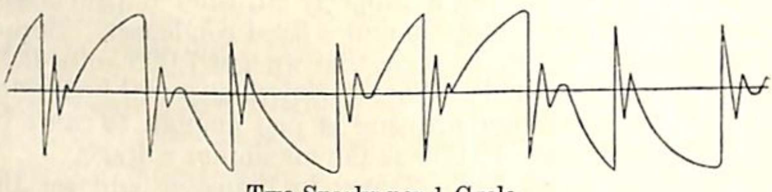
FIG. 103.

Suppose the machine gave us 50 ~. Since we are loading and firing the gun twice in every cycle it will take $\frac{1}{100}$ of a second to charge up the condenser on the average.

Suppose, further, that the discharge takes the form of a jig having 10 complete cycles at a frequency of 100,000 ~.

Hence the duration of the jig is $10 \times \frac{1}{10^5}$ or $\frac{1}{10000}$ of a second, so that the charging up takes 100 times as long as the discharging. An attempt to show this has been made in the Fig. 103, but the time of the life of the jig has had to be exaggerated in order to show the damping.

At the conclusion of the jig there will probably be left a certain small residual charge in the condenser, such a charge as was just unable to force its way across the gap. This charge may find itself either helping or opposed to the application of the new charge from the transformer. This may hasten or retard the charging process. Again, the spark-gap sometimes does not fully regain its insulation at the conclusion of a jig, so that it breaks down at a lower voltage than its length would indicate. We see, therefore, that an exactly evenly spaced torrent of jigs cannot be expected.



Two Sparks per ½ Cycle.

FIG. 104.

From the above reasoning it follows that if the gap be closed in so that it will break down at a lower voltage, then the condenser may be charged and discharged twice or more often in each half-cycle. Again we might have, say, two sparks one half-cycle, three in the next, two in the next, and so on, and in general the smaller the gap the more jigs we shall get per second. By "spark frequency" we mean "jigs per second" and it is upon the spark frequency that the "pitch" of the note heard in the receiving telephones depends.

For a given transmitting circuit having supply at a given voltage the spark frequency will be altered as the gap is altered. Less energy *per jig* will be radiated with a short gap than with a long one, because the energy in a condenser varies with the square of the voltage, but the total work done in any one second may be the same as that done with a longer gap giving fewer but more powerful jigs.

Conversely to the above, we may say that if the spark-gap be opened out beyond (in this case) 2·5 mms., we shall not get as many as one jig per half-cycle. It is here that the resonance in the charging circuit makes itself particularly felt.

Observe what happens. The transformer drives a charge into the condenser, a charge which does not raise the terminal P.D. of the condenser sufficiently to cross the gap. The charge, therefore, returns into the transformer secondary the way it came and gets there *just in time* to join forces with a new charge in the new direction. This double charge then enters the condenser in the opposite way and probably raises it to a sufficiently high pressure. Now if the natural time period of the charging circuit had not agreed with that of the applied E.M.F., then this first apparently futile charge would have found itself either just too late or just too early to "chip in" with the new charge, and some of the secondary voltage would have had to be expended in overcoming the old returning charge.

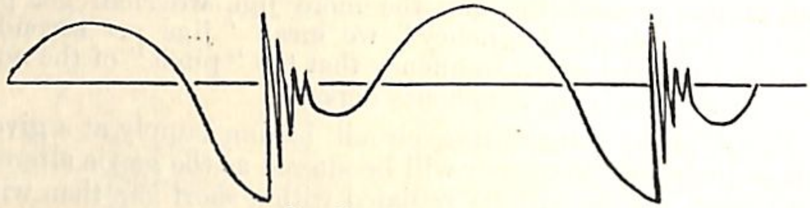
Under these circumstances of resonance we may get one spark every two, three, or more "swings" or half-cycles of E.M.F. These are illustrated in Fig. 105 (*a*), (*b*), and (*c*).

Notice again that we pay for these strong sparks in getting fewer of them per second.

It is in this way that we can obtain the very large voltage at the condenser terminals by a judicious use of the phenomenon of electrical resonance, a state of affairs which the commercial supply companies avoid owing to the enormous strain set up on the insulation.

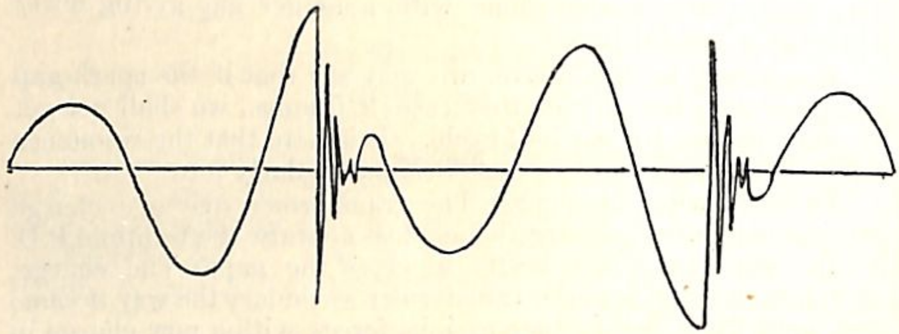
Notice that the effect at the condenser terminals during the charging process, when resonance in the charging circuit is attained, is precisely similar to that produced in the aerial when it is in resonance with (has the same LS value as) the primary. A larger current flows owing to the absence of reactance and also the voltage becomes "built up" to a much greater value than it would otherwise reach.

Now for a given circuit having a given fixed spark-length and A.C. voltage, it follows that the spark frequency will depend upon that of the A.C. supplied to the condenser, but that if resonance be attained at one frequency we must alter the value



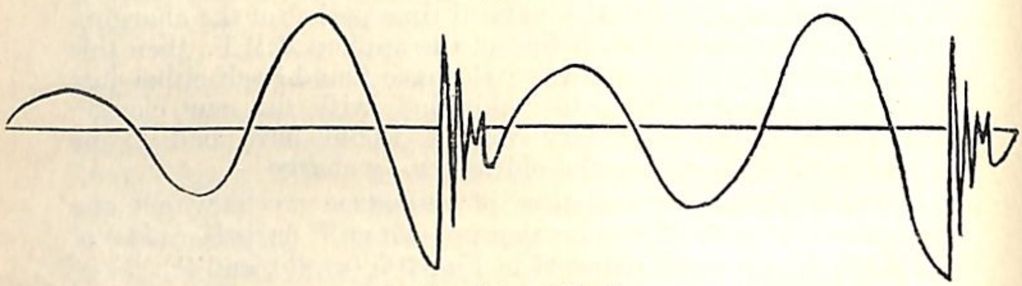
One Spark per Cycle.

(*a*).



One Spark per $1\frac{1}{2}$ Cycles.

(*b*).



One Spark per 2 Cycles.

(*c*).

FIG. 105.*

of the impedence coil in order to preserve resonance at the new frequency.

Further, assuming resonance with two different frequencies, the power taken with the higher one will be greater than that developed with the lower one, so that if we employ a fairly high frequency of supply in the effort to produce a high spark frequency to give a musical note, the machine must take a large number of watts from the dynamo.

Notice that if the frequency be doubled we must reduce the inductance of the impedence coil, not to half its previous value but to one quarter thereof, for the frequency varies inversely as the square root of the L and S, the S being fixed.

* Figs. 103, 104, and 105 (*a*) are on the scale of 4·6 cms. to the cycle; Figs. 105 (*b*) and (*c*) on a scale of 3 cms. to the cycle.

We are now in a position to speak in more specific terms of the work done in sending wireless messages.

Suppose we have a resonant circuit with a transformer of 100 to 1 step-up, supplied from a rotary at 80 cycles and 60 volts R.M.S. The capacity is 16 jars and spark-length 6 mms. What will be the energy per jig and what will be the power developed?

When the spark voltage is about three times the applied secondary voltage we may count on the resonance of the circuit giving us one spark per cycle.

The transformer gives us a maximum P.D. of $100 \times 1 \cdot 4 \times 60$, that is 8,500 volts. Six mms. require 21,000 volts about.

We shall be getting 80 sparks per second if we keep the key pressed for that whole second, and each spark represents a certain number of joules of work.

The energy stored up in a condenser of S farads charged to E volts is $= \frac{1}{2} SE^2$ joules, so in this case we have

$$\text{Energy} = \frac{1}{2} \times \frac{16}{9 \times 10^8} \times \frac{21 \times 21 \times 10^6}{1} \text{ joules}$$
$$= 3 \cdot 92 \text{ or nearly 4 joules.}$$

The energy of each jig is 4 joules.

If we keep the key pressed continuously the rotary will have to supply energy at the rate of 4×80 or 320 joules per second. Joules per second are watts, so that the W.T. circuit is dissipating energy at the rate of $\cdot 32$ K.W., or practically $\frac{1}{3}$ of a kilo-watt.

When actually signalling the mean power taken will be less than this, since the spaces between the elements of a symbol and between symbols will give the rotary a rest.

Suppose we are signalling at 20 words per minute, that the words average five letters each, and that each letter is made up of three signs and is equal to nine dots in all.

Then in one minute we shall send $20 \times 5 \times 9 = 900$ dots, or 15 dots per second. A dot therefore lasts $\frac{1}{15}$ sec.

Now of the nine dots going to make the average letter at least four will not be made—that is, they form the "spacing."

So that we can count on actually making $\frac{5}{9}$ of $900 = 500$ dots in the minute or $8 \cdot 3$ dots every second.

Now in one second we have 80 jigs, and since each dot takes $\frac{1}{15}$ sec., it will consist of $\frac{80}{15}$ or about five jigs (one jig per cycle).

Consequently every second we make use of $5 \times 8 \cdot 3$ or about 44 jigs.

Signalling therefore uses only 44 out of the 80 available jigs per second, and the power taken for signalling will be but little more than half that taken when the key is kept pressed continuously.

In this case, the signalling power taken from the transformer is—

$$44 \times 3\cdot92 \text{ joules per second}$$
$$= 172 \text{ watts}$$
$$= \cdot172 \text{ K.W.}$$

To obtain the power for a continuous "long" we use the formula

$$\text{Watts} = \tfrac{1}{2}\,SE^2N \text{ where } S = \text{farads}$$
$$E = \text{spark voltage}$$
$$N = \text{number of sparks per second.}$$

Where the resonance of the circuit and spark-length gives us one spark per cycle we may write

$$\text{Watts} = \tfrac{1}{2}SE^2f \text{ or, using jars}$$
$$= \frac{SE^2f}{18 \times 10^8}$$

So that if we increase the spark so that double the previous voltage is required and use a condenser one-quarter the previous value the power will be the same, *provided* the number of sparks per second is the same.

This fact is utilised to give a greater variety of wave-lengths for transmitting.

Thus two condensers of 80 jars each may be put in parallel (giving 160 jars) and worked at 8 mm. spark, an arrangement which is suitable for long waves.

To send short waves, since there is a certain irreducible minimum for the primary inductance, we have to reduce the capacity.

By putting the two 80-jar condensers in series we have 40 jars now capable of standing double the spark. Forty jars means one-quarter the energy and double the spark means four times the energy nearly. Hence the total energy per jig remains the same.

Now in order to keep the same number of jigs per second and still get the 16 mm. spark it will be necessary to use a transformer of higher step-up. To attain this end the two halves of the secondary winding of the transformer are kept separate in that instrument, and their terminals brought out to a well-insulated series-parallel switch. By this means we get a small step-up but large current output when the two halves are in parallel, an arrangement suitable for charging the larger condenser; whereas when they are in series we have double the step-up but a small current, which is what we require for charging the small condenser.

It is easy to remember that the transformer secondaries should be in series when the condensers are in series, in parallel when the condensers are in parallel.

It is here again that the superiority of the impedence over the choking coil obtains. If we had a choker, it would be necessary to have it adjustable, so that the large value of the inductance could be taken when the condensers were in series, but the small one used when they were in parallel.

The impedence coil, on the other hand, needs no alteration, provided that the alteration in the capacity of the condenser be in the ratio of 1 to 4. If this be the case, as in the instance just discussed, and if the transformation ratio be altered accordingly in the proportion of 2 to 1, it is clear that the total LS value of the charging circuit remains unaltered (*see* p. 206). For this reason:—The inductive effect of the impedence coil on the secondary circuit has been shown to equal that of its own inductance multiplied by the square of the step-up. Hence with the large condenser we have the small step-up and the small inductive effect of the impedence coil. With the condenser reduced to one quarter of its previous value we have double the step-up, the step-up squared is four times its previous value, the inductive effect of the impedence coil being therefore four times what it was before. The capacity is decreased and the inductive effect increased in the same ratio, so that the product of the two remains the same.

When calculating out the power necessary to supply a circuit we must be on our guard against one error which is liable to creep in.

The capacity of a condenser is found to remain constant for steady pressures, but, as the frequency of the current gets higher, condensers have an apparently smaller capacity.

This is quite independent of the alteration of the capacity of a Leyden jar owing to brushing, so that it is an effect independent of the voltage, having merely to do with the frequency. Careful measurements of the capacities of glass, ebonite and air condensers at different frequencies tend to show that the capacity of an air condenser is constant for all frequencies, whereas those of the other condensers are constant for all frequencies between 25 and 400 cycles, but fall considerably when the frequency gets high enough to be called "oscillatory" (*see* p. 18), that is, of the order of 100,000 cycles.

The low frequency capacity of an ebonite condenser is about 5 per cent. higher than its oscillating capacity.

Thus, we may now take another example.

An ebonite condenser of 190 jars (oscillating frequency) discharges across an 8-mm. gap 350 times per second. What power is taken from the transformer?

The capacity from the point of view of the charging circuit $= 190 + \left(\frac{5}{100} \text{ of } 190\right) = 200$ jars, approximately.

The spark voltage is about 26 kilo-volts.

Energy per jig $= \frac{1}{2}SE^2$ joules.

$$= \frac{200 \times 26 \times 26 \times 10^6}{2 \times 9 \times 10^8}$$

$= 75$ joules.

Pressing the key continuously we have

Power $= 75 \times 350$ joules per sec.

$= 26{,}000$ watts.

$= 26$ K.W.

The signalling power will be less than this, but since the efficiency of the transformer could not exceed 97 per cent., and that of the alternator and the motor that drives it 70 per cent., the total direct current signalling input will not fall far short of 21 or 22 K.W.

It will now be convenient to study the current in the different parts of the circuit.

The current flowing into the condenser will have a maximum value = pSE where E is the spark voltage and S = farads.

If we are getting 350 sparks for 350 ~ f = 350, p = 2,200.

$$C_2 \text{ max.} = \frac{2{,}200 \times 200 \times 26 \times 10^3}{9 \times 10^8}$$

$$= \frac{2 \cdot 2 \times 2 \times 26}{9}$$

$= 12 \cdot 7$ amps.

Now the R.M.S. value of the current supplied by the secondary of the transformer (while the key is pressed) will be less than ·707 times this value, because during the first half-cycle the circuit is getting up its swing, and the current is not so big as it is just before the gap gives way.

However, we have roughly

$C_2 = \cdot 6$ of $12 \cdot 7$.

$= 7\frac{1}{2}$ amps. R.M.S.

The primary current C_1 will be found by multiplying C_2 by T, the step-up (neglecting losses). Suppose T to be 20 : 1.

Then

$C_1 = 20 \times 7\frac{1}{2}$.

$= 150$ amps. R.M.S.

The signalling current will be about 70 or 80 amps. R.M.S.

This multiplied by the R.M.S. volts will give the apparent mean signalling watts, which, as we have seen, is about 25 K.W. This means that the A.C. low-tension volts will be about 350–400 R.M.S.

It will be seen that the high-powered set in question entails a considerable secondary current, so that the transformer secondary winding is made of fairly thick wire, in order to keep down the copper loss and prevent heating.

We will now see at what rate (that is, the power at which) the installation works during the life of the jig.

The charging circuit is kept in a state of quiescence by the electrical inertia of the inductive circuit. The oscillatory circuit, however, displays surprising activity.

Suppose the wave-length sent out by the small set above exemplified to be 2,300 feet. The LS of the discharging circuits would be

$$\left(\frac{2{,}300}{206}\right)^2 \text{ or } 124{\cdot}5 \text{ mic jars.}$$

The frequency would be $\dfrac{4{\cdot}8 \times 10^6}{\sqrt{LS}}$ cycles

$$= \frac{4{\cdot}8 \times 10^6}{11{\cdot}15}$$

$$= 4{\cdot}3 \times 10^5 \text{ cycles.}$$

The time period $= \dfrac{1}{4{\cdot}3 \times 10^5}$ secs. or

$$= \frac{1}{\cdot 43} = 2{\cdot}32 \text{ micro-seconds.}$$

Now assume the damping to be such that 10 complete cycles are performed before the swings become so feeble as to be negligible. The jig therefore lasts 10 × 2·32 or 23·2 micro-seconds.

Now the jig commenced with four joules of energy (*see* p. 43).

At the end of 23·2 micro-seconds this energy has been dissipated—partly as heat, but also in the form of electro-magnetic waves.

In $\dfrac{23{\cdot}2}{10^6}$ seconds four joules are used.

In one second $\dfrac{4 \times 10^6}{23{\cdot}2}$ joules would be used if energy were dissipated at the same rate for one complete second.

During the discharge, then, the oscillatory circuit does work at the rate of

$$\frac{4 \times 10^6}{23{\cdot}2} \text{ or } 1{\cdot}72 \times 10^5 \text{ joules per sec.}$$

This is an "activity" of 172,000 watts or 172 K.W.

The aerial, therefore, radiates energy intermittently only, but while it is radiating, albeit the time during which it does so is short, the violence of its activity is enormous.

Now while the jig is going on, the voltage will be gradually dropping on account of the damping. Assume that the mean voltage throughout the jig is half the R.M.S. value of the initial voltage.

In our example, this latter was 21 kilo-volts maximum value.

Hence the mean voltage of the whole jig would be about

$$\tfrac{1}{2} \times \cdot 707 \times 21 \times 10^3 \text{ volts.}$$
$$= 7 \cdot 43 \text{ kilo-volts.}$$

Now the mean power of the jig was 172 kilo-watts, so that if watts = C × E,

$$\text{The current (in kilo-amps)} = \frac{\text{K.W.}}{\text{kilo-volts}} = \frac{172}{7 \cdot 43} = 23.$$

The primary current therefore is 23,000 amps., an astonishing result, considering the apparently feeble circuit in question.

It is because this enormous current is so short-lived that it does not melt the conductors of the primary; but it must not be forgotten that the current is really there, and that provision must be made for carrying it without undue ohmic loss and consequent resistance damping.

For this reason the primary of the oscillating system is made of large-sized copper tubing. Owing to the "skin effect" of high frequency currents a tube is as good a conductor for jigs as is a solid rod of the same material. This is a phenomenon which will be discussed later.

The figures and calculations in the above examples do not profess to any great degree of accuracy, but at any rate they will give the reader an idea of the dimensions of the quantities in which he deals in the different parts of his transmitting circuit.

It has been noticed that the primary receives a certain amount of energy fairly slowly and that it parts with it at an enormous rate.

Now it is never fair to spark into a primary oscillator for a long time at a stretch, unless that oscillator be provided with some means of getting rid of its energy.

Unless the aerial be connected up and unless the aerial be fairly in resonance with the primary, the latter will be unable to get rid of its energy in the form of electro-magnetic waves at all, so that the energy must take the form of *heat*.

If the primary inductance is made of a coil of large copper tubing, as will probably be the case, the coil will not get hot, but the condenser will. This might not matter if a glass plate condenser were being used, but it will seriously damage an ebonite condenser if the heat be allowed to accumulate in this manner. Now it may sometimes be desired to spark fairly continuously without creating any disturbance in the ether—that is to say, with the aerial disconnected. An occasion like this might arise when testing a magnetic key for endurance under normal full-load conditions. It is a matter of common experience that signalling with loose coupling heats up the condensers more than if the coupling be tight.

The best way to avoid heating up the condensers by this cause (except when the aerial is connected) is to insert a piece of fairly thin wire in series with the primary coil. This wire will get hot and will thus radiate the heat harmlessly away into space. Another way would be to allow the magnetic field due to the primary coil to generate eddy-currents in an iron plate hung near to the place usually occupied by the mutual coil.

Limitations of Power applicable to Ships.

As has been noticed already, the size of a ship's aerial is not very great. It is, therefore, quite possible to overload it to such an extent that it commences to "brush." Now this may be due to using too tight a coupling (*see* p. 67), but if we fix the coupling as low as, say, 4 per cent., we may still be overloading the aerial and causing it to brush.

This brushing, being evidence of an excessively high voltage in the aerial, will, of course, be more marked with very long waves than in the case of those which are but little longer than the natural wave-length of the aerial.

This is because the longer waves necessitate the use of a great deal of artificial inductance in the shape of the aerial coil, and it is the back E.M.F. of this inductance that produces the very large voltage across the deck insulator, which shows itself further as brushing. However, taking the most favourable wave-length, that is, that which is just a little longer than the natural wave-length of the aerial, we see that the brushing limit will be reached by an overdue increase of the initial energy of any one jig.

In other words, there is a certain fixed limit beyond which it is no good increasing either the primary condenser or the length of the spark.

The 44 joules represents about the limit that can be used effectively in a ship's aerial, and corresponds to an 8 mm. spark with 160 jars or a little more than a 16-mm. spark with 40 jars. This would suit a large ship whose aerial will have a natural wave-length of, say, 1,500 feet. For smaller ships such a set would be over-large, a 6-mm. spark on 45 jars being sufficient, while a destroyer might use 8 mm. on about 16 to 18 jars with advantage.

Now since the energy per jig is limited, what shall limit the number of times we use that energy per second? It is upon this that the power installed will depend.

When telephonic reception is used it is found that each jig in the transmitting circuit will produce one "click" in the telephone diaphragm. The frequency of these clicks will determine the "pitch" of the note heard in the telephones.

A high spark frequency, therefore, gives a high-pitched note while a slow spark frequency gives a low-pitched note.

To give out the note equivalent to the middle "C" on the piano, the telephone diaphragm must vibrate 256 times a second. The "octaves" higher or lower take double as many and half as many vibrations respectively. The human ear can distinguish notes of frequencies varying from 16 to 33,000 per second, but it is thought that the most sensitive hearing is obtained when we are listening to that part of the gamut which corresponds to the middle of the piano scale.

From the point of view of the human ear, therefore, everything points to a frequency of a few hundreds being the best.

When we come to consider the frequency at which the telephone diaphragms vibrate most easily we find that they possess a natural frequency considerably in excess of 200 or 300, being most sensitive to impulses of a frequency of the order of 800 or 900.

It seems possible, then, that if we use a machine giving about 350 ~ and taking one spark per cycle, we should obtain a good note for the human ear, about the "F sharp" above the middle "C," whereas if we closed up the spark-gap so that we got one spark per half-cycle we should get a note an octave higher, to which the human ear might not possibly be so sensitive, but which would produce a proportionately louder noise in the telephone because its frequency is more suited to that of the telephone receivers. Lately great advances have been made with very highly pitched notes. These are the considerations which fix the limits on the best spark frequency and so on the power used.

A peculiar effect is to be noticed if we put the spark half-way between the two original places. There will be too much voltage to give but one spark per cycle and not enough to give two sparks per cycle. In the telephones at the other end it will be possible to hear apparently the high and the low notes going on simultaneously with possibly the superimposition of intermediate notes (like those on a bugle) which are called the "harmonics" of the fundamental lowest note. The whole thing sounds as if someone were playing a chord by striking several strings on a fiddle.

The value of a musical note at the receiving end for reading through or over atmospheric or other interference cannot be over-estimated, and will at once be recognised by anyone who hears the musical spark for the first time.

As has been previously indicated, a musical note, or, as we may call it, a "singing spark," may be obtained by using a frequency of supply of the order of 300 cycles. Now it is not commercially practicable to make a rotary converter to give this high frequency, so that sets designed to give a musical note by this means must be provided with a motor alternator. We have seen that the voltage of the A.C. mains from such a machine may be varied by altering the strength of the exciting current in the field magnet windings of the alternator.

Now in order to get the true 300 sparks per second, one per cycle, it will be necessary to adjust the A.C. voltage to suit the particular spark-length we are using, more volts being required for a long than for a short spark in order to keep the spark frequency the same.

Too much voltage with a small spark will give too many sparks, and the note will be consequently mixed up with higher harmonics. Too few volts, on the other hand, with a long spark will give too few sparks, so that the note will be "gruff" and ragged. In practical work too much attention cannot be paid to this adjustment. The spark must be just long enough to get the requisite range and the voltage then altered till the best note is heard in the transmitter's telephones.

It has already been mentioned that a high spark frequency tends to the formation of an arc between the balls. This will inevitably ruin the purity of the note at the receiving end, and must be avoided. Where a fixed gap of the ordinary pattern is used it is found that a powerful blast of air is necessary in order to get rid of the arcing. The conditions to be fulfilled are that each new jig shall have a new piece of air to traverse—in other words, the air between the balls must be changed every $\frac{1}{300}$th of a second. The air-blast, in addition to changing the hot air between the balls for cool, also helps to keep the spark electrodes cool, "gills" or fins being formed upon the leading-in conductors in order to provide a large cooling surface. If a small spark be used it is possible to get one spark per half cycle, but it then becomes necessary to provide an additional impedence coil to prevent arcing.

When A.C. is used to charge up the condenser, there is no doubt that the ideal form of spark-gap is the synchronous rotating one. The principle is that a star-shaped or studded wheel, revolving between two fixed electrodes, is driven at such a speed that two opposite spokes will sweep past the fixed studs at intervals exactly corresponding to the frequency of supply.

This might be accomplished by driving the wheel direct on the same shaft as the alternator, giving the wheel half as many spokes as there were poles on the alternator field, supposing one spark per cycle were required.

A very easy adjustment of the wheel on the shaft would then make it possible to ensure that no spark could pass unless the E.M.F. were at its maximum value. The difficulty of arranging such a rotating gap in a ship would be almost insuperable unless the transmitting and receiving instruments could be placed in separate compartments, but at Machrihanish this system was most successfully used by Professor Fessenden for trans-Atlantic signalling, the purity and penetrating quality of the note being most remarkable.

Another method of producing a note is by means of the non-synchronous rotating gap. In this system a low frequency supply should be used and a revolving studded wheel driven by a separate small auxiliary motor. The speed of the wheel has no predetermined connection with the frequency of supply, and no attempt is made to produce an absolutely regular succession of jigs. All that we can do with this arrangement is to break up the spark into a succession of small sparks, giving the spark some 600 "opportunities" to pass per second. The clearance between the fixed and moving studs must be made very small, so that instead of a few large sparks passing between fixed balls we have an equivalent amount of energy radiated per second in the form of many small sparks. It is hopeless to expect a perfectly pure note from this device, because twice in every cycle the supply voltage cannot help falling to zero. Whenever this happens one or several "opportunities" for a spark to pass must be missed.

As a general rule it is found in practice that the most penetrating note is obtained, and the one most nearly pure, when the speed of the studded wheel is as high as possible and the clearance of gap very small. A further adjustment may be obtained by altering the frequency of supply slightly, the step-up of the transformer, and the value of the impedence in the circuit.

The non-synchronous rotating gap is pre-eminently suitable, until some better arrangement presents itself, for small power sets supplied from rotary converters.

To judge when the note is as good as possible, it is found that listening in your own telephones—that is, those in the actual transmitting office—does not give very reliable results.

It is better to take a detector to a casemate or cabin a few yards away from the office, push a little artificial aerial, consisting of a few feet of Patt. 611 wire, out of the scuttle or port, and listen in the telephone, while someone else makes trial of the adjustments above indicated.

A new method of producing a "singing spark" has lately come into use, one such system being that of Baron von Lepel.

The Lepel System.

The Telefunken Company have a similar system, which they call the "quenched spark."

The Lepel system appears to work but poorly with alternating current, the best note being given by D.C. at about 400 volts.

Briefly, the system consists of an oscillator forming the primary of a sending circuit, whose condenser is large, being about 500 jars. The spark-gap consists of two or more copper electrodes in the form of discs. These are piled up one on top of the other with a minute gap between them formed by one or two discs of foreign notepaper having holes about 1 inch in diameter through their centres. The copper discs are provided with gills to radiate away the heat, and the whole group of electrodes form either a single or multiple spark gap of very small length, which is called the "generator." Coupled very tightly to this primary oscillator, both directly through the generator and inductively through an oscillation transformer, we have the aerial wire system having a small aerial coil for fine adjustment.

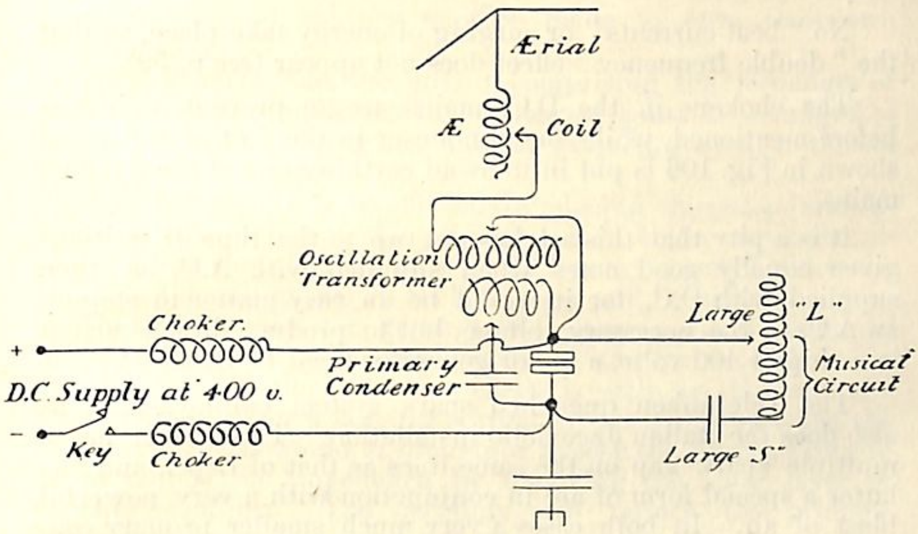


FIG. 106.

When the generator is supplied with direct current through a pair of "chokers," oscillations of high frequency having jigs almost continuously going on, form in the primary and are radiated by the aerial. The tight coupling is necessary in order to get rid of the energy directly it is formed in the primary. Now if such waves were received by an ordinary receiving circuit very little noise indeed would be heard owing to the high spark frequency. It would only appear as a prolonged hiss in the telephones. The production of the musical note is effected by joining in parallel with the primary another oscillating circuit whose LS value is very large indeed, so that its natural frequency is equal to the vibration frequency of the note which it is desired to emit. This low-frequency circuit will superimpose its oscillations on the top of the jigs and will cause them to assume an intermittent form instead of being of the nature of continuous undamped oscillations.

There is no doubt that this system, if properly tuned and properly adjusted, does emit a most beautiful note more like that of a bugle than anything else, and that fair distances can be covered with a small expenditure of power.

The tuning and adjustments, however, are critical and troublesome, and at present there seems to be a difficulty in making the set capable of sending out a large range of different wave-lengths.

Other advantages are undoubtedly that the pressure in the aerial is small owing to the minute gap used, and owing to the rapid quenching of the spark only one wave is emitted as the primary hands over its energy to the aerial practically in one or two swings, the aerial then radiating at its own natural frequency.

No " beat currents " or surging of energy take place, so that the " double frequency " effect does not appear (*see* p. 59).

The chokers in the D.C. mains are to prevent arcing as before-mentioned, while the condenser in the foot of the aerial shown in Fig. 106 is put in to avoid earthing one of the dynamo mains.

It is a pity that this set has not (up to the time of writing) given equally good notes when supplied with A.C. as when supplied with D.C., for it would be an easy matter to step-up an A.C. to the necessary voltage, but to produce direct current in a ship at 400 volts, a motor-generator must be installed.

The Telefunken quenched spark system employs A.C., as also does the Italian Jacoviello installation. The former has a multiple spark gap on the same lines as that of Lepel, and the latter a special form of arc in conjunction with a very powerful blast of air. In both cases a very much smaller primary condenser is used with tight direct coupling, and the auxiliary musical circuit is dispensed with.

The whole secret of the quenched spark effect is to restore the insulation of the spark gap at the instant when the current in the primary has fallen to zero at the end of the first " beat." At this instant the whole of the energy is in the aerial, so that if we can chill the gap sufficiently rapidly its ohmic resistance will now be so high that the aerial cannot hand back any of its energy to the primary by causing the latter to oscillate again, but must get rid of its energy entirely by radiation. It thus oscillates at its own natural frequency, just as would a " plain aerial," but in this case its damping is not caused to be unduly great because there is no spark gap in the aerial.

These systems are sometimes said to operate by " shock." That means that the energy is imparted to the aerial in the form of a sudden shock, while the aerial oscillates with a damping due practically only to radiation.

Now that telephonic reception is almost universal, it is to be anticipated that the importance of musical notes is greatly on the increase.

Induction coils with A.C.

We will now give a few hints with reference to the use of coils with A.C. for charging condensers.

Coils are not efficient transformers, owing to their secondary windings being of such high resistance and also to the fact that their open iron magnetic circuit causes them to take rather a large "magnetising current" (*see* p. 138).

Since they are not so efficient they cannot be said to follow exactly the laws governing the use of transformers. For one thing their inductance, even when on full load, is always considerable, and so they may be made to form their own impedence coils.

As a general rule, the circuit comprising the secondary of the coil and the condenser to be charged, must be arranged to have an LS value giving it a natural frequency equal to that of the alternating supply.

This can generally be effected by placing the secondaries in series or parallel, but the primaries had better never be in series since the choking effect will be very great, besides the fact that the voltage across each primary will be halved.

Using two coils, the greatest total step-up will be attained by connecting the primaries in parallel and the secondaries in series. Now if the inductive effect is still too big and the rotary should show a lagging current by speeding up when the key is pressed, it would at first sight appear the proper thing to do to reduce the impedence by removing the outer layer of primary winding. You certainly will reduce the primary inductance by so doing, but you are also increasing the step-up. Since the inductive effect of the primary depends upon the square of the step-up (*see* p. 144) we shall probably find that we have made things worse. For this reason two four-layer coils in parallel will have a smaller impedence effect than will two three-layer ones.

For charging a large condenser we shall in general require both coils in parallel.

For a small condenser it will be best to join the secondaries (at any rate) in series with each other and possibly to use only one of the primaries. For very small condensers—such, for instance, as for "plain aerial"—it will be best to use one coil only, inserting the secondary of the other coil in series with the high-tension mains as a choker. In all cases, a large capacity calls for a low and a small one for a high charging frequency.

The same applies to using D.C. with hammer make-and-break. To get the best spark with D.C. on plain aerial, use the secondaries of two coils in series and the primary of one coil only, leaving the primary in the other coil merely for the sake of the iron core.

CHAPTER X.

The Transmitting Circuit Complete.

Fig. 107 shows a typical transmitting circuit, from which that of any particular installation may indeed differ considerably in detail, but with which general similarity will always be found.

The general principles of the circuit are already familiar to us. Briefly we have D.C. supplying a rotary converter or motor alternator. The machine is below armour and the starter and field regulator (or regulators) are in the office, whether that be below armour or not. From the slip-rings come the A.C. mains in series with which we have several safety arrangements, the signalling key, and finally the primary of a step-up transformer. Across these mains we may have a voltmeter, but this is not necessary when a rotary converter is fitted, for the volts cannot be varied. Anyhow we shall probably have a frequency meter, and if this instrument be supplied alone it is well to connect it across the mains somewhere between the cut-outs and the transformer, for then if the frequency meter show anything we know at once that not only is the machine running but also that the cut-outs in the A.C. mains have not "blown." The terminals of the secondary winding of the transformer are connected to two bare copper wires carried on porcelain insulators. These constitute the high-tension mains, and together with the primary of the oscillator must be regarded as the most dangerous parts of the circuit to touch.

Most of the other devices shown in the figure are safety arrangements of some kind. It is with these that we now have to deal.

Safety Arrangements.

The safety arrangements can be divided into two rough headings :—

(1) Those intended to protect life ;

(2) Those intended to prevent damage to instruments.

Now to take the protection of life first. Normally in a small spark installation where a rotary converter is used the voltage of the A.C. mains is not to be regarded as dangerous, for its value never exceeds that of the ship's D.C. mains even when at its maximum. For a shock to prove fatal about a quarter to half an ampère of current will be necessary, 1 ampère being certainly enough to kill a man. Now the resistance of the human body varies in different individuals, and also the danger of the shock will depend on the state of health ; but nominally the resistance of a man from one hand to the other is about 2,000 ohms. A

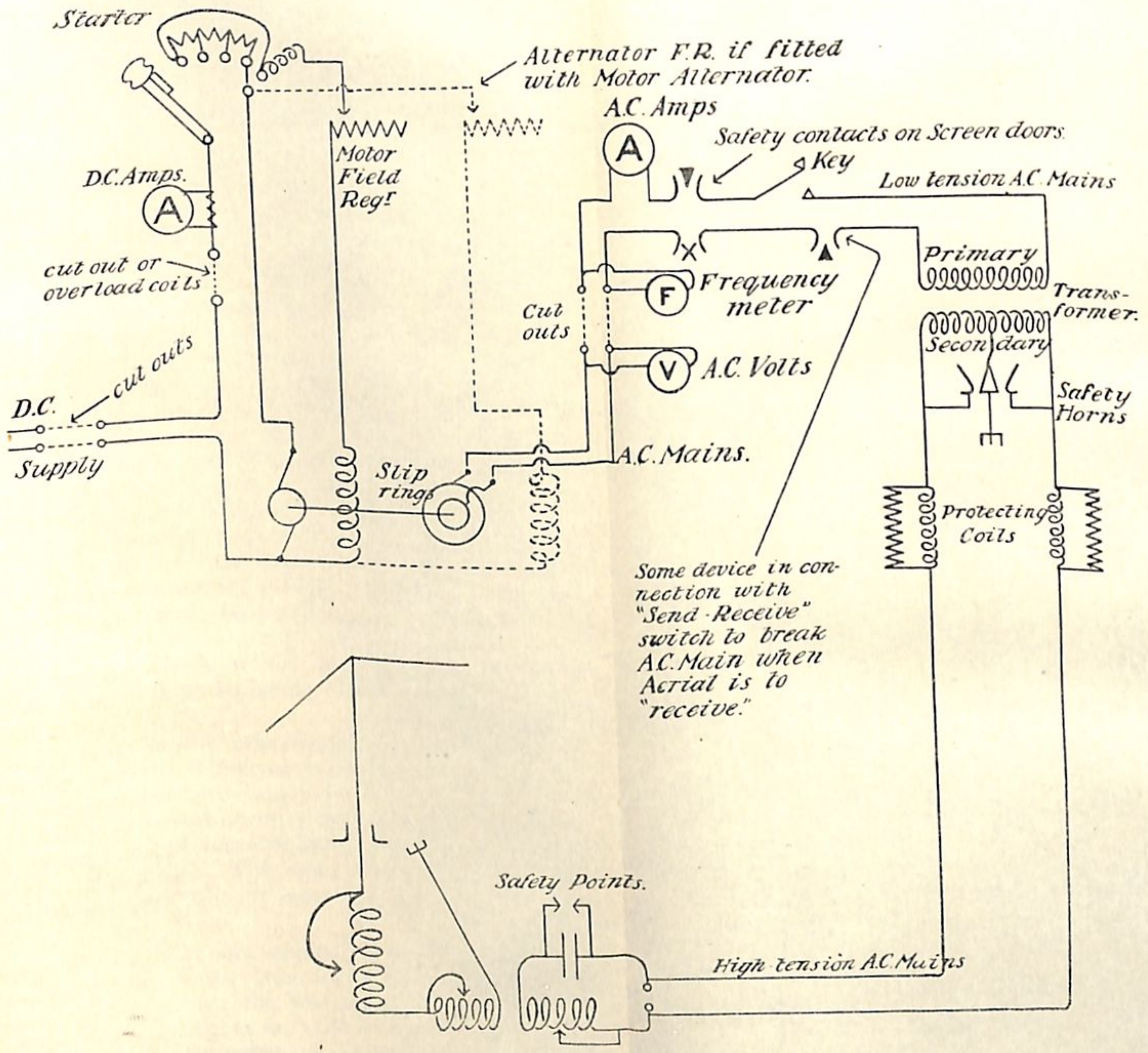

Starter
Alternator F.R. if fitted with Motor Alternator.
A.C. Amps
A
Safety contacts on Screen doors.
Key
Low tension A.C. Mains
D.C. Amps.
A
Motor Field Reg.r
cut out or overload coils
Primary
F
Frequency meter
Transformer.
Cut outs
Secondary
V
A.C. Volts
cut outs
Safety Horns
D.C. Supply
A.C. Mains.
Slip rings
Protecting Coils
Some device in connection with "Send - Receive" switch to break A.C. Main when Aerial is to "receive."
Safety Points.
High tension A.C. Mains

FIG. 107.

shock down the spinal cord is far the most serious. In order to prove dangerous, therefore, the voltage must have a maximum value of about 400 or 500, although a fatal case has occurred of 200 volts alternating R.M.S. This, however, was in exceptional circumstances when the victim was partially immersed in a swimming-bath. A rotary converter running in a 100-volt ship cannot give a dangerous shock to one touching the slip-rings or low-tension A.C. mains, but the mild shock felt will be more disagreeable than that from the same ship's D.C. mains, due to the alternating or impulsive character of the current.

Where a motor alternator is used giving a voltage of about 400 R.M.S., we must regard this pressure, although the part of the circuit is called the "low-tension mains," as being dangerous.

The rendering of these cables inaccessible unless the leads are broken close back near the machine involves encasing them in leaden tubes and enclosing in metal boxes the places where the conductors are exposed for connections. The lids or covers of these boxes must automatically break the A.C. mains where they first enter the office. This result is attained by using a rather complicated "safety circuit" carrying direct current, which circuit is broken immediately one of the boxes referred to is opened. The breaking of these wires switches off current from a solenoid or sucking magnet, the latter operating a double-pole break in the A.C. mains.

In small sets these precautions are not necessary.

Now take the leads from the secondary of the transformer. They will certainly be at a dangerous voltage, and if a transformer be in use the shock would be very severe indeed, even in small sets, and undoubtedly fatal in medium and large sets.

An induction coil, on the other hand, gives a very high voltage certainly, but the "internal resistance"—that is, the resistance of the secondary winding itself—is of the order of 10,000 ohms, so that sufficient current cannot be drawn from the terminals to prove fatal, of however low resistance may be the human body at the time. The same reason prevents the firing of an electric gun-tube by means of a Menotti Daniell cell.

To render the high-tension mains inaccessible we might enclose them in a lead casing from which they would have to be highly insulated, but then the primary of the oscillator is in direct connection with them, so that it is much simpler to cover in the whole circuit by means of an iron cage or screen. The latter is earthed to the side of the office, so that it is always safe to touch.

The opening of either of the doors of the screen must automatically render it impossible to get any current through the primary of the transformer. These safety contacts on the screen doors are indicated in Fig. 107.

If the transformer be situated outside the screen care must be taken that the secondary terminals are inaccessible unless the primary leads be disconnected from the A.C. mains.

Again, if the cage be large enough for a man to get inside it, the fastening of the door must be capable of being closed from the outside only. Thus it is only by collusion between two men that anyone could possibly touch a "live" high-tension wire.

The aerial circuit must often of necessity be situated outside the screen, but the shock from the aerial will probably not be fatal of itself, because, although the voltage is enormous and the resistance but small, the high-frequency current will flow only on the skin of a person touching it, and but little shock will be felt. The shorter the wave-length the less will be the shock because the frequency is higher. Until recently no case had occurred of a man taking a long spark from the aerial of a large power set; but one has now happened in which the aerial sparked about 10 inches into a man with no evil effects. However, it is necessary to place a guard screen around the feeder where it issues from the roof of the W.T. office, and also arrangements must be made so that no one goes aloft when the ship is sending, for the true danger of the aerial shock lies in the fact that if a man aloft gets but a small shock from the aerial, or even from the induced current in a wire stay, he will probably loosen his hold and fall down.

It is difficult to say whether a man holding on to the aerial and touching nothing else would receive a shock or not. Birds sitting on the roof wires have been observed to fall off into the water, but whether they were electrocuted or drowned is not apparent.

Protecting the Instruments.

Instruments have to be protected against—

(1) Accidental excess currents and pressures due to faults in themselves.

(2) The large back E.M.F.s of locally induced high-frequency currents.

Taking the first cause of damage. We have seen that the D.C. supply mains to the rotary converter or motor alternator, and also the A.C. low-tension mains, are protected against burn-outs due to excessive current by means of double-and-single pole cut-outs, and also possibly by an overload coil in the starter of the machine. The double-pole cut-outs in the alternating mains may possibly be dispensed with, for if a short-circuit develops in these mains, a very large direct current input will be called for to the D.C. side of the machine, so that the D.C. overload coil will operate, or else the D.C. cut-outs will blow.

For the same reason it is not necessay to fit cut-outs of fine wire in the high-tension mains from the secondary of the transformer, for a short-circuit here will cause a very large A.C. low-tension current to flow into the primary of the transformer. Further, cut-outs in a high-tension wire are dangerous things to have fitted, for if they blow there is a great danger of fire since they arc and fly all about.

The fusing of cables or melting of insulation due to the large heating effect of excessive currents is thus prevented in all parts of the circuit.

Now the insulation of cables is designed to give safety at all normal voltages likely to be met with. Take now the secondary of the transformer, as shown in Fig. 108. Suppose that we are getting an R.M.S. voltage of 10,000 across the terminals. The maximum voltage, which is what will strain the insulation most, will rise to 14,000 volts each way—that is, each terminal will alternately become at a pressure of 7,000 volts above and below "earth" potential, or "zero." The thickness of the insulation on the secondary winding of the transformer is calculated so as to be sufficient, with a fair margin of safety, to stand this pressure.

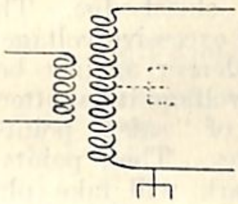


Fig. 108.

If, now, an earth leak were to develop on one side of the transformer, the terminal on this side would automatically be fixed at zero potential. Hence the other end of the winding would be alternating between 14,000 volts above and below earth instead of 7,000 volts. Since the casing and core of the transformer are connected to earth it is evident that the insulation of the winding of the secondary of the transformer will be excessively strained at this point. To obviate this, the centre point of the secondary winding is permanently connected to earth, which therefore prevents the outer ends becoming at a greater potential above or below earth than their normal 7,000 volts. Under these conditions, should a "dead" earth develop at one terminal of the winding, that half will be put on short-circuit, the condenser will only get half its proper pressure, the spark, if large, will fail, while the short-circuited half will call for a large primary current, excessive A.C. primary current will flow and probably the A.C. cut-outs will blow—if not, then those in the D.C. mains supplying the machine. If it is but a small leak, there will be more than the normal A.C. flowing and the spark will fall off in quality.

In addition to this, the transformer is protected against any excessive rise in its own voltage by having safety-horns fitted across its terminals. Where the centre point of the winding is earthed we generally have the gap between the horns subdivided into two portions, the centre horn being earthed.

The gap or gaps between the horns is so arranged that if the terminal voltage of the secondary rise above its normal working limit, then an A.C. high-tension metallic arc will form across the gap. This arc, due to its own heat, will rise, sliding along the wires. The higher it rises the longer becomes the gap which it must bridge, so that it automatically blows itself out. The peculiar whistling noise of such an arc is quite distinctive and will warn the operator that an excessive voltage is being generated.

Further, there is no mistaking the appearance of a metallic arc from that of an oscillatory spark. Whereas the latter is brilliantly white and crackling, the former is purplish red and furry in appearance and is more silent.

The bends of the wire forming the safety horns must be kept the exact prescribed distance apart, and the points of nearest approach are generally chamfered off so as to present to each other a sort of blunt chisel-edge. This edge assists in the formation of the arc if excessive voltage be reached.

To protect the condenser against being punctured by such an abnormal rise of voltage it is fitted with an automatic discharger in the form of "safety points" or "discs" the latter having sharpened edges. These points or edges are set at such a distance that a spark will take place before the terminal pressure of a condenser rises to such a value that the dielectric would be likely to be punctured. It is important, after sparking has taken place across these points or discs, that the points should be re-sharpened and reset, or that a fresh unburnt piece of disc should be turned into position. Otherwise the limiting voltage will be raised and the safeguard disappear.

It should be noted that if several condensers be placed in series, it is not quite safe to rely on having a pair of points for each condenser, but another pair of points, right across the whole system should be used, because otherwise one of the pairs of points might be a shade closer together than are the other ones. In this event that pair would be the first to "go," leaving the other condensers to stand a very sudden "rush" of excess voltage with which the other points might not be able to deal before damage ensued.

It is commonly the practice, where several condensers are employed in series, to earth the centre point of the centre condenser. This ensures that the safety points and safety horns are correct and also equalises the capacity to "earth" of each condenser. This earth connection is not shown in Fig. 107, since it will be differently arranged in different condensers.

It is not necessary that these earth connections above referred to should be made on to the main earth of the W.T. office, since the currents they carry have nothing to do with the transmission of signals, but they should be made on to the iron of the ship by the shortest and least inductive leads possible.

Protection against Induced Currents.

An unarmoured cable running near any oscillatory circuit will have high frequency currents induced in it, so that if it present any inductance at all, there is the certainty of a high back E.M.F. appearing at its ends. To prevent this happening to cables whose insulation is not designed to stand very high pressures, we must screen the leads by enclosing them within a conducting pipe. This is effected in the case of the D.C. supply, safety and lighting circuits of the office, by wiring them with lead-cased cable, the lead casing of which must be earthed at frequent intervals by means of short, non-inductive strips of metal. This is a point which is liable to receive but scant attention, especially the fact that where a cable leaves off, say at a cut-out or instrument, and goes on again beyond it, the lead casing should be connected up across the break as shown in Fig. 109.

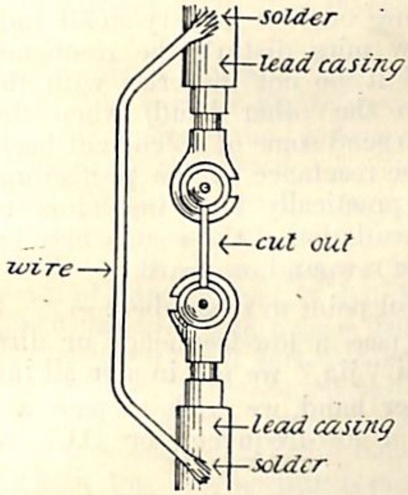


FIG. 109.

Another way is to place high-resistance carbon rods between the core of the cables and earth or even by means of Leyden jars connected in the same manner, for the jar will allow any high frequency induced current to pass harmlessly away to earth, but will efficiently stop any leakage of low-frequency or direct current.

There is no doubt that the fact of the high-frequency circuits being enclosed in a metallic cage will screen most of the low-frequency mains in the office from the inductive effects of the oscillatory currents; but any cable which passes within the confines of the screen *must* be lead-cased and its casing must be earthed at frequent intervals.

Protecting Coils.

There remains one other source of damage to transmitting instruments. When the condenser discharges across the gap there are really two circuits by which the current may flow. That which carries almost the whole of the current is, of course, the low-inductance circuit across the spark-gap. Nevertheless, the high-frequency current may also try to flow by the other path, namely back through the secondary of the transformer. Naturally a high-frequency current trying to take an inductive path will meet with enormous opposition, so that very little waste of energy will ensue; but it is this very opposition set up by the windings of the secondary that constitutes the danger. We see that the secondary produces a very large back E.M.F. against the passage of the high-frequency current. Consequently the back E.M.F. between turn and turn of the secondary winding may rise to a sufficiently high value to puncture the insulation between the turns. In order to prevent this effect we have a coil of wire of about 200 to 300 mics inductance placed in series with each high-tension main.

The back E.M.F. of these protecting coils to the low-frequency charging current is very small indeed, nor does the addition of a few mics disturb the resonance of the charging circuit, provided it be not in series with the *primary* of the transformer. On the other hand, when the high-frequency discharge tries to send some of its current back along the high-tension mains, the reactance of the protecting coils becomes so large that they practically form insulators to high-frequency currents. The insulation of these coils may be punctured; but they can easily be rewound on board.

This is a useful point to remember:—

If we wish to pass a low-frequency or direct current but to deny passage to a "jig," we put in a small inductance.

If, on the other hand, we wish to pass a "jig," but to bar the passage of a low-frequency or D.C., we use a small condenser.

Now protecting coils under certain circumstances have proved worse than useless. Being mounted on a baseboard the two coils have a certain small capacity effect between them. This capacity, combined with the inductance of the two coils, form an oscillatory circuit which may happen to have the same LS value, and therefore the same natural frequency as has the primary oscillator. Should this happen, then resonant currents will be set up in the protecting coils, high-frequency currents will be impressed on the end turns of the transformer windings, with the result that those turns will have their insulation punctured. Whether this effect is taking place or not can be ascertained by putting a small "point" spark-gap across each coil; if resonant currents should be flowing, then there will be a much larger back E.M.F. between the ends of any one coil than there ought to be; this large voltage exhibits itself as a spark.

This "local" resonance in the coils cannot be foreseen in any particular case, and might be obviated by rewinding the coils with a different number of turns of wire, but by then the damage might have been done, so it is better in any case to destroy the LS value of the small oscillating circuit by shunting the coils by means of high non-inductive resistances in the shape of carbon pencils.

Protecting Receiving Instruments.

The receiving instruments must be protected (1) against being sparked into direct from the transmitting installation, and (2) having induced currents set up in them.

The protection against the first danger is effected by some device which makes it impossible to spark unless the aerial be disconnected from the receiving set.

This is indicated in Fig. 107 by a break in the A.C. main which will not be closed until the aerial is to "send"; but the actual device used and its mode of operation will differ in the several Service installations. The handbooks will give all necessary information.

Should any high-voltage current find its way into the receiving instruments, the various lightning-arresters and the "breakdown fuze" will relieve the pressure before any of the receiving condensers are punctured.

To guard against (2) the induced currents, the receiving instruments are screened from the inductive action of the transmitting instruments by being placed inside the silent cabinet. The carcase of this cabinet is double, a false bottom and top allowing ventilation. The spaces between the inner and outer carcases are packed with felt, and between this layer of felt and the inner surface of the outer skin lies a complete cage of wire netting. The netting is electrically continuous all round the cabinet and also at the top and bottom. A gland is fitted by means of which the wire netting is effectually earthed.

It is hoped that the information contained in this concluding portion of the chapter may never have to be applied, since prevention is better than cure. The book, however would be incomplete without a reference to

Resuscitation from Apparent Death from Electric Shock.

The urgent necessity for prompt and persistent efforts at resuscitation of victims of accidental shocks by electricity is very well emphasised by the successful results in the instances recorded. In order that the task may not be undertaken in a half-hearted manner, it must be appreciated that accidental shocks seldom result in absolute death unless the victim is left unaided too long, or efforts at resuscitation are stopped too early.

In the majority of instances the shock is only sufficient to suspend animation temporarily, owing to the momentary and imperfect contact of the conductors, and also on account of the resistance of the body submitted to the influence of the current. It must be appreciated also that the body under the conditions of accidental shocks seldom receives the full force of the current in the circuit, but only a shunt current, which may represent a very insignificant part of the whole.

When an accident occurs, the following rules should be promptly executed with care and deliberation :—

1. Remove the body at once from the circuit by breaking contact with the conductors. This may be accomplished by using a dry stick of wood, which is a non-conductor, to roll the body over to one side, or to brush aside a wire, if that is conveying the current. When a stick is not at hand, any dry piece of clothing may be utilised to protect the hand in seizing the body of the victim, unless rubber gloves are available. If the body is in contact with the earth, the coat-tails of the victim, or any loose or detached piece of clothing, may be seized with impunity to draw it away from the conductor. When this has been accomplished, observe rule 2. The object to be attained is to make the subject breathe, and if this can be accomplished and continued he can be saved.

2. Turn the body on the back, loosen the collar and clothing about the neck, roll up a coat and place it under the shoulders, so as to throw the head back, and then make efforts to establish respiration (in other words, make him breathe), just as would be done in the case of drowning. To accomplish this, kneel at the subject's head, facing him, and seizing both arms draw them forcibly to their full length over the head, so as to bring them almost together above it, and hold them there for two or three seconds only. This is to expand the chest and favour the entrance of air into the lungs. Then carry the arms down to the sides and front of the chest, firmly compressing the chest walls, and expel the air from the lungs. Repeat this manœuvre at least 16 times a minute. These efforts should be continued unremittingly for at least an hour, or until natural respiration is established.

3. At the same time that this is being done, someone should grasp the tongue of the subject with a handkerchief or piece of cloth to prevent it slipping, and draw it forcibly out when the arms are extended above the head, and allow it to recede when the chest is compressed. This manœuvre should likewise be repeated at least 16 times a minute. This serves the double purpose of freeing the throat so as to permit air to enter the lungs, and also, by exciting a reflex irritation from forcible contact of the under part of the tongue against the lower teeth, frequently stimulates an involuntary respiration.

To secure the tongue if the teeth are clenched, force the jaws apart with a stick, a piece of wood, or the handle of a pocket knife.

4. The dashing of cold water into the face will sometimes produce a gasp and start breathing, which should then be continued as directed above. If this is not successful the spine should be rubbed vigorously with a piece of ice. Alternate applications of heat and cold over the region of the heart will accomplish the same object in some instances. It is both useless and unwise to attempt to administer stimulants to the victim in the usual manner by pouring them down his throat.

While the above directions are being carried out, a doctor should be summoned, who, upon his arrival, can best put into practice rules 5, 6, and 7, in addition to the foregoing, should it be necessary.

5. Forcible stretching of the sphincter muscle controlling the lower bowel excites powerful reflex irritation and stimulates an inspiration frequently when other measures have failed. For this purpose the subject should be turned on the side, the middle and index fingers inserted in the rectum, and the muscle suddenly and forcibly drawn backward towards the spine. Or, if it is desirable to continue efforts at artificial respiration at the same time, the knees should be drawn up and the thumb inserted for the same purpose, the subject retaining the position on the back.

6. Rhythmical traction of the tongue is sometimes effectual in establishing respiration when other measures have failed. The tongue is seized and drawn out quickly and forcibly to the limit, then it is permitted to recede. This is to be repeated 16 times per minute.

7. Oxygen gas, which may be readily obtained from a chemist in cities or large towns, is a powerful stimulant to the heart if it can be made to enter the lungs. A cone may be improvised from a piece of stiff paper and attached to the tube leading from the gas cylinder, and placed over the mouth and nose while the gas is turned on during the efforts at artificial respiration.

CHAPTER XI.

The Aerial Wire or Antenna.

We will now consider the principles of design and construction of the aerial wire system, often called the antenna.

The simplest form of radiator or antenna is a single metallic wire upheld in a nearly vertical position by an insulator from a mast, tower, or chimney, the wire being either bare or covered with insulation.

The Wire Used.

Since the high-frequency currents which are employed in the radiator flow only on the "skin" or surface of the conductor which carries them, it will be better to use several separate thinnish wires than one thick one.

If insulated wire be used in a ship, the insulation would very soon get covered with a semi-conducting film of soot, which, forming a skin to the wire, would carry a certain considerable proportion of the aerial current and therefore cause great resistance damping. For this reason bare copper wires have lately been used, the latest pattern consisting of three strands of about 20 gauge wire laid up together. This wire is very light and strong, but if used absolutely bare it is found that the action of the sulphur fumes from the funnels has a corroding effect upon the metal, causing it to become brittle and spoiling its "temper." The funnel gases combine with the moisture in the atmosphere, producing sulphuric acid, so that the practice is to cover the wire with a thin film of black enamel which resists the acid and protects the wire.

It should be remembered that this enamel must be carefully scraped away before making any junctions in the wire, for its insulation resistance is very high indeed in spite of the minute thickness of the coating. After a junction has been made the bared portion of the wire should be painted over with more enamel which is supplied for the purpose. This enamel is very volatile and if poured out into shallow dishes will quickly evaporate, becoming thick and useless. The tin should not be left open longer than necessary.

This importance of making all joints in the wire with the greatest possible care cannot be too much emphasised.

Although a badly-made aerial may send nearly as well as will a well-made one, on account of the transmitting energy being sufficient to "jump" any small break in the continuity of the conductor, yet when it comes to receiving, the minute currents will be unable to overcome any high-resistance junction and great loss of efficiency will ensue.

It is a troublesome job to make an aerial. Accordingly whenever a new aerial has to be made it should be made as carefully and as strongly as possible, with special attention being paid to the measurements of the wire. If these precautions are taken, the aerial when once up will remain up for a very long time without giving any trouble. It is advisable to lower the aerial as little as possible, for every time it is lowered something will be sure to get damaged.

The wire should never be soldered at any place which is going to be in a state of tension, for the temper is spoiled by the application of heat and the wire thereby rendered brittle.

All sharp points, roughnesses, burrs, and sharp bends or kinks must be smoothed off or otherwise avoided, because they assist in the leakage of energy in the form of brushing.

Brushing really is the commencement of puncture of the air dielectric of the aerial condenser (*see* p. 28).

Regarding the metal employed, we may notice that since the currents flow only on a very thin skin on the surface of the wire it is not of such vital importance to have very "low resistance" metal for the construction of an aerial as it is for the construction of a circuit which has to carry low frequency or direct current.

The chief thing is to avoid having a wire made of a magnetic material such as iron. A bare iron wire will, owing to its permeability which causes the "skin effect" to be much more marked, present an apparently enormous resistance to the passage of high-frequency currents unless it be overlaid with a film of non-magnetic substance such as zinc. A well-galvanised steel or iron wire will do very well for an aerial provided that the galvanising is not rusted off. Steel rigging wire, being stronger than copper wire of the same weight, is used for the aerials of destroyers, ships where it is most important that the aerial should not entail much supervision because there is but one operator borne, and because the sea-going conditions are much more severe than in a large ship.

Phosphor bronze makes a good material for aerials, and Professor Fleming speaks highly of aluminium. It is doubtful, however, whether this latter metal would withstand successfully the action of salt water or spray, especially if it were connected up to any metal other than aluminium.

Insulation.

The insulation of the aerial is a very important matter.

Defective insulation will account not only for a considerable loss of efficiency when transmitting, but also for a very large loss in receiving, especially in receiving waves which are much longer than the natural wave-length of the aerial.

One is only too apt to regard the minute currents and voltages found in the receiving circuit as being hardly worthy of high conductivity wires of high insulation, but the very fact of their weakness is the most cogent reason for not throwing away any of their puny strength.

Dielectric Leakage.

The first thing to notice in considering the insulation of any circuit destined to carry an oscillatory current is that any and every sort of insulation does not insulate. That is to say, that a piece of insulating material whose resistance to continuous currents may be millions of megohms, may be perfectly capable of transmitting the whole aerial current of a wireless station. The insulating properties depend not only upon the material used, but also very largely upon the shape of the insulator.

If the insulator be in the form of a thin sheet between large conducting plates, it really forms a condenser of considerable capacity, and the high-frequency aerial current will pass "through" it (*see* p. 106) with as little loss as if it were a thick conductor. We shall remember that the back E.M.F. of a condenser varies inversely as the capacity and the frequency. Accordingly, even a condenser of very small capacity (such as may be made by twisting two short pieces of insulated wire together) possesses a capacity which is not negligible and which, if subjected to a sufficiently high frequency E.M.F., may pass a considerable dielectric current. Two cases may be cited. If a large sheet of wire gauze or netting be suspended on insulators a foot or two above the ground, the condenser thus formed is capable of transmitting large currents, such as are used in transmission of W.T. signals, provided the frequency be high. The second case may actually happen in the receiving circuit.

If two insulated wires lie, or are wound side by side throughout a few feet or inches of their length, sufficient current may pass between them to actuate the receiver. This is not, of course, a leakage "conduction current" through the insulation, but a dielectric "displacement" current across the dielectric.

In many problems of wireless telegraphy this effect must be taken into account, more particularly in the design of oscillation transformers for use in the receiving circuit.

A "non-inductive" resistance—that is, a coil of wire wound on the bight—need not act as a continuous conductor at all when carrying a high-frequency current, and may possibly conduct such a current equally well when the bight is severed as when the conducting circuit is complete.

Insulation of any circuit, therefore, which is intended to carry jigs means not only high ohmic resistance of the material used, but also a very small capacity between the conductor to be insulated and other conductors, whatever they may be.

In the case before our notice the conductor we wish to insulate is the aerial wire itself, and the "other conductors" from which we wish to insulate it will consist of wire stays, the masts, decks and hull of the ship. All these things may be taken as being more or less connected to "earth," which forms one plate of the open oscillator, the wire itself forming the other plate.

It follows, therefore, that all the insulation for the aerial must be very *thick*, that is, the distance between the separated conductors must be large compared with their areas.

Surface Leakage.

It is also important that any path from one conductor to the other over the surface of the insulator should be very long if high transmitting voltages are to be used, for otherwise sparks may travel along the surface and constitute a leak, even if the insulation be not actually punctured. Remember that the greatest tendency to leak exists on the surface or skin of the insulator.

To provide this long surface-path without undue elongation of the insulator, the insulating tube called the "deck insulator," which is used to lead the aerial into the office, is fitted with a series of collars called anti-spark discs.

Hooded ebonite insulators also furnish this long surface-path, and also, if suspended the right way up, keep the "stalk" of the insulator dry and so preserve its insulation resistance.

In this connection it should be noticed that it is of little benefit to use a hooded insulator if the hood be merely screwed on, for an uncovered rod of the same size as the centre piece would be quite as efficient. The spark will travel up the film of air on the threaded part of the insulator and thus through the hood without any difficulty.

To make a hooded insulator efficient, the threads must be smeared with "Chatterton's compound," which is worked like sealing wax, and the hood then screwed hard up while the compound is still hot, so that the smeared threads are drawn up inside the hood. When the compound sets hard, a good water and air-tight joint should be formed. Care must be taken, if two hooded insulators are to be joined in series that one hood catches rain-drops which run down the wire when the ship is at anchor, and that the other catches those which generally come from ahead when the ship is under way. This may entail fitting them base to base, as, for instance, in the forward haul-out of the roof of an aerial when the wire slopes downward from the main to the fore W.T. yard. It should be noticed further that once sparks have begun to pass across the surface of an insulator, a burnt or carbonised streak is formed. This mark is semi-conducting, and the longer the insulator is left in that condition the worse it will become and the greater the leakage.

It is useful to wash the outside surface of insulators periodically with fresh water to remove incrustations of salt or soot.

They should not be smeared with oil with the idea of making water run off, as this will tend to cause dust or soot to settle on the surface.

From what has been said it will be seen that ordinary insulation tests, such, for instance, as testing with a megger between the aerial and earth, are no good unless the insulators themselves be well designed for insulating high-frequency currents, and that where we want to insulate one conductor from another we must be certain that there is no capacity effect between them. This becomes increasingly important with short waves having very high frequency jigs. The ohmic resistance part of the insulation, on the other hand, becomes increasingly important with long waves, for long waves necessitate much added inductance in the office, and consequently greater back E.M.F. across the deck insulator.

The deck insulators are always accessible, while those aloft are not so easy accessible, yet it is by no means invariably the custom to keep the deck insulation spotlessly clean.

Form of Aerial.

We will now consider the best form of aerial under different circumstances.

There are two main principles to be remembered in the design of an aerial wire. Firstly, the higher the antenna the more rapidly will the energy be radiated, and, secondly, the larger the capacity of the antenna the larger will be the total amount of energy at our disposal for radiation for a given voltage in the aerial (for $Q = SE$).

This means that the higher the aerial the more efficient is the open oscillator as a radiator of electro-magnetic waves, and the larger the capacity the lower will be the voltage necessary for the charging of the aerial with a given amount of energy. Conversely, the larger the capacity the larger will be the charge necessary to raise the pressure in the aerial to the maximum working limit—that is, the voltage when brushing just begins to take place.

The most strongly radiative antenna is the straight vertical wire, commonly called the "Marconi aerial," since it was with this type of antenna that Marconi first demonstrated the practicability of telegraphy without connecting wires. The capacity of such an aerial is, however, very small, so that it is now customary to connect to the top of the vertical wire or wires a system of wires more or less parallel to the surface of the earth.

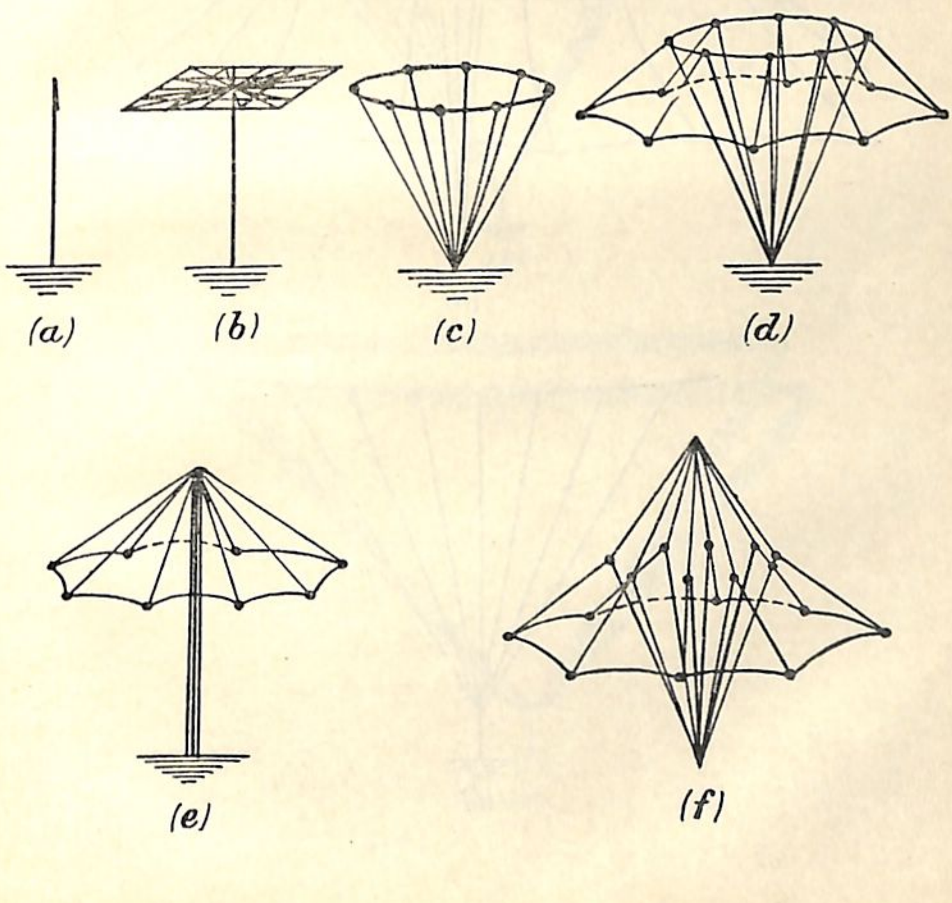
The ideal aerial, therefore, consists of a large overhead area, carpet, or "roof" stretched out parallel to the earth at as great an elevation as possible, and connected to earth by several vertical wires. The large overhead carpet makes for a large capacity, the great height is necessary for efficient radiation, yet tends towards a small capacity, so that the two desiderata, the great height and the large capacity, are antagonistic. We, therefore, have to adopt a compromise in practice by getting masts as high as possible, and then making the overhead area as large as possible.

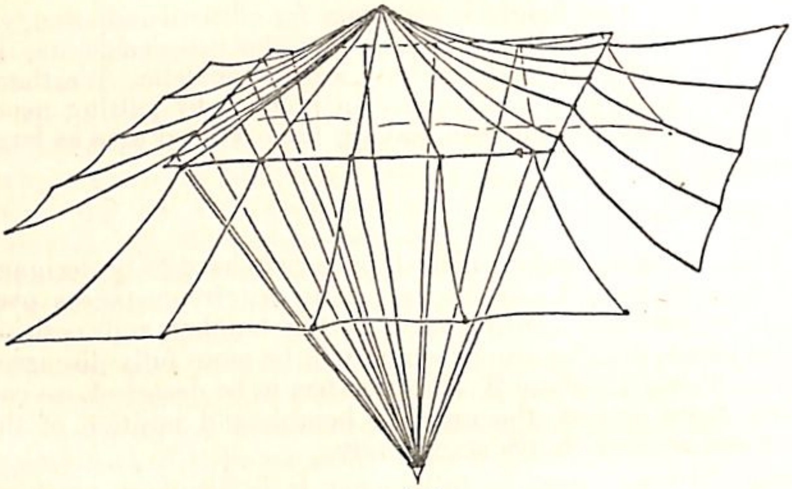
Aerials ashore.

The conditions under which ships' aerials have to be designed considerably restrict our choice, owing to circumstances over which we have no control, such as the number and position of the masts, &c., conditions which will be more fully discussed later; but when a shore W.T. station has to be designed, we can choose, more or less, the number, height, and position of the masts and arrange things accordingly.

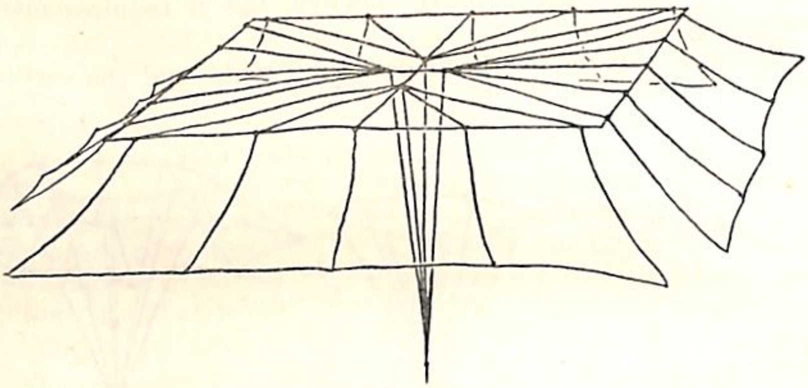
Fig. 110 will explain fully what it is required to show. (*a*) gives the Marconi aerial; (*b*) its development into the more efficient form of a "roof" or "carpet" type; (*c*) is the inverted cone type, one which is fairly effective, but it requires many masts.

We shall call the overhead part the "roof," and the vertical part the "feeder."





(g)



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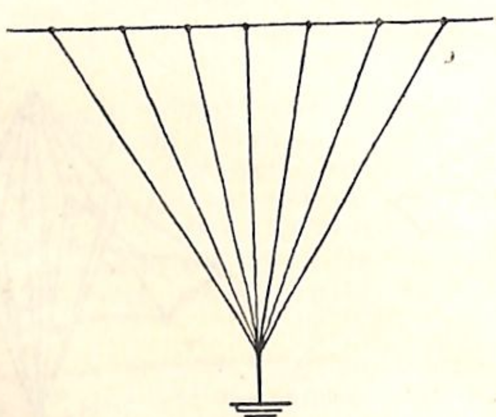


(i)

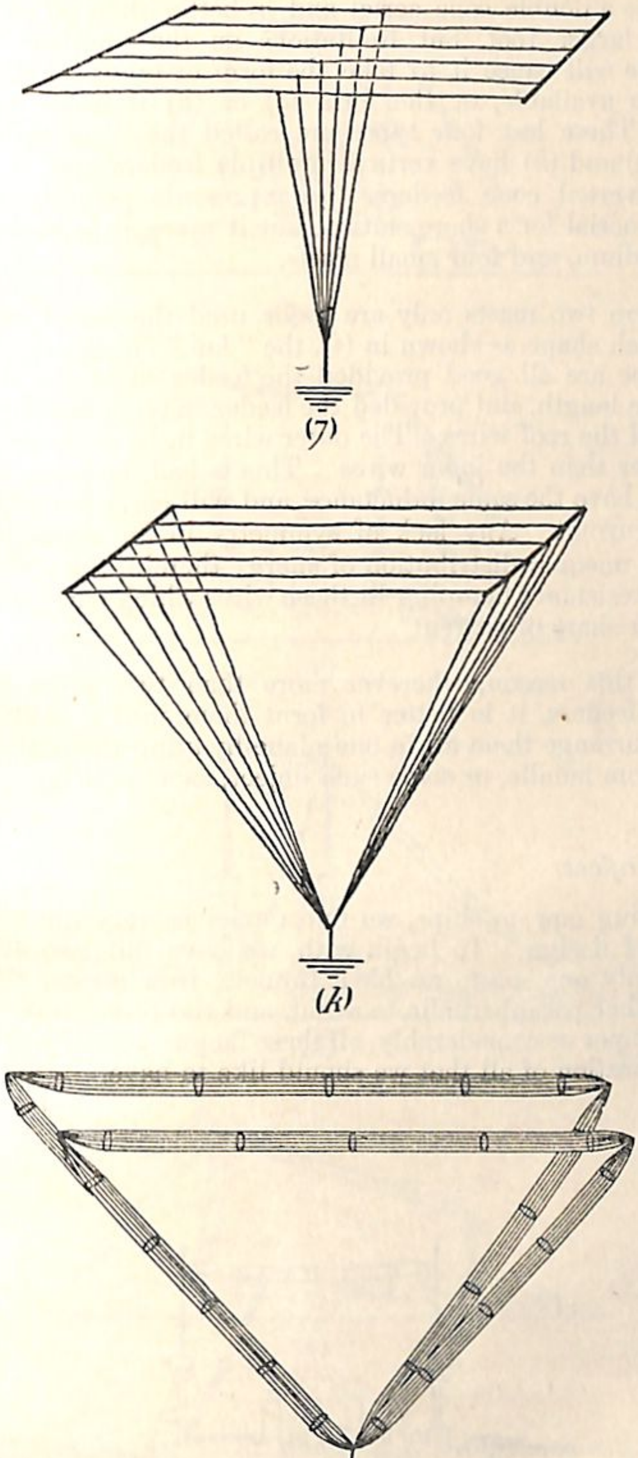


Fig. 110.

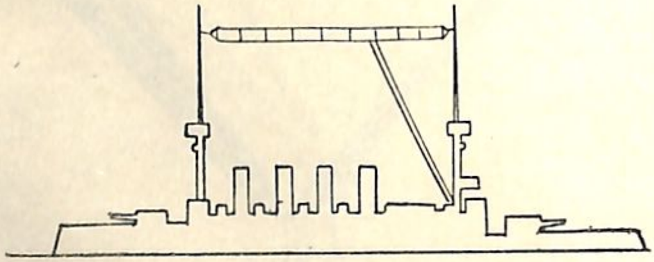
(*d*) is a double cone aerial and is better than (*c*) on account of the larger roof, but limitations on the number of masts available will cause it to take the form of (*e*) or (*f*) if but one mast be available, or the form (*g*) or (*h*) if more masts are fitted. These last four types are called the "umbrella" roof, while (*e*) and (*h*) have vertical multiple feeders and (*f*) and (*g*) have inverted cone feeders. (*g*) represents possibly the best form of aerial for a shore station, but it takes at least one large, four medium, and four small masts.

Where two masts only are to be used the aerial must take some such shape as shown in (*i*), the "fan," (*j*), (*k*), or (*l*). The last three are all good provided the feeder wires are all nearly the same length, and provided the feeder in (*j*) is attached to the centre of the roof wires. The outer wires in (*i*) must necessarily be longer than the inner wires. This is bad, because the wires will not have the same inductance, and will carry unequal shares of the current. Any lack of symmetry in an aerial is bound to cause unequal distribution of energy therein, the result being a great resistance damping in those wires which carry more than their fair share of current.

For this reason, wherever more than two wires are used for the feeders, it is better to form them into a cage or tube than to arrange them all in one plane by tying them at intervals to a broom handle, or some such object, as a spreader.

Aerials afloat.

Coming now to ships, we find ourselves very limited in our choice of design. To begin with, we have but two and sometimes only one mast, we have funnels, iron masts, stays, and many other paraphernalia to avoid, and the position of the office may hamper us considerably, all these factors possibly preventing the realisation of all that we should like to have.



(*a*)

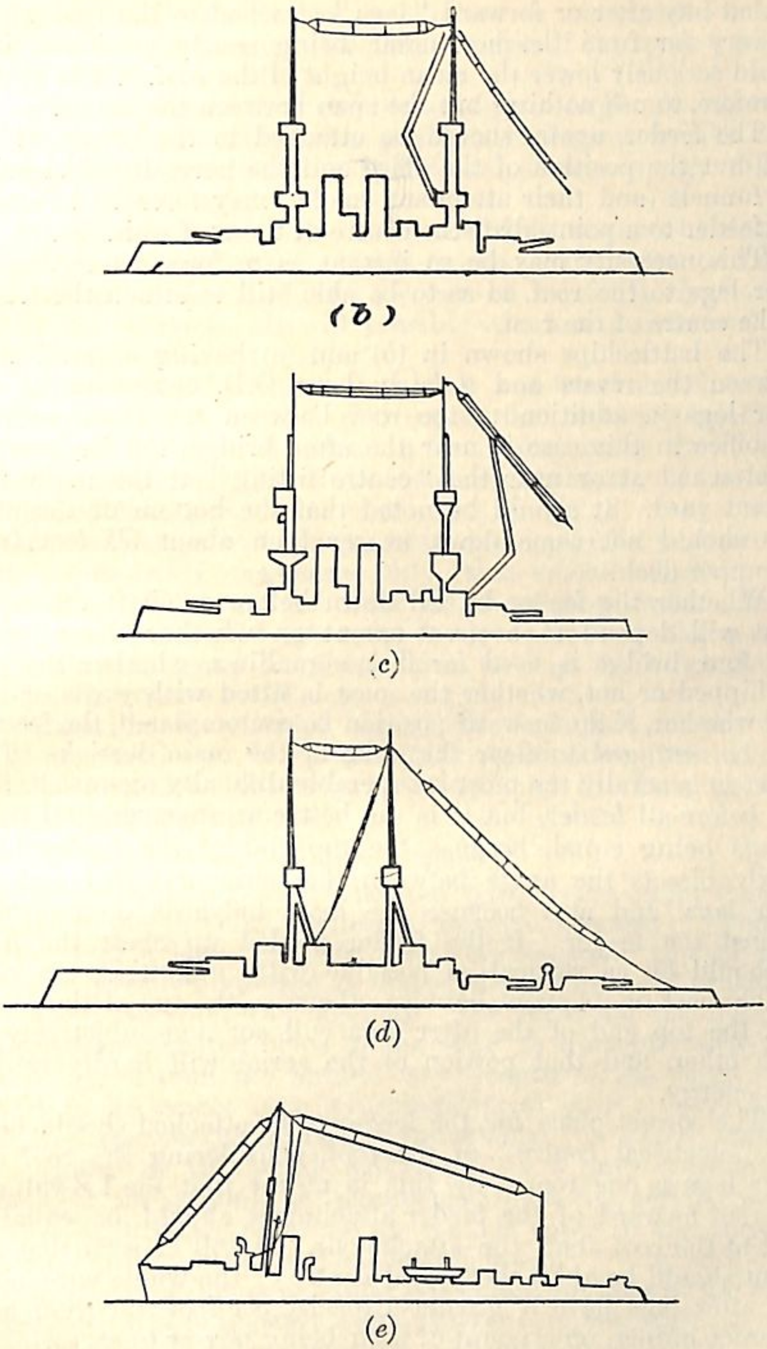


FIG. 111.

The best ships for W.T. purposes will be those with a very large spread between the masts, so that we can get all our roof at the maximum possible height. Such a ship as shown in Fig. 111 (*a*) will have but a very short Q.D. and forecastle, so that any after or forward "legs" attached to the roof would be very far from the horizontal, being nearly vertical. This would seriously lower the mean height of the roof. It is better, therefore, to use nothing but the span between the masts.

The feeder, again, should be attached to the centre of the roof, but the position of the office and the necessity of clearing the funnels (and their attendant smoke) may force us to attach the feeder to a point abaft the centre of the roof as in (*a*).

This necessity may be so instant as to force us to employ after legs to the roof, so as to be able still to attach the feeder to the centre of the roof.

The battleships shown in (*b*) and (*c*) having a small span between the masts and a fairly long Q.D. causes us to use after legs in addition to the roof between the masts. Since the office in this case is near the after bridge, the feeders will be attached at or near the "centre fitting" at the main top-gallant yard. It should be noted that the bottom of the after legs should not come down nearer than about 50 feet from the upper deck.

Whether the feeder be led down before or abaft the main-mast will depend to a great extent on whether the after or the fore bridge is used for flag signalling, whether the gaff is shipped or not, whether the mast is fitted with yards or not, and whether, if the forward position be contemplated, the feeders can be arranged to clear the wake of the main derrick. This latter is generally the most insuperable difficulty against having the before-all feeder, but it is the better arrangement, all other things being equal, because the top end of the feeder more nearly bisects the angle between the horizontal roof and the after legs, and also because the loose halyards do not blow against the feeder. If the feeder be led up abaft the mast it should be as vertical as possible without getting too close to the mast or its stays, because otherwise the top of the feeder and the top end of the after legs will act non-inductively on each other, and that portion of the aerial will hardly radiate any energy.

The correct place for the feeder to be attached should be in the "electrical centre" of the roof, considering the roof and after legs as one roof. By this is meant that the LS value of the roof forward of the feeder attachment should be equal to that of the roof abaft the attachment. It will be seen that this point should be abaft the actual centre of the whole wire, since the after legs have a greater capacity per foot run than have the roof proper, on account of their being nearer to earth.

This is an additional reason for attaching the feeder a little way down the after legs as shown in (*c*).

Several ships have employed a small "forward leg" with advantage in these and in modern large ships.

In all cases both the roofs and the feeder should be led as far away as possible from any earthed objects such as stays, and the feeder especially should not be allowed to run parallel to any wire stay for any considerable distance, even if the space between the two be considerable.

If the two cross at a considerably wide angle the stay will not be in such a favourable position to be cut by the lines of magnetic force from the feeder, and so less energy will be absorbed by the stay.

(*d*) shows the lead of feeder in one of the modern battleships whose offices are forward. It will be seen that the feeder bisects the roof angle very well, and yet can be led fairly clear of the smoke and derrick. It will possibly interfere a little with the flag signalling.

The reason why smoke has such a deleterious effect both on the transmitting and also upon the receiving efficiency of a ship is that it forms a semi-conducting earth leak, which consequently lowers the insulation resistance of the aerial condenser dielectric.

In small ships with short masts, and especially in destroyers and scouts with one mast only, this smoke effect is very important. We must in these ships employ rather shorter after legs than would otherwise be the case and also a small main mast in some cases, as shown in Fig. (*e*), which gives a typical destroyer's aerial.

Again, in these ships the whole fore part of the ship is often smothered in spray, which again, since the water is salt, forms a leak to earth. Consequently the fore-legs must not be carried down too far.

Further Advantages of Large Capacity.

We see with regard to the roof part of the aerial that the maximum height and maximum area are necessary. The advantages of a large capacity aerial are several. One of them we have already investigated, that is, the reduction of brushing; but when we come to "load up" the aerial by the insertion of inductance in the office in the effort to transmit waves very much longer than the natural wave-length of the aerial, it is found to be much more advantageous to have a large aerial capacity than a large initial inductance. A small increase of capacity in the aerial will result in a very considerable saving in the amount of inductance which the aerial coil has to supply in order to bring up the LS value of the aerial to the required quantity to give the long wave.

On the other hand, an equal percentage increase of the aerial inductance will only cause a saving of a very few mics.

This applies to transmitting and also to receiving. Now if so many turns of aerial coil be saved by having a large capacity aerial, we have so much less back E.M.F. across the top and bottom of the aerial coil, that is, between the inside and the outside of the deck insulator. The insulation of the latter is therefore less strained, and the tendency to brush in the lower parts of the feeder reduced. It is always in the part of the aerial which is nearest to earth—that is, where the air dielectric is thinnest—that brushing tends to commence.

Further, not only is the total back E.M.F. across the whole aerial coil (or tuner in the case of receiving) lessened when the capacity is large, but also the back E.M.F. between turn and turn is lessened.

Hence the loss by leakage across faulty insulation between the turns of the coil is reduced. Due to this chance of leakage across the turns of an aerial coil, we may note that the longer the wave-length to be transmitted the better must be the insulation between the turns, and that the more turns we have in, the greater the chance of coming across a weak spot in the insulation.

The leakage loss across faulty insulation will vary directly as the wave-length, so that to send or receive a wave-length twice as long as a former one, we must have the insulation between turn and turn of our aerial or tuner coil twice as good if the leakage loss is to remain the same.

Another advantage of a large capacity aerial in the receiving circuit is that for a given induced voltage in the aerial the current will be larger in one of large capacity than in one of small capacity, for, again, $Q = SE$.

From the point of view of receiving, however, there is one disadvantage of the large capacity aerial in that atmospheric disturbances produce more interference in such an aerial than they do in a small one. For this reason some of Marconi's large stations have a large aerial for sending and a small one for receiving, which latter is joined in with the other one while transmitting. When sending is completed the large aerial may be made to insulate itself from earth by being fed from the aerial coil through a small spark-gap. The transmitting energy is quite sufficient to jump this gap without appreciable loss, but it forms an efficient insulator for the weak currents used in the receiving circuit. Such an arrangement is sometimes called an "anchor" spark-gap.

Owing to the small size of their aerials, destroyers are markedly immune from interference due to atmospherics.

Number of Wires used.

So far we have been considering the questions which limit the lengths of the wires employed for ship's aerials, that is, we have been looking at the aerial from "broadside-on" to the ship. We will now turn to the consideration of how many wires are necessary, and look at the aerial from forward or aft.

The reason why a multiple wire is used for the roof is to get a larger area and so a larger capacity than would otherwise be the case. Now the calculation of the capacity of a wire of given length suspended at a given height above the earth is a rather complex one, for reasons which will be more apparent later. It would seem at first sight that if we doubled the number of overhead wires we should double the capacity, but this is not the case. Two wires hoisted up parallel to and at a considerable distance from each other, will have a joint capacity nearly twice that of a single wire, but as the wires approach each other, the joint capacity becomes less, so that when the wires are within a foot of each other very little extra capacity is obtained by the use of the second wire.

We see, therefore, that, as a rule, a few wires spaced fairly far apart are better than very many wires near together, as far as the total capacity is concerned. The multiplication of wires in an antenna, whether in the roof or in the feeder, has, however, another effect. Putting many wires in parallel with each other decreases the joint inductance of the aerial and also its resistance to high-frequency currents. This causes a reduction in brushing. Since the inductance is reduced by a multiplicity of wires, the LS value and wave-length would decrease on this account, but since the multiple system increases the capacity, it is generally found that the nett result is an increase of LS value and wave-length, unless the wires be very close together.

It is found also that there is a limit of " nearness " for any pair of roof wires, so that if we wish to get as many wires up as possible, we shall either have to have very long aerial yards or else arrange the wires symmetrically in the form of a cylinder or " sausage."

In practice one such " sausage " system is slung on each side of the mast, the number of wires in each varying from eight in the large cylindrical ones for high-power sets, to two, one slung below the other, in destroyers.

We must notice that not only does the power to be used in the transmitting set, or rather the amount of initial energy of each jig, determine the number of wires, but also the fact that the strength of the rigging in small ships is not sufficient to stand a large number of wires. The directions in the handbooks of the various installations must be followed carefully in arranging and hoisting up the wires.

It is customary to describe an aerial by stating first how many parallel systems of cylinders there are, and then how many wires go to each cylinder. Thus:—" A double eight-fold," " a double two-fold " will describe the largest and smallest aerials referred to above.

In large cruisers with a great mast spread, three and even four cylinders have been used; these would be called treble and quadruple eight-fold aerials respectively.

The third cylinder makes a slight increase to the total capacity, the fourth but very little difference indeed, for the wires are by then getting much too close together.

The cylinders between the masts must of necessity run parallel to each other, but if after-legs are used, there is generally a chance of getting their lower ends further apart than are their upper ends. A battleship, having a good beam carried well aft, enables us to straddle the after-legs considerably without sacrificing much " flatness " of roof.

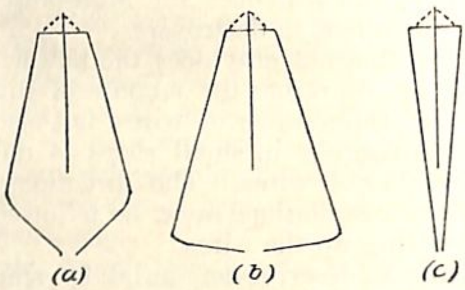
Wires in the Feeders.

The number of feeders used will be the same as the number of cylinders of roof.

The addition of an extra wire to the feeder will alter the inductance or capacity of an aerial by an inappreciable amount; but the reason why manifold feeders are employed is because they tend to reduce brushing. Remember that a multi-fold feeder must take a cylindrical shape, and that, however, many wires are used in roof or feeder, *every* feeder wire must have a good contact to *every* aerial wire at the place where the feeder is joined in. This last remark applies to cases where the feeder is not attached to the "centre fitting" but to some intermediate spreader.

Lead of the Feeders.

If two feeders only are employed and if the office be in the centre line of the ship, it is usually easy to stay the feeders so that they will be equidistant from all such large earthed objects as the masts and funnels. The lengths of the feeders should be identical, but this may be almost impossible where the office is not in the centre line of the ship. In any case a long lead of horizontal wire should be avoided, especially where this lead has to pass close to earth for a considerable portion of its run.



(a) (b) (c)

Fig. 112.

Looking at the ship from forward or aft, the feeders should present the shape shown in Fig 112 (*a*). This arrangement gives a fairly large capacity to the feeder, but the separation should not be carried to the extreme shown in (*b*), for this brings in the long horizontal non-radiative lead and also entails a sharp bend which will facilitate brushing.

The close-up position shown in (*c*) reduces the capacity of the feeders and tends to increase smoke losses, for if the feeders be close together, then if any smoke blow on one wire, it will also envelope all the others, whereas a wide spread will generally ensure that only half the feeder is enveloped.

The difficulty of preserving symmetry when more than two feeders are employed is obviously greater than before.

However many are used all possible efforts should be made to make the feeders equidistant from each other and also from all large objects connected to earth.

It is usually very difficult to see exactly the best position whereto the guys should be attached, without carrying out a process of trial and failure. Observation from a boat some little distance away is very helpful.

Aerials for Short Waves.

When an antenna has to be put up in a large ship for the transmission of very short waves it is more efficient if the roof type be avoided, for if it be sufficiently high to radiate at all well, its natural wave-length will be too long. Accordingly a four-fold vertical wire of the Marconi type is better. It should be noted that departure from the true vertical may be advantageous in order to avoid bringing the aerial into proximity with a large earthed body, for the "screening" effect of funnels, masts, &c., is very serious when short waves are employed. This was first demonstrated in the series of classical experiments on the screening effect of land which were carried out in 1901–2 by Rear-Admiral Sir H. B. Jackson in the Mediterranean. Of this screening of electro-magnetic waves we shall have more to learn later.

The Capacity of an Aerial.

The calculations of capacity for wires are very complicated and need not appear here. It will be sufficient to indicate the first principles on which the results are obtained. We shall remember that it is not strictly correct to speak of the capacity of any conductor, since the storage of energy is a function, not of the conductors, but of the dielectric (*see* page 3).

Take a Marconi aerial as shown in Fig. 113.

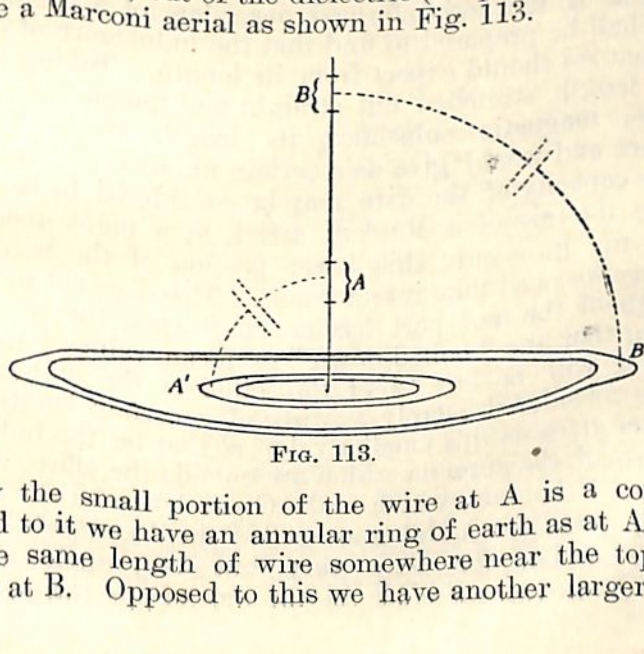


FIG. 113.

Now the small portion of the wire at A is a conductor. Opposed to it we have an annular ring of earth as at A′. Now take the same length of wire somewhere near the top of the wire, as at B. Opposed to this we have another larger ring as at B′. Now the capacity of the condenser AA′ will be larger than that of BB′, for the dielectric is much smaller in thickness, and the large size of the ring B′ will make but little difference, since the opposing wire is no larger. Hence the capacity of the different parts of the aerial is not constant, that of the lower portions being greater than those of the upper ones.

Accordingly, when we measure practically the capacity of an aerial the result we get is really the sum of all these little condensers, since they are all in parallel with each other, and this "boiled down" value of the capacity may be considered, in a straight Marconi aerial, to be concentrated at a point a little less than halfway up the wire, in fact at about ·4 of the way up. Now this is where the roof aerial shows its superiority. By getting more wire overhead we not only increase the total capacity, but really increase the height at which its mean value may be considered to be concentrated. It is upon this height of the mean position of the capacity that the efficiency of an antenna chiefly depends.

It must not be forgotten that in every aerial one part thereof will have a certain capacity effect on the other parts, so that what actually happens in an aerial, complicated as it may already have seemed, is really of a very abstruse nature.

However, we are principally concerned with that capacity (in jars) which we get on measuring with a wavemeter, and to distinguish this aerial capacity outside the office from that of any other condenser we may be using, the Greek letter "S," written σ and pronounced "sigma," is used.

Inductance of an Aerial.

We have seen that the capacity of the aerial cannot be regarded as if the aerial formed one plate of a condenser, so that we shall be prepared to find that the inductance of the wire is not what we should expect from its length. Taking the wire of given length, stretched out straight and remote from iron or any other magnetic substance, its length would limit the inductance and would give us a certain number of mics. Now since the capacity of the wire may be considered to be concentrated, in the case of a Marconi aerial, at a point about ·4 of the way up, it is only this lower portion of the wire whose inductance we need take into account. This does not mean that the length of the roof part has no effect upon the total inductance, but that the "boiled-down" or mean value of the aerial inductance will be but ·4 of the value of the inductance of the wires considered merely as wires of a certain length. The wavemeter gives us this smaller value, so that for the inductance of all parts of the antenna which are outside the office, we have the symbol λ (lambda) which is the Greek letter "L."

These quantities λ and σ are called the "constants" of that particular aerial, for they vary but very little whatever we may do inside the office in the way of inserting artificial inductance or capacity. If an inductance be put in the foot of an aerial λ is found to increase by a very little.

It must be borne in mind that λ and σ (especially σ) will not remain constant unless the aerial be kept hauled out uniformly at all times. Further, it is probable that σ will vary if the awnings be spread or furled and if the decks be wet or dry. This cause of error in the resultant wave-lengths will be but small except in the longer wave, where a very slight alteration in the capacity may cause a considerable alteration in the total LS value, for the capacity is to be multiplied by a large inductance. This does not matter very much, for it is the *percentage* alteration with which we have to deal, and this will be independent of the wave-length; but we may notice that it may be advisable to check the tuning of the aerial for the long waves from day to day, especially if the weather be very changeable.

A matter of a difference of three or four turns on the aerial coil may be anticipated in the case of the longest ship's wave.

Another cause of alteration of σ will be that due to any alteration of the position of the feeder by the rolling of the ship, or the action of the wind. It is the lower part of the feeder especially which we must try to keep rigid, for any small alteration here will have most effect upon the capacity. Hence the value, where main-deck offices are fitted, of a rigid copper pipe for the lower part of the feeder until it is clear of all large masses of iron, such as the after-turret or shelter-deck. The pipe should be carried in easy curves, not given any sharp bends.

This arrangement is shown in Fig. 114 and has the additional advantage of making the aerial less liable to damage during evolutions.

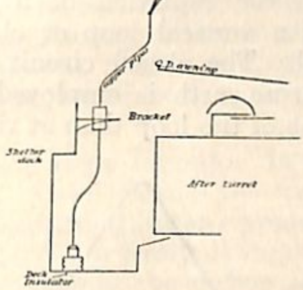


Fig. 114.

The product of λ and σ is written $\lambda\sigma$, being called the "resonance constant" or "oscillation constant" of the aerial alone (*see* page 252). The "natural wave-length" of the aerial will, of course, be given by

$$W = 206, \sqrt{\lambda\sigma} \ (\lambda\sigma \text{ in ships is usually less than } 90).$$

The reader should be on his guard, when reading books on W.T., against assuming that the writer means "LS" when he mentions "oscillation constant," for some writers mean $\sqrt{LS}$ when they use this expression. Again, λ is sometimes used to represent wave-length.

Directive Antennæ.

In the case of the "Marconi aerial" and in the case of those roof aerials where the feeder is attached to the centre of the roof and the latter is symmetrical about the feeder, the intensity of the radiation is uniform all round the transmitting station. In other words the "range" of the station will be equal in all directions as far as the aerial is concerned.

A problem which presented itself very soon after the practical inception of W.T. was the limitation of this uniform all round radiation to a certain direction.

It was obvious that some means were required to effect that which a lens or mirror effects in the case of light.

Hertz had shown that electro-magnetic radiation of short wave-length could be reflected by means of metallic mirrors, and that it followed the laws of light. By means of parabolic mirrors he thus concentrated electro-magnetic radiation into a beam.

This, however, can only be done if the length of the wave be small compared with the dimensions of the mirror.

Hence, since wave-lengths are now employed ranging up to 20,000 feet or more, there is no possibility of constructing mirrors sufficiently large to concentrate such waves in any required direction.

A new line of investigation, however, was opened up by the observation that the radiation of a sloping antenna and particularly that of a vertical loop or closed circuit radiator, was not symmetrical. The closed circuit radiator is shown in Fig. 115 (notice that no earth is employed), and its radiation is stronger in the plane of the loop than at right angles to it.

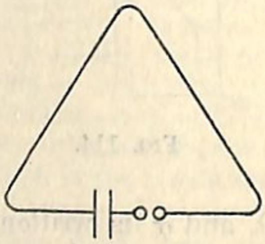


FIG. 115.—Closed radiator.

The two chief methods of a symmetrical radiation are developments of this idea.

Many experimenters seem to have been working on the same problem at the same time, some of them trying to direct transmitted waves, others trying to locate the source of waves.

These experiments, whether conducted from the point of view of transmission or reception, resulted in the "directional" aerial. Stone and De Forest in America, Slaby, Braun and others in Germany, Marconi and Commander (then Lieutenant) Ryan in England, arrived independently at their own conclusions, but Marconi was the first to patent and instal the directive aerial on a large scale. This he did at Clifden and Glace Bay, while Poldhu has since been made directive towards the SW.

The bent directional aerial as fitted at these stations is horizontal for the greater part of its length. It is "fed" from the end *nearest* the station with which communication is desired, the other end being, of course, insulated.

Such an aerial will radiate most strongly in a line passing from end to end of the roof wires, and most strongly of all in that direction *away* from which the wires point when looked at from the feeder end.

The radiation is consequently weakest at right angles to these directions.

Ships' aerials, and especially those in destroyers, are more or less directional, owing to the lack of symmetry in the disposition of the masts, so that a ship will send most efficiently when heading towards or away from the destination of the signals.

Also, since the law of exchanges holds good for electric radiators, this form of bent antenna receives or absorbs the energy of waves most easily when they are arriving from that direction which is opposite to that in which the free end of the aerial points.

Hence, two similar bent antenna when set up back to back—that is, with their free ends pointing away from each other—form a system of radiator and receiver which has a greater range in that position than in any other at the same distance, or, conversely, they will not require so much power for reliable communication than as would be the case had the aerials been symmetrical.

Fig. 116 shows a "polar diagram" in which the distance of the curve from the centre whence the rays emanate, gives, to some scale, the relative strengths of signals at different bearings from a bent antenna. Conversely, it may be taken to be a map showing the reliable range of the station in different directions. The free end of the aerial is supposed to be pointing towards the 180° portion of the circle.

We see, then, that when an aerial is bent away from any point of the compass, it both sends best towards and receives best from that quarter. It is found that the inequality of intensity or radiation becomes less marked at very long distances than at short ranges.

The shape of the curve shown in Fig. 116 is accounted for in theory by considering the antenna to be a combination of a closed and an open oscillator. The shape of the curve will,

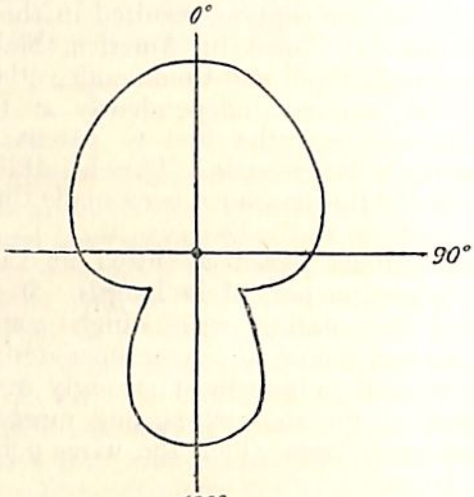


FIG. 116.—Bent aerial. Marconi system.

of course, be different for different aerials, for the longer the aerial in proportion to its height, the more marked does the directive effect become; but this decrease of height can be obtained only at the expense of good radiating properties, so that a long, low aerial will not send or receive strong signals at all. The falling off of strength due to the small height and great length is not so marked in receiving as in transmitting; indeed, signals can actually be received on an insulated wire lying along the ground, whose inner end is earthed through the receiving device.

It is seen, therefore, that the shape of a directive antenna is again a compromise. Height gives strong signals but poor directive effect, while length gives good direction but bad signals. A ratio of height to length of 1 to 10 is a good working basis.

The earth connection plays rather an important part in a bent aerial directive system, better results being obtained when the contact is made out towards the opposite station than if made under the aerial itself. (*See* Fig. 117.)

FIG. 117.—Marconi bent aerial.

Braun's System.

Braun's system has not yet been employed on a large scale. He employs three aerials set up at the points of an equilateral triangle. In these antennœ he can produce oscillations which differ from each other in phase by any required amount.

By these arrangements it is possible to cause the waves emitted by the whole system to combine together and assist one another in a certain direction, but to neutralise each other in certain other directions. It is well known, for instance, that waves of light or waves of sound can in this way interfere so that two light waves may actually destroy each other and produce darkness, and two sound waves neutralise each other and produce silence.

This effect is called the interference of waves. Braun found that by a proper arrangement of the antennæ and adjustment of the phase difference, the radiation of the three antennæ could be combined together in a certain region out of the whole azimuth of 360°. (*See* Fig. 118.)

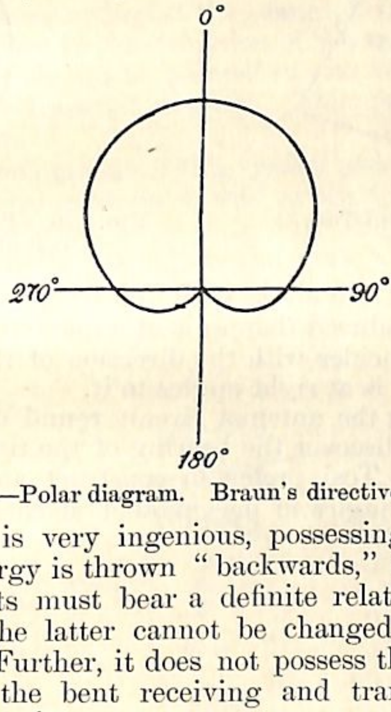


FIG. 118.—Polar diagram. Braun's directive system.

This method is very ingenious, possessing the advantage that but little energy is thrown "backwards," but the distance apart of the masts must bear a definite relation to the wavelength, so that the latter cannot be changed without having portable masts. Further, it does not possess the simplicity and practicability of the bent receiving and transmitting aerials employed by Marconi.

The Bellini-Tosi System.

Lieutenant A. Tosi and Signor E. Bellini, of the Italian Navy, have devised another ingenious system of directive W.T., stations having been set up at Dieppe and Havre. They employ a nearly closed circuit transmitting antenna, consisting of two aerial wires suspended from one mast, the wires being stretched out as shown in Fig. 119 so as to give them the form of a triangle. If oscillations be set up either by means of the direct or magnetic method of coupling, radiation takes place from this nearly closed antenna which is not symmetrical, but is greatest and equal in two directions in the plane of the antenna and *zero* at right angles to that plane ; in other directions varying in accordance with the radii of a figure-of-eight polar curve, as shown in Fig. 120. This directional effect holds good for receiving as well as transmitting. In the former case, the detector, of whatever form it may be, is placed in the centre of the lower or horizontal side of the triangular aerial.

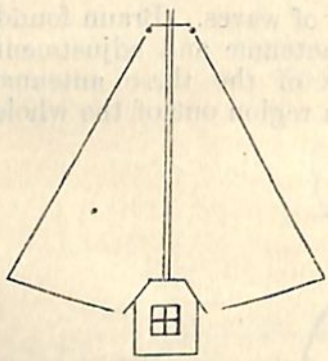


FIG. 119 —Bellini-Tosi.

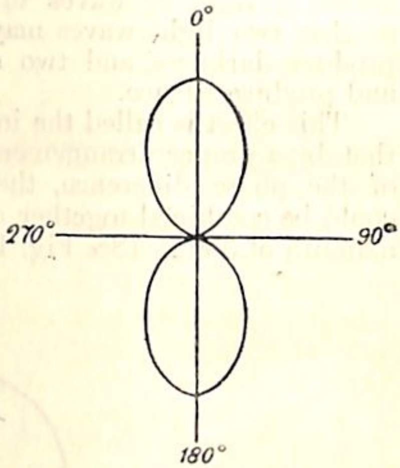
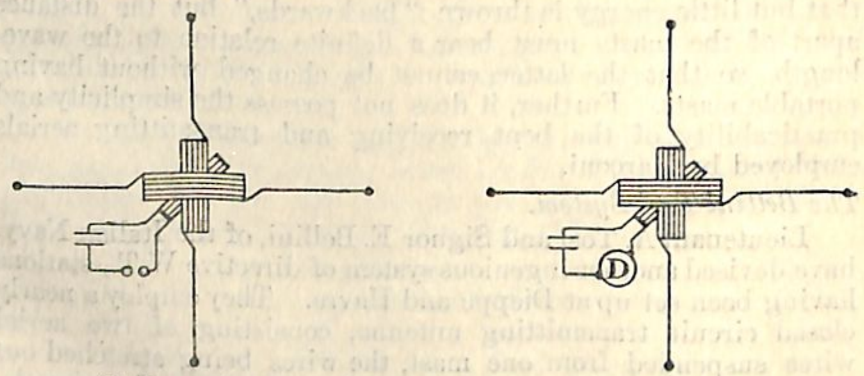


FIG. 120.—Polar diagram. Bellini-Tosi directive system.

When such a circuit is used for reception the intensity of the oscillations induced therein is at a maximum when the plane of the circuit coincides with the direction of the incident waves, and zero when it is at right angles to it.

By swivelling the antenna circuit round on its vertical axis it is possible to discover the bearing of the transmitting station, but Bellini and Tosi prefer to construct and erect two such circuits at right angles to one another at each station as shown in Fig. 121.



(*a*) Transmitting, (*b*) Receiving.

FIG. 121.—Bellini-Tosi System. Plan.

Each of these circuits contains in its lower part a coil which can be acted upon inductively or can act inductively upon another circuit placed in an intermediate position, which last circuit either contains the oscillation producing arrangement if it be a transmitter, or the oscillation detecting arrangement, if it be a receiver.

The arrangements are shown in Fig. 121 (*a*) and (*b*). The third coil is mounted on a vertical pivot, being smaller than the two fixed coils. It is, therefore, capable of revolving within the space embraced by them. For sending this coil acts as the primary of an oscillation transformer and for receiving as the secondary, and it is connected up to a condenser and spark-gap for sending as in (*a*) or to a condenser and detector for receiving as in (*b*).

Suppose now that the waves are falling upon the station coming from a certain direction. All that it is necessary to do in order to determine the point of origin of the waves is to twist this moving coil round on its vertical axis.

When signals are strongest the plane of the coil is pointing, one way or the other, in the direction of the transmitting station. Similarly, the coil should be pointed in the direction in which it is required to transmit signals. This device is named a "radiogoniometer."

The latest development of this system seems to show that by employing a vertical antenna as well as the triangular ones, one of the circuits employed being as in Fig. 122, the radiation can be confined entirely to one side of the circle.

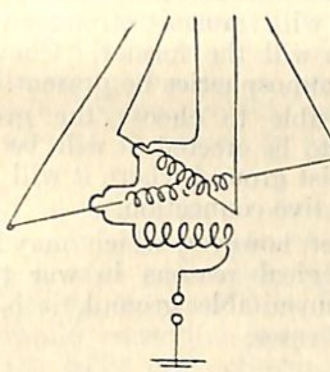


Fig. 122.

The principle on which this system works is the same as that which governs the "polarization" of light. (*See* p. 270.)

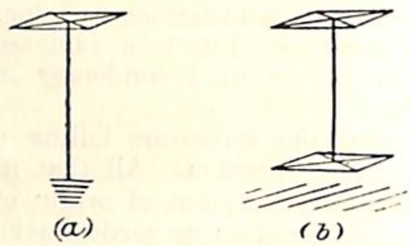
No earth connections are used except on the vertical open oscillator. If the others be earthed, all directive effect is lost.

The Earth Connection.

The precise function of the earth connection in the propagation of electro-magnetic disturbances is still somewhat obscure.

The theory of earths will be dealt with in the chapter on Ether Waves. The fact remains, however, that a "good earth" plays a very prominent part in making a station efficient for sending or receiving.

Usually, we try to make a good low-conductivity connection by means of metallic wires or plates with the actual surface of the ground itself, but it is also possible to get good results by making the lower part of the aerial form a large condenser with the ground surface.



Conductive Earth. Capacity Earth.

FIG. 123.

These two arrangements are shown in Fig. 123, (*a*) being the conductive earth, (*b*) the capacity earth, sometimes called the "balanced aerial," or "electric counterpoise."

The balanced aerial is more free from atmospheric interference than is the conductive type, but of two similar aerials, one with a counterpoise and the other with a conductive ground connection, the latter will transmit stronger waves with a given input of energy than will the former. Conversely, it will also receive better unless atmospherics be present.

Where it is possible to choose the ground on which a permanent station is to be erected, it will be possible generally to select a site on moist ground where it will be easy to make a low-resistance conductive connection.

For a portable set, however, which may have to be set up, for tactical or strategical reasons in war time, on very dry, rocky or otherwise unsuitable ground, it is better to use the balanced aerial in all cases.

The Balanced Aerial.

The balanced aerial is greatly favoured by Sir Oliver Lodge, but unfortunately, in order to get the best theoretical results, the two capacity areas should be symmetrical about the spark-gap or mutual coil; in other words, the transmitting installation must be halfway up the feeder.

The obvious impracticability of this arrangement has led to a compromise in putting the instruments near the ground line and extending the capacity earth out to one side. Thus we have an ordinary aerial with its own $\lambda\sigma$ value above the transmitting set and another low horizontal aerial between the instruments and earth having its own $\lambda\sigma$ value.

In tuning, these two values should be the same. Further, the upper and lower "carpets" will have a certain capacity effect between them, the upper carpet having one capacity to earth and the lower another.

The sum of all these three capacities should be as low as possible.

Regarding the practical considerations for fitting up such an electric counterpoise to a portable set, it follows, from the fact of a single mast and umbrella-type upper aerial being used, that the same guys which support the "skirt" of the upper aerial may be utilised to hold the lower network at a convenient height above the ground level.

It must be borne in mind that the air space between the lower network and the ground does really carry a dielectric current, and that a severe shock can be taken off these wires.

If such an arrangement be used, that is, a lower carpet directly underneath the upper one, the area, in plan, of the lower should at least equal that of the upper carpet.

This latter consideration applies also to the other kind of ground connection.

The Conductive Ground Connection.

Here, since we wish to cause the area of ground with which conductive connections are made to be at least as large as the plan of the roof part of the aerial, it will be necessary, in a shore station, to have a large number of wires, if possible of equal length, radiating outwards in all directions from the station (if the latter be for "all round" work), each wire being connected to the ground by means of a plate buried beneath the surface.

Now if we could be sure of every plate making equally good connection with the ground, it might be a good thing to lay each wire along the ground and connect it at intervals to many earth plates, but if we do this it will be found that the plates nearest the office would carry the largest amount of current, while those near the outer circumference of our earth circle would take but little current. This effect is not due to the ohmic resistance of the whole wire being greater than that of its part, but to the fact that if a high-frequency current have a choice of two paths, one of them being inductive and the other less inductive or non-inductive, the current will choose the path of least inductance, in spite of the fact of its being possibly of higher resistance than the other.

This is because of the enormous back E.M.F. set up by a wire of only a few mics inductance, when the current changes its strength and direction several thousand times per second.

It is a point with which we shall have to deal in the design of a ship's earth connections.

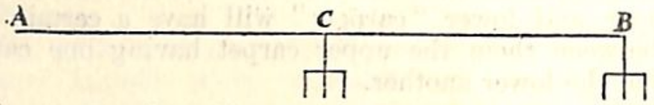


FIG. 124.

Now let AB represent one of the wires radiating out from the office, which is situated at A. Suppose we connect the outer end B to an earth plate and an intermediate point C to another plate, the self-induction of the part CB will cause the plate C to conduct more current to earth than will the plate B. If C happen to make a poor connection to earth, then, however good the contact at B, the outer end, there will be a large heat loss in that earth wire.

Where a permanent shore station is set up, it follows that it is better to rely on one ring of earth plates only, to make these plates take the form of a circle whose centre is the feeder and whose diameter is equal to that of the roof, and from each plate, or pair of plates, to take a radial wire to the station.

These wires, converging inwards on the feeder, are insulated from earth except at their outer ends, their inner ends being fixed to some form of "earthing ring" which surrounds the "leading-in insulator" (the deck insulator). To the inner side of this earthing ring is secured the lead from the bottom of the mutual coil in the transmitting set and the lead from the earth connection of the receiving set.

Similarly, inside the station, these leads above referred to are insulated from earth until they reach the inside of the earthing ring. This is a point to which we shall again refer on dealing with ships' earth connections.

Coming outside the shore station office again, we may notice that the radial wires, in being led clear of earth till their outer ends are reached, should be stayed up on short poles, so as to be at least 6 feet from the ground. This enables people to walk about without tripping over them, and also forms a protection against a broken end of the "live" part of the roof falling on anyone while the station is sending.

With regard to the earth plates themselves and to the way in which they make connection, thin wide sheets are preferable to thin rods, and, further, great depth is not required if the ground be moist. Mud and sea-water make excellent connections, but are not always available.

Should the ground, once moist, become dried up in the summer, very little falling off in the strength of signals need be anticipated, *provided* the earthed wires cover a very large area, for then the earth connection, although non-conductive, will take a large capacity (or "displacement") current. Every effort should, however, be made to get at some moisture, even if the plates have to be buried some depth or taken some little distance away in consequence.

In this connection it may be mentioned that where an earth has to be made in dry sand through which water percolates only after some depth is reached, it is better to drive down galvanised iron pipes by means of a pile-driver than to bury thin plates by digging. Sand will not stand at a steeper slope than about 30°, so that the labour of excavating a hole deep enough to reach the water is very great. The copper sheathing from old wooden ships makes the ideal material for earth plates, but well galvanised iron is nearly as good and is far less likely to be stolen.

For a temporary station in which a conductive earth is to be employed a very good earth may be made, if the ground be covered with *growing* grass, by laying thereon wire netting such as is used for chicken-runs and simply weighting it down in places with stones. A torpedo net makes a good earth under the same conditions. The thousands of blades of grass, being conductors, make excellent contact with the netting. Again, care should be taken that the wires are not covered with rust.

As with the wires composing the aerial, so also with those composing the earth, their arrangement should be symmetrical about the station both as regards length and disposition, for any lack of symmetry will result in those wires which are of the least inductance carrying more than their share of current, an ohmic loss of energy being introduced.

Earth Connections in Ships.

A ship's earth is usually very good compared with that of the average shore station, particularly in the case of steel ships. We must, however, bear in mind the tendency of high-frequency currents to select the path of least inductance, and also their property of flowing only on the skin of the metal which carries them.

Suppose, for instance, that the office is of iron, situated on the upper deck and that the earth connection is made on the "floor" of the office. Then the aerial currents must somehow get outside the office in order to charge and discharge one of the plates of the aerial condenser—that is to say, they must reach the surface of the sea.

At first sight it would appear that the earth, being straight on to the metallic portion of the hull, is as "good" and as low-resistance as we could wish; but the peculiar currents with which we are dealing will have a long path to traverse before their destination is reached; thus, they must spread out over the floor of the office, flow up the inside of the walls, converge along the inside of the ceiling, emerge through the hole carrying the deck insulator, spread out over the outside of the top, travel down the outside of the walls, out along the upper deck, down the ship's side, and eventually get to the surface of the sea.

Now, all that portion of their path which lies outside the office is possibly beyond our means to improve, but we can at least save the currents the task of flowing over the skin of the inside of the office, for it must be remembered that the skin effect is much more marked in iron than in copper, so that larger ohmic losses will ensue. Further, in flowing from deck to bulkhead, and from the latter to the roof of the office, riveted joints must be encountered, and these joints, with their attendant mill-scale, may be none too good electrical contacts even for direct current.

Also, the ordinary paint used contains lead, which forms a poorly conducting skin on the interior surface of the office, and this also would be detrimental.

The total effect of all these small losses, although possibly insufficient to cause much falling off in sending efficiency, will certainly tell against good reception.

It is for these reasons that the actual ends of the circuits (both sending and receiving) which it is desired to earth are connected by means of flat wide insulated strips to the iron roof which is secured round the deck insulator—that is, they are insulated from earth until they actually make contact on the roof of the office.

It is not necessary that the insulation should be very thick, for if the leads be short and fairly non-inductive there will be but little D.P. between any part of the strip and earth ; but the importance of thus insulating the earth wires becomes more instant where under-water offices are employed.

In a case like this last the aerial is led up between decks through an iron trunk, one deck insulator being fitted at the bottom thereof and another at the top where the aerial emerges into the outside air. Within the trunk the feeder consists of a copper tube provided with some device for compensating for elongation and contraction with changes of temperature. Inside the trunk and close to its walls run several vertical wires equally spaced round the circumference, the wires forming a sort of cage surrounding the feeder.

The wires are, of course, insulated from the trunk and from each other, except at their top and bottom ends, where they are connected to the iron decks. A door on some convenient intermediate deck gives access to the interior and a ladder is fitted for the inspection of any part of the tube. Care must be exercised to see that the earth wires are not bent, broken or made to touch the inside of the trunk.

With regard to the losses outside the office, we can do but little if the latter be made of iron and if it be built on the upper deck. Here the currents must flow along the iron which underlies the teak planking of the deck before they get to the ship's side. In this respect it is well to remember that if the deck were wet with salt water probably a large portion of the earth current would pass over the surface of the deck instead of sinking down to the underlying iron. However, with an iron office built on the after-bridge, shelter-deck or any other place whence the only conductors leading to the ship's side are a few iron stanchions, it will be well, should the office be near the mast, to connect up the outer zinc ring to the mast by a short wide piece of sheet zinc or copper. This sheet should not be put in quite as short as it will go, for the vibration of the mast due to the working of the main derrick will drag it from its bolts, or, at any rate, will transmit vibration into the office. A short length of bight should be left.

If the office be built of wood, and is also upon the upper deck, then it becomes imperative to have as many zinc strips as possible (outside the office) connected to the office earth, their outer ends going by as short a path as possible to different points on the ship's side. This may necessitate joining up several strips of zinc end to end; if so, these joints should not be riveted but well-soldered. Zinc lying on the deck will soon be torn away, so that it is well to arrange joints so that those portions which are most subjected to traffic can be easily disconnected and replaced.

Masts and Rigging.

The question of the effect of lightning conductors and rigging may be considered as follows:—

The effect of a conducting body near to the aerial, when transmitting, depends on the size, shape and position of the body, but it is different under each of the following conditions:—

(*a*) When the body is highly insulated from earth and other conducting bodies.

(*b*) When the body is but indifferently insulated from earth or connected to earth through a conductor of comparatively high resistance.

(*c*) When the body is connected to earth through a conductor of comparatively low resistance (*i.e.*, is "well-earthed").

Under conditions (*a*) the current induced between the body and earth will be very small, and its effects can be neglected; but if the body be fairly large, or be placed fairly near the aerial, it can still have the effect of causing brushing.

Under the conditions (*b*) the current induced between the body and earth may become great; as it flows through a path of high resistance there may be a considerable loss of energy (C^2R loss); and under certain circumstances there may be considerable local heating. The loss of energy will mean a reduction of the signalling range, and the local heating may in bad cases set fire to the wooden mast, blocks, &c.

Under conditions (*c*), although the induced current would be greater than under conditions (*b*), the loss of energy will in general be less, because the path of the current is of low instead of high resistance (that is, C^2r will be less than c^2R).

The reduction of signalling range will not be so great as under conditions (*b*), as a portion of the wireless energy, represented by the induced current, will be reflected back or re-radiated from the conductor and will be usefully employed instead of being entirely absorbed in resistance, as it would be under conditions (*b*).

The lower the resistance the less the loss, and the larger the proportion of energy that is reflected back.

In addition to the losses caused by the induced currents just considered, conducting bodies near the aerial will cause it to brush (*see* p. 219). The loss of energy, and therefore of range, caused by brushing may be very serious, especially when the aerial is working at approximately its maximum power. If the conducting bodies are well insulated from earth they will not cause the same brushing as if they are connected to earth by either a high or low resistance path. Earthed conducting bodies that are near the aerial may cause subsidiary waves to be transmitted; these waves may interfere with the reception of short waves by neighbouring ships. If a ship have two installations, a defect of this nature in the long wave set will seriously jamb reception by the short wave set.

The effects of conducting bodies near a receiving aerial are as follows:—

If they are "well earthed" they will screen the aerial and cause part of the incoming waves to be reflected away into space instead of being absorbed by the aerial.

If they are connected to earth by paths of high resistance, part of the incoming waves will be expended in inducing currents whose energy will be expended in heat, *i.e.*, in the high-resistance path over which they flow.

From these considerations it follows that:—

The best conditions for W.T. in a ship are those of conditions (*a*), that is, high insulation; but if this cannot be obtained, perfect electrical connection (*c*) is preferable to faulty insulation or imperfect connection (*b*). In a ship the lower part of the mast is of steel. It is hardly practicable to insulate the lower stays. Numbers of wires are taken up the mast, such as cables to the masthead flashing lamp, fire control leads, &c. Also everything aloft is liable to get coated with a semi-conducting film of salt or carbon (soot).

It is impossible, therefore, to obtain the best conditions (*a*), and it is desirable to obtain the next best (*c*). This can be done by fitting lightning conductors of low resistance and with thoroughly good connections. These lightning conductors will take a large proportion of the currents which would otherwise take the other available paths of higher resistance.

It is nevertheless most desirable to obtain the best conditions (*a*) wherever possible. As there are many stays and as in many cases they come very near to the aerial or feeders, it is a decided advantage to insulate them in as many places as practicable. If they are not insulated the loss in range, due to their screening effect on the aerial and to the waste caused by brushing, would have a marked effect on the range of the ship.

Wherever lightning conductors are fitted, it is most important to see that they have good low-resistance connections made between them and all mast bands, fittings, &c., that come near to them ; or else, where in any particular instance connection is undesirable, the lightning conductor should be kept well insulated and outside the limits of any sparking likely to be caused between the fitting and the lightning conductor by induced W.T. effects. If these precautions are not taken, loss of energy and local heating will probably occur at all places where there are faulty connections or bad insulations, with possible resultant damage.

It would also be desirable, wherever possible, to avoid any imperfect contacts between different conducting bodies, for instance, the hemp serving which separates the wire from the thimble at the ends of wire stays, is very liable to get sparked through and set on fire by induced W.T. currents ; while this sparking is going on, and afterwards, when the connection through the burnt yarn is one of high resistance, there is a continual waste of energy.

To obtain the best effects, therefore, such imperfect contacts should be short-circuited wherever they exist. It may be found, however, that short-circuiting them will in some cases decrease the receiving efficiency, showing that the insulation had been previously fairly good for the low receiving voltages, and that the short-circuiting has merely increased the "screening." On the other hand, the sparking that occurs on transmitting may be more harmful than a slight decrease in receiving efficiency, and the sparking and burning away of yarn may be considered objectionable.

In some cases when short waves are being used and long lengths of wire are concerned, it is found better to earth the ends of the wires instead of insulating them ; the earth connection throws the wires further out of resonance with the wave. It has been found better, when receiving a short wave on a small aerial, to earth the main aerial rather than to insulate it.

The conditions at shore stations differ from those in ships, since the mast may be entirely of wood, and if lightning conductors are not fitted it is possible to approach nearly to the best conditions (*a*) above. If there be a good earth connection at the shore station, one approximating to that obtainable in a ship, the shore station should be more efficient than a ship fitted with a similar installation.

The masts at high and medium power shore stations are consequently fitted with portable lightning conductors; these conductors are triced up whenever the aerial is lowered.

When the aerial is up it forms an efficient lightning conductor and affords sufficient protection for the masts; the buildings are further protected by being screened by the earth wires.

CHAPTER XII.

ETHER WAVES.

We shall now proceed to investigate what is commonly supposed to be the "mechanism" of an electro-magnetic or "ether" wave. First of all, we must deduce some arguments in support of our conception of what the ether actually is.

The facts that electrified bodies or magnets attract or repel each other at a distance, and that electric currents can create other currents in wires at a distance, and that these actions are not entirely dependent upon the presence of any material substance in the interspace, but can take place also through a perfect vacuum (that is, in the absence of air) have always impressed competent thinkers with the idea that there must be an "electro-magnetic medium" which forms a vehicle for the transference of these actions across the intervening space. It may be that when a satisfactory explanation of the real character of this medium is found it will furnish at the same time an explanation of what actually transmits the "pull" of gravity.

The observation that light takes time to pass from one place to another, and that it comes to us from far distant stars across interstellar space, which, as far as we know, is not full of ponderable "matter" as we know it, is a proof that light must either be a substance bodily transmitted like a letter sent by post, or else a physical state, or change of state, which is propagated through a stationary medium.

Innumerable optical experiments have proved that light is, without doubt, an *undulation*, and that, therefore, there must be something which undulates. The velocity with which this undulation travels has been measured with considerable exactness, and has been found to be very close to 300,000 kilometres, 186,000 miles or 1,000 million feet per second. The speed at which any disturbance travels through any elastic medium is determined by the square root of the number obtained by dividing its elasticity by its density. No known form of tangible material has such a large elasticity or small density as to permit an undulation or disturbance of any kind to travel through it at a speed of 1,000 million feet per second, so that the ether must have enormous elasticity combined with very small density. The atmosphere, for instance, is a material possessing elasticity, or resistance to compression, and likewise density. If, however, a sudden compression is created in it at any place, this state of compression is propagated through it, in the form of sound, at the rate of only about 1,100 feet per second. Even in hard steel the propagation of a compressional or extensional strain travels only at the rate of about 18,600 feet per second. Accordingly, we are compelled to admit that if light is due to vibrations propagated through a medium at this tremendous rate of 186,000 miles per second, the medium capable of this must possess qualities very different from those of any form of tangible matter with which we are acquainted. The medium called the ether must necessarily be universally diffused, and must interpenetrate all ordinary matter. It cannot be exhausted or removed from any place, because no material is impervious to it. As far as we know, it is not affected by gravitation; but ordinary ponderable matter stands in some very close relationship to it. It must also possess in great degree some form of elasticity—that is, resistance to some kind of change of state produced in it—and it must also possess inertia, or a quality in virtue of which a change so made in it tends to persist. We are not justified in making the assumption that its elasticity, like that of ordinary matter, is a resistance to change of bulk or shape, or that its inertia is necessarily an inertia with regard to motion. It is, however, clear, that the ether has the property of being capable of storing up energy in large quantities and transmitting it from one place to another, as shown by the fact that enormous amounts of energy are hourly being transmitted from the sun to the earth.

With this brief summary of what our conceptions of the ether must be, we will now see how the actual transference of a disturbance may be conceived to take place.

Disturbances on the surface of water take the form of waves which travel along at definite speeds; but the water does not move forward as a whole, for a cork floating on the surface merely bobs up and down as a wave passes beneath it. So also we may consider the ether to consist of innumerable minute particles which are capable of being displaced against their elastic reaction from their normal positions in space, and may imagine that if the displacements are caused at regular intervals of time then an undulatory disturbance of a definite frequency or wave-length will be propagated forwards. We notice, in the case of water, that the particles of water merely move up and down, while the disturbance travels horizontally—that is, at right angles to direction of vibration of the particles. The disturbances in air, which we call sound, consist of to-and-fro movements of the air particles which are parallel to the direction of motion of the waves themselves, the latter consisting of alternating conditions of compression and refraction of the air.

The movement of the particles in ether waves is always at right angles to the direction of propagation of the wave; but they need not necessarily vibrate only in one plane as in the case of the vertical vibration of water. In the case of light the particles must be considered to vibrate in all directions provided that they move at right angles to the direction of propagation, whereas the W.T. waves vibrate in only two directions, the electric and magnetic movements being at right angles to each other at any point on the wave "front." Light waves also can be "polarised" or forced to vibrate in one direction only. This type of vibration is called transversal, as distinguished from the longitudinal vibration of the particles in sound waves.

When one particle of a substance is caused to vibrate, it induces its neighbours to follow it, and starts them vibrating at the same frequencies but in different phases, each particle causing its neighbour to vibrate (passing the word, so to speak) at a definite time-interval after itself has started. The vibrations may be longitudinal or transversal, as described above, or they may be circular or elliptical, but if they are regular the waves produced are regular.

The amplitude of the wave depends upon the extreme limits from its normal position of the vibration of each individual particle. The wave-length depends upon the time taken for one complete vibration of each particle and upon the velocity with which the displacement or vibration is propagated from one particle of the substance to another.

Whether the ether consists of electricity or not does not concern us, but we may possibly say that electric charges, or "electrons," are the only things which have a "grip" on the ether, and that when they are vibrating the ether vibrates with them.

When a particle is subject to several forces at the same time, its resultant movement depends on the resultant of the forces and will vary as the forces vary, so that a body can, in effect, vibrate in more than one way at the same time, and can produce complex waves where vibrations are superimposed on each other. This is shown every day at sea by the small waves or ripples on the slopes of large ones, or the short waves from local winds superimposed on, and propagated in the same or different directions from the long swells due to distant storms. We are already familiar with the "beat currents" in the aerial. When at their maximum strength we have two superimposed frequencies which happen to be acting in unison, but when the current dies away before "beating" again, the two frequencies happen to be in opposition. We know also that our ear-drums will vibrate to several notes at the same time, so that we can not only hear, but distinguish at will, the words uttered by either of two speakers who are talking at the same time.

The vibrations producing ether waves, and consequently the wave-lengths and frequencies, are of an almost infinite range. For instance:—

For frequencies varying from 15×10^{14}, that is 1,500, trillions per second to those of 870 trillions we have waves whose lengths are from 8 to 13·5 microns (*see* p. 42). These rays are invisible to the eye, but they have chemical action on a photographic plate. They are called "X" or ultra-violet rays.

With longer rays of 740 trillion cycles and 16 microns in length we get violet-coloured light, the wave-length increasing throughout the whole gamut of colours of the spectrum in the following order of magnitude. Short wave violet, then blue, green, orange, red, the red light having a frequency of 430 trillion cycles and a wave-length of 27 microns. Notice that the scale of visible rays extends only over a little less than one "octave." (The top note of an octave has double the frequency of the bottom one, *see* p. 219.)

Below the red light rays we have invisible "infra-red" vibrations which are felt as heat. These have frequencies from 430 down to 20 trillions, and the longest heat wave is therefore 600 microns or little more than half a mil.

Then comes a huge gap of 45 octaves, where it is reasonable to suppose that future research will bring to light hitherto undreamt-of forces—possibly thought-forces work on these rays. The shortest true Hertzian or wireless wave that has been measured is a little under a quarter of an inch, while the longest has reached 1,000,000 miles.

Different bodies will be opaque or transparent to rays of different frequencies. Generally when a body is opaque to any ray it may be said either to absorb or to reflect the energy of the ray (possibly both), for remember that the ray either *is* energy or carries it. If, on the other hand, a body is transparent to any particular ray, it does not absorb the energy, but transmits it.

Thus, the heat rays of the sun can be concentrated by means of a burning-glass and caused to ignite a piece of paper even though the rays had previously passed through a glass tank of water. A fire-screen, again, in stopping the heat rays itself gets hot. Water being a non-conductor of heat transmits heat rays without itself getting hot, but the glass fire-screen being a conductor of heat absorbs some of the heat energy and possibly reflects some of it back into the fire. Ether waves of all lengths are subject to absorption in this way; they are also capable, to a certain extent, of diffraction, or the property of curling round an obstruction; of reflection and of refraction. This latter means that they are capable of being bent out of their straight line of propagation by passing through a lens or prism. They can therefore be focussed by mirrors or lenses, but in the case of wireless waves the large size of the mirror or lens necessary precludes this method of directing them.

Since conductors of heat are opaque to heat rays, it follows that conductors of electric charges will generally be opaque to wireless waves. They will, in fact, partially absorb and partially reflect the wave energy. Insulators, on the other hand, are generally transparent to wireless waves, but in transmitting them they absorb some of its energy, though not much.

Reflection and Absorption of Ether Waves.

If ether waves impinge upon a reflecting surface they are retransmitted in a definite direction depending upon the angle at which they strike the surface. If the mirror is a flat surface the angle between the arriving ray and the plane of the mirror will be the same as that between the departing ray and the mirror. This is expressed by saying that the angles of incidence and reflection are equal. By the interposition of a reflector, therefore, the directed waves may be detected at a point outside their original line of propagation.

Air at atmospheric pressure, about 760 mms. of mercury, is a very good insulator; that is to say, it will transmit electric vibrations with but very little absorption of energy.

Well-known facts in regard to meteorites and other cosmical phenomena show that the thickness of the shell of air which envelopes the earth is not more than about 100 miles.

The thickness of the air "blanket" is therefore small when we remember that the earth's diameter is 8,000 miles, and that we can transmit signals for distances of 2,000 miles.

Now the higher we rise above the earth's surface the less heavy does the superincumbent layer of air become, so that at a height of about 40 miles the barometer would show a pressure of only 1 mm. Air at this pressure somewhat suddenly becomes a good conductor. So good a conductor does it become that a layer of air at this pressure, only half an inch in thickness, will not allow a wireless wave to pass.

Still further up its conductivity drops again, so that when we emerge beyond the layer of air we may say that the ether is the best dielectric known.

It is just at this height of 35 to 40 miles that we get air becoming a good conductor due to the critical pressure arrived at. The upper shell of conducting air, then, is separated from the earth by a layer of non-conducting air whose thickness, 35 miles, is less than one hundredth part of the earth's radius, and the conducting properties of the upper shell are such that it is 40 times a better conductor than is the surface of the sea, and over 600 times better than damp soil.

This upper shell of conducting air, although it is transparent to light rays of high frequency, reflects our longer electric waves so that they can travel "round the corner," so to speak, and be detected at a point far below the horizon.

In the same way searchlight signals can be thrown on a cloud at night, a ship out of direct visual sight being able to see the illumined cloud and read the signals. Fig. 125 (*a*) shows to scale the curvature of the earth and the height of the upper shell of conducting air. The height has been exaggerated in Fig. 125 (*b*) in order to show how the path of the wireless rays, which normally would travel in straight lines, is carried round the earth by reflection.

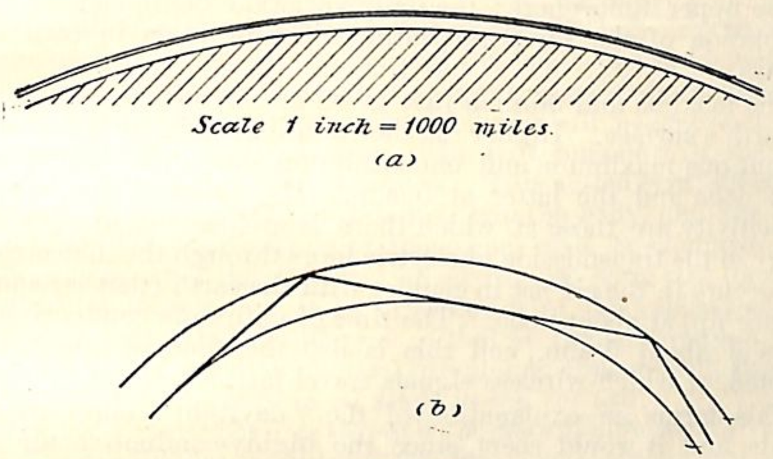


Fig. 125.

No doubt the conducting properties of the earth itself also tend to direct or guide the waves over the horizon, just as drops of water slide over a window-pane, but it is seen that even if this guiding action of the earth were absent it would still be possible to signal over the earth's curvature.

It must be admitted that some such deflection of the waves takes place, for between Clifden and Glace Bay the curvature of the earth presents a "mountain" nearly 200 miles high.

Other causes of reflection may, and often do, exist, such as large bodies of electrified air, or heavily charged clouds, which would cause interference between direct and reflected waves and make electrical "shadows" in certain places—that is, at points at which, owing to conditions outlined above, either the waves are so attenuated that they cannot be detected or that they are completely neutralised.

We therefore find that it is practically upon the condition of what we may call the "wireless dielectric" that the reliability or otherwise of this method of signalling depends. The wireless dielectric is the non-conducting air up to the height of 35 miles —the highest mountains are less than six miles high—and if the non-conducting properties of this layer of air become poor then absorption and too early reflection will take place.

The insulation of the lower strata of air is by no means constant, its conductivity being subject both to regular and irregular changes.

The most important of the regular variations in conductivity is the diurnal variation corresponding to the daily variation of atmospheric electrification. The greatest electrification near the surface of the earth occurs between 8 and 10 a.m., and from 10 p.m. to 1 a.m., the least effect being at 2 p.m. and 4 a.m.

The effect is most probably due, directly or indirectly, to streams of electrified particles, ejected by the sun, impinging on the upper atmosphere; the daily variation being caused by the rotation of the earth presenting different parts in turn to the rays.

The maxima and minima just given are those observed near the earth's surface. Higher up, the variation, as far as is known, has but one maximum and one minimum daily, the former at about noon and the latter at 5 a.m. The times of maximum conductivity are those at which there is greatest dissipation of energy in the transmission of electric force through the dielectric. This occurs in the air *not* in contact with the earth (that is, some distance up) at about noon. The time of minimum conductivity occurs at about 5 a.m., and this is also the time, as might be expected, at which wireless signals travel farthest.

This forms an explanation of the "daylight" effect upon signals, and it would seem, since the highly-conductive air is transparent to waves of very high frequency, that the absorption of energy due to the daily rise in conductivity, would be greater with waves of high than with those of low frequency. It is well known, for instance, that short waves sometimes give a much larger night range than day range, whereas the longer waves are more uniform in their ranges.

The whole question is still in the rudimentary stages of investigation, and the marked increase in short-wave night range may be due to causes connected with the transmitting circuit itself. Prof. J. J. Thomson has shown that the energy loss is greater with *long* than with *short* waves, and that the greatest loss occurs near the transmitting aerial, and not uniformly throughout the "range."

It would seem, therefore, that it is more necessary for the transmitter to be cloaked in night than for the receiver to be in a dark part of the earth. When, however, both are enveloped in darkness the most reliable signalling will take place.

Long-distance transmitting will be at its best for the longest time out of the 24 hours when the two stations lie on the same meridian, for if they be on an east and west line they will not have the whole interspace covered with darkness for so long as if they were north and south of each other.

The irregular changes in conductivity of the atmosphere, other that those due to day or night, are probably due to an infinity of causes. Stormy weather, or the approach thereof, excessive moisture in the atmosphere, local hot winds such as the scirocco, all tend to reduce the strength of signals, although there may not be any "atmospheric" discharges going on in the telephones.

In Canada an increase of range to six times the normal has been observed immediately after an Aurora Borealis.

Refraction of Ether Waves.

When ether waves impinge on transparent bodies at any angle other than the "normal," that is, other than at the perpendicular to the surface of the body, if their velocity in the transparent body, on account of its elasticity or density, be different from that at which they were previously moving, that part of the wave first entering the body will move either faster or slower than it did before. The part outside will, therefore, either gain on it or fall behind it. This action will affect each portion of the wave from it as it enters the body, and the result will be that its direction of movement will be changed. The effect is to bend the wave out of its original path, and the action is called refraction. It is on account of the velocity of light through water being different to that of light through air that causes a stick partly immersed in water to appear bent, provided that the stick be held at an angle to the vertical.

Ether waves passing through the atmosphere, whose density varies at different points and different levels, are subject to this bending action.

Diffraction of Ether Waves.

When waves meet a body in their path (for instance, when the comparatively long waves used in wireless telegraphy impinge upon a high island or mountain range) at the points where the wave front cuts the extreme width of the island, new centres of disturbance are created, which radiate some of the wave energy to points behind the island. It has the effect of bending the waves, or allowing them to curl round behind the object. This action, which is called diffraction, also takes place at the summit as well as at the water's edge. The amount of action will depend upon the wave-length. From the new centres of disturbance waves are sent out, which interfere with each other, not being propagated in the same directions. The result is that for a certain distance, depending upon the width and height of the obstacle, and upon the wave-length, a shadow exists beyond it where reception is impossible. Thus the obstacle has a screening effect which depends upon its shape, being independent of the different screening effects depending upon the conductivity or magnetic properties (permeability) of the land (*see* p. 12), which constitutes the obstacle.

Partial reflection of the waves backwards towards their source takes place on the side of the obstacle nearest the source.

The best illustration of this is shown by the motion of water round a rock on a windy day. The small back waves on the windward side are reflected to windward. The waves circling or bending round the rock are diffracted. The still water in the lee of the rock is the shadow, in which no action exists. At a distance, depending on the size of the rock and the wave-length, the zones of interference disappear, the regular waves from the two sides of the rock unite, and there is no evidence of its existence at points beyond, though it has diminished the total strength of the waves.

For the above reason high land between two stations may stop signalling entirely if either station be close under the mountain, but signalling may be carried out at greater ranges when no high ground is in the *immediate* neighbourhood of either station. In any case signals will be weaker than if no high land intervened. Long waves are less affected by land screening than are short ones.

The effects of reflection and diffraction on waves passing over irregular country are most pronounced. The effects of reflection, refraction and absorption in the atmosphere are equally pronounced, the qualities of the atmosphere varying greatly in all three respects from day to day and between day and night.

The Function of the Earth.

The original open oscillator of Hertz did not employ the surface of the earth to form one plate of the circuit, his oscillator being of the "linear" or "dumb-bell" type, as shown in Fig. 126. When, however, we employ an earthed oscillator as a radiator, the electrical properties of the earth become of great importance.

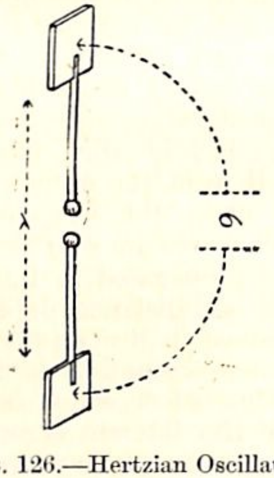


FIG. 126.—Hertzian Oscillator.

We must remember that the depth to which the high-frequency currents penetrate into the substance of the ground is not very great, so that we have to deal with the conductivity, or other properties of the upper layers only, of the earth's crust.

An ordinary high-frequency current will not be perceptible at a greater depth than 15 metres in moist soil. Damped oscillations (jigs) will penetrate even less than this amount. The effective resistance of the earth is therefore greater than that of an "earth return" for any low-frequency or direct current system. Again, the depth of the useful layer in salt water is only one-quarter of that in earth, that is about 4 metres; but as the conductivity of salt water is about 17 times as great as that of soil, the effective resistance of the sea is much less than that of land.

If the land contain iron ores or other magnetic material the depth of penetration is enormously decreased, so that the effective resistance rises very largely.

These facts probably account in great part for differences in the possible distance of transmission over hills of various materials, which were first observed by Sir Henry Jackson.

The chief results of his observations may be summarised thus:—

If the maximum possible distance over open sea be taken as 100 miles, the distance when sandstone or shale intervened was 72, with hard limestone 58, and with limestone containing iron ores 32 miles. It must be borne in mind that generally much the greater part of the whole distance was over sea, so that had the distance between the stations been completely composed of the substances enumerated, the differences in maximum range would have been still more marked.

Now, recollecting that sandstone has a much higher resistance than sea water, and limestone than sandstone, and that limestone containing iron ores has both high resistance and permeability, we are at once driven to the conclusion, that the distance to which wireless transmission is possible is governed to a large extent by the specific resistance and magnetic permebility of the useful upper layer of earth or sea. Since, therefore, the nature of the earth's surface determines the distance to which signals can be transmitted, it is clear that, whatever be the distribution and shape of the lines of electric or magnetic force composing a wave, transmission depends essentially on the action of the earth, at least in any earthed system.

It is within everyday experience that short waves suffer much more in passing overland (even flat land) than do long ones. This would be due to the smaller penetration of high than that of lower frequency currents. The useful "layer" of earth becomes shallower and the consequent resistance greater.

These are the main effects of the different compositions of the earth's crust over which the waves glide.

The actual function of the earth on the propagation of waves is a much debated point, especially as regards the difference, if any, in the cases of conductively earthed and balanced aerials.

It is not clear as to how much of the "guiding" effect whereby waves are propagated round the curvature of the earth is to be attributed to reflection from the upper layer of conducting air, and how much to the "gliding" action by which the bases of the waves are conceived to be attached to and guided by, the conducting surface of the earth.

The Form of a Wave.

In the case of the linear oscillator (Fig. 126) when the jig is taking place and the charges most widely separated (the current being zero and just about to change direction), we may imagine lines or "tubes" of electric force to be connecting each unit of positive electricity on one end to its "opposite number," a unit of negative electricity on the other end (Fig. 127 (*a*)). For clearness of conception we may picture these lines of force as having a real existence and exerting an elastic pull tending to draw the positive and negative ends together, while at the same time these lines of force, provided they are running in the same direction, tend to repel each other. In the example we have the top half charged positively and the lower half negatively. As

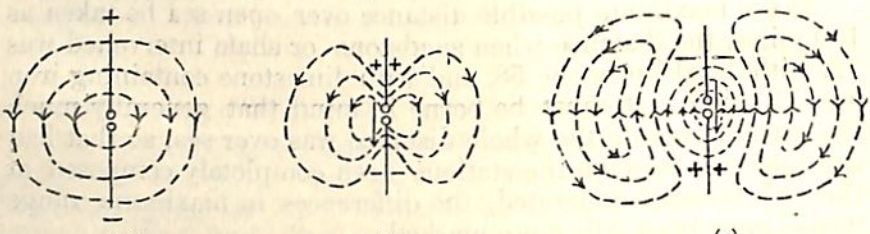


Fig. 127.

the open oscillator discharges, the current will commence to flow downwards across the gap. The ends of the electric lines of force slide together along the wires, as in Fig. 127 (*b*), and finally unite as in (*c*). The current now goes on flowing on account of the back E.M.F. of inductance and charges up the oscillator, producing new electric lines of force with reversed polarity, the first electric disturbance having been "snapped off" in the form of closed loops. The first disturbance is forced outwards by the birth of the new electric field, for the directions of the lines in the inner surface of the first and the outer surface of the second are the same.

As the current oscillates in the circuit, we see that a series of closed loops of electric force are flashed off into space, each repelling its predecessors to make room for the latest born, and each loop representing lines of force alternately in opposite directions.

Similarly we must imagine the wires to be surrounded by rings or ripples of magnetic force, whose intensity will vary with the current strength and whose direction will alternate as does the current. Further, these lines of force are horizontal, being in a plane at right angles to the current-carrying wire and consequently at right angles to the most advanced portions of the electric lines of force. Further, the two natures of radiation, electric and magnetic, though possessing the same frequency, wave-length and velocity, differ from each other in phase by 90 degrees. The magnetic field is zero when the electric field is at a maximum, and *vice versâ*.

This type of oscillation, causing symmetrical loops to travel outwards, is called a "free wave" system, and is that which results from using an "Hertzian" or dumb-bell oscillator excited in the middle.

The case of an earthed aerial wire excited at its lower end presents a different form of electrical disturbance, as shown in Fig. 128.

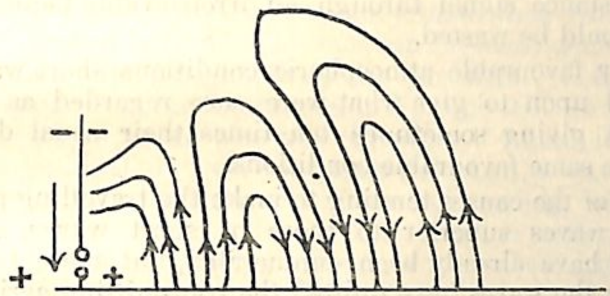


FIG. 128.

The effect is the same as if only half of the Hertzian oscillator had been regarded, at any rate when the waves have travelled some little distance from the aerial. The loops are "grounded" at their lower ends, these ends being perpendicular to the earth near the surface and bent a little backwards higher up. This rising effect of the "older" waves is due to the mutual repulsion of adjacent tubes of force composing any one wave. The inner ones repel the outer ones, causing them to increase in height.

The variations of electric and magnetic field strength at different points measured along the direction of propagation of a wave are shown by the ordinates of the two curves in Fig. 129, which shows, in perspective, the vertical and horizontal planes at right angles to each other, the line of intersection of the planes being parallel to the direction of motion of the electro-magnetic wave.

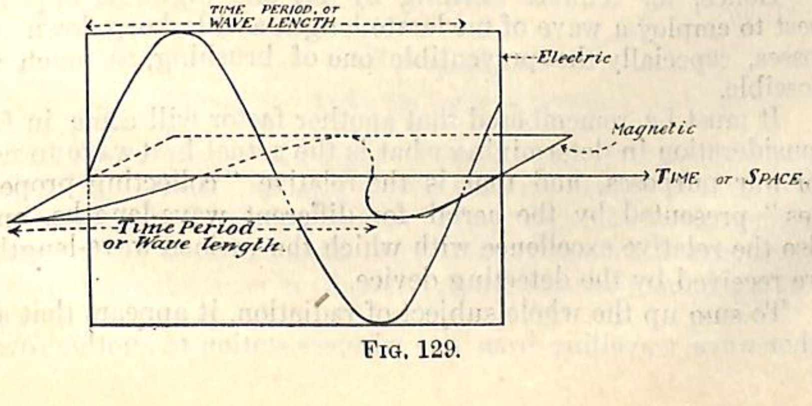


FIG. 129.

The difficulty of arriving at any definite experimental proof of the theory of the mechanism of these waves is due to the multiplicity of causes in variation of strength of signals, so that when studying one cause of dissipation of energy it is well-nigh impossible to eliminate the others.

We may now mention a few points regarding the advisability of using long or short waves for transmission from ships. We must bear in mind that, for war purposes, what is required is the greatest reliability under all conditions.

To be able to send enormous distances by night, but to be limited to 150 miles or so by day, is not desirable, for it might easily happen that if one had to wait till nightfall before getting a long-distance signal through, an irretrievable tactical opportunity would be wasted.

Under favourable atmospheric conditions short waves may be relied upon to give what were once regarded as "freak" distances, giving sometimes ten times their usual day range under the same favourable conditions.

Some of the causes tending to make the travelling properties of long waves superior to those of short waves, especially overland, have already been enumerated, but these take effect only after the waves have quitted the transmitting aerial.

The "efficiency" of the radiation at the transmitting end may be found by comparing the total energy radiated throughout the jig to the initial energy with which the jig commenced.

Taking an aerial whose natural wave-length is about 1,800 feet, it is found that when transmitting a 2,000-feet wave 46 per cent. of the total energy supplied is radiated, the remainder being used up in heat, brushing, &c. With a 3,500-feet wave about 14 per cent. and with a 5,500-feet wave only 4 per cent. gets away into space. This is due to the long wave having a longer time period, and therefore a longer time for heat losses, &c., to operate during each half-cycle.

With long waves it therefore becomes extremely important to keep down all losses to the absolute minimum possible.

The short wave gets itself radiated much more efficiently than does the long one, but, once out and away, the long one suffers absorption due to many causes to a far less extent than does the short wave.

Hence, for reliable working by day and night, it appears best to employ a wave of moderate length and to keep down all losses, especially the preventible one of brushing, as much as possible.

It must be remembered that another factor will come in for consideration in determining what is the actual best wave to use for war purposes, and that is the relative "collecting properties" presented by the aerial for different wave-lengths, and also the relative excellence with which the various wave-lengths are received by the detecting device.

To sum up the whole subject of radiation, it appears that an ether wave travelling from one wireless station to another over rough country and through an atmosphere of varying density, working its way around and over mountains, being buffeted from thunder-clouds at one point and absorbed by semi-conducting gases at another, not to mention several other enemies to its progress, may be said to pursue an adventurous journey; the wonder seems to be, in fact, that it ever gets through at all.

Fundamental and Harmonic Oscillations.

It is well known that a stretched string, such as a violin string, can vibrate not only as a whole but can divide itself into oscillating sections, having lengths respectively equal to one-half, one-third, and one-quarter, &c., of the whole length, in which case it emits notes of higher frequency than when vibrating as a single undivided length. This fact can be easily demonstrated by means of a rope hanging from the yard-arm. If slow, even jerks be applied to the bottom end, the rope will sway out in the form of a bow to one side and the other. Again, if a single quick jerk be given and the rope then held taut, a wave will be seen travelling up the rope till it reaches the top, where it is reflected, travels down the rope to the hand, is reflected there and starts up again to the top and so continues until its energy is damped out.

If a number of equally timed jerks be given at a quicker rate than the first slow sweeps, a succession of waves at equal intervals is sent up the rope. When reflected back they meet others coming up whose lengths are equal to their own. At some points the rope tends to move a certain distance in one direction with the direct wave, and the same distance in the opposite direction with the reflected wave; the result is that at that point it does not move at all. These points are found at intervals along the rope which are one-half a wave length apart; at all points the rope moves or vibrates in the resultant direction (algebraical sum) of the direct and reflected wave impulse, and what are called stationary waves are set up in the rope. The points at which there is no movement are called "nodes" of motion, and points at which there is a maximum movement are called "loops." This is shown graphically in Fig. 130.

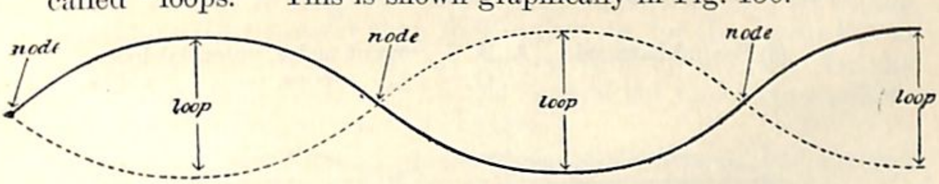


FIG. 130.—Nodes and loops of motion.

It is clear that at the point of support there cannot be any movement. Hence the ends of the rope are always at a node of movement. So, when we come to apply impulses to the end of a conducting wire, the other end (being insulated) must be a current node, because no current or movement can take place there. It can, however, and it is easily seen that it must, be a potential loop, for where there is no movement at the point of support there is the greatest pressure or tendency to move. (Fig. 131.)

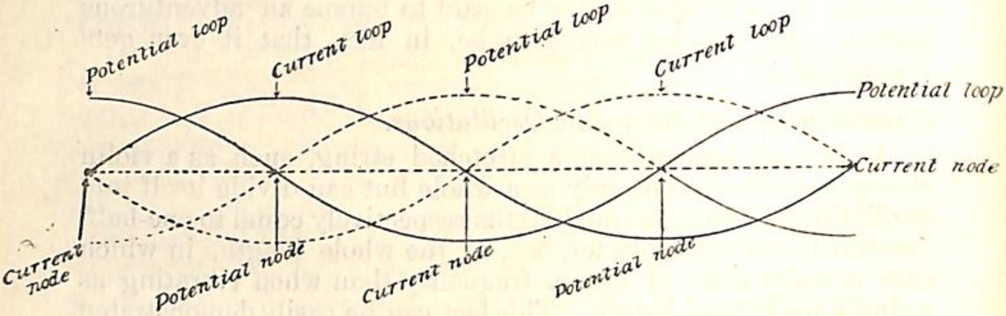
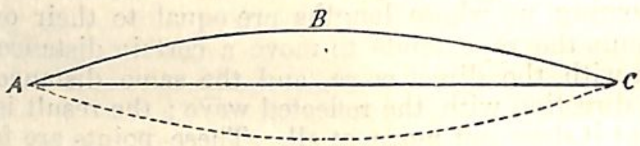


Fig. 131.

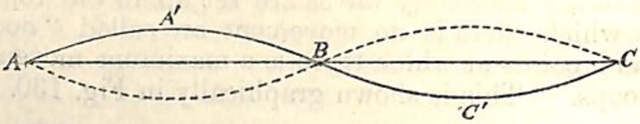
Now to return to the violin string. Here we have a string possessing mass and elasticity stretched between fixed points. If the string be plucked and allowed to vibrate naturally, the main oscillations, which give us the fundamental or natural wave-length, will show a movement (or current) loop at the centre of the wire, nodes at its ends.

Similarly potential loops will be formed at the ends and a potential node at the centre. (*See* Fig. 132 (*a*)).

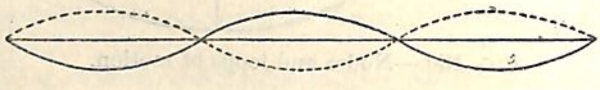
Movement of stretched string.



(*a*) Fundamental. A = current note, potential loop.
B = „ loop, „ node.
C = „ node, „ loop.



(*b*) Second harmonic. A, B, C, current nodes, potential loops.
A′, C′, „ loops, „ nodes.



(*c*) Third harmonic.

Fig. 132.

Now if we place a finger lightly on the string, not hard enough to alter its tension, but just hard enough to " kill " or damp out the current loop at that point, we turn the centre of the string into a current node.

This causes the string to divide itself up into two halves, each half vibrating with double the previous frequency. The note given out will be one octave higher than the fundamental, and goes by the name of the "second harmonic." The fundamental and second harmonic are shown in Fig. 132 (*a*) and (*b*) respectively. Similarly, by putting two fingers on the string so as to divide it into three equal parts, we get four current nodes, three loops; but four potential loops and three nodes. (*See* Fig. 132) (*c*).

It is not necessary to keep two fingers on the string, since if one only be placed a third of the way from either end of the string, the latter will automatically divide itself into three separately vibrating sections. The note given out will have three times the frequency and one-third the wave-length of the fundamental. It is called the third harmonic.

In the same way, the string may be made to divide up into any number of sections, odd or even, each fresh one giving out a higher note than its predecessor. The second, fourth, eighth and sixteenth harmonics will all be octaves above the fundamental, while all the others, up to the 5th inclusive, must make harmony, not discord, when sounded together. They make up the common "major" chord.

The higher notes of a bugle are all harmonics of the fundamental lowest note. The bugler brings out the higher notes at will by pressing his lips more firmly together so as to force the high-frequency notes into prominence.

It was noticed in the case of the string that the fundamental wave was twice the length of the string, while the harmonics are one-half, one-third, &c., of the fundamental.

Now in an aerial wire we have the top end insulated, so that it must be a node of current and a loop of potential.

The bottom end, however, is automatically at zero potential, for it is earthed. Hence the bottom must be a node of potential but a loop of current.

It is easy to see that the current in the lower part of the aerial must be greater than that higher up, for the feeder has to carry coulombs wherewith to charge itself up and also for the charging of the roof, whereas the ends of the roof have nowhere beyond them requiring any charges.

We see, therefore, that the stationary waves of current and pressure in the aerial will be as if we had hidden half the violin string in a box. The Hertzian oscillator behaves like a vibrating string, but an earthed aerial excited at the bottom behaves like an organ-pipe or whistle.

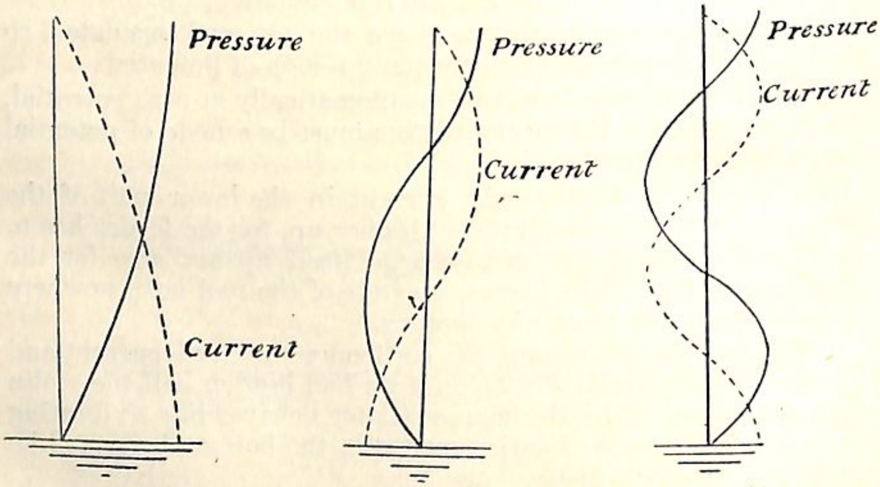
Near the end at which you blow a whistle is an opening which puts that end at atmospheric pressure. Here there is greatest motion and least pressure of air. The far end of the whistle is closed, so that we get maximum pressure and no motion.

Hence it is impossible to get the even-numbered harmonics in an aerial wire, organ-pipe or whistle, unless we earth the top of the aerial or open the ends of the pipe or whistle so as to get a loop of current and a node of potential there.

All musical instruments, whether wind or string, give out their fundamental wave-length most strongly, but in addition to this long wave other shorter ones, the harmonics, are also radiated. Strings and open-ended wind instruments can send out odd and even numbered harmonics. Closed wind instruments can only give out odd numbered ones.

People with highly trained "musical ears" can detect the presence or absence of the harmonics sent out, but all people can tell the difference between a "G" on a bugle and the same note on a piano. It is the number of harmonics present, superimposed on the fundamental, that give the character or "colour" to a note and enables us to tell from what instrument it emanates. Again, we recognise the voices of our friends by this means.

Now the aerial wire gives us only the odd-numbered harmonics, having wave-lengths one-third, one-fifth, one-seventh, &c., of the fundamental, corresponding to frequencies of three times, five and seven times the "natural" frequency. When, therefore, we send out a 2,100-feet wave we are also emitting a weak 700-feet one, a still weaker 425-feet one, and so on. This does not usually cause any interference, and it cannot be prophesied whether any one aerial will send out harmonics of sufficient strength to affect another aerial tuned to receive the smaller waves or not. It appears to be a property depending upon the distribution of capacity in the aerial.



(a) Fundamental. (b) Third or 1st odd harmonic. (c) Fifth or 2nd odd harmonic.

Fig. 133.

The pressure and current in the aerial for the fundamental and its harmonics are shown, in the case of a vertical Marconi aerial, in Fig. 133.

(*a*) shows the fundamental, the wave-length being four times the height of the aerial; (*b*) should be called the "third" but it is often called the "first odd" harmonic; (*c*) is the fifth or the second odd harmonic, and so on. It should be noted that a ship sending on a 700-feet natural wave would probably interfere considerably with the reception of a 2,100-feet wave, more so indeed than would the 2,100-feet sending interfere with 700-feet reception. If it be desired to eliminate the harmonics from the large transmitting aerial, on account of their interference with short-wave reception, we may either (1) get rid entirely of the small wave by shunting the transmitting set with a small L and S in series whose LS value equal that of the obnoxious harmonic, or (2) alter the wave-length of the harmonic so as to enable it to be cut out by the short-wave receiver. This can be done by shunting a few turns of the mutual coil with a condenser, the tuning of the fundamental being checked to prevent alteration of its own length.

Production of Harmonics.

Should it be required to send out a short wave from a large aerial we can, if its length be but slightly less than the natural wave-length of the aerial, get resonance by inserting a condenser in series with the aerial, thus artificially reducing σ. Otherwise, if still determined to keep to the large aerial, especially if the short wave be less than one-third the natural wave-length of the aerial, we may force the short wave high-frequency vibrations on the long aerial.

This is done by coupling, very tightly, a closed oscillator (of the desired small LS value) to the aerial and exciting this closed circuit inductively, either tight or loose coupling being obtainable, by means of the primary closed oscillator.

This method is not very satisfactory, since it is difficult to tune the aerial circuit proper to the correct wave-length, which should be three times the short wave. Owing to the asymmetry of the aerial oscillator, the exact proportions of three times, five times, &c., do not hold good, and it is only by trial and error that the correct adjustment of the aerial coil can be found, so that radiation is at its maximum and tuning correct. The harmonic method of sending short waves from large ships is liable to give trouble by radiating, with considerable strength, other undesirable waves, and it may sometimes be preferable to use a special small aerial whose fundamental is correct for the short wave. Although this aerial will suffer from screening in a ship, yet it is more satisfactory in that it will cause much less interference in the organisation of the fleet. The large aerial need not be lowered, but the two (or more) ends of the feeders should be taken some distance away from the deck insulator and well earthed, not insulated. The objections to this method are that it takes time to shift over from a short to a long wave, that the range is not quite so long, and also that changing from one to the other is almost impossible by night. The small aerial should be kept coiled down in a box having the lengths of its guys carefully marked, for any alteration in its position, if put up only periodically, will throw the circuit out of resonance.

We may mention that reception of short waves is better on the small than on the large aerial, besides being much more free from atmospheric and other interference. Improvements in the receiving circuit will probably remedy this defect.

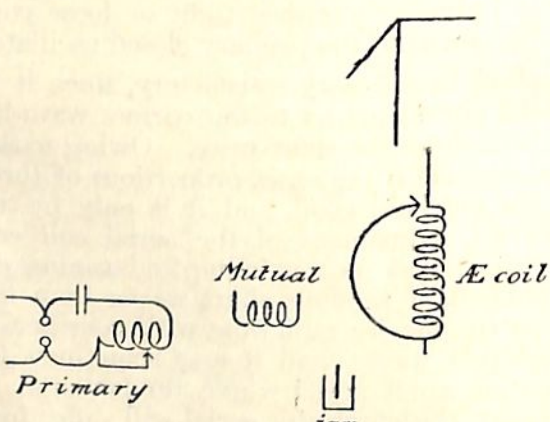
The process of tuning by harmonics in practice is as follows :—

(1) Tune primary as usual.

(2) Tune another closed oscillator whose "L" is the mutual coil, to the same LS as the primary. This is done in the ordinary way with vacuum tube. Leyden jars will be useful for the condenser in this circuit.

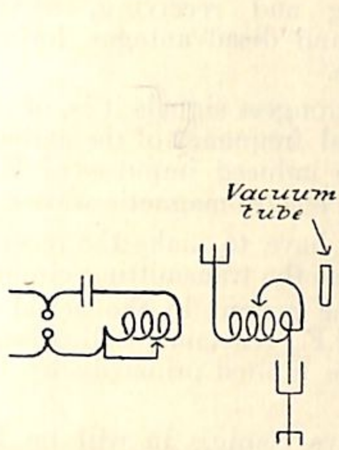
(3) Tune the aerial circuit by "plain aerial," having first removed the Leyden jars in (2), to *four* times the correct wave-length. For rough adjustment the "plain aerial" tuning may be omitted, and the position of the aerial coil be judged by reference to the clips of longer wave-lengths, which would be already in place.

(5) Couple up the whole system. The circuits with wavemeter omitted, are shown in Fig. 134.



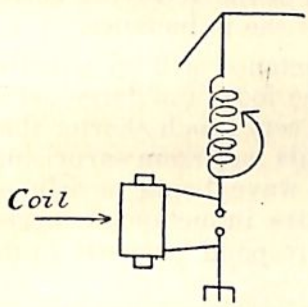
(*a*)

Tuning primary.



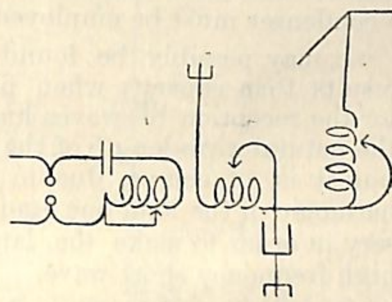
(b)

Tuning intermediate circuit.



(c)

Tuning aerial.



(d)

Circuit complete.

Fig. 134.

CHAPTER XIII.

The Receiving Circuit.

As we have already noticed for transmitting, the greater the height and capacity of the aerial, the stronger will be the signals received; but under some circumstances, such as when we want to keep down the radiation damping of the aerial for receiving, it may be advantageous to use a low aerial.

A large capacity tends to make atmospheric interference more pronounced, and a large inductance gives greater selectivity, but in a ship it is almost impossible to have two different aerials for transmitting and receiving, so that the aerial embodies advantages and disadvantages for receiving which constitute a compromise.

In order to get the strongest signals it is, of course, necessary so to adjust the natural frequency of the aerial that it is equal to the frequency of the induced impulses of E.M.F. applied to it by the passage of the electro-magnetic waves.

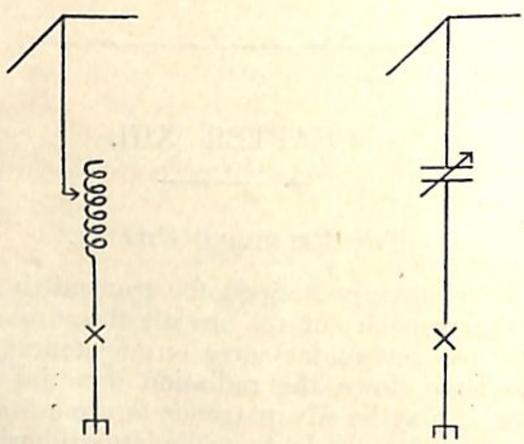
In other words, we have to make the receiving aerial have the same LS value as has the transmitting circuit.

If this be so, then the current in the aerial will be in phase with the induced E.M.F., reactance will disappear, and the current strength will be limited primarily by the resistance of the wires.

In general, the wave coming in will be longer than the natural wave-length of the aerial, so that the addition of a certain amount of inductance in the foot of the aerial is necessary in order to produce resonance. Should the wave be shorter than the natural or fundamental of the receiving aerial, a condenser must be employed instead of the inductance.

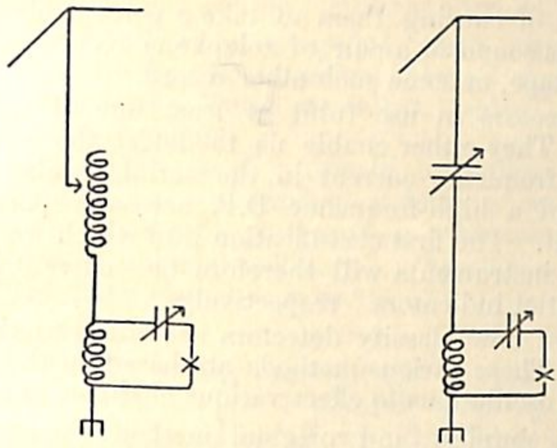
It may possibly be found that inductance will give better results than capacity when placed in the foot of a large aerial for the reception of waves known to be very much shorter than the natural wave-length of the aerial. This may seem surprising, but it is, of course, due to the short wave being nearly an harmonic of the long one, and a little extra inductance is necessary in order to make the large aerial respond properly to the high frequency short wave.

A receiving circuit may be likened to a transmitting circuit with the detector replacing the spark gap. Assuming that the detector has no inductance, we may cause the circuit to take the form of Fig. 135, *a*, *b*, or *c*.



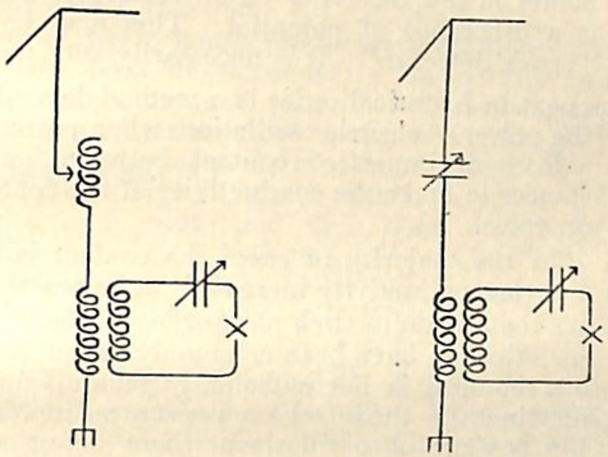
(*a*)

(i) Long (ii) Short.



(b)

(i) Long. (ii) Short.



(c)

(i) Long. (ii) Short.

FIG. 135.

In the first place we have "plain aerial," in the second a "direct coupling," while an "inductive" coupling is shown in the third. Each figure shows the arrangement for long and short waves respectively.

Whatever circuit is used, the best one to use, and, if a coupling be employed, the best coupling to use, will depend not only upon the characteristics of the incoming jig, but also on the properties of the detecting device.

Before entering upon the consideration of the best circuit to use in any given instance, it will be well to look at the various detectors in use.

Classification of Detectors.

Since the current induced in the aerial by the passage of the waves is not directly appreciable to our senses, we must use some means of causing them to take a perceptible form—that is, to give us sound in a pair of telephone receivers, ink-marks on a paper tape, or some such other record.

The detectors in use fulfil at least one of the following functions. They either enable us to detect the existence of a small high-frequency current in the aerial, or else give us an indication of a high-frequency D.P. across a portion of the aerial circuit. The first classification into which we may divide our several instruments will therefore be "current indicators" and "potential indicators" respectively.

We must now classify detectors according to their method of action. These various methods are based on the property of the electric oscillations to effect various changes, as follows:—

(1) The simplest and original method is that of Hertz himself, and consists of observing (with a microscope if necessary) spark discharges passing between points on the receiving circuit between which there is a difference of potential. This may be called a "spark detector." It is necessarily very insensitive.

(2) The next in historical order is a method depending upon the power of electric oscillations when passed through a loose or imperfect contact between certain substances to make the conductivity of the contact better or worse.

In the majority of cases the contact is improved and the conductivity increased, and since the surfaces are then made to stick more or less perfectly together, such devices have been commonly called "coherers," but the term is not sufficiently general, since it does not include those whose resistance increases with the passage of oscillations (these being sometimes called "anti-coherers"), and it is therefore better on the whole to speak of them as "imperfect contact" oscillation detectors.

(3) Those depending upon the faculty of oscillations to affect the magnetic properties or state of magnetic metals. These are called "magnetic" detectors.

(4) A large class which depend upon the ability of jigs to heat a fine wire or substance of high resistance. These are called "thermal" detectors.

(5) "Electrolytic" detectors operate by the agency of the chemical action of electricity, a property by which it can split up a liquid electrolyte (*see* p. 196) into its constituent elements.

(6) The "rectifiers" allow currents to flow easily in one direction but with difficulty in the other. This property may be called "uni-directional" or "unilateral conductivity."

These latter detectors can be further subdivided into—

(*a*) Those which employ rarefied gases which are permeated by the negative "ions" or particles of electricity. These are called "valve" or "ionised gas" detectors.

(*b*) Those which employ certain crystalline substances which have a greater resistance one way than the other to high-frequency currents. These are called "crystal rectifiers." We shall consider each of these classes in turn.

Spark Detectors.

These are hardly of any practical use on account of their lack of delicacy. The original detector used by Hertz consisted of a nearly closed loop of wire having a minute gap. Sparks passed across the gap when the loop is held in such a position as to be influenced by electro-magnetic radiation.

Imperfect Contact Detectors.

The use of the coherer, producing a permanent record on a tape, has now been discontinued in the Service on account of the greater selectivity and ease of over-reading provided by detectors which give a sound in telephone receivers.

Marconi's coherer consists of a small glass tube containing two silver plugs fitting tightly inside the tube. The plugs nearly touch each other, and their outer ends carry platinum wires, which are sealed into the extremities of the tube. In the space between the plugs lies a pinch of nickel and silver filings, 95 per cent. of nickel and 5 per cent. of silver, carefully sifted. The air is exhausted from the tube and the latter sealed up. Normally the resistance of this tube is high, owing to the bad contact made by the filings loosely falling together by their own minute weight. When, however, oscillations are passed along it, the filings stick together, greatly reducing the resistance of the whole. A small local cell is then able to send a direct current through, which will operate a relay, the latter in turn switching on the current from another local battery to an inker. After the filings are cohered or stuck together by the action of the jig, they require to be shaken up again before they regain their insulation properties. Consequently, in parallel with the inker is joined a "tapper." The latter consists of an electric bell where the coherer takes the place of the gong.

Of the self-restoring coherers, or those which do not require a tapper to destroy the conducting property of the cohered instrument, is Lodge's disc coherer.

Here we have a small steel knife-edged disc slowly revolving by clockwork. Its edge just dips beneath the surface of a small pool of mercury on which floats a thin film of heavy oil. The wheel carries down with it a thin coat of oil, which insulates it from the mercury until the arrival of a jig, when the oil film gives way, and enough current can flow from a local cell across the mercury and the wheel to operate a siphon recorder.

The Castelli coherer has a globule of mercury between a steel and a carbon plug inside a glass tube. It is said to be self-restoring.

S. G. Brown has recently constructed a self-restoring coherer, where a small compressed pellet of lead peroxide is gently squeezed between a platinum and a lead plate. Its action, however, is more probably that of an electrolytic valve.

Several other forms of imperfect contact detectors, such as the Massie steel and carbon, the Walter tantalum and mercury, and the Branly copper and steel have been invented; but all these suffer from the same disadvantages, lack of reliability and failure when interference occurs on the same wave-length. The musical note transmitting circuit enables the operator to read the desired signals even through a great deal of interference, which the coherer can never do, unless used with the telephone. Only the self-restoring ones can be so used. The actual theory of the coherer is a debated point, but we may classify them all as potential operated devices, and consign them to cases where the operators are unskilled and a permanent record desirable, where interference is not likely, and where the maximum range is not required to be great.

(3) *Magnetic Detectors.*

The operation of magnetic detectors depends on the fact that iron does not take up or give up its magnetism immediately on the application of the magnetising force. This is said to be due to the hysteresis of the iron (*see* p. 132). When in this condition the iron is very sensitive to any changes in the magnetising force, a very small alteration of which will produce a very large alteration in the strength of the magnetic field.

Many patents have been taken out for various forms of magnetic detectors, the best known and most widely used being that of Marconi, patented in England in 1902.

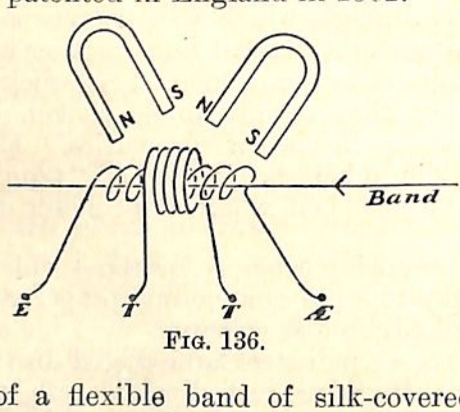


FIG. 136.

It consists of a flexible band of silk-covered iron wires, moved by clockwork around two pulleys which support it. On a glass tube, through which the band passes, is wound a primary winding of insulated wire. This is laid on in one layer, and has an inductance of 70 to 80 mics. It is placed in series with the aerial, since the detector is current-operated. Round the primary we have a secondary winding of fine wire, having a resistance of 150 ohms, to the ends of which are connected, in series, two telephone receivers, each of 75 ohms resistance. A condenser of from 50 to 200 jars placed across the telephone leads is found to "sharpen" the sound in the listeners, but the condenser has no "tuning" effect on the waves being received.

Close to the secondary winding are placed two permanent horse-shoe steel magnets. In the form in which the detector is supplied, the two north poles are together, the south poles being apart.

It is found, however, that by reversing one of them, and adjusting their positions as in Fig. 136, it is possible to reduce the "breathing" sound heard when signals are not being received; a slight increase of sensitiveness is also noticed.

This abolition of the breathing noise has one disadvantage, in that the detector may stop without the operator noticing it. Hence it is well to fit a small lamp, which shines on one of the pulleys, so that frequent inspection will ensure that the clockwork has not stopped unnoticed.

Again, if the operator should attempt to get better results still by readjusting the magnets, putting "keepers" or other magnets against them, or what not, he should be on his guard against jumping to the conclusion that any increase of strength of signals is necessarily due to increased sensitiveness.

Alteration of the position of the magnets will inevitably alter the inductance of the primary winding, so that it may happen that better results are obtained, not through any

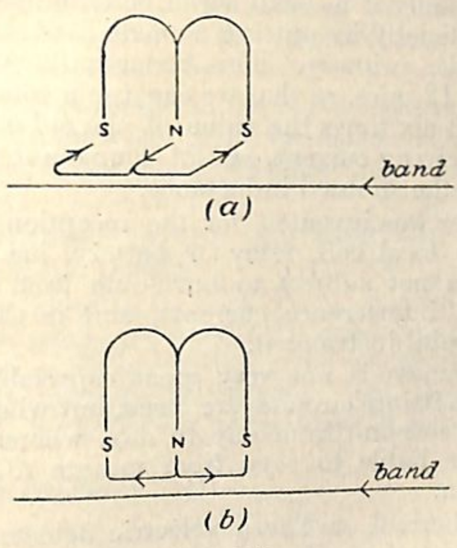


FIG. 137.

previous fault in the detector, but in a previously faulty tuning adjustment which has been unconsciously improved. The action of the instrument is described by Marconi as follows:—

As the iron band moves past the magnet poles, the magnetic field, which must flow largely through the iron path, gets distorted, as shown in Fig. 137 (*a*), due to the hysteresis of the iron. Oscillatory currents set up in the primary now destroy, for the moment, the hysteresis of the iron, and the field "flicks" back, once per jig, into its normal position, that which it would occupy were the band not running (as in Fig. 137 (*b*)). This moving field cuts the secondary winding and induces therein a unidirectional impulse of current through the telephones.

It is important to remember that only one impulse of current is obtained in the secondary for one complete jig in the primary. Further, it is found that the action of the jig on the primary is not "cumulative," that is, the detector is influenced by but the first one or two swings of current in the transmitted jig. This renders the instrument rather unsuitable for the reception of loosely coupled transmitted waves, and, again, since it must carry current, it is diffcult to get strong signals with a small condenser in the aerial.

Accordingly, it will be affected by waves of other length than the one which we want to receive, and if we use a loose coupling at the transmitting end, in the effort to reduce interference with other waves, it becomes still more unsuitable.

Owing to its large inductance and dislike of a small condenser in series with it, it becomes especially bad for the reception of short waves.

To receive short waves on the M.D. it is found to be of advantage, but only if a small aerial be employed, to reduce its inductance artificially by putting a small L of 15 mics or so, in parallel with the primary. This reduces its joint inductance down to about 12 mics, so that we can use a condenser in series with it of about six times the value of the old one. This gives us a larger receiving current, but of course a lot of it is wasted going through the shunted inductance.

The detector was invented for the reception of long waves. It requires no local cell, relay or battery, has practically no adjustments, is not subject to burn-outs from atmospheric or very powerful interference currents, and is therefore a very reliable and useful instrument.

Its sensitiveness is not very great, especially when loosely coupled transmitting circuits are used, but what sensitiveness it has remains constant from day to day, whereas that of some of the others is liable to vary from minute to minute for no apparent reason.

(4) The Thermal or Thermo-electric detectors make use of the heating effect of the jig currents. The total heat developed

per second will be proportionate to the square of the effective R.M.S. current during that time. This mean square value is called the integral value of the current. If the jigs succeed each other at short intervals, the total heat produced per second may be fairly large.

These instruments, therefore, have a "cumulative" action, and are affected by the whole jig, not, as in the case of the M.D. by the first one or two swings of current. They are essentially current-operated.

The jig is passed through a very short, very fine wire, having fairly high specific resistance. The wire is enclosed in a vacuum. The whole arrangement is called a "bolometer" or "barreter." The small rise of temperature may be detected in various ways.

(*a*) Let the hot wire expand the air in a bulb, forcing water down one branch of a "U" tube and up the other. This is called a hot-wire thermometer. It is no good for receiving signals, but can be usefully employed, when properly calibrated, in the laboratory.

(*b*) The wire, when hot, will have a different resistance to what it has when cold, so that it will cause direct current from a local cell to vary in strength when passed through the fine wire and a pair of telephones in series.

This is the principle on which Fessenden's barreter is worked. He also employs a liquid barreter on the same principle, only a fine tube filled with high-resistance liquid takes the place of the wire.

(*c*) The wire may be caused to heat up a thermal junction (*see* p. 54) which will produce a direct current through a sensitive galvanometer. This method is chiefly of use in quantitative experimental work. Duddell and Fleming have constructed instruments of this kind.

The wavemeter now used in the Service acts on this principle, but, of course, the currents in the wavemeter when tuning up a transmitting circuit are much stronger than those found in a receiving aerial.

(*d*) The expansion of the wire itself has been used for detecting the current therein.

It may be mentioned that these hot-wire quantitative instruments are much more useful in dealing with continuous oscillations such as those produced by arc systems than those produced by successions of decadent jigs, since the integral current is much larger in the former than in the latter.

(5) *Electrolytic Detectors.*

Fessenden and Schlömilch independently invented in 1903 the modern form of electrolytic detector.

It consists essentially of a vessel having as one electrode a very fine short wire of platinum, offering therefore an extremely small surface. This is generally made the anode or positive pole (*see* p. 196). The other electrode is a platinum, lead or silver plate of much larger surface, and the two are immersed in an electrolyte, which may be nitric acid, dilute sulphuric acid, or any other aqueous electrolyte yielding oxygen or hydrogen gas on electrolysis.

The anode must be of very fine wire indeed, and is generally sealed into the end of a fine glass tube, a minute portion only projecting; it can, of course, be fitted to the end of a micrometer screw by means of which it can be lowered gradually beneath the surface of the electrolyte. This latter method is rather unsuitable for ships, for the surface of the fluid would often be in a constant state of agitation.

If a small direct E.M.F. from a potentiometer and voltaic cell be applied through a pair of telephones to such a cell, a small current will flow from the platinum point through the electrolyte to the metal plate. A minute bubble of oxygen gas forms on the anode, or point, hydrogen being given off at the cathode. This minute bubble "polarises" (*see* p. 30, T.M., Vol. I.) the cell, and thereby reduces the current practically to zero.

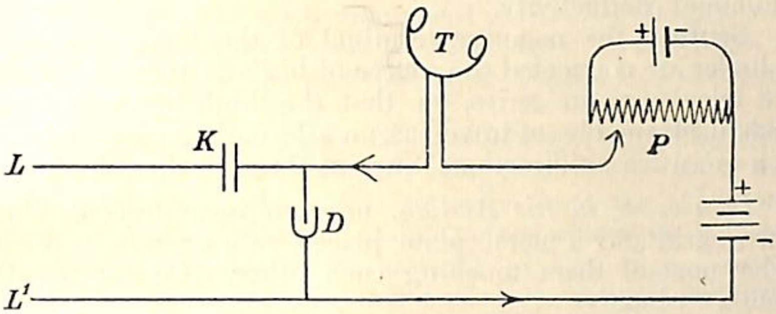
Under these conditions, if oscillations are sent through the cell they destroy the polarisation, knocking the bubble off its minute seating, so that the direct current increases, but it returns to its former value on the jig ceasing, because the bubble at once re-forms. The momentary rush of direct current naturally affects the telephones. The loudness of the sound heard in the telephones is an exact measure of the energy of the oscillations passing through the cell, except when they are very strong, in which case another effect appears to enter in which complicates the phenomenon.

It is a voltage-operated detector, and the adjustment of the direct voltage by means of the potentiometer has an important bearing upon its sensibility.

To adjust the latter, increase the direct voltage till a roaring noise is heard in the telephone. This means that the bubbles are forming and breaking off under the action of the direct voltage of the local cell, so that the voltage must now be reduced till the noise just stops. Now the cell will be in its most sensitive condition, for any minute increase of voltage applied to the cell, such as will happen when oscillations pass, will upset the unstable equilibrium of the bubble with the greatest ease.

The correct voltage is usually obtained with between two and and three dry cells in series. It is, therefore, best to put in two permanently, and to use the potentiometer across the third one only.

The "local" circuit of the electrolytic may be as in Figure 138.



D = Electrolytic. T = Telephones (high resistance).
P = Potentiometer.
K = Condenser to prevent the cells "running down" through the oscillating circuit.
L, L^1, connected to points where an oscillating D.P. occurs.

Fig. 138.

It is much more sensitive than the M.D., and is suitable for short waves. The points are, however, liable to "burn-outs" due to induced currents, heavy interference, or severe atmospherics; they are difficult to make in a ship, and several must be kept ready for use on a multiple-way switch. There are several adjustments to make irrespective of those in the actual oscillating circuit, and the detector will, therefore, give but poor results in the hands of men who do not thoroughly understand its peculiarities.

(6) *Rectifying Detectors.*

The rectifiers owe their existence to the great difficulty of getting an indicating device sufficiently sensitive to record weak currents or voltage of high-frequency alternations; our present most sensitive indicators are those working with direct or unidirectional currents. Hence, anything which will present a large resistance to currents passing in one direction, but a low resistance to those passing in the opposite direction, may be used to convert or "rectify" an alternating into a direct current. The "rectified" current will certainly be pulsative—that is, its strength will change from instant to instant—but it will still be unidirectional.

Of the valve rectifiers are Fleming's "Oscillation Valve" and Lee de Forest's "Audion."

Fleming's Oscillation Valve consists of a 12-volt carbon-filament incandescent lamp, the filament being surrounded by a metal cylinder which is connected to a third terminal brought out through the glass by a platinum wire.

The filament does not touch the inside of the cylinder at any point, but when the lamp is glowing, being burnt from a small battery of secondary cells, negative "ions" or electric particles are projected from the filament, bombarding the interior surface of the cylinder. The highly-rarefied gas which is thus carrying a stream of negative electricity then presents unilateral conductivity.

Between the negative terminal of the lamp and the metal cylinder are connected the source of high-frequency E.M.F. and the telephones in series, so that the high-frequency current finds itself unable to travel as an alternating current but flows as a pulsative unidirectional current through the telephones.

De Forest, in his Audion, uses an incandescent filament, a wire grid and a metal plate placed side by side in the above order, none of them touching each other. De Forest calls the plate a "wing."

The filament is burnt from a separate secondary battery, a small primary battery being connected, in series with a pair of high-resistance telephones, to the plate and the filament.

The +ve terminal of this last battery must be joined to the plate, so that when the lamp is incandescent a small current leaks across the vacuum from the filament to the plate, traversing the telephones and local battery.

Now, according to Dr. de Forest, when oscillations are applied between the grid and the filament, the conductivity of the rarefied gas is altered, the strength of the leakage current through the telephone altered, and sounds produced in the telephones.

If this be the real action on the instrument, it would appear to be on a slightly different principle to that of Prof. Fleming, in that his seems to act entirely as a rectifier while de Forest's acts by change of conductivity combined with a unilateral conductivity.

The sensitiveness of the Audion depends on the brilliance of the lamp, and, unfortunately, it is greatest when the lamp is at full brilliance. When burnt at this capacity the life of the lamp is very short indeed, so that expense would preclude the general adoption of the Audion. Were it not for that one drawback it would seem that the ideal detector had arrived, for it is wonderfully sensitive, very stable, being unaffected by excessive currents, and can be made extraordinarily selective.

It should be noted that potentiometers or adjustable rheostats are required for the adjustments of voltage for the two batteries, so that these make for more "handles to turn," always a possible source of errors.

Crystalline Rectifiers.

Many crystalline substances possess the curious property of unilateral conductivity. The first substance to be especially noticed in this respect was carborundum.

If high-frequency oscillations be applied to a lump of this substance it is found that telephone receivers in series with a battery will give signals when connected across the crystal.

Whether the action is entirely rectifying or partially thermal is not yet determined. The temperature of the crystal seems to matter very little, nor does immersion in oil alter the property; but the fact that a local cell is necessary in order to get the best results points to the fact that some change in resistance is brought about.

Many substances are now being tried, several being on the market in the form of complete receptors. Some have local batteries (with potentiometers) in series with the telephones, others do not require them. Again, a few will work well with low-resistance telephones, while most require high-resistance receivers having many turns of fine wire, for they are essentially voltage-operated, so that the current will be small.

They one and all depend for their sensitiveness upon the nature, area, and pressure of a contact, either between a metal and a crystal or between two unlike crystals. Hence the phenomenon is connected with some surface effect—that is, it is not due to any action taking place in the interior of the body.

It is possible that the explanation of their action is the same as that of the coherer, being due to the imperfect contact.

It is interesting to note that when a small external E.M.F. from a local cell is employed, its direction must coincide with that of the natural rectified current across the crystal junction. If the terminals of the cell be reversed, the sensitiveness is decreased.

Being, as above-mentioned, voltage-operated, they are best supplied from the secondary terminals of an oscillation step-up transformer whose primary forms part of the aerial circuit. The large induction of this secondary winding, if worked in conjunction with a condenser, makes the detector supply circuit very persistent; moreover, a variable coupling between the primary and secondary can easily be arranged, so that great receptive selectivity can be attained. Further, some of these rectifiers possess quite phenomenal sensitiveness, but, so far as has been found at the present moment, none of them come up to a very high standard of stability.

They are liable to lose sensibility from excessive vibration, atmospheric discharges, heavy signalling from a neighbouring ship, small induced currents from one's own transmitting gear, and even for no apparent reason at all. They must be disconnected when transmitting, and, preferably, "screened" inside a box.

In stability they fall far short of the Audion and the M.D., but in sensitiveness they far exceed the latter, and are also much more suitable for the reception of short waves.

To enumerate the most notable at the time of writing, we have:—

The Perikon, consisting of a contact between copper pyrites, otherwise known as chalcopyrite or bornite, and zincite. The latter material is rather rare, owing probably to its having been exploited only in a limited area. The perikon requires no local cell, but if such a cell is used its +ve pole should be connected to the bornite crystal, the pressure being about ·2 volt. Low-resistance telephones can be used, but much better results are obtained with high-resistance ones. The exact degree of pressure and the most favourable points of contact are important factors in determining the strength of the signals. In hunting about for the best contact, the crystals should never be allowed to grind together, but the moving one must be lifted clear from the other before movement.

The pyrites is somewhat soft and crumbles on friction, and when worn smooth the stones are very insensitive. Their good qualities can be restored to a certain extent by washing their surfaces with carbon disulphide, or with insulating oil.

In order to guard against the detector losing its receptive qualities unnoticed by the operator, it is necessary, unless signals are coming in continuously, to have a small buzzer circuit fitted up inside the silent cabinet. The buzzer itself should be outside, supplied from a dry cell and actuated by a bell-push. The push and a few feet of wire will be within the cabinet, the former close to hand. On the circuit being completed weak induced currents will be caused to flow in the detector circuit, giving a buzzing noise in the telephones if the detector be in adjustment.

It is a good thing to have two detectors on a double pole two-way switch, and to adjust them to the same degree of sensibility, so that, if one fail, the other may be switched in without loss of time.

Across the telephones, which should be of high resistance, it is found advantageous to have a small condenser of about five jars. This has nothing to do with the tuning of the circuit to any particular LS value, but appears to have some bearing upon the excellence with which the detector will respond to musical sparks of a certain pitch.

The Graphite-Galena.

This detector has a small piece of the core of a "Koh-i-noor" lead pencil pressed lightly in contact with a lump of galena, a sulphate of lead.

The surface of the latter is flaked off until a sensitive spot is found. It appears to be fairly stable, and rather more selective but less sensitive than the perikon.

Carborundum.

A crystal of this substance is placed in contact with a suitable metal—copper or carbon have been used. It requires a potentiometer of the order of 12 volts, which is an undesirable complication.

We may now divide up the various detectors into headings according to their method of action :—

(1) Those which, under the action of electric oscillations, undergo a change which is equivalent in its effect to an alteration of resistance.

Of these are the imperfect contact, the thermal, and electrolytic detectors. The first and last are voltage-operated and the thermal current-operated. They all need a local cell in series with some detecting device for direct currents joined across the detector.

(2) Those which, under the action of oscillations, undergo a change which induces an electromotive force in another associated circuit. Of these are the magnetic and thermo-electric types, both being current-operated and neither requiring any local cell.

(3) Those which possess unilateral conductivity, offering a greater resistance to the passage of a current in one direction than in the other.

Of these we have the valve and crystal rectifiers. Some of these require local direct current supply, others do not.

Reviewing the action of detectors generally, we remark that in some of them, the thermal and rectifying detectors, the energy of the oscillations created in the receiving circuit is allowed to expend itself directly in affecting the indicating instrument. In the case of the coherer, electrolytic, and magnetic detectors, on the other hand, the energy merely releases the energy of some external source, and it is this which affects the receiving instrument. In these last cases we have what is called a "trigger" action, because it is similar to the operation by which the pressure of the finger on a trigger releases the energy of the charge, which in turn propels the projectile.

Application of the Detector to the Aerial.

Current-operated detectors must of necessity be placed in some way in series with the aerial, so that the receiving circuit need not be very complicated. On the other hand, they are liable to interference on account of the only path to earth being through themselves. It was largely with the idea of gaining greater selectivity that it was proposed to supersede the magnetic by a voltage-operated detector, such as the crystalite ones.

All detectors consume energy ; their connection to the aerial is, therefore, equivalent to placing a certain amount of resistance in series with it in whatever manner the detector is connected. It is found by experiment that the strongest signals are received when a certain fraction of the total energy is taken up by the detector.

It is, therefore, best not to connect a detector directly in series with the aerial, but to couple it either directly or inductively as shown in Fig. 135 (*b*) and (*c*).

With the *direct* coupling three movable contacts should be provided on the aerial tuner, in order that the coupling may be so regulated that the maximum strength of signals can be obtained. This may be effected on the aerial tuner itself, or a separate "mutual" may be provided, whose inductance may be counterbalanced by a condenser if necessary. This is shown in Fig. 139.

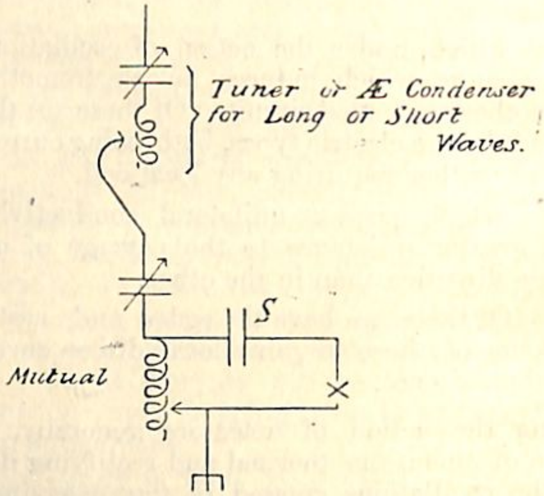


FIG. 139.

With inductive coupling the most favourable coupling can be found by moving the coils nearer together or farther apart. Again, it may be convenient to have the tuner and detector quite separate, so that the coupling is effected through an air-core oscillation transformer wound so as to step up the voltage, if using a voltage-operated detector.

This is shown in Fig. 140.

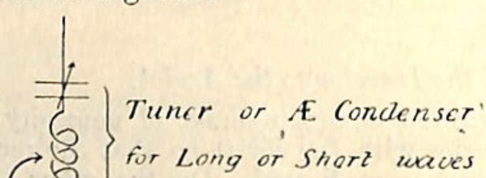


FIG. 140.

This is one of the best and simplest of receiving circuits.

In these last two diagrams the condenser S has nothing to do with the tuning, but merely prevents any direct current from local cells (used with the detector) from running to waste through the inductance.

We see, then, that the detector circuit is untuned, or "aperiodic."

To make the circuit still more selective, we have a second tuned circuit as in Fig. 141.

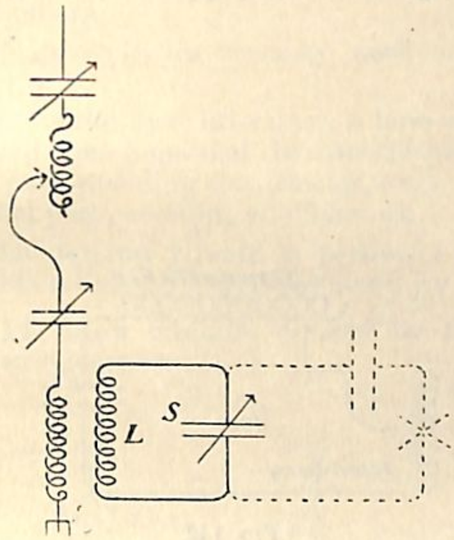


FIG. 141.

The detector circuit is shown dotted. Here the closed oscillator LS is tuned to the proper LS value for resonance. By helping ourselves to the D.P. across the capacity S in this last figure, we obtain for the benefit of the detector, not only the stepped-up voltage of the oscillation transformer, but also the resonance voltage across the condenser.

We shall find that signals will be just as strong as with the arrangement in Fig. 140, while the distance between the coils may be made much greater. Hence the effect of atmospheric disturbance will be much less felt.

When this secondary tuned circuit is used, it must be borne in mind that many different combinations of L and S may all give the same LS value. The best proportion of L to S will depend on the type of detector in use. About 6,000 mics to every jar is correct for most of the crystalite ones.

On account of this necessity for a very large inductance and very small capacity in the closed secondary oscillator, it is sometimes found convenient to have a separate adjustable inductance in series with the secondary of the oscillation transformer. The latter may be of the order of 2,000 mics, while the former (called the strengthener) may go up to 5,000 mics.

If the variable condenser, which must be of high insulation resistance, range from 0 to 2 jars, we shall have a secondary of wide enough range for all practical work. Another advantage of the strengthener is that by having the secondary of the transformer adjustable we may vary the coupling without shifting the coils. Thus, to tighten the coupling, transfer some of the inductance off the strengthener on to the secondary; to loosen, do the opposite.

The *oscillatory* circuits then appear as in Fig. 142.

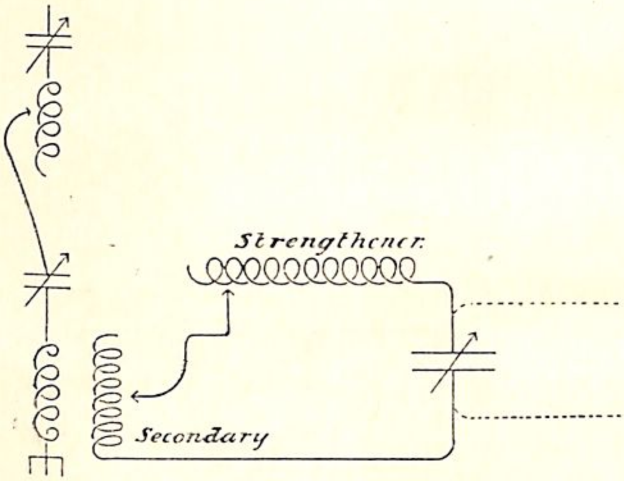


FIG. 142.

The actual detector circuit will vary according to whether a local cell and potentiometer are required or not. If they are, we may have the circuit shown in Fig. 138; if not, we may dispense with the small fixed condenser above referred to, but use a telephone condenser if required. In any case the actual detector circuit is aperiodic. This, it will be seen, must be so in any of the valve or rectifying types, for a periodic circuit must allow a true alternating current to pass.

Atmospheric Interference.

The difficulty of reception through atmospheric interference is familiar to all operators. It is well known that a high, piercing musical note can be read with ease under conditions of atmospheric disturbance which would render the reception of a low spark-frequency impossible. Apart from this consideration—which at once demonstrates the superiority of telephonic over tape reception—we have to see what can be done to reduce the strength of the disturbances in the listeners without undue reduction of our own signals.

The reason why atmospherics will appear, no matter to what wave-length the receiving circuit is adjusted, is that the aerial gets charged up to a given pressure, then discharges itself at its own natural frequency, whatever that may happen to be at the time. Thus, whatever the natural frequency of the aerial, that of the detector circuit will be the same, so that the atmospherics will be recorded.

This argument is based on the assumption that an atmospheric possesses no true natural frequency of its own; but experience shows that very short waves are fairly immune from interference, while of the long waves one may be considerably more free than others.

To cut out atmospherics, we may work on the following principles:—

(*a*) Give the aerial two LS values, a false and a real one. We will then hope that the atmospherics will take the false path, avoiding the detector, while the signals take the real path, avoiding the false one.

(*b*) Make the detector circuit so persistent as to be set in oscillation only by a well-sustained jig.

Figs. 143, 144 show circuits devised by Marconi for use with the magnetic detector.

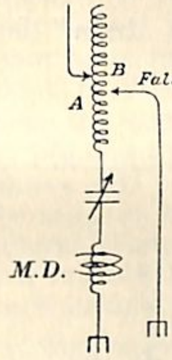


FIG. 143.

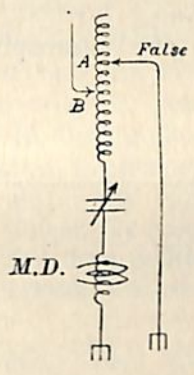


FIG. 144.

The nearer A is to B the greater will be the cutting-out effect, but the weaker will our own signals become.

These two circuits employ the principle in (*a*).

The principle of (*a*) and (*b*) is shown in Fig. 145, another arrangement of Marconi's, in which a cascade of resonant circuits is used.

Here if LS = resonance constant of transmitting circuit:—

$$L_1S_1 = L_2S_2 = \text{etc.} = (L_3 + MD) \times S_3 = LS.$$

Each fresh resonant circuit of small capacity and large inductance tends to make the whole circuit more persistent, while each false earth connection tends to provide a path for the disturbance to get to earth without affecting the ensuing portion. It will be seen that the M.D. is not a very suitable detector for this arrangement.

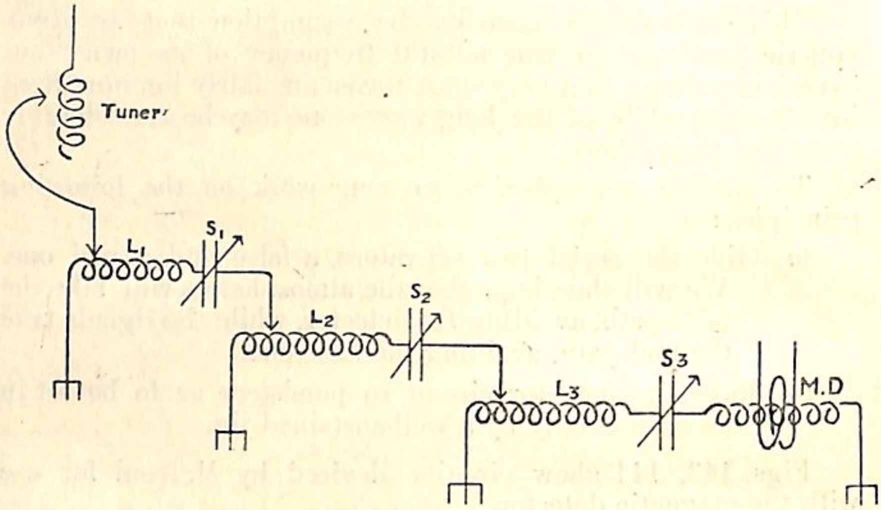


FIG. 145.

Another type of "atmospheric drain" is worth trying (Fig. 146).

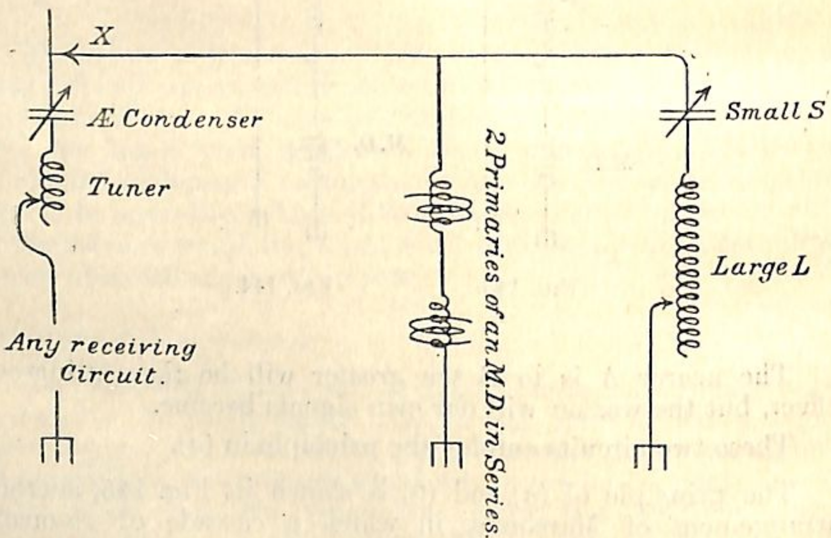


FIG. 146.

First tune up the receiving circuit till signals are strongest. Then connect up X, put on a pair of listeners to the drain detector, and vary the small S and large L till atmospherics are loudest. When this happens they will obviously be weakest in the real receiving circuit.

It must be remembered that loosening the coupling of the oscillation transformer will tend to make the detector circuit more persistent and lessen atmospherics.

Deliberate or Accidental Interference.

This may be classified as:—

(*a*) On your own wave-length. This will obviously be the worse case possible. If the signals of the ship you require are stronger than those of the interfering ship, the best thing to do is to throw the receiving circuit slightly out of adjustment, till the interference is so weak as to be negligible. In doing this do not forget to revert to the proper adjustments as soon as you have finished.

Secondly, if interference is stronger than your friend's signals (after you have got him working on maximum power) then your only hope is in over-reading.

It is here, again, that the advantage of a musical note at the transmitting end, and of an "ear for music" at the receiving end, comes in. If one ship only is interfering deliberately you must use your common sense and knowledge of the regulations in deciding whether you go on, hoping to snap the message in during gaps in the interference or whether you get on to another tune. Experience shows that one ship only cannot interfere deliberately on full power for more than about eight hours. He may therefore delay, but will probably not entirely stop communication on the wave-length he is using.

(*b*) On another wave-length. This will often occur, and calls for the greatest care and consideration on the part of operators. To minimise the evil, circuits, both transmitting and receiving, are to be made as selective as possible, provided the range is not unnecessarily reduced, and no attempt should be made always to reduce interference to zero, but only to bring it down so that its strength is small compared to that of signals on your own wave-length. In any case we must observe that:—

(1) Only signals of vital importance should be sent by W.T.

(2) Operators must pay attention to what their fellows are doing. For instance, a signal comes in for transmission—*do not call up*

on full power, unless you have authority to use the Silence or Priority signs, until you are satisfied that no one else in your own fleet is receiving on one of the neighbouring waves. This you can easily do by reading the "G's" and "D's" of your "opposite number."

In order to minimise interference by your own transmitting instruments, you should work as follows:—

(1) Start with your loosest possible coupling and reduced power. If this will not range far enough you can then—

(2) Increase power, using full spark, and tighten the coupling up to 1 per cent.

(3) If full spark and 1 per cent. coupling be insufficient, then begin to tighten the coupling gradually up to the maximum which you are allowed to use in your own particular fleet.

The transmitting circuit should have been tuned up so that the tightest coupling you can get (with the correct adjustments on) will not exceed this maximum which is laid down for Home or Foreign ships, as may be applicable in your own particular case.

These last notes, although dealing with transmitting circuits, are put into the receiving chapter because they should be read in conjunction with interference.

CHAPTER XIV.

High-Frequency Measurements.

As has already been pointed out, certain quantities have different values according to the nature of the current flowing in the circuit. It is therefore necessary, when calibrating or measuring any apparatus designed for high frequency currents, to allow for this difference.

Resistance of Conductors.

The resistance of a wire to steady currents is directly proportional to its length, inversely to its cross-section. This assumes that the current is evenly distributed throughout the cross-section of the wire. We have seen in the case of high-frequency currents, that the current flows only on the "skin" or surface of the conductor which carries it. If, therefore, a wire of any considerable thickness is used for carrying such a current, it is obvious that the core or centre fibres of the wire carry little if any current at all. The *effective* cross-section of the wire is thereby lessened and its resistance increased. This effect is enormously increased when the metal is a magnetic one.

For this last reason, we are extremely careful to use copper in preference to iron wire for aerials, or, if iron has to be used, to see that it is well galvanised.

Now the relationship which exists between the D.C. and high-frequency resistance of a wire, besides depending upon the magnetic properties of the metal, and upon the shape in which the wire is wound up, depends also upon the frequency of the current and the diameter of the wire.

The higher the frequency, the thinner the "skin" of current, the less the effective conductivity, and the greater the effective resistance. Further, the thicker the wire, the more metal will be wasted. Consequently, although the effective resistance of a thick wire will still be less than that of a thin one, the conductivity will not increase with the square of the diameter as we find it for direct currents, but will vary approximately directly as the diameter. Prof. J. J. Thomson has calculated that the thickness of the conducting skin of metal is about $\frac{1}{15}$th mm. in the case of copper, while that of iron is only $\frac{1}{200}$th mm.

Lord Rayleigh has given a useful formula for the connection between high and low frequency resistance. This applies to round copper wires, stretched straight out, or, if bent, then coiled in a spiral whose diameter is large compared to the thickness of the wire.

Let d be the diameter of the wire in cms.

Let ρ be the specific resistance of the metal (*see* p. 28, Torpedo Manual, Vol. I.) and f be the frequency, which is supposed to be of the order of 10^6. Then if R be the ordinary D.C. resistance and R′ the high frequency one, we have

$$R' = R \times \frac{\pi d}{2}\sqrt{\frac{f}{\rho}}$$

Notice that $\frac{\pi d}{2}$ is half the circumference of the wire.

For copper wires we have a simpler and more useful derivative from the above :—

$$R' = R\frac{\pi d\sqrt{f}}{80}$$

Applying this formula to a bare No. 16 S.W.G. wire whose diameter is ·163 cm., taking $f = 10^6$ we have

$$R' = R\,\frac{3{\cdot}1416 \times {\cdot}163 \times \sqrt{10^6}}{80}$$

$$= R \times 6{\cdot}4.$$

So that the H.F. resistance is 6·4 times the low frequency or direct current resistance.

Again let there be a thick copper rod 1 cm. in diameter.

Then
$$R' = R \times \frac{3{\cdot}1416 \times 1 \times \sqrt{10^6}}{80}$$

$$= R \times 39.$$

The R′ is nearly 40 times the R.

The deductions which we draw from the above reasoning in considering the design of apparatus for high-frequency currents are:—

(1) Always use copper if possible.

(2) If you have a large current (as in a primary), a wide thin strip is better than a solid rod of the same weight, and a hollow pipe is just as good as a solid rod of the same diameter.

(3) Since a thin wire will be permeated even with a high-frequency current, the ideal conductor for such currents would be a bundle of fine insulated wires of, say, 36 S.W.G. This bundle should consist of many strands laid up loosely either in the form of a rope or in that of a ribbon.

The following table gives the increase of resistance of copper wire at a frequency of 400,000 cycles:—

Diameter of wire.	Increase of high over low frequency resistance.
0·2 mm. - - -	1 per cent.
0·4 - - - -	22 ,,
0·8 mm. - - -	120 ,,
2·0 mms. - - -	650 ,,
4·0 mms. - - -	1,000 ,,

In addition to this increase of resistance due to the skin effect of the high-frequency current, we have also to bear in mind that a wire coiled up into a close small spiral may have an effective resistance nearly double what it had when stretched out straight.

It therefore becomes difficult to say how much energy is actually dissipated in the form of heat from an oscillator, due to the resistance of the conductors.

Resistance of Spark.

When dealing with oscillators containing spark-gaps, we become concerned with the ohmic resistance of the spark itself. Naturally, we are now talking of the spark when passing—that is, regarding it as a conductor—not of the insulation resistance of the spark-gap before the spark takes place. This latter should, of course, be very high indeed.

When, however, the spark passes, the incandescent air between the plugs becomes a comparatively good conductor, and it is well that this is so, for otherwise we should not get any oscillations at all.

Many measurements of the resistance of electric sparks have been made, but reliable information is very difficult to come by, owing to the dissimilarity of the conditions under which different scientists have worked.

The factors which affect the resistance of the gap appear to be, in addition to the length of the gap, the diameter and curvature of the ends of the plugs, and the nature, temperature, and pressure of the atmosphere in which the spark takes place. The capacity of the condenser charged also affects the results.

In the case of a damped train of oscillations, or jig, the spark resistance is not constant during the successive oscillations, since the spark resistance depends upon the quantity of electricity carried across the gap. In the same way the resistance of an electric arc depends upon the current flowing across it. The greater the quantity of electricity carried across, the less is the resistance.

It follows, then, that the larger the capacity used the less is the resistance for a gap of a given length. Further, the greater the pressure of the air (or gas) in which the spark takes place, the more difficult it is for the spark to pass—that is, more pressure is required to break it down. It appears, then, that a small spark with high-pressure gas would give less damping than a large spark in ordinary air.

It is not considered necessary to give curves showing resistance and length for different capacities, on account of the conditions under which scientists have experimented being considerably different from those obtaining in our Service installations.

The spark resistance may be taken as being of the order of from $\frac{1}{2}$ to 4 or 5 ohms.

Spark Voltages.

The measurements of the minimum P.D. which will just give a spark across a given gap are difficult to make, and many scientists have arrived at slightly different results.

In practice, to determine the maximum P.D. across any two points in a high-frequency circuit, we may connect a spark-gap across them and take the measure of the longest gap which just gives a spark. Then, from the following tables we shall get a fairly accurate measurement. Such a spark-gap is then called a "testing" spark-gap, and should be capable of reading down to least a quarter of a millimetre.

The testing spark-gap may consist of two sharp points, or of two cylindrical plugs, or spherical balls. In any case points must be kept clean and sharp, and balls clean and smooth. The gap must also be kept cool, for the voltage is reduced when the gap gets warm.

For spherical balls of different diameters we may use the curve given in Fig. 147.

For plugs of the shape and size of the Mark II. set we use the curve in Fig. 148.

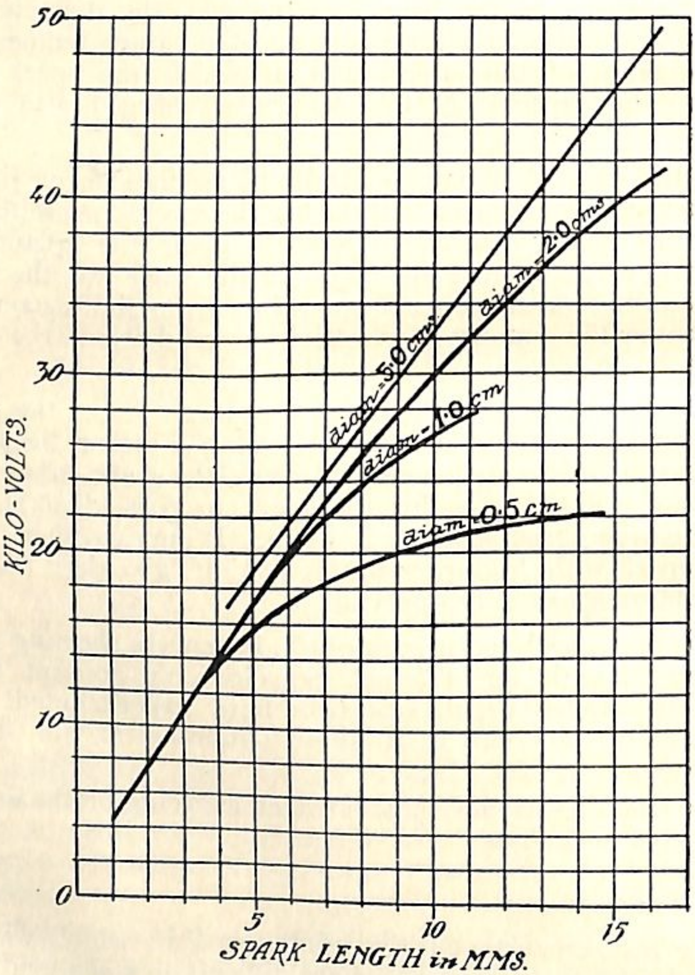
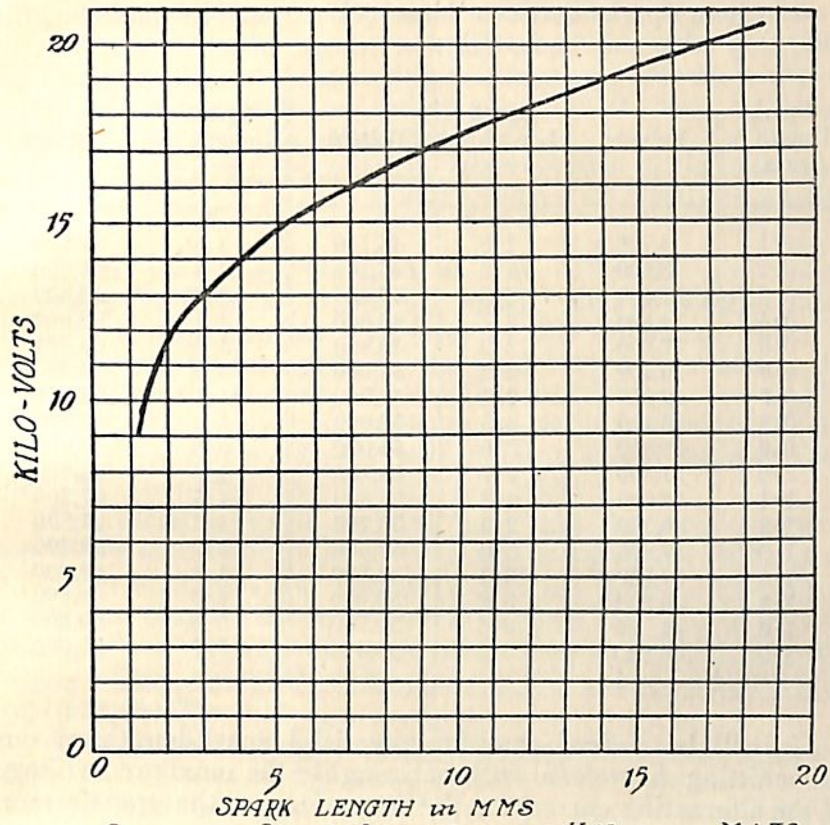


Fig. 147.



Curve of Spark Length and Voltage in MrkII Gap

FIG. 148.

For sharp metallic points, use the following table:—

TABLE OF STANDARD SPARKING DISTANCES BETWEEN SHARP NEEDLE POINTS IN AIR.

Kilo-volts.		Distance.		Kilo-volts.		Distance.	
R.M.S.	Max.	C.M.S.	Inches.	R.M.S.	Max.	C.M.S.	Inches.
5	7·08	0·573	0·225	100	141·4	24·4	9·60
10	14·1	1·19	0·47	110	155·5	27·4	10·75
15	21·2	1·84	0·725	120	169·8	30·1	11·85
20	28·3	2·54	1·00	130	184·0	32·9	12·95
25	35·4	3·30	1·30	140	198·0	35·4	13·95
30	42·4	4·13	1·625	150	212	38·2	15·0
35	49·5	5·08	2·00	175	248	45·3	17·8
40	56·6	6·23	2·45	200	283	52·1	20·5
50	70·8	9·02	3·55	250	354	65·0	25·6
60	84·9	11·8	4·65	300	424	78·8	31·0
70	99·0	14·85	5·85	350	495	91·8	36·1
80	113·2	18·0	7·10	400	566	104·5	41·2
90	127·2	21·2	8·35				

For long sparks between brass balls 2 cms. in diameter, the following table may be useful :—

Spark Length in cms.	Voltage.	Spark Length in cms.	Voltage.	Spark Length in cms.	Voltage.
0·1	4,700	1·8	44,700	3·5	61,100
0.2	8,100	1·9	46,100	3·6	61,800
0·3	11,400	2·0	47,400	3·7	62,400
0·4	14,500	2·1	48,600	3·8	63,000
0·5	17,500	2·2	49,800	3·9	63,600
0·6	20,400	2·3	51,000	4·0	64,200
0·7	23,250	2·4	52,000	4·1	64,800
0·8	26,100	2·5	53,000	4·2	65,400
0·9	28,800	2·6	54,000	4·3	66,000
1·0	31,300	2·7	54,900	4·4	66,600
1·1	33,300	2·8	55,800	4·5	67,200
1·2	35,500	2·9	56,700	4·6	67,800
1·3	37,200	3·0	57,500	4·7	68,300
1·4	38,700	3·1	58,300	4·8	68,800
1·5	40,300	3·2	59,000	4·9	69,800
1·6	41,300	3·3	59,700	5·0	69,800
1·7	43,200	3·4	60,400	5·1	70,300

It will be noticed that for any fixed spark-length of our transmitting set we can work out roughly the maximum voltage of the alternating current in the secondary of the transformer. In order to get the R.M.S. value of this voltage we must connect across the terminals of the condenser or spark-gap a high-reading electrostatic voltmeter. From these two readings other measurements can be deduced, as we shall see later.

Wavemeter Measurements.

We have already seen how the wavemeter can be used for tuning up the transmitting circuit. This, the most important function of the instrument, consists essentially in measuring the LS values of circuits, or of adjusting them to predetermined values. We are not, then, concerned with the actual number of mics or jars in the circuit to be measured, but merely with their product.

Before passing on to see how we may actually measure an inductance or capacity itself, we have a few more points to notice in the measuring of LS values.

Measuring LS Values.

When the circuit to be measured is accessible—that is, when we are *not* measuring an " incoming " wave from another ship—the general lines to be followed will depend chiefly upon whether the condenser in the circuit will " stand " a spark.

If the design of the condenser is such that we may spark into it without fear of puncturing the dielectric, and if the wire composing the inductance will stand the oscillatory current, we simply insert a spark-gap in series with the oscillator, using as short and non-inductive leads as possible, excite the circuit with an induction coil, and measure in the ordinary way with the wavemeter.

Under these circumstances the process is exactly like measuring the LS value of the primary of the transmitting oscillator.

If the condenser be such as will not stand the voltage necessary to form an oscillatory spark, then it becomes more difficult to measure the LS value of the circuit to which it belongs. In a ship, perhaps the best way is to measure the inductance and capacity separately, multiplying the results together afterwards. If, however, a variable, known closed oscillator (whose condenser will stand a spark) be available, then the circuit can be measured as a whole.

This variable closed oscillator may take the form of a vane condenser immersed in oil, a spark-gap and a known inductance.

If the condenser and inductance be previously calibrated, it is obvious that we can tell the LS value of the circuit for any graduation of the variable condenser. Now excite this circuit by means of an induction coil, placing the unknown circuit in proximity to it.

If the known circuit, while being sparked into, be varied until its LS value is the same as that of the unknown circuit, it is obvious that oscillations induced in the latter will be at a maximum.

This state of affairs will be indicated by the thermo-galvanometer belonging to the wavemeter being placed in series with the unknown circuit. Again, we notice that the leads to this thermal junction must be as short and non-inductive as possible, so as not to introduce errors which will be appreciable.

On page 57 will be found directions for measuring the $\lambda\sigma$ value of an aerial, while page 202 gives the best arrangements of the coils (if two be used) according to the size of the capacity.

Measuring Inductance and Capacity.

Suppose in the first case, that the unknown inductance is capable of carrying a transmitting jig current, or that the unknown capacity, as the case may be, is capable of standing a spark.

Note that a wavemeter inductance should never be sparked into if it can possibly be avoided. Also, that if the unknown condenser exceed 50 jars we must use at least two parts of Patt. 611 wire in parallel for the inductance, or else the wire may be fused (*see* p. 218).

We will now suppose that no known fixed condensers or inductances are available.

To *measure an unknown capacity* which will stand a spark :—

First build up the condenser into an oscillating circuit of the closed type, using a spark-gap and an inductance of suitably sized wire, according to the probable size of the condenser, as explained above. Excite this circuit by means of a coil. Measure the LS value of the circuit as thus built up. Suppose it to be "A" mic-jars by wavemeter.

Now insert into the oscillating circuit any known inductance of, say, "J" mics. J should not be less than the original inductance employed. Now take a second wavemeter measurement, which we will call "B" mic-jars. B will obviously be greater than A, for additional inductance has been used. If LS be the value of the circuit containing the unknown capacity S, then we have—

$$\mathrm{LS} = \mathrm{A}$$
$$\text{and } (\mathrm{L} + \mathrm{J})\,\mathrm{S} = \mathrm{B}$$
$$\text{Hence } \mathrm{LS} + \mathrm{JS} = \mathrm{B}. \quad \text{For LS write A.}$$
$$\text{Then } \mathrm{A} + \mathrm{JS} = \mathrm{B}$$
$$\text{or } \mathrm{JS} = \mathrm{B} - \mathrm{A}$$
$$\text{That is, } \mathrm{S} = \frac{\mathrm{B} - \mathrm{A}}{\mathrm{J}}.$$

It is easy to remember to subtract the small from the large LS value and divide by the known inductance inserted. An LS value divided by an L must necessarily give an S as quotient,

It is in this way that σ for an aerial may be measured, If we then wish to deduce λ we only have to divide A by σ for if

$$\mathrm{A} = \lambda\sigma,$$

$$\text{then } \lambda = \frac{\mathrm{A}}{\sigma}.$$

To measure an unknown inductance which will stand sparking :—

Build up into a closed oscillator as above, using Leyden jars. Measure the capacity of the jars as above and divide "A" by this capacity. The result will be the inductance of all the wire in the circuit, including that of the leads to and in the spark-gap. A correction must be deducted to allow for this.

Another way of measuring either capacity or inductance under the above conditions, is to join up an unknown capacity with a known inductance, or an unknown inductance with a known condenser, as the case may be, and simply to measure the LS value of the combination. Then the LS value, divided by the known L or the known S, as the case may be, will give the value of the unknown S or L respectively. These results, again, will need correction on account of leads to and in the spark-gap having to be considered as forming part of the inductance in the circuit.

Measuring inductances and capacities which *will not* stand a spark :—

Inductance.

Rig up any oscillation circuit with jars and Patt. 611 wire.

Measure its LS value by wavemeter, using the proper wavemeter inductance. Then measure its LS value, using your unknown inductance in your wavemeter, either in series with, in parallel with, or instead of your previous wavemeter inductance.

Let L be the wavemeter inductance and x the unknown one. Let S_1 be the wavemeter capacity in the first case and S_2 in the second. Then, since the LS value measured in both cases is the same, we have, when x replaces L,—

$$LS_1 = xS_2, \text{ so } x = \frac{LS_1}{S_2}.$$

Or, if x is in series with L, we have—

$$LS_1 = (x + L)S_2, \text{ so that } x = \frac{LS_1 - LS_2}{S_2} = \frac{L(S_1 - S_2)}{S_2}.$$

Or, if x were in parallel with L, we have—

$$LS_1 = \frac{xL}{x + L} S_2, \text{ so that } LS_1x + L^2S_1 = xLS_2$$

$$\text{and } x = \frac{L^2S_1}{LS_2 - LS_1} = \frac{LS_1}{S_2 - S_1}.$$

Several different ways should be used, and the mean taken.

Capacity.

A condenser that will not stand a spark is very difficult to measure in a ship, where a standard variable oscillator is not available. A rough approximation can be found by measuring a built-up circuit on the lines indicated above, using the unknown condenser in parallel or series with the wavemeter condenser.

Ordinarily it will be good enough to test your unknown condenser in the receiving circuit, trying it instead of one of the known condensers, or in parallel therewith, when an idea will be quickly arrived at as to how many jars the condenser is "worth." Another method of measuring λ and σ will be dealt with after we have seen how to calculate inductances and capacities.

Measuring the LS value of a distant Radiant Circuit.

This process is generally called, "measuring an incoming wave." It entails the use of the wavemeter in the receiving circuit, the strength of the sound in the telephone receivers being used instead of the thermo-galvanometer in order to tell when the wavemeter is in resonance with the distant circuit.

We therefore remove the thermal junction and short-circuit the terminals on the wavemeter to which it is ordinarily attached. The wavemeter is then placed in series with the earth lead from the receiving instruments, a suitable inductance selected (as hereinafter to be explained) and the whole short-circuited, for the time being, by means of the switch provided on the top of the wavemeter condenser for the purpose.

The circuit is shown in Fig. 149.

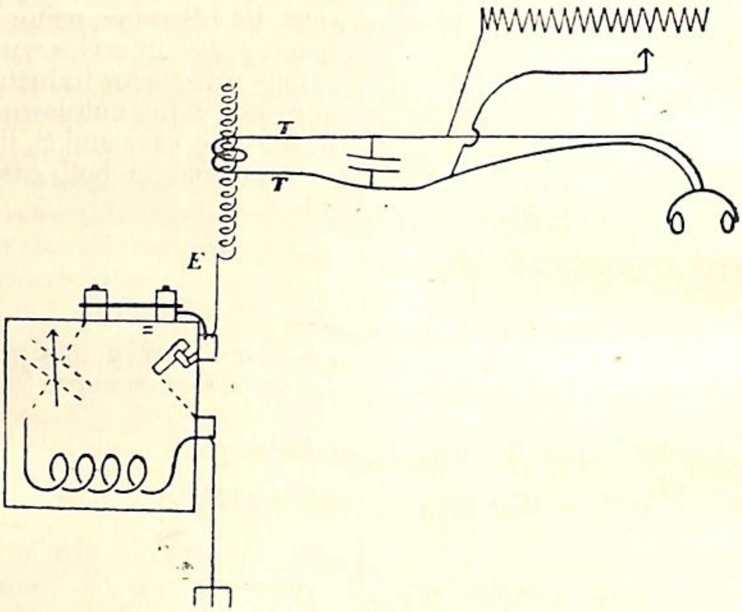


Fig. 149.

Now get the ordinary receiving circuit carefully into resonance with the waves coming in. If the M.D. be used, it is often very convenient to shunt the telephones by means of a resistance, so as to cut down the strength of signals to any desired amount without affecting the tuning. A slight difference in the strength of weak signals is much more easily detected than the same difference in loud signals.

Remember that however weak the signals are made, they must not be made so by the receiving circuit being out of resonance.

Now switch the wavemeter into the circuit by opening the switch, its inductance and capacity being in series with each other and with the circuit. Alter the wavemeter condenser till signals are strongest. By reducing the strength of signals it will be possible to make them entirely inaudible when the condenser pointer is moved about four degrees away from its best position.

It is well to get the best position roughly at first, using strong signals, then to "fine down" the reading with weak signals.

Notes on the Use of the Wavemeter.

These further notes are in amplification on those embodied in Chapter IV.

Selecting Inductances.

On p. 53 reference is made to the capacity of the wavemeter condensers being read off from a curve connecting the capacity in jars with any graduation, in degrees, of the scale of the condenser. Now the value of the condenser in ships' wavemeters is roughly from 0 to 1 jar, and the curve is obviously most likely to be correct at values of about half a jar.

Hence, we always try to work with the pointer at about the middle of its run, a capacity of about half a jar, and consequently an inductance whose value in mics is about twice the LS value to be measured (in mic-jars).

In tuning up a transmitting set, or in checking the adjustments of a ship, it is easy to select the right inductance because we know beforehand what the LS value is, or has got to be, When, however, we come to measure an unknown LS value we must make a guess. If the wavemeter reading comes down below say 50° we must take a smaller inductance; if above 120° we take a larger one.

Saving time in tuning Coupled Oscillators.

Referring to p. 63, we see that the process of getting exact syntony between the primary and aerial circuit consists in measuring the two outgoing LS values and adjusting the aerial coil until the mean of the LS values equals the LS value to which the primary was tuned originally.

Now, since the wavemeter curve is nearly a straight line, and since it nearly runs out to zero capacity for zero on the scale of degrees, we may say that the capacity varies almost directly as the scale readings. This can be verified by seeing how nearly the capacity at 100° is double that at 50°. For values of 10° or 15° at about the middle of the scale, the capacity varies exactly as the reading.

Now, since we are using the same wavemeter inductance all the time, we see that if S varies as the degrees, then LS does so also. Hence, if the *mean of the two readings*, taken in degrees, is equal to the reading to which we tuned the primary, then we can say at once that perfect resonance is obtained.

It will be remembered that no measurement of coupling should be attempted until the mean of the LS values is correct.

Suppose, for instance, that the reading for tuning the primary was 83°. On measuring the resultants we get two swings of 80° and 94° respectively. The mean of these is 87°, so we must reduce the aerial until we get the swings at, say, 79° and 87°, whose mean is 83°.

To avoid the waste of time of adding 87 to 79 and dividing by two, the best way is to say "Long wave so many degrees above 83, short wave so many below 83."

Thus, in the first instance, we say to ourselves "80 and 94. 94 is 11 above, and 80 is 3 below 83. The *above* has it." In the second case we have "79 and 87, 4 above and 4 below 83. Mean correct, the thing is in tune."

It is seen that what we are trying to do, in adjustment for resonance, is to get the two swings equidistant from, (one above and one below) the swing to which we tuned the primary. When we have done this, the mean of the two LS values is correct and we may go on to measuring the coupling.

Measuring the Coupling.

We know that the further apart the two resultant LS values the tighter is the coupling, so that the number of degrees "above" or "below" may be use as a measure of the coupling to save us working out the LS values and wave-lengths each time, as shown on p. .

Taking the wavemeter curve (and a slide rule if available), and knowing the LS values of all the wave-lengths for which we want to tune, we prepare a family of curves beforehand, as follows:—

We must first assume that the coupling varies directly as the distance apart of the two swings; that is to say, suppose we had "4 above and below," as above, on working out the coupling we might find the coupling was 5·5 per cent. Now the assumption is that if the swings had been 75 and 91, that is "8 above and 8 below," then the coupling would be $5 \cdot 5 \times 2 = 11$ per cent. Also, if the two readings "ran together" and were both equal to 83, then the coupling is so loose as to be zero.

This assumption is only approximately correct, because the coupling varies with the wave-lengths of the two waves. These lengths vary, not directly as the capacity (or degrees), but with the square root of the capacities.

However, for couplings under 10 per cent. we can say that the couplings vary directly as the distance apart of the readings for the two waves.

It is generally more convenient to take the number of degrees "above and below" the primary reading rather than the total number between the two outer readings, for then we are reminded that the "above and below" must be equal, so that resonance is exact, before we measure or calculate coupling.

Taking a wavemeter curve, we may now work out a few examples to illustrate the process. We want to tune up to 100 LS, wave = 2,060 feet.

Choosing a wavemeter inductance of (say) 197·2 mics and adding in the "wavemeter mutual," taking the result to the nearest mic, we find the total

$$L = 197 \cdot 2 + (\text{say})\ 5 \cdot 2 + \cdot 4 \text{ (for leads in wavemeter)}$$
$$= 202 \cdot 8$$
$$= 203 \text{ mics nearly.}$$ The nearest mic may always be used for numbers over 100 mics.

$$S = \frac{LS}{L} = \frac{100}{203} = \cdot 493 \text{ jars.}$$

Wavemeter capacities should always be worked to three places of decimals.

Now on the curve ·493 corresponds to 89°.

This is logged down on a piece of paper as:—

"K" Tune. LS = 100. 197·2 mics inductance }
W.L. = 2060. 5·2 mics mutual } 89°.

Now assume we got two swings 10° "above and below."

Long wave 99° = ·544 jars. LS = 110. Wave = 2,160 ft.

Short wave 79° = ·438 jars. LS = 89. Wave = 1,940 ft.

Notice that the mean of the LS values $= \frac{199}{2} = 99 \cdot 5 = 100$ nearly.

Difference = 2,160 − 1,940 = 220 feet.

$$\text{Coupling} = \frac{220}{20 \cdot 60} \text{ (for } 2{,}060 = 206\sqrt{100}\text{)}.$$
$$= 10 \cdot 7 \text{ per cent.}$$

We now take a piece of squared paper marking "degrees above and below" as abscissæ and "coupling per cent." as ordinates, as in Fig. 150. Each must be graduated from zero.

Mark off 10·7 per cent. corresponding to 10° above and below, and join this point by a straight line to "0 per cent. and 0°"—the bottom left-hand corner.

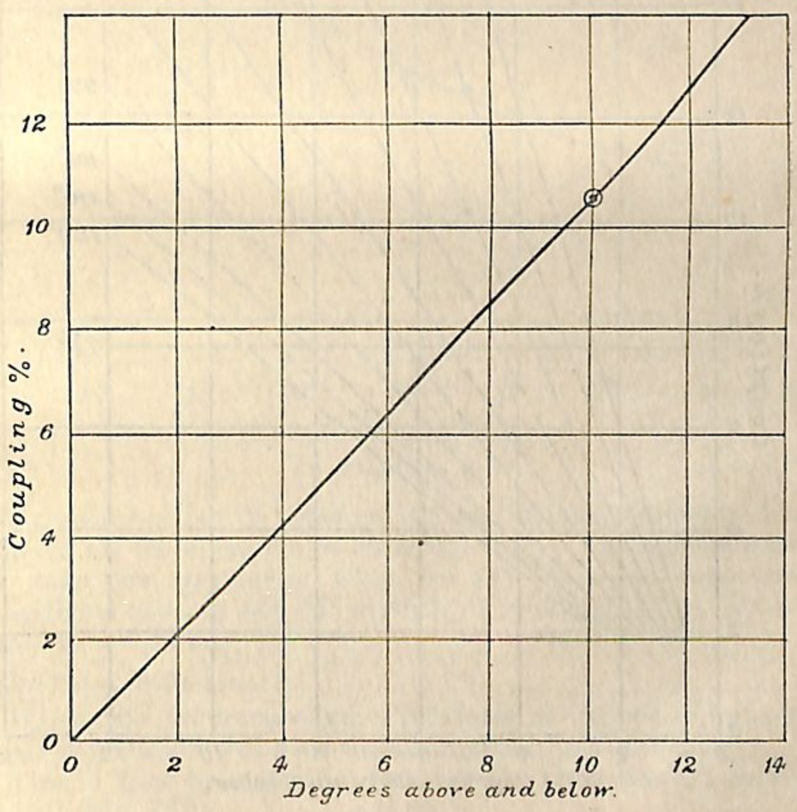


FIG. 150.

What you have now is a curve (although it is really a straight line) which automatically solves the proportion sum:—

"If 10° above and below mean 10·7 per cent. coupling, what coupling corresponds to 4°, 5° or 8° above and below?"

Reading off from the curve the answers are seen to be 4·3 per cent., 5·35 per cent., and 8·5 per cent., respectively.

Conversely, we may say "I want to tune up to a 6 per cent. coupling. How far apart should my readings be?" The answer is 5·6° above and below, so that our readings should be $89° + 5\frac{1}{2}° = 94\frac{1}{2}°$ and $89° - 5\frac{1}{2}° = 87\frac{1}{2}°$ respectively.

This curve will do for any LS value whose wavemeter capacity works out at about 90°, but it will not do for one of 80° or 100°.

It is easy to remember that when the wavemeter condenser reading is about 90°, then each degree "above and below" is roughly worth 1 per cent.

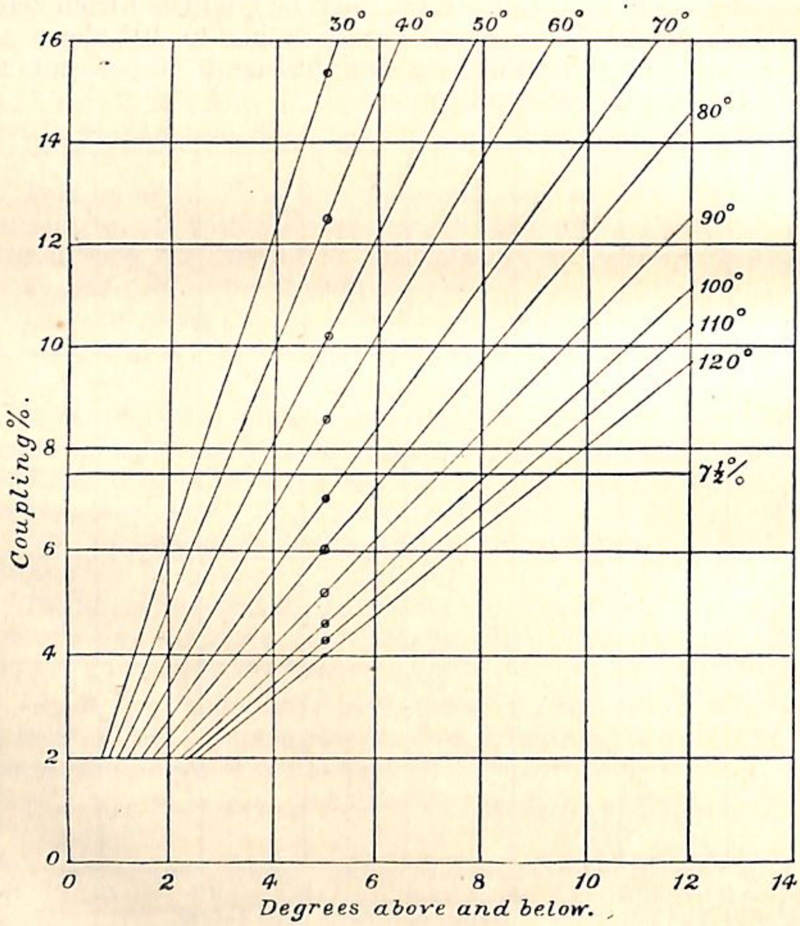


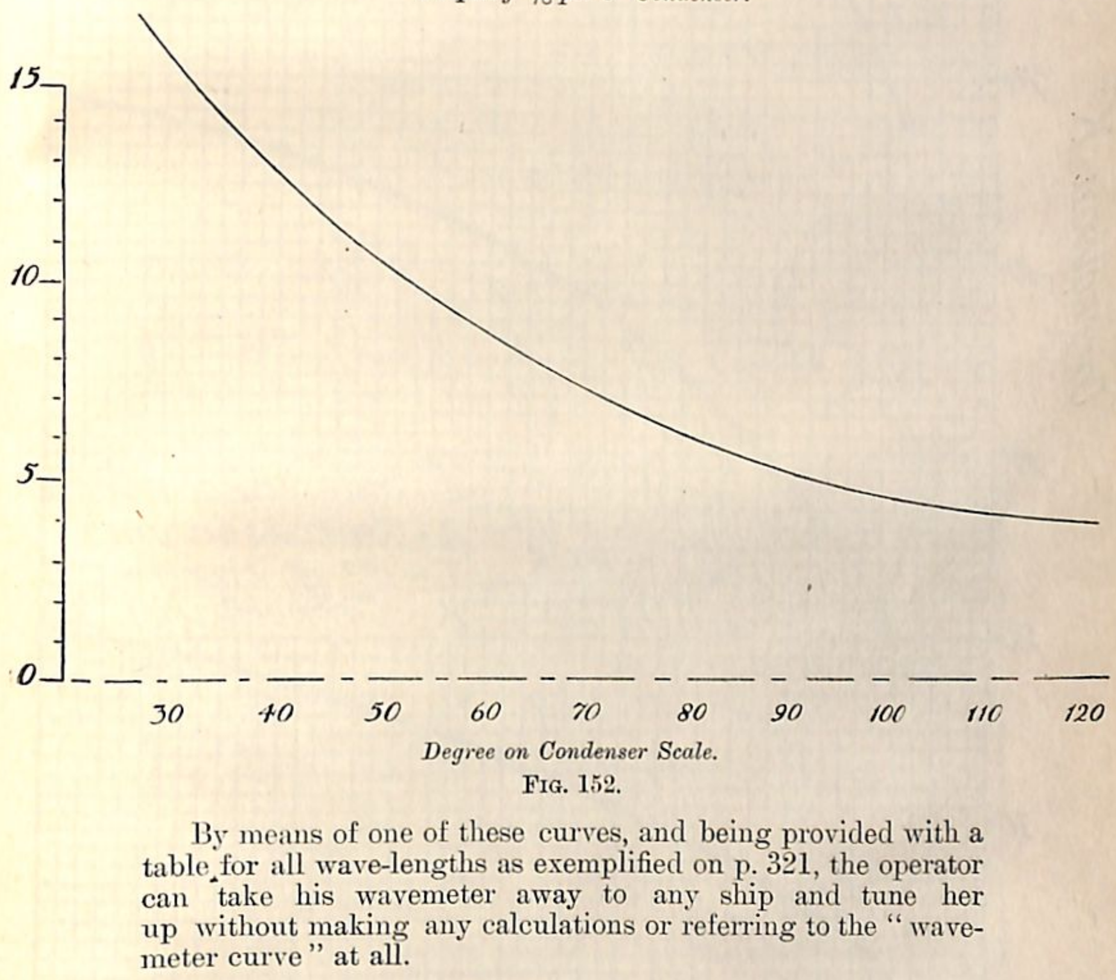
Fig. 151

If the capacity be less than 90°, each degree will cause a greater alteration in coupling; if more than 100°, less alteration than 1 per cent. per degree.

The reader should work out this "time-saving curve" for himself, taking, for example, an LS of 600. With this he can either use the 1,000 mic inductance and rather a large condenser, or the 2,000-mic one and rather a small condenser.

By extending this principle still further, he may make a family of curves as in Fig. 151, giving couplings for any 10° on the wavemeter condenser, or one curve, as in Fig. 152, giving the couplings "per degree" or "per 5 degrees" above and below for any reading on the condenser.

Coupling °/₀ per 5° Condenser.



Degree on Condenser Scale.

FIG. 152.

By means of one of these curves, and being provided with a table for all wave-lengths as exemplified on p. 321, the operator can take his wavemeter away to any ship and tune her up without making any calculations or referring to the "wavemeter curve" at all.

Calculating Inductances.

When the inductance takes the form of the coil or helix, a simple calculation will give the approximate self-induction.

This is done by means of Commander Yeats-Brown's curve, given in Fig. 153.

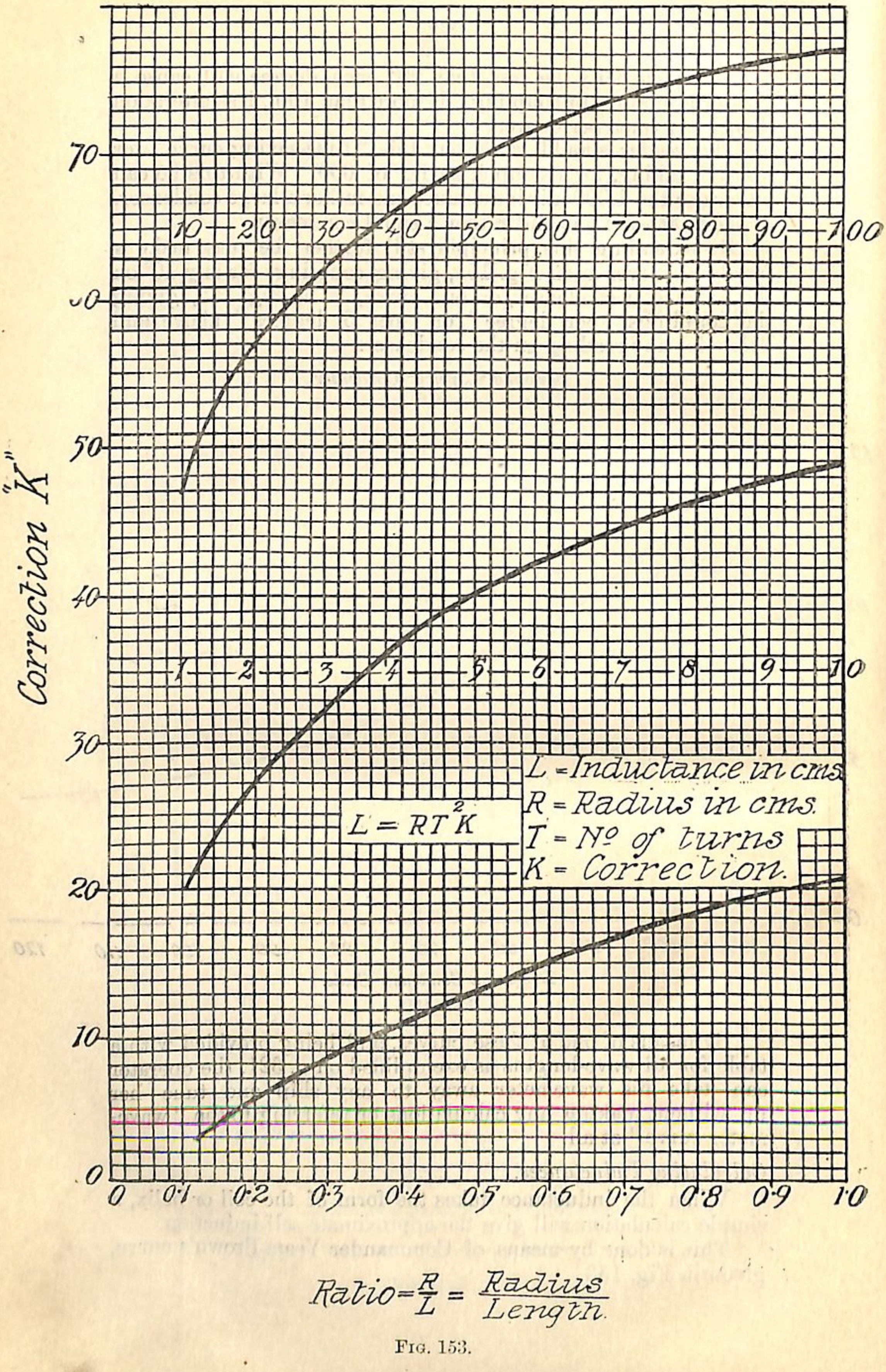

Correction "K"
70
60
50
40
30
20
10
0
10 20 30 40 50 60 70 80 90 100
1 2 3 4 5 6 7 8 9 10
L = RT²K
L = Inductance in cms.
R = Radius in cms.
T = Nº of turns
K = Correction.
0 0·1 0·2 0·3 0·4 0·5 0·6 0·7 0·8 0·9 1·0
Ratio = R/L = Radius/Length

Fig. 153.

A coil having a radius of r cms., containing t turns of wire in one layer, will have a self-induction given by

$$L = rt^2k \textit{ centimetres, so that}$$

$$L = \frac{rt^2k}{1000} \textit{ mics.}$$

In this formula "k" is a "correction" looked out as the ordinate of the curve where the abscissa is the ratio $\frac{r}{l}$, or the radius of the coil divided by its length.

Having a given coil, we measure its radius and length and count the number of turns. Divide r by l and look out "k" from the curve.

The only difficulties which arise are:—

(*a*) When the wire is thick, its mean radius should be taken. This is most easily found by dividing the mean *girth* by 2π.

To get the mean girth, measure round the core only and then round the wire as wrapped on the core. The mean of these lengths, in cms., gives the mean girth, or actual length of one turn of wire.

(*b*) When the wire is wound on a square or octagonal former, we find the radius of the cylinder which would have the *same girth* or perimeter. In other words, we proceed exactly as in (*a*) whether the wire be thin or thick.

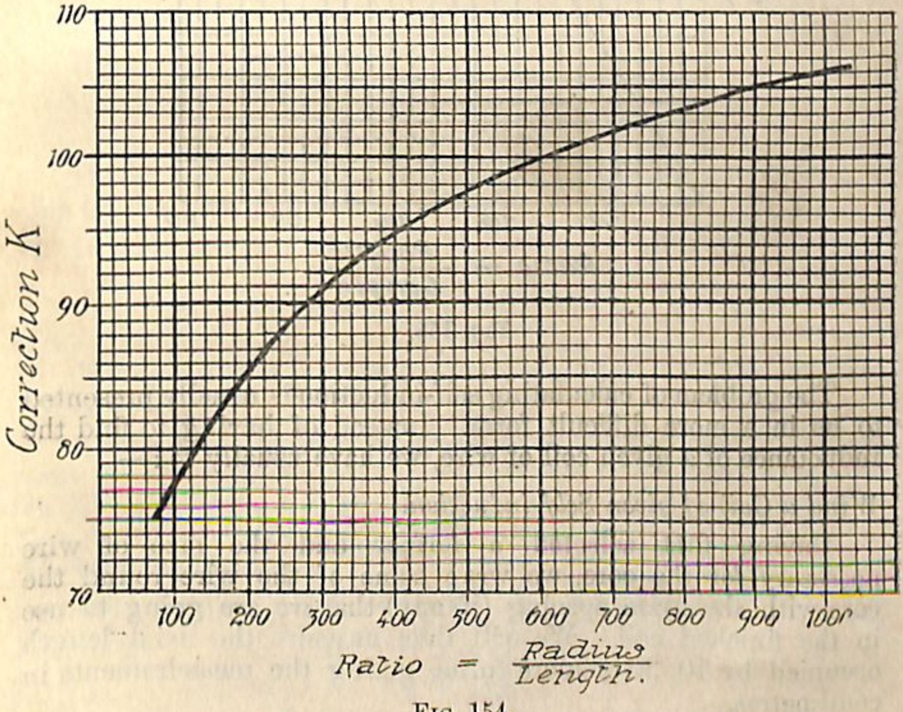


FIG. 154.

(*c*) Where the ratio $\frac{r}{l}$ is greater than 100, use the curve in Fig. 154 to find k.

(*d*) When the ratio $\frac{r}{l}$ is less than ·1, use the curve in Fig. 155.

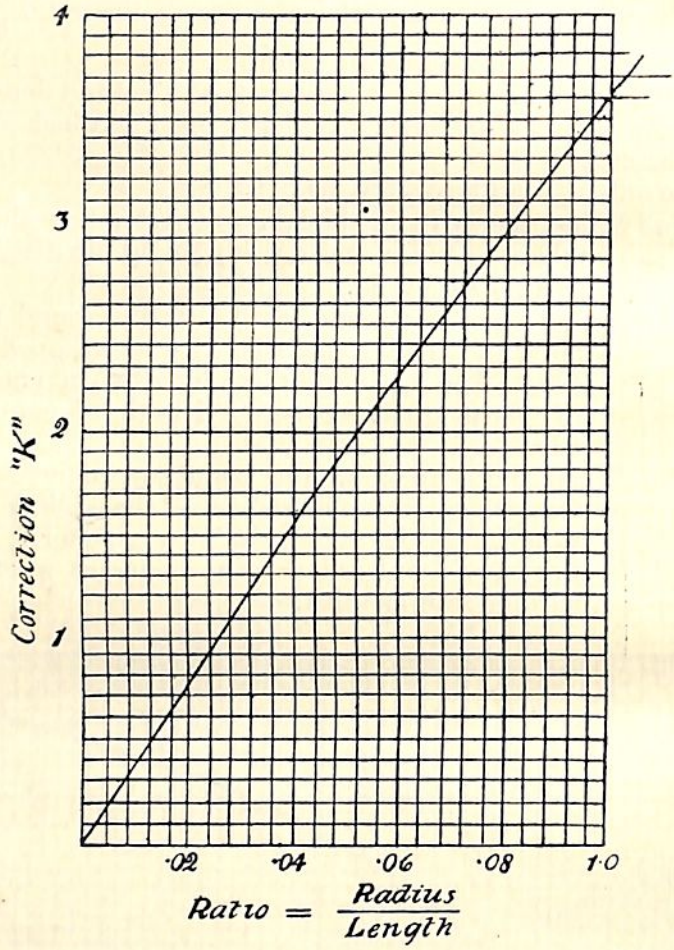


FIG. 155.

The problem of calculating self-induction is usually presented to us in a more difficult form. Instead of having to find the inductance of a given coil of wire, we have usually to :—

Wind a Coil of given Self-induction.

Having first selected a former and the size of wire necessary for the core, we wrap some of the wire round the core with the same spacing (if any) that we are going to use in the finished coil. We will then measure the axial length occupied by 10, 20 or more turns, taking the measurements in centimetres.

Suppose we have an idea that somewhere between 100 and 200 turns will be correct for our particular inductance.

Assume 100, 130, 160 and 200 turns, working out the inductance in each case. Probably, none of these numbers will be the exact number of mics we require. By making a rough curve of mics and turns we can then pick out fairly exactly the number of turns necessary.

In connection with the method of calculating above described, it must be borne in mind that:—

(*a*) If there are several layers of wire, or

(*b*) If very thick wire be wound on a small diameter former, then the self-induction as calculated will be too large.

(*c*) If the wire be much spaced, as on a transmitting aerial coil, the calculated inductance will be too small.

(*d*) The calculations are useless if any iron be inside the coil core or near the coil.

Inductances in Series and Parallel.

In Series.

The joint inductance, L, of any number of inductances in series is given by

$$L = L_1 + L_2 + L_3 + L_4 + \ldots\ldots$$

This is true for any frequency.

In Parallel.

Here

$$\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \ldots\ldots$$

If they are all of the same value, divide the inductance of one by the total number in parallel.

If there are only two of them

$$L = \frac{\text{Product}}{\text{Sum}} = \frac{L_1 L_2}{L_1 + L_2}.$$

Notice that the joint inductance is always less than the least of them.

These formulæ for inductances in parallel must be used only for high-frequency circuits where R is small compared to X (*see* p. 102).

Calculating Capacity.

The capacity of a condenser may be calculated from the formula

$$S = \frac{AK}{4\pi d}.$$

Here, S is in cms. of capacity, so that we must divide by 1,000 to get the answer in jars. A is the effective area in square cms. of the dielectric charged—that is, of the dielectric which is clothed both sides with conducting foil.

K is a number depending upon the material comprising the dielectric.

d is the thickness of the dielectric in cms.

The number denoted by "K" is called the S.I.C. or specific inductive capacity of the material used.

The "holding capability" of an air dielectric is taken as unity, and the capabilities of other materials are compared with that of air and their S.I.C. values are calculated accordingly.

For instance, a piece of glass might have an S.I.C. of 8. This means that a condenser with an air dielectric had a capacity of 1 jar, then if glass were substituted for the air, without altering the size or distance apart of the plates, the capacity would be increased to 8 jars.

The S.I.C.'s of different substances are given in the following table.

Table of specific inductive capacities, sometimes called "*Dielectric Constants*" :—

Flint glass (dense) - - -	10·1
Flint glass (light) - - -	6·57
Crown glass (hard) - - -	6·96
Mica - - - -	4 to 8
Shellac - - - -	3·0
Ebonite - - - -	2·05 to 3·15
India-rubber (pure) - - -	2·12
India-rubber (vulcanised) - -	2·69
Paraffin wax - - - -	2·0 to 2·3
Turpentine - - - -	2·2
Petroleum - - - -	2·2
Beeswax - - - -	1·9
Vulcanite - - - -	2·5

These values are for 15° centigrade thermometer. Different temperatures affect the S.I.C. as also do variations in the voltage applied.

The dielectric with which we are most concerned, ebonite, may be taken as having a value of 2·5.

The formula given above may be written in a more convenient form, giving the capacity in jars direct from the measurements, eliminating π from the expression.

$$S = \frac{AK}{12600 \times d} \quad \text{where } A = \text{cms.}^2,\ d = \text{cms.} \qquad \text{or } S = \frac{AK}{4946 \times d} \quad \text{where } A = \text{ins.}^2,\ d = \text{ins.}$$

In calculating A, the "effective area" of the dielectric, we must be careful when a large condenser, consisting of several sheets joined in parallel, is under consideration.

The rule is to take the area of any one piece of foil—for it is only where the dielectric is covered with foil that the charges lie—and multiply it by the number of dielectrics. For example: in Fig. 156 (*a*) we have five dielectrics, and in (*b*) only four.

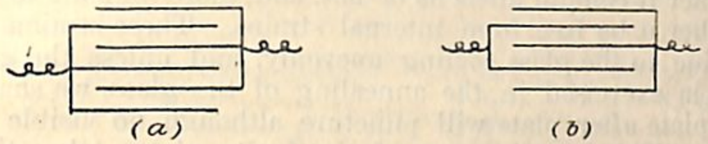


FIG. 156.

In designing a condenser of a given capacity, we have to consider not only the number and area of the sheets, but the nature of the work which the condenser is intended to perform.

In no case should adhesives, such as paste or "seccotine" be used to attach the foil to the dielectric.

Regarding condensers used for receiving purposes, mica or air is the most suitable where fixed condensers are concerned, ebonite or air being used for variable ones.

Air dielectrics are used only for very small condensers, on account of the low S.I.C. of this substance causing the condenser to be unnecessarily bulky.

For transmitting condensers we have to consider, not only the substance which is most favourable mechanically, but also whether the material possesses sufficient "dielectric strength" to avoid puncture at the high voltages employed.

The solid dielectrics all have the disadvantage that, when once punctured, they are useless till repaired, a process which may take a long time, or even be impossible, in a ship.

On the other hand, a gaseous or liquid dielectric will repair itself directly a spark has passed across it.

An air dielectric is in use at Clifden. It is very efficient electrically and never requires any attention. The drawback to its use in ships is that a condenser must be very bulky. This is firstly because air at atmospheric pressure has but little dielectric strength, so that either the plates must be placed far apart (so reducing capacity) or else many sections must be placed in series. Secondly, we remember that any air condenser must be more bulky than its rival of higher S.I.C.

Oil is a good dielectric, it is self-repairing and of moderate dielectric strength. Consequently the plates might be nearer together than in the case of the air condenser, but they would have to be made rigid and self-supporting, like the plate in the wavemeter condenser. Any warping or alteration of the relative positions of the two sets of plates would result in an alteration in capacity and probably a short-circuit across the condenser.

Coming now to *solid* dielectrics.

Paraffin wax will melt on heating, and heat is bound to be generated after prolonged signalling.

Glass is very good provided it can be obtained free from flaws. Much depends upon the manufacture of the glass, whether it contain air-bells or not, and, more difficult to detect, whether it be free from internal strains. These strains are set up, due to the glass cooling unevenly, and unless the greatest care is exercised in the annealing of the glass, we shall find that plate after plate will puncture although no visible defect exists. This weeding out of the faulty plates takes time, is very annoying and might lead to a breakdown in a ship just at the moment of sending an important signal. Moscicki makes a very good glass condenser.

Mica is perhaps the most perfect dielectric known as far as its electrical properties go. It is very efficient, of great dielectric strength, considering its minute thickness, but it cannot be obtained in large sheets except at prohibitive prices.

Compounds, like *Micanite*, *Vulcanite* and *Woodite* possess the common disadvantage of non-uniformity of quality and structure besides being not very efficient.

Ebonite can be obtained in large sheets of very uniform quality and thickness. It has a moderately high S.I.C. so that condensers are not too unwieldy. It is fairly efficient electrically. It is of high dielectric strength so that many sections do not have to be employed. A sheet of ebonite $\frac{1}{32}$ inch thick will stand a 4-mm. spark between balls, the maximum working spark being about 2 mms. When a larger spark is to be employed we put sections of the condenser in series with one another, allowing one section for each 2 mms. of spark.

It is safe to work an ebonite condenser at a greater spark length than this, allowing (2 mms. per section) + 2 more "for luck."

The reasons why several sections of thin-sheeted condensers are used instead of one condenser made of thick ebonite are, firstly, because the price of good quality ebonite of uniform thickness increases rapidly with the thickness, and, secondly, because thin sheets are *relatively* stronger than thick ones. Thus, two sheets in series, each $\frac{1}{32}$-inch in thickness, would bear a spark which would puncture one thickness of $\frac{1}{16}$-inch.

Safety points are placed at the correct distance apart, joined across the condenser, to give warning when the safe working voltage is being exceeded. The points (or disc) must be kept at the correct distance apart and must also be kept sharp. (see p. 230)

Dielectric strengths of various substances are expressed in "kilo-volts per centimetre thickness," the voltage given being roughly that required to puncture the substance of that thickness.

They are given in the accompanying table, showing how the dielectric strength alters inversely with the thickness.

Substance.	Thickness, cms.	Dielectric Strength Kilo-volts per cm.
Air at normal pressure and temperature	0·02	57·5
" " "	0·10	43·6
" " "	0·40	34·5
" " "	1·00	29·8
" " "	1·40	28·8
Crystal glass - - - -	0·1	285
" - - - -	0·3	224
" - - - -	0·6	168
Window glass - - - -	0·2	160
Ebonite - - - -	0·093	538
" - - - -	0·186	434
India-rubber - - - -	0·135	476
" - - - -	0·270	318
Mica - - - - -	0·001	2000
" - - - - -	0·01	1150
" - - - - -	0·02	950
" - - - - -	0·05	750
" - - - - -	0·10	610
Vaseline oil - - - -	0·4 to 0·8	60
Olive oil - - - -	"	70
Linseed oil (raw) - - -	"	83
" (boiled) - - -	"	55

Construction of Ebonite Transmitting Condensers.

All ebonite transmitting condensers are immersed in a tank of insulating oil. This oil, by excluding air, assists in the insulation of the condenser, preventing the access of moisture to the dielectric. It also tends to prevent brushing, which would very soon destroy the sheets, making them puncture at a very low voltage. Again, it is a good non-conductor of heat, so that the condenser is kept fairly cool.

The danger of heating in an ebonite condenser is very real. When hot the material gets soft and is liable to melt. The smell of burning or smouldering ebonite is very distinctive and offensive. It should be known to every operator, so that he may know enough to stop sending if he smells it.

In the construction of the condenser itself, great care must be taken to exclude all air from between the foil and the dielectric. For this reason, each sheet of ebonite has a sheet of foil squeezed down on each side. This means that when two sheets are put together, there will be two sheets of foil where at first sight one would have sufficed.

The foil is cut smaller than the ebonite, a margin of about 1½ inches being left all round except where the "tab" leads up to the terminal. The corners of the foil must be rounded off, to reduce the tendency to brush, and the foil must be well smoothed down on the sheet, the whole operation being accompanied by plenty of oil to cause the foil to adhere and to assist in the exclusion of air-bubbles. All air-bells must be smoothed out from the centre, by means of some spatulate instrument which will not tear the foil. It saves time to test each plate of the condenser as it is built up, using the proper test spark-length. Any faulty plate will then puncture before the building goes any further.

When completed, the whole condenser is compressed firmly between thick ebonite sheets and compression plates of wood or thin steel.

Regarding the *oil* used. The tank must always be kept full of oil right up to the brim, no air-space or "ullage" being permissible. Oil used for condensers must never be exposed to the air for any length of time, for it rapidly absorbs moisture and loses its insulating properties. Cans must always have their plugs screwed hard on when not in use.

Again, the presence of any foreign body, such as fluff, dirt, or grit, inside the tank, will assist in brushing and possibly cause a complete breakdown.

It is, therefore, imperative to see that the inside of the tank and the condensers themselves are scrupulously clean before filling the tank with oil; to see that the oil strainer is clean before use; never under any circumstances to allow old oil to be used, and never to permit oil to be strained through any textile fabric, such as bunting, which would be likely to part with any small hairs or fluff.

Condensers in Parallel and Series.

With condensers S_1, S_2, S_3, S_4 &c., in *parallel*, we have the joint capacity $S = S_1 + S_2 + S_3 + \ldots\ldots$

If they are all the same value, and there are N of them in number :—$S = NS_1$.

When in series we have the joint capacity less than the least one so that

$$\frac{1}{S} = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3} + \ldots\ldots$$

If they are all the same value :—

$$S = \frac{S_1}{N}.$$

If there are only two, S_1 and S_2, we have

$$S = \frac{\text{Product}}{\text{Sum}} = \frac{S_1\,S_2}{S_1 + S_2}.$$

Calculating λ *and* σ *from Transmitting Adjustments.*

The following is the best method of finding λ and σ instead of by sparking into the aerial.

Make out a curve of mics and turns for the aerial coil, as shown in Fig. 157.

To do this, let us take an example.

Suppose the mutual coil be fixed, with an L of 10 mics. Let the aerial coil be wound on a cylindrical former 14 inches in diameter, the turns being $\frac{1}{4}$ inch apart. With 50 turns on the coil, we work out the inductance of various turns as shown below.

$$\text{The radius} = \frac{14}{2} \times 2 \cdot 54 = 17 \cdot 8 \text{ cms.}$$

Turns.	l.	Ratio $\frac{r}{l}$.	K.	L mics.
5	3·18	5·6	41·4	18·4
10	6·35	2·8	31·8	56·6
20	12·7	1·39	23·1	164
30	19·0	0·94	19·6	314
40	25·4	0·7	16·4	470
50	32·0	0·557	14·0	625

Turn this table into the form of a curve, as shown in Fig. 157, we can then read off the inductance of any number of turns required.

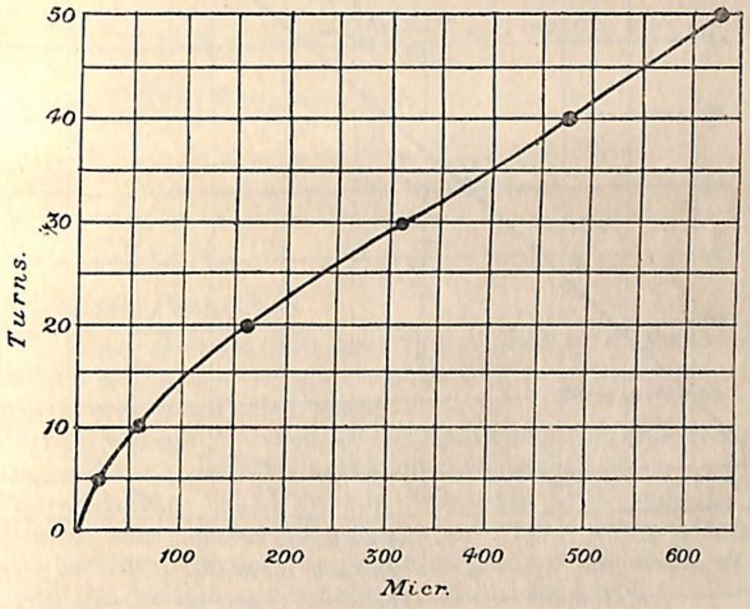


Fig. 157.

Now imagine this set to have been tuned up to five wavelengths, called "A tune," "B tune," &c., with LS values as shown below. Also we shall suppose the aerial coil adjustments, with corresponding mics as found from the curve, be as in the following:—

Tune.		Wave.	LS.	Turns on Æ Coil.	Mics Æ Coil.	Æ Coil + Mutual.
A.	-	2,520	150	5	20	30
B.	-	3,260	250	13	84	94
C.	-	4,130	400	20	163	173
D.	-	5,050	600	25	236	246
E.	-	6,510	1,000	41	492	502

Now make a curve, connecting LS values and mics added to λ, that is total mics added—the sum of aerial and mutual coil.

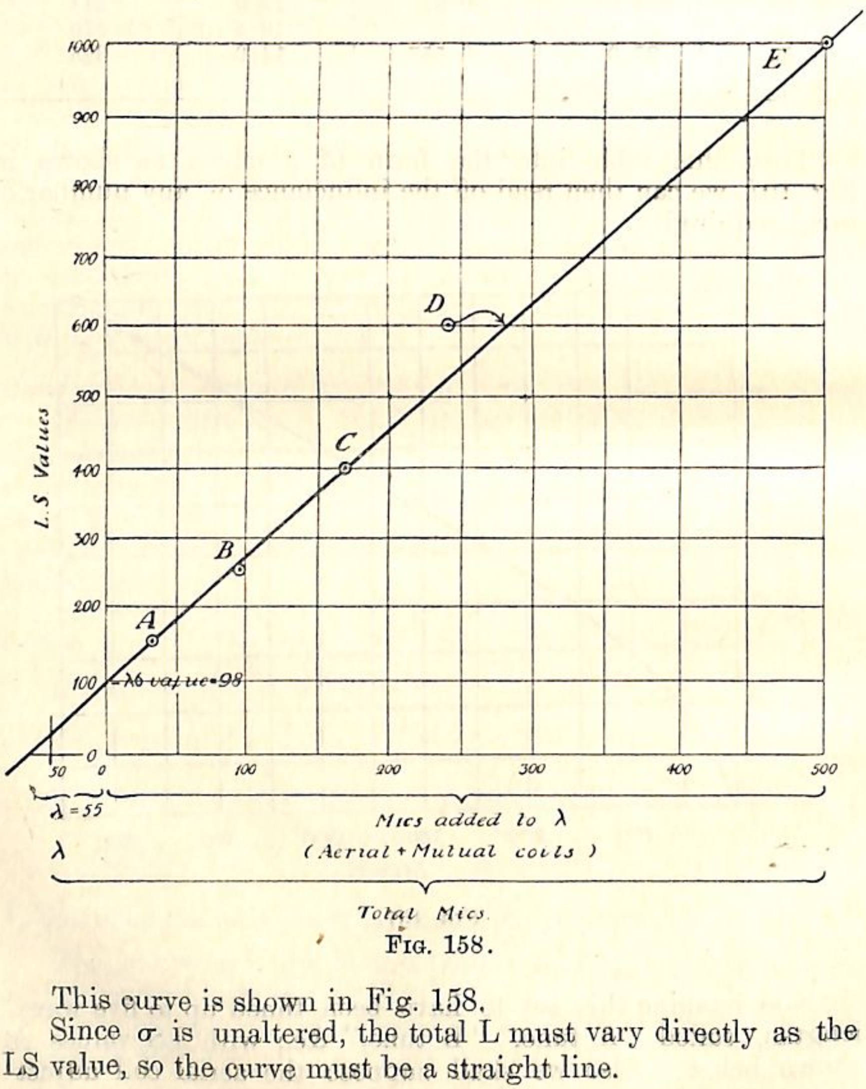


FIG. 158.

This curve is shown in Fig. 158.

Since σ is unaltered, the total L must vary directly as the LS value, so the curve must be a straight line.

In all probability, as in this case, no straight line can pass through all the five points plotted on the squared paper.

Rule the line as fairly as possible through all those that are *nearly* in a straight line.

In Fig 158 the 246 mics for LS = 600, falls considerably outside the line, so that in all probability there was a mistake in the tuning.

How great is the mistake? It seems from the curve that 280 mics would be correct for LS = 600, so 270 are wanted on the aerial coil.

270 mics go to about 27 turns, so we are two turns wrong on the aerial coil.

Hence we have an easy method of checking the *accuracy of tuning*.

Fig. 158 will, however, tell us more than this. It will first give us how many mics (and from Fig. 157 how many turns) are required to get *any* LS value. Next it appears that the LS value with 0 mics added (that is, the $\lambda\sigma$ value) is 98 LS, so that the natural wave-length is 2,040 feet.

Again, the curve, prolonged to the left, cuts the "mic" line at 55 mics, which is λ.

Also any LS divided by its corresponding total L will give us σ.

Thus 400 LS requires $\underline{173 + 55}$ mics in all,

$$\text{So S} = \sigma = \frac{\text{LS}}{\text{L}} = \frac{400}{228} = 1{\cdot}76 \text{ jars.}$$

Again, 1,000 LS requires 502 + 55 mics in all.

$$\text{So S} = \sigma = \frac{\text{LS}}{\text{L}} = \frac{1{,}000}{557} = 1{\cdot}79.$$

So we see that σ is about 1·78 jars.

Note that $\lambda\sigma = 1{\cdot}78 \times 55 = 98$.

Damping and Persistency.

We have already seen that the oscillatory discharge of a condenser across a spark-gap results in a train of waves whose energy is continually decreasing.

We now come to consider the laws governing this decaying action, and the principles on which it is measured.

A pendulum, when set in vibration will come to rest gradually, the number of swings performed before a state of rest is attained depending principally upon the mass of the bob and the friction against the air and at the pivot.

So also in an oscillator we shall be prepared to find that the greater the electric "mass" (inductance) and the less the resistance of the circuit, the more slowly will the oscillations die away.

If the amplitudes of successive excursions of a pendulum bob (measured at one side only of its swing) be recorded and compared, it will be found that the amplitude of each successive excursion bears a constant ratio to that of its predecessor. In this way the swings follow the "law of compound interest," in that each one is a certain *percentage* of its predecessor. Hence when the action first commences the difference between successive swings is large, but when they are feeble very little difference is evident. To illustrate this kind of variation, take a glass of water and pour away a quarter of it. The glass is now three-quarters full. Now pour away, *not* another quarter of the glass, but a quarter of what is *left* therein. Again pour away a quarter of what is left, and so on many times. Theoretically, the glass would never be emptied, but in practice we should soon find that the quantity remaining would be negligible. In this case it is seen that each remainder is 75 per cent. of the preceding one.

Again, take a stick or piece of wire and cut it into halves. Lay one piece aside and halve the other. Lay one of these halves aside and again halve the other. Go on doing this until the last piece is so small as to be incapable of being further subdivided. Now lay the sticks out at equal intervals in order, keeping all their butt ends in line, as in Fig. 159.

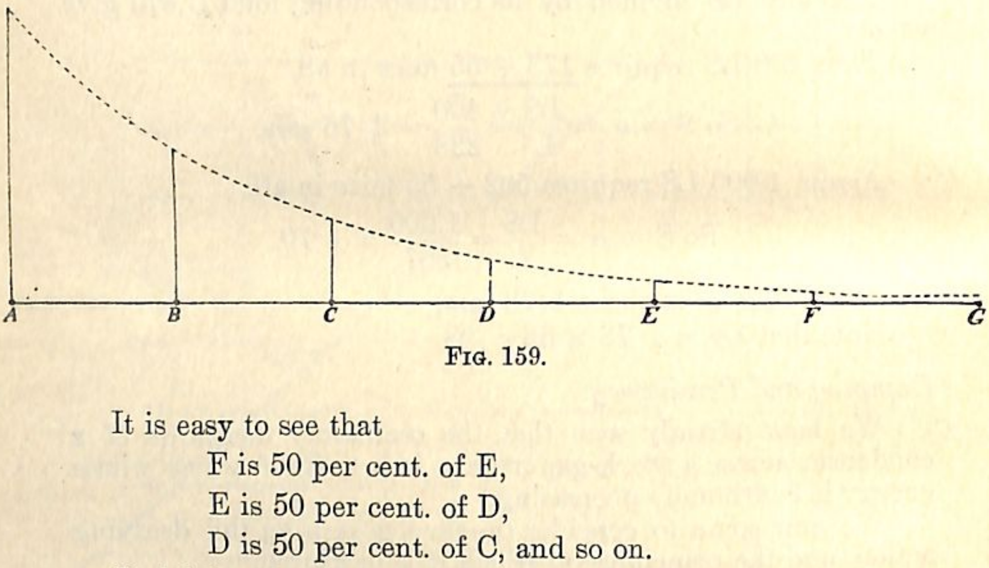


Fig. 159.

It is easy to see that

F is 50 per cent. of E,

E is 50 per cent. of D,

D is 50 per cent. of C, and so on.

By joining the tops of all the sticks by a dotted line, we obtain a peculiar curve, whose right-hand end is continually getting nearer and nearer to the horizontal line, but which never quite touches it.

Let us now take the diagram of a jig, as in Fig 160.

Joining all the tops of the curves by the dotted line, we again have this peculiar *logarithmic curve.* The slope of this curve is exactly proportional to the height of the ordinates.

In this jig diagram let the amplitude of B be 80 per cent. that of A; that of C be 80 per cent. that of B, and so on.

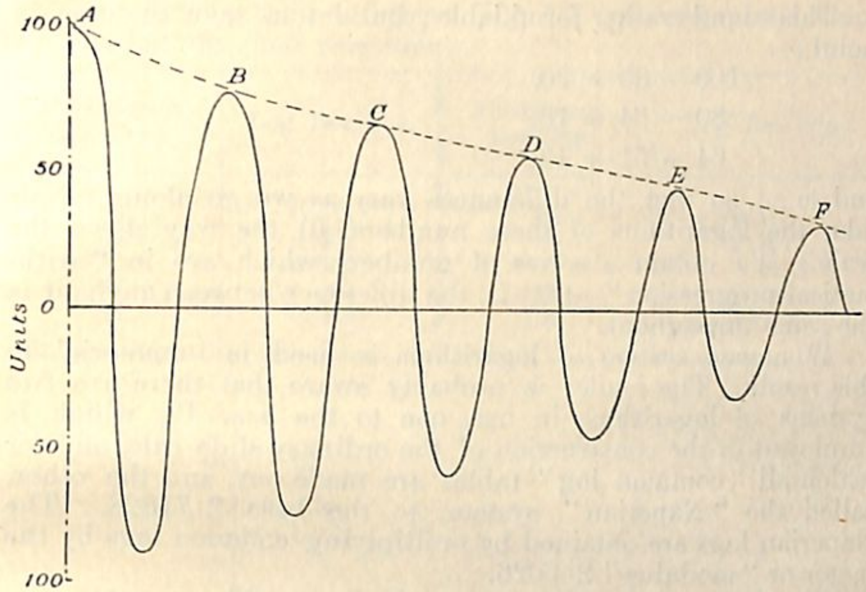


FIG. 160.

Assume the amplitude at A to be called 100 units. We can now make a table for all the other amplitudes :—

A = 100.		
B = 80	per cent.	of 100 = 80.
C = 80	,,	of 80 = 64.
D = 80	,,	of 64 = 51·2.
E = 80	,,	of 51·2 = 41.
F = 80	,,	of 41 = 32·8.
G = 80	,,	of 32·8 = 26·2.

We now want to see what relationship connects these numbers, 100, 80, 64, &c. They are said to be in "geometrical progression," since each one is the *same* percentage as its predecessor, so we might measure damping by a percentage in this manner. This would be inconvenient, because the greater the damping the lower will be the percentage. Persistency, however, being the opposite of damping, is measured by this means. *Persistency* is measured by the percentage ratio between any two consecutive swings in the same direction.

Mention has been made of a logarithmic curve. We will not go into the theory of logarithms here, but every number has a logarithm which may be found from a table.

A peculiar property exists with regard to these numbers, 100, 80, 64, &c. The differences between them, taking any pair of consecutive ones, are not constant, but the differences between the logarithms of any pair of consecutive ones are constant for any given percentage of persistency.

This sounds rather formidable; but let us take the case in point:—

$$100 - 80 = 20,$$
$$80 - 64 = 16,$$
$$64 - 51 = 13,$$

and so on, so that the differences vary as we go along. Now take the logarithms of these numbers all the way down the scale. We obtain a series of numbers which are in "arithmetical progression"—that is, the difference between any pair is the same throughout.

Whatever system of logarithms is used is immaterial to this result. The reader is probably aware that there are two systems of logarithms in use, one to the base 10, which is employed in the construction of the ordinary slide rule, and for which all "common log" tables are made out, and the other, called the "Naperian" system, to the base 2·71828. The Naperian logs are obtained by multiplying common logs by the factor or "modulus" 2·3026.

We will now amplify our table for an 80 per cent. persistency:—

Swing.	Amplitude.	Difference in Amplitude.	Common Log. of Amplitude.	Difference in Common Logs.	Naperian Log. of Amplitude =Com. Log. × 2·3026.	Difference in Naperian Logs. = δ.
		Not constant.		*Constant.*		*Constant.*
A. -	100		2·0000		4·6052	
		20		·0969		·2231
B. -	80		1·9031		4·3821	
		16		·0969		·2231
C. -	64		1·8062		4·1590	
		12·8		·0969		·2232
D. -	51·2		1·7093		3·9358	
		10·2		·0965		·2232
E. -	41		1·6128		3·7136	
		8·2		·0969		·2232
F. -	32·8		1·5159		3·4904	
		6.6		·0966		·2246
G. -	26·2		1·4183		3·2658	

Instead of going through the process of taking common logs, converting them into Naperian and then taking the difference, we may take the difference between common logs (here = ·0968 about) and multiply it by 2·3026, thus getting the Naperian difference.

Here ·0968 × 2·3026 = ·223

This result (·223) is called the "logarithmic decrement" (abbreviated to log. dec.), sometimes the "damping decrement." It is denoted by the symbol δ (delta).

The following table and curve (Fig. 161) give the relationship between log. dec. and persistency.

Persistency. Per Cent.	Log. Dec. = δ.	Persistency. Per Cent.	Log. Dec. = δ.
60	0·511	85	0·163
65	0·432	90	0·1076
70	0·357	95	0·0513
75	0·288	98	0·0202
80	0·223	100	0·0000

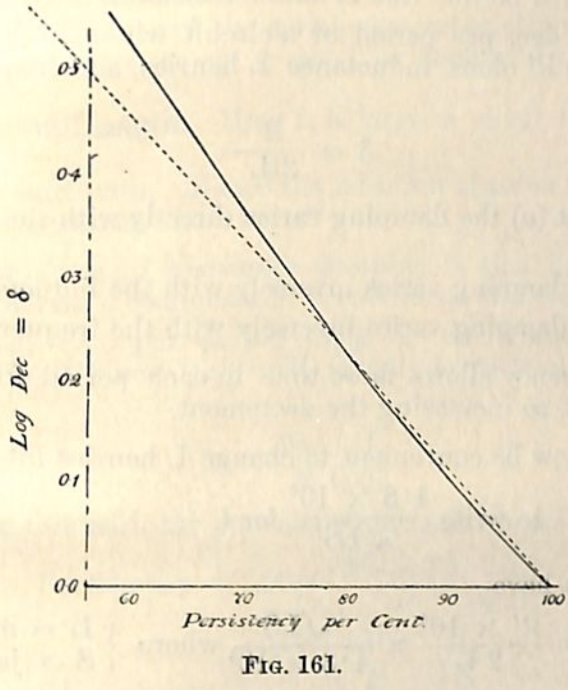


FIG. 161.

The reader should notice that we may speak of the log. dec. per complete period or the log. dec. per half-period, according as the amplitudes plotted are consecutive ones in the same direction or in opposite directions. Most writers now employ (as we shall) the log. dec. per complete period.

Looking at the curve in Fig. 161, we notice, by comparing it to the ruled dotted line, that at the right-hand end it is nearly a straight line. For persistencies above 75 per cent. and for log. decs. below about 0·2, we may so consider it.

The equation to this particular straight line is

$$\delta = \frac{100 - P}{90} \text{ or } P = 100 - 90\delta, \text{ where P is the persistency.}$$

The above formulæ are called "empyrical." They are only approximately correct, having been constructed from the curve on a false assumption. For log. decs. greater than 0·2 the persistency is greater than that given by these formulæ. The straight line is shown dotted in Fig. 161, so that the reader can see how the error comes in for very heavy dampings where δ is greater than 0·2.

We have already seen that damping is due to two causes :—

(1) Ohmic resistance.

(2) Radiation.

A closed oscillator which is not parting with any of its magnetic energy by induction into another adjacent circuit may be considered to be non-radiative. That is to say, the damping of the jigs will be that due to ohmic resistance only.

The log. dec. per period of a circuit whose high-frequency resistance is R′ ohms, inductance L henries, and frequency f, is given by :—

$$\delta = \frac{R'}{2fL}$$

Note that (*a*) the damping varies directly with the resistance (*see* p.   ).

(*b*) The damping varies inversely with the inductance.

(*c*) The damping varies inversely with the frequency.

A low frequency allows more time in each period for the heat losses to act, so increasing the decrement.

It will now be convenient to change L henries into mics and to write $\frac{4{\cdot}8 \times 10^6}{\sqrt{LS}}$ for f.

We then have

$$\delta = \frac{R' \times 10^6}{2\,L} \times \frac{\sqrt{LS}}{4{\cdot}8 \times 10^6} \text{ where } \begin{cases} L = \text{mics,} \\ S = \text{jars.} \end{cases}$$

$$\text{So } \delta = \frac{R'}{9{\cdot}6}\sqrt{\frac{S}{L}}$$

This last is a useful formula. It can now be combined with the empyrical formula given above, so that we have

$$\text{Persistency} = 100 - \frac{90}{9{\cdot}6}\,R'\sqrt{\frac{S}{L}}$$

$$= 100 - 9{\cdot}4\,R'\sqrt{\frac{S}{L}}$$

This formula is not quite true for a closed oscillator containing a spark-gap, because the resistance of the gap is continually varying (getting greater towards the end of the jig ; nor is it true when two circuits are coupled together unless the coupling be very loose.

Looking at this last formula, we see that in a circuit containing a large capacity and small inductance, where $\sqrt{\frac{S}{L}}$ is necessarily large, it is of vital importance to keep the resistance low in order not to have heavy damping. A persistent circuit will therefore have as low resistance, as high inductance and as small capacity as possible. This may be easily attained in the receiving circuit, especially where the detector is not a current-operated one, but the large transmitting primary condenser is essential in order to store sufficient initial energy for the jig. However, every effort is made to reduce the resistance of the primary inductance.

Take now the case of the aerial wire, especially when loaded up with inductance so as to send or receive a wave longer than its natural length. Here L is large, σ small, so that $\sqrt{\frac{S}{L}}$ is small to start with. Hence the addition of a few ohms in the tuner does not cause much harm.

Another form of resistance damping is that due to faulty insulation across a condenser or across turns of a coil of wire.

The log. dec. per period of a circuit whose insulation resistance is R ohms (this will usually be several million) is given by

$$\delta = \frac{94}{R}\sqrt{\frac{L}{S}}$$

Combining this with the persistency formula we see that

$$\text{Persistency} = 100 - \frac{90 \times 94}{R}\sqrt{\frac{L}{S}}$$

$$= 100 - \frac{8460}{R}\sqrt{\frac{L}{S}}$$

Notice that as the insulation resistance falls, the damping increases, and that the larger the L and smaller the S the better must the insulation resistance be.

Thus, the insulation resistance of the deck insulator, of the strain insulators for aerial, and for the small condensers used inside the cabinet, the insulation resistance between turn and turn of aerial coil or tuner must all be high, and the longer the wave-length the higher must be the resistance.

Why then, we might naturally ask, is it necessary so to insist upon high insulation resistance for the transmitting condenser, which is large, with a small inductance? This is largely a question of voltage, for where the voltage is high there will be a large leakage loss (C^2R) if the resistance of the condenser or spark-gap falls.

Again, in the charging circuit we have $\sqrt{\frac{L}{S}}$ very large, so that unless the condenser be well insulated the resonance effect will not be so marked, and loss of efficiency will ensue.

Radiation damping.

This is a very difficult quantity to determine, but will in general be much larger—if the open oscillator be an efficient radiator—than the resistance damping.

No formulæ are applicable to any sort and shape of aerial, since the damping will depend on the height, shape, thickness and number of wires in addition to their electrical properties.

The log. decs. of a Marconi plain aerial, with a spark-gap of about 5 ohms resistance at its foot, are roughly

$$\delta \text{ (radiation)} = \cdot 2 \text{ to } \cdot 4,$$

and

$$\delta \text{ (resistance)} = \cdot 02 \text{ to } \cdot 04.$$

This means, since the total log. dec. = the sum of the two (radiation and resistance) log. decs., that the oscillations are completely extinguished after about 10 complete cycles or less.

The number of complete oscillations in a jig which occur before the amplitude falls to $\frac{1}{10}$th of the initial amplitude will of course depend on the log. dec.

The greater δ, the fewer will be the swings.

Prof. Fleming gives a simple formula:—

Number of complete oscillations till amplitude falls to $\frac{1}{10}$th its initial value . . . $\left.\right\} = \dfrac{2 \cdot 3026 + \delta}{\delta}$.

This may be written

$$N = \text{Number} = 1 + \frac{2 \cdot 3026}{\delta}.$$

The following table is derived from this formula:—

δ.	N.	δ.	N.
1·0	3·5	·1	24·0
0·8	4·0	·08	30·0
·6	5·0	·06	39·0
·4	7·0	·04	58·0
·3	8·5	·03	78·0
·2	12·5	·02	116·0

Good tuning is not possible with less than 15 waves in the jig. It is for this reason that "plain aerial"—owing to the great radiation and resistance damping—is not a selective method of sending or receiving.

Measurement of Damping by means of Wavemeter.

From the formula

$$\delta = \frac{R'}{2\,f\,L}$$

calculate the log. dec. of the wavemeter circuit. Call this log. dec δ_2.

When the wave meter is loosely coupled to another circuit whose log. dec. we wish to measure, we spark into the circuit and adjust the condenser to D_m degrees to give the maximum reading of the galvanometer. Call this reading G_m, allowing for any index error due to the pointer, when at rest, not setting at zero. Now move the condenser pointer up or down from D_m, till the galvanometer points to *half* its previous deflection (to $\frac{G_m}{2}$), in degrees. Let this adjustment be called D degrees.

Then we have

$$\delta_1 + \delta_2 = \pi \frac{D_m \sim D}{D_m},$$

where δ_1 is the log. dec. of the circuit being measured.

The expression $D_m \sim D$ is the number of degrees that the pointer has moved *away* from D_m.

The two observations—one with D less than D_m and one with it greater, will give two values for $(\delta_1 + \delta_2)$. The mean is taken, δ_2 subtracted, and the remainder is δ_1, the log. dec. required.

If the coupling be not very loose between the two circuits, this value of δ_1 will be too large. The best coupling to use is found when loosening the coupling is found not to decrease the damping.

Another way of finding δ for a circuit containing a spark-gap is due to V. Bjerknes.

Let V be the max. P.D. across the spark-gap, or "spark voltage" (*see* p. 312), and *V* be its R.M.S. value as measured by an electrostatic voltmeter (*see* p. 161).

Then the log. dec. per period is :—

$$\delta = \frac{N}{4f} \cdot \frac{V^2}{\mathit{V}^2},$$

where f is the frequency, and N = number of jigs per second.

Substituting

$$\frac{4 \cdot 8 \times 10^6}{\sqrt{LS}}$$

for f, we have

$$\delta = \frac{N\,V^2\,\sqrt{LS}}{1 \cdot 92 \times 10^7 \times \mathit{V}^2},$$

where L = mics and S = jars.

This method may be used for finding the total damping decrement of an open oscillator.

Sharpness of Tuning.

By "sharpness of tuning" is meant the way the current falls off in a circuit when it is not quite in resonance with another circuit. This is most noticeable in any selective receiving circuit. A "sharp" adjustment is attained when a very small alteration of L or S causes a great falling off in the strength of signals.

It is controlled principally by the dampings of the two circuits. A well-sustained jig of many oscillations will always give "sharper tuning" than will a heavily damped jig. The looser the coupling at the transmitting end, within limits, the sharper will be the tuning at the receiving end, the more selective the wave, and the less interference will be experienced by other ships looking out on different wave-lengths.

Conversely, the less the damping at the receiving end, and the looser the coupling of the detector on to the aerial, the sharper will be the adjustments for any incoming wave, the more selective the circuit, and the less interference will be felt by the ship from the transmission of other wave-lengths by other ships.

MATHEMATICAL APPENDIX.

LIST of LETTERS and SYMBOLS used in this book for ELECTRICAL QUANTITIES.

Quantity = Q.
Current = C.
E.M.F. = E.
Potential = V.
Resistance = R.
Specific resistance = ρ.
Capacity = S.
S.I.C. = K.
Lines of force = N.
Self-induction and inductance = L.
Mutual inductance = M.
Maximum values (capitals) = C.E.V.
Instantaneous values (small) = c.e.v.
R.M.S. values (italics) = *C.E.V*.
Frequency = f.
$2\pi f = p$ = angular velocity.
Reactance = X.
Impedence = Z.
Phase difference angle = ϕ.
Log. dec. per complete period = δ.

ARITHMETIC.

Multiplication.

The product of a number with itself is called a *power* of the number.

Thus 7×7 is the second power or square of 7.
,, 12×12 ,, ,, ,, ,, ,, ,, ,, 12.
Again $8 \times 8 \times 8$,, ,, third ,, ,, cube ,, 8.

The square of 7 is written 7^2, so that $7^2 = 49$; $12^2 = 144$, &c.

The cube of 8 is written 8^3, so that $8^3 = 512$.

The "higher" powers, 4th, 5th, &c., are denoted in a similar manner.

Thus—

$$2^2 = 4,$$
$$2^3 = 8,$$
$$2^4 = 16,$$
$$2^5 = 32, \text{ and so on.}$$

It is seen that the small number *indicates* how many times the original is multiplied by itself. It is therefore called the *index*.

The process of finding the powers of a number is called *involution*.

Multiplication of large numbers is best performed with the "partial products" arranged sloping from right to left.

Example—Multiply 257,813 by 2,481.

```
    257813
      2481
  --------
  515626     \
  1031252     |
   2062504    > Partial products.
     257813  /
  ---------
  639634053   Ans.
```

The reason for this will be more apparent when we come to approximations with decimals.

Shortened Working.

To multiply by 5, add a 0 and divide by 2.

Example—$48 \times 5 = 240$, that is $\frac{480}{2} = 240$.

To multiply by 25, add 00 and divide by 4.

Ex. $8 \times 25 = 200$, that is $\frac{800}{4} = 200$.

To multiply by 125, add 000 and divide by 8.

Division.

Always we have dividend = divisor × quotient + remainder.

Thus $27 \div 6$ has $27 = \underbrace{6 \times 4}_{24} + 3$.

When the divisor splits easily into "factors" it is generally advisable to divide by factors instead of working by "long division."

Ex. $43190 \div 35$. Now $7 \times 5 = 35$. 7 and 5 are "factors" of 35.

```
7)43190
 5)6170   Hence 43190 contains 6170 sevens.
   1234     ,,   6170    ,,    1234 fives.
```

Therefore 43190 contains 1234 (7×5's) *i.e.*, 35's.

If the division cannot be made *exactly*, care is required in finding the remainder.

To find the remainder,

Take an example :—

191103095 ÷ 288. Now 144 × 2 = 288.
Hence 12 × 12 × 2 = 288.
We will use these factors.

2)191103095			Remainder.
12) 95551547	- 2's and 1 unit over	-	1
12) 7962628	- 24's and 11 2's over	-	22
663552	- 288's and 4 24's over	-	96
	Total remainder	-	119

Hence 288 "goes" into 191103095 663552 times with 119 over.

Rule.—To find the remainder, multiply each *partial* remainder by all the factors which precede it, *except the factor which produced it*, and add up all the products.

"Long" Division.

It is best to place the quotient *over* the dividend, not to the right of it as is sometimes done.

Ex. Divide 123456 by 397.

```
       310
397)123456
    1191
     435
     397
     386
```

Ans. 310 times and 386 over.

Signs and Abbreviations.

Equality =. *Ex.* 7 × 6 = 42.

Addition +. ,, 7 + 6 = 13.

Subtraction −. ,, 7 − 6 = 1

Multiplication ×. Sometimes " . " is used, placed *on* the line.

Ex. 7 × 6 or 7 . 6 = 42.

Division ÷, or — Dividend above and divisor below ; or

Ex. $42 \div 6 = \frac{42}{6} = 42/6 = 7$.

∴ Means "*Therefore*" or "*hence.*"

∵ ,, "Because" or "since."

Brackets are of various shapes ( ), { }, [ ], and ‾‾‾‾ or ____, and indicate that the quantities between them must be treated as a whole.

Thus $5 \times (7 - 5) = 5 \times 2 = 10$.
But $(5 \times 7) - 5 = 35 - 5 = 30$.

Again $(42 - 7) \div 5$ means $35 \div 5$ and might be expressed $\dfrac{42 - 7}{5}$.

It is of *great importance* to realise that the —— in $\dfrac{42 - 7}{5}$ is *really a bracket.*

Multiplication with Brackets is often expressed by writing the quantities side by side without the $\times$ sign.

Ex. 3[5] means 3×5 or 15, *not* 35.
So $(5 - 3)(7 - 4)$ means $2 \times 3 = 6$.

This last might be written $\overline{5 - 3}\ \overline{7 - 4}$, but brackets are not usually used like this, owing to the chance of error in drawing the line.

When several brackets occur one pair within another, find the value of the innermost one first.

Ex. $3\{7 + [9 - (8 - 3)]\}$.
This $= 3\{7 + [9 - 5]\}$.
,, $= 3\{7 + 4\}$.
,, $= 3 \times 11$.
,, $= 33$.

Decimals.

The meaning of a Decimal.

Decimal fractions (Latin, "decem," ten) are simply an extension of the ordinary method of writing numbers.

Take the number 111. Here each 1 has 10 times the value of the 1 next to it on the right.

If we put a "·" (point) after the units figure (thus:—111·) we may continue the number to the right—$\overset{HTU}{111}\cdot\overset{th}{11}$, and each 1 will *still* be 10 times the value of the one on the right, $\overset{H}{1}$ (hundreds) is 10 times the value of $\overset{T}{1}$ (tens), and $\overset{U}{1}$ (units) 10 times that of $\overset{t}{1}$. Consequently $\overset{t}{1}$ indicates a tenth part ($\frac{1}{10}$) of a unit, $\overset{h}{1}$ a tenth of $\overset{t}{1}$, that is a hundredth part ($\frac{1}{100}$) of a unit, and so on.

Hence we see 111·11 might be written :—

$$100 + 10 + 1 + \frac{1}{10} + \frac{1}{100}.$$

Be careful to distinguish between

7·3 which is $7\frac{3}{10}$, and 7.3 which is $7 \times 3 = 21$.

Zeros or cyphers to the right of a decimal do not affect its value; nor do they to the left of the "point" if *there were no numbers* there previously.

Thus ·070 is the same as ·07 and the same as 0·07. They all mean :—

$$0 + \frac{0}{10} + \frac{7}{100} + \frac{0}{1000} \text{ which reduces down to } \frac{7}{100} \text{ or } \cdot 07.$$

Figures to the *right* of the point are called *Decimal Figures.*

The number of decimal figures is referred to as the number of decimal places.

If there be no "whole number" to the left of the point, the first decimal figure (not zero) is called the "first significant figure."

Thus, when we say that a measurement has been taken "correct to 2 places of decimals," we mean that the measurement does not err by more than 1 per cent of one unit.

·01 is 1 per cent.

Again in ·003125 the first significant figure is 3. That is, if we were dealing with inches, we should have ·003125 inch or "3 and a bit" "mils." (*See* p. 42.)

It is owing to the great ease with which the accuracy of physical measurements can be indicated that the importance of decimals is so great.

Addition and Subtraction of Decimals.

These operations are carried out as with whole numbers, but we must be careful to get all the "points" vertically under one another.

Addition.

1·007 + 53·28 + ·92603 will be :—

Ex.
```
 1·007
53·28
  ·92603
--------
55·21303
```

Subtraction.

Ex. 73·1 − 17·123.

```
73·100   Here we (mentally) add
17·123     zeros as shown in italics.
------
55·977
```

A useful thing to remember in subtracting a decimal expression from a whole number is shown below.

Ex. 73 − 17·1234567.

```
73·0000 etc.
17·1234567
----------
55·8765433
```

Working :— 7 and *3* are 10, carry one

6 and 1 = 7 and *3* are 10 „

5 and 1 = 6 and *4* are 10 „

This is the old way.

Now notice that except for the last decimal place (3 under 7) we have all the others making *9* when added to their corresponding decimal place in the lower line.

Thus 6 and *3* = 9, 5 and *4* = 9, 4 and *5* = 9, 3 and *6* = 9, 2 and *7* = 9, 1 and *8* = 9. All we do, then, is to write down those numbers which make the figures in the lower row up to 9.

Multiplication of Decimals.

General rule.—Forget all about decimal points, multiply as numbers and then mark off from the right as many decimal places as there were in the two factors *combined.*

Thus $7\cdot132 \times 10$

Consider this as 7132×10.

$= 71320$ result $71\cdot32$ (2 places).

Again $2\cdot2 \times \cdot4$.

$22 \times 4 = 88$. 2 places to be marked off.

Ans. $= \cdot88$.

In multiplying a decimal by 10, 100, 1000, etc., shift the decimal place 1, 2, 3 etc. places to the *right.*

Ex. $7\cdot132 \times 40$. This can be written $71\cdot32 \times 4$.

```
 71·32
     4
------
285·28
```

Ex. $6\cdot125 \times 48$.

```
* 6·125        or factorially      6·125
     48                                6
 ------                           ------
  24500                           36·750
  49000                                8
 ------                          -------
294·000                          294·000
```

Division of Decimals by *Whole Numbers.*

Dividing by 10, 100, 1000 etc., shift the decimal point 1, 2 3 etc., places to the *left.*

Ex. $17\cdot234 \div 10 = 1\cdot7234$.

Ex. $\cdot012 \div 100 = \cdot00012$.

Division by Factors.

Ex. $\cdot007132 \div 64$. Factors 8×8.

```
8)·007132
8)·0008915
  ·0001114375
```

Notice that zeros are added to the right-hand end if the division does not at once "go out."

* Until he is familiar with decimals the reader had better use the "General rule" given above.

By "Long" Division. Note that here is where the advantage of writing the quotient above the dividend appears.

```
       ·0001114375
64)·007132
      64
       73
       64
        92
        64
        280
        256
         240
         192
          480
          448
           320
           320
```

The position of the decimal point fixes itself if the quotient be written as advised.

Division by a Decimal.

Take an example :—

12 ÷ 4 = 3.

Also 120 ÷ 40 = 3 and 1200 ÷ 400 = 3.

Similarly 1·2 ÷ ·4 = 3 and ·12 ÷ ·04 = 3.

The quotient remains unaltered provided we multiply divisor *and* dividend by the same number.

Suppose we have

4·375 to be divided by ·831. The answer will be the same if 43·75 is divided by 8·31,
or if 437·5 " " " 83·1,
or if 4375 " " " 831.

The General Rule is :—Make the divisor a *whole* number by shifting its decimal point to the right the requisite number of places, shifting that of the dividend the *same* number of places. Then divide the new dividend by the new divisor.

Example (1) :—

Divide 3·762 by ·0785.

·0785 becomes 785 and 3·762 becomes 37620.

```
      00047·92
785)37620
     3140
      6220
      5495
       7250
       7065
        1850
```

Quotient is 47·92 to two places of decimals.

Example (2) :—

Taking the same digits as before, divide 3·762 by 7·85.
We have 376·2 to be divided by 785.

```
      000·4792 . . .
785)376·2
    314·0
    -----
     62·20
     54·95
     -----
      7·250
      7·065
      -----
       ·1850
```

The quotient here is ·4792..., the same sequence of figures, but with the decimal place altered.

Relationship between decimals and vulgar fractions.

As we have seen, ·1 is merely another way of writing $\frac{1}{10}$, so to convert a decimal into a vulgar fraction we have a *rule* :—

"Write the figures to the right of decimal point as the numerator, and for denominator a 1 followed by as many 0's as there were decimal places."

Examples :—

$$\cdot 3125 = \frac{3125}{10000}$$

$$\cdot 001 = \frac{1}{1000}$$

Very often we can cancel the results down by dividing top and bottom by 2 or 5.

For instance $\frac{3125}{10000} = \frac{625}{2000} = \frac{125}{400} = \frac{25}{80} = \frac{5}{16}$

So that ·3125 has the same value as $\frac{5}{16}$.

Learn the following :—

$\frac{1}{4} = \cdot 25$, $\frac{1}{2} = \cdot 5$, $\frac{3}{4} = \cdot 75$.

The advanced student may find the following useful :—

$\frac{1}{8} = \cdot 125$, $\frac{3}{8} = \cdot 375$, $\frac{5}{8} = \cdot 625$, $\frac{7}{8} = \cdot 875$.

To do the reverse of the above, namely, to convert a fraction into a decimal, divide the numerator by the denominator.

For instance—express $\frac{3}{4}$ as a decimal :

```
  0·75
4)3·000
  2·8
  ---
   ·20
   ·20.   So 3/4 = ·75.
```

Let us now try another—express $\frac{1}{6}$th as a decimal:

$$
\begin{array}{r|l}
 & 0\cdot1666 \\
6 & 1\cdot000 \\
 & \cdot6 \\
\hline
 & \cdot40 \\
 & \cdot36 \\
\hline
 & \cdot040 \\
 & \cdot036 \\
\hline
 & \cdot0040
\end{array}
$$

The remainder is *always* 4, so that the quotient never "comes out."

In fact we could write the answer ·16666666 . . . . going on writing for ever, and we should never get to an absolutely true result.

This means that every extra 6 we add brings us a little nearer the correct value.

Such a decimal is called a "recurring" one and would be written

$$\cdot1\dot{6}.$$

In electrical measurements we shall very seldom come across these decimals. In fact we need not concern ourselves whether a decimal does eventually recur or not, or whether it is an "indeterminate" one.

An indeterminate quantity is one which, when expressed as a decimal, never "comes out" to an absolute value and yet never recurs.

An example of such a quantity is $\sqrt{2}$ which = 1·4142 . . . . or π which = 3·141592818 . . . .

If we take all decimals to 4 places we shall be making quite negligible errors.

Thus ·1$\dot{6}$ becomes ·1667;
$\sqrt{2}$,, 1·4142;
π ,, 3·1416.

Approximation.

No practical measurement, whether of length, mass or time, can ever be absolutely exact.

All we can hope for, say, in cutting off a yard of serge, is to make the length cut off *differ* from the true yard by as small a quantity as possible. We wish to see what the greatest permissible error shall be.

Suppose we lay down that our errors shall not exceed one per cent.

That means that if we ask for a piece of cloth 100 inches long, neither we nor the draper will be dissatisfied if we get anything under an inch too little or too much.

Suppose we had asked for 100·5 (or $100\frac{1}{2}$) inches. Then we should have been pleased to get anything over 100·4 and under 100·6 inches. The error in this case is not greater than $\frac{1}{10}$th inch in 100 inches, one in 1000 or ·1 per cent.

If any number contains 3 digits it is correct to $\frac{1}{100}$th part of itself.

If any number contains 4 digits it is correct to $\frac{1}{1000}$th part of itself, and so on.

We see, then, that it is the *first* four figures—excluding cyphers to the left of a figure—that are important.

Let us take an example.

We measure the LS value of a circuit:—

L of wavemeter = 202·4 mics.
S ,, ,, = ·387 jars.

Multiplying, we have

```
   2024
    387
  -----
   6072
  16192
   14168
  -------
  78·3288
```

It would be quite accurate enough if we were to call LS = 78·3.

If we want extreme accuracy we should have LS = 78·33, because 288 is nearer to 300 than to 200.

We must remember that readings on the wavemeter condenser cannot be taken to nearer than half a degree, so that, although it looks very nice to say LS = 78·3288, yet it is no more likely to be true than if we said LS = 78·33;

LS = 78·3;
or even LS = 78.

The more figures we have, the nearer the approximation. These are called *significant figures*, and for all practical purposes we need never get our results to more than 3 significant figures. All intermediate work should be done to 4 figures, the answer being given to 3 figures.

Suppose we worked out a wave-length carefully and found

it was	701·678 feet,	we should	call it	702;		
if it were	701·427	,,	,,	,,	701;	
,, ,,	2015·87	,,	,,	,,	2016 or even 2020;	
,, ,,	2014·38	,,	,,	,,	2014 ,,	2010.

These examples should show the reader what he dare do (and should do) in disregarding minute errors.

He should note carefully the difference between "4 places of decimals" and "4 significant figures."

Example: ·0012 inch is correct to $\frac{1}{10000}$th *inch*, because it is taken to 4 places of decimals; but it has only *two* significant figures and may be nearly $\frac{1}{20}$th *of its own length* incorrect.

The application of this principle will save a lot of superfluous work in long calculations.

Example:—

Multiply 431·267 by 3·9425:

(1) exactly.

(2) to 4 significant figures.

(1)

```
431·267
  3·9425
---------
1293801
 3881403
  1725068
   862534
   2156335
-----------
1700·2701475
```

(2)

```
*4̶3̶1̶·2̶6̶|7̶
  3·9425
---------
1293·80 |
 388·14 |
  17·25 |
    ·86 |
    ·21 |
---------
1700·26        Result to 4 figures = 1700.
```

Square Root, or Evolution.

For the W.T. formula $W = 206\sqrt{LS}$ we often have to find the square root of a number; that is, a number which, multiplied by itself, gives us the original number. For instance:

The square root of 64 is 8, for $8 \times 8 = 64$.
" " " " 100 " 10 " $10 \times 10 = 100$.
" " " " 9 " 3 " $3 \times 3 = 9$ and so on.

This is written $\sqrt{64} = 8$.

Now it is very seldom that we have numbers like 49, 64, 81, 100, 121, 144, etc. which are "perfect squares." We may

* Here we first multiply by 3. It is generally best to retain *two* figures more than the number required to be correct. Here we have retained *one* more (5 figures), so we cross out the 7, and begin multiplying by 3 at the digit 6, *carrying two*; and so on. After multiplying by 3 put a dot over it, cross out the 6 and multiply by 9 at the digit 2, *carrying* 6. In each case the number we *carry*, adding it to the first partial product, is the number we *should be carrying* if we had multiplied out all the figures in the top line which have been crossed out.

have to find the square root of 68 say. That will obviously lie between 8 and 9, for $\sqrt{64} = 8$ and $\sqrt{81} = 9$. So that $\sqrt{68} = 8 +$ something.

The process is purely mechanical and can best be illustrated by an example.

Example (1) :—

Find $\sqrt{5329}$.

```
    7  3
  7)53'29
    49
143)429
    429
```

So that result = 73.

(*a*) Mark off the figures in pairs from *the right* (53'29).

(*b*) Take the nearest lower square root of 53 = 7 and write it in two places as shown, putting 49 under 53. Remainder = 4.

(*c*) Bring down the next *pair* of figures, 29, so we have 429. *Double* the last quotient and put it as a divisor = 14 on left of 429.

(*d*) Remembering that the quotient is to be written in 2 places, we see 143 × 3 gives us 429.

Example (2) :—

Now find $\sqrt{537 \cdot 248}$ correct to 5 significant figures. Here we mark off in pairs *left* and *right* from the decimal point.

```
         23·1786
     2)5'37·24'80'
         4
    43)137
       129
   461)8·24
       4·61
  4627)3·6380
       3·2389
 46348)·399100
        ·370784
463566)2831600
       2781396
```

Result = 23·1786 .... or correct to 5 figures :—

" = 23·179.

Let us now prove this. (23·179) × (23·179) should give us 537·248. It will probably do so very nearly.

```
  23·179
     23·179
  ---------
 463·58
  69·537
   2·3179
   1·62253
    ·208611
 ----------
 537·246041
```

So that the square of 23·179 is 537·25 (to 5 figures), which is the same as before.

We may occasionally require $\sqrt{\cdot 0037}$ or some such expression. Here we again mark off in pairs starting from the decimal point.

```
    6)·00′37′00′00′
         36
         -----
  1208)10000
          9664
          -----
  12162)33600
          24324
          -----
          .....
```

* Notice that each *pair* of 0's means only *one* here.
Proof ·06082 × ·06082.

```
   6082
   6082
  ------
  36492
   48656
    12164
 -----------
 ·0036990724
```

·0036990724 is *very* nearly = ·0037.

ALGEBRA.

There will be no need to go very deeply into this subject for the purposes of this book. Briefly we may say that algebra treats of *quantities* as does arithmetic, but that its scope is larger.

The *figures* used in arithmetic can have but one definite value, whereas the *symbols* used in algebra may have any value we choose to assign to them.

The *symbols* used are letters, usually of the English, sometimes of the Greek, alphabet. In every case it must be borne in mind that a letter really stands for a number.

The Greek alphabet is here given for reference.

Letter. Small.	Capital.	Name.	English equivalent.
α	Α	Alpha	a
β	Β	Beta	b
γ	Γ	Gamma	g
δ	Δ	Delta	d
ε	Ε	Epsīlon	ĕ (as in "met")
ζ	Ζ	Zeta	z
η	Η	Eta	ēē (as in "meet")
θ	Θ	Theta	th
ι	Ι	Iota	i
κ	Κ	Kappa	k
λ	Λ	Lambda	l
μ	Μ	Mu	m
ν	Ν	Nu	n
ξ	Ξ	Ksi	x
ο	Ο	Omicron	ŏ (as in "olive")
π	Π	Pi	p
ρ	Ρ	Rho	r
σ	Σ	Sigma	s
τ	Τ	Tau	t
υ	Υ	Upsīlon	u
φ	Φ	Phi	ph
χ	Χ	Chi	ch (as in "school")
ψ	Ψ	Psi	ps
ω	Ω	Omega	ō (as in "broke")

Two letters written *together* are to have their numbers multiplied.

If a = 2 and b = 3, then $ab = 2 \times 3 = 6$.

A letter written by itself (with nothing to its left) has a +'ve value.

Thus $b + a = +3 + 2 = +5 = 5$.

So $b - a = +3 - 2 = +1 = 1$.

$a + b = 5$ (as before).

but $a - b = +2 - 3 = -1$.

So also we could have

$$\frac{a}{b} = \frac{2}{3} \text{ and } \frac{b}{a} = \frac{3}{2} = 1\tfrac{1}{2}.$$

A letter and a number written together follow the same rule.

Thus $5a = 5 \times a = 5 \times 2 = 10$.

$3b = 6$.

Again $7a - 3b = 14 - 9 = 5$.

It will be seen that we have algebraical "expressions" reduced to their absolute arithmetical values by *substituting* the values for a and b.

Be very careful to distinguish between the two methods,

Algebra, $ab = 2 \times 3 = 6$; and

Arithmetic, $23 = (2 \times 10) + 3$.

Take the expression 5ab. Its value is evidently 30. We see at once that 5, a, and b are all *factors* of 30, and therefore of the whole expression.

Whenever (as here) one of these factors is a *number* it is called the "co-efficient" of the other factors.

In 5ab, 5 is the coefficient of ab.

In $206\sqrt{LS}$, 206 is the coefficient of $\sqrt{LS}$.

When the coefficient is *unity* we omit it. We do not write "1a," but merely "a."

The *index* for powers is already explained. Here $a^2 = 2^2 = 4$. $b^3 = 3^3 = 27$; and $ab^2 = 2 \times 3^2 = 18$; and $a^2 b^2 = 2^2 \times 3^2 = 36$. Also note that $(ab)^2 = ab \times ab = a^2 b^2$.

Unless a bracket is used, the index refers to the one letter over which it is written, and to that one only.

Practically all the algebrical expressions with which we are concerned take the form of an "equation"—that is, two expressions connected by an = sign.

Thus we have

$$(1)\ W = 206\sqrt{LS}$$

$$(2)\ C = \frac{E}{Z}$$

$$(3)\ Z = \sqrt{\{R^2 + X^2\}}$$

and so on.

An equation thus used becomes a "formula"—that is, an expression which we carry about with us and which we use when necessary, substituting the numbers for the figures.

Thus, we come to a direct current switchboard and see Amps 350, volts 79. We wish to know what the resistance of the whole circuit is. We say to ourselves

$$\text{"}C = \frac{E}{R}\text{," that is } 350 = \frac{79}{R}.$$

This leaves us with a set of numbers and a letter. In order to "solve" this equation—in other words, to find the numerical value of R, the one unknown quantity left—we have to put the "unknowns" to one side and all the "knowns" on the other side of the equality sign. It is this operation with which we must be familiar.

It will be agreed that :—

(*a*) If two things are equal their halves are equal.
„ „ „ „ „ doubles „
In other words, we may multiply or divide both sides by the same number.

(*b*) If two things are equal their squares, square roots, etc., are equal.

$$\text{Thus if } \frac{W}{206} = \sqrt{LS}$$

$$\text{Then } \left(\frac{W}{206}\right)^2 = LS.$$

$$\text{Also if } LS = 81$$

$$\sqrt{LS} = \sqrt{81} = 9.$$

(*c*) If equals are added to equals the wholes are equal.

(*d*) „ „ „ subtracted from equals the remainders are equal.

Thus if $a = 6$, then $a + 3 = 6 + 3 = 9$.
or $a - 2 = 6 - 2 = 4$.

Let us now take the case in point :—

$$350 = \frac{79}{R}.$$

Multiply both sides by R :

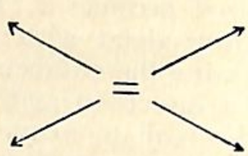
$$350\,R = \frac{79\,\cancel{R}}{\cancel{R}} = 79.$$

Divide both sides by 350 :

$$\frac{350\,R}{350} = \frac{79}{350}.$$

$$\text{Hence}\quad R = \frac{79}{350} \text{ ohms.}$$

It is seen that we can move numbers and letters thus :—



across an equal sign, *provided* there are only multiplication and division signs.

$$\text{Thus, } C = \frac{E}{R} \text{ is the same as } \frac{C}{E} = \frac{1}{R},$$

$$\text{which „ „ „ „ } RC = E,$$

$$\text{„ „ „ „ „ } R = \frac{E}{C}.$$

Again if $\frac{a}{b} = \frac{c}{d}$ Then we can turn the whole upside down and say $\frac{b}{a} = \frac{d}{c}$

or, we can say $ad = bc$.

But if $a = \frac{b}{c + d}$; then if we are to transfer the c across the equals sign we must take the d as well, so that we have to treat $c + d$ as a whole—

$$a(c + d) = b;$$

that is $ac + ad = b$.

Transferring across when there are only +'s or −'s.

Take

$$7a + 10b = 4a + 12b.$$

Suppose we want to collect all the "a's" to one side, and the "b's" to the other.

The rule is :—take them straight across, changing the sign. Thus :—

$$7a - 4a = 12b - 10b.$$

This is $(7 - 4)\,a = (12 - 10)b$.

" " $3a = 2b$.

Then, if we like, $\frac{a}{b} = \frac{2}{3}$, or $a = \frac{2}{3}b$.

In arithmetic we often meet with expressions like $70 - 50 = 20$, but we never have to subtract a larger number from a smaller, as often happens in algebra.

$+ 1 - 2$ has no arithmetical meaning at all, but a number standing alone with a minus sign may have a very definite meaning in algebra.

Thus, suppose we speak of distances on land, not only regarding the space but regarding direction also.

Suppose we say we are going to call directions towards the North positive, those towards the south negative.

A man walks from Portsmouth northwards to Cosham. His progress northwards is + 5 miles when he arrives. He now returns. Arithmetically he has walked 10 miles when he arrives at the Town Hall, but his *progress* northward is $+ 5 - 5 = 0$. Again, he goes on walking south for another mile. On reaching the Clarence Pier his progress is + 5 miles from Town Hall to Cosham *and* − 6 miles from Cosham to the sea.

Adding these two algebraically we have his progress northward $= 5 - 6 = - 1$ mile. We not only know, then, that he finishes 1 mile from the Town Hall, but that he is now situated 1 mile to the south of it.

This will, perhaps, explain the expression "algebraical sum."

The same thing happens regarding *products* of quantities. Thus $(+4) \times (+3)$ means—

"4 miles northwards taken 3 times"

This is obviously = 12 miles northwards.
= + 12 miles.

Again $(-1) \times (+2)$ means :—

"1 mile southwards, taken twice over"; that is to say, 2 miles southwards.

This = − 2 miles.

But $(-2) \times (-2)$ means—

"Two miles southward taken twice over, but in the reverse direction."

This = 4 miles southward reversed
= 4 ,, northward
= + 4.

We thus arrive at the *Rule of Signs* :—

The product of two terms with *like* signs is +'ve, that of two terms of *unlike* signs is −ve.

Hence we see that $(-a) \times (-a) = +a^2$.
and $(+a) \times (+a) = +a^2$.

So that the square of any number, + ve or − ve, is *always* +'ve.

TRIGONOMETRY.

Trigonometry involves the study of angles. Angles are usually measured in degrees, 90 degrees go to a right angle, 4 of these making up the complete circle. There are 360° swept out if a line (Fig. 1) revolves thus :—

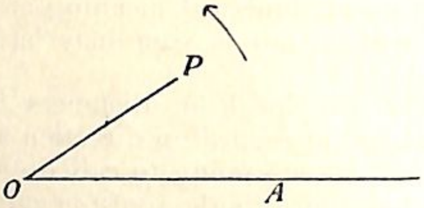


Fig 1.

OP, pivoted at O, sweeps round *once* in a counter-clockwise direction, starting and stopping along the line OA.

Each degree (°) is subdivided into 60 minutes (′).
,, minute ,, ,, ,, 60 seconds (″).

The *unit* in this case is the right angle.

Circular measure of angles is often used, bringing in another unit, the *radian*.

In all circles the $\frac{\text{circumference}}{\text{diameter}}$ is a fixed number.

This number is 3·1416 and is denoted by π.

Thus a mast 1 foot thick will measure 3·1416 feet round, a tube 10 feet thick will measure 31·416 feet round, and so on.

Let the diameter be D.

Then circumference $= \pi D$.

$$\text{The } radius \text{ is } = \frac{D}{2} = \text{distance from centre to circumference.}$$

$$\text{So that since } r = \frac{D}{2} \text{ and } D = 2\,r$$

$$\text{Then circumference} = 2\pi r.$$

Circumference is generally written $\odot^{ce}$.

Circle is $\odot$, Circular $\odot^{r}$.

An "arc" is a portion of the circumference. It must be measured *along the curve.*

The Radian.

Take a $\odot$ as in Fig. 2.

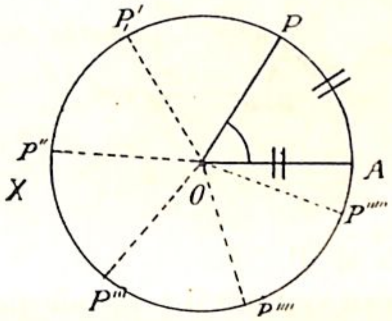


Fig 2

Suppose the arc AP is equal to the radius OA or OP. Then the angle $P\hat{O}A$ is always the same for all circles. It is called a *radian*, and its value in degrees, etc., is about 57° 17′ 44″.

This we can prove as follows :—

The whole O^{ce} APX back to A again measures 2π times OA.

That is 2π times the arc AP (for AP = OA).

So that if we laid off more arcs PP′, P′ P″, etc., we should get in "6 and a bit" of them.

Thus a whole $\odot$ contains 2π such angles as $P\hat{O}A$.

That is 360° ,, 2π radians.

And 180° ,, π radians.

$$\text{Since } \pi \text{ radians} = 180°$$

$$\text{Then 1 radian} = \frac{180°}{\pi} = \frac{180}{3\cdot1416} \text{ degrees.}$$

$$\text{,, \quad ,,} = 57°\,17'\,44''.$$

By this unit we can measure any angle. This is the $\odot^r$ measure.

The $\odot^r$ measure of an angle is the number of radians it contains. It can always be found by drawing an arc across the legs of the angle and dividing the length of the arc by the radius.

$$\odot^r \text{ measure} = \frac{\text{arc}}{\text{radius}}.$$

Angles which are to be given in degrees, etc., are generally marked with English letters; those in $\odot^r$ measure with Greek letters. The commonest of the latter are θ and ϕ. π is *always* meant to mean $3{\cdot}1416$. It is, therefore the $\odot^r$ measure of $180°$.

Trigonometrical Ratios.

Take any angle less than a right angle.

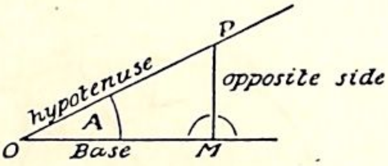


FIG. 3.

Call this angle $\hat{MOP}$, "A."

Let PM be drawn so that it is perpendicular to OM—that is, so that $\hat{PMO}$ is $90°$.

Then $\frac{PM}{OP}$ is called the *sine* of A.

$\frac{OM}{OP}$ " " *cosine* of A.

$\frac{PM}{OM}$ " " *tangent* of A.

The line PM—facing the angle A—is called the "opposite side."

The line OP—facing the right angle—is called the "hypotenuse."

The line OM—between A and the right angle—is called the "base."

These ratios are always the same for the same angle, no matter how long the legs OP, OM are, or whether we drop PM from one leg or the other.

We might have our figure thus

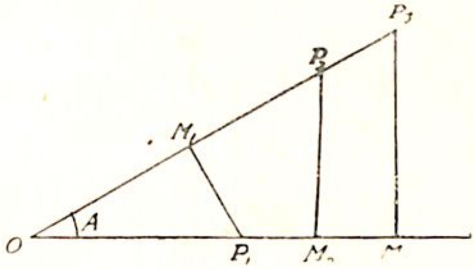


FIG. 4.

The sine of A would be $\frac{P_1M_1}{OP_1}$ or $\frac{P_2M_2}{OP_2}$ or $\frac{P_3M_3}{OP_3}$ and so on.

Sine, cosine and tangent are contracted to sin, cos, and tan.

Take an angle of 45° with OM and PM 1 inch long. Then OP is found to be 1·4 inches ($\sqrt{2}$) long.

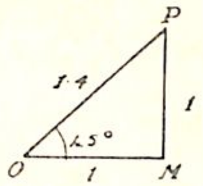


FIG. 5.

Then $\sin 45° = \frac{1}{1·4} = ·7 = \frac{PM}{OP}$
$\cos 45° = \frac{1}{1·4} = ·7 = \frac{OM}{OP}$ } So that the sine and cosine of 45° have the same value.

$\tan 45° = \frac{1}{1} = 1 = \frac{PM}{OM}$.

Take 30°. If we have OP 2 inches,
PM 1 inch, and
OM 1·7 inch, we shall have the angle at O = 30°.

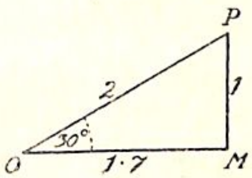


FIG. 6.

$$\text{Sin } 30° = \frac{1}{2} = ·5.$$

$$\text{Cos } 30° = \frac{1·7}{2} = ·85.$$

$$\text{Tan } 30° = \frac{1}{1·7} = ·577.$$

Take 60°. This is the same triangle as before, turned round.

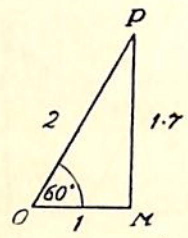


FIG. 7.

$$\text{Sin } 60° = \frac{1 \cdot 7}{2} = \cdot 85.$$

$$\text{Cos } 60° = \frac{1}{2} = \cdot 5.$$

$$\text{Tan } 60° = \frac{1 \cdot 7}{1} 1 \cdot 7.$$

Tabulating these we have

	0°	30°	45°	60°	90°
Sin	0	·5	·7	·85	1
Cos	1	·85	·7	·5	0
Tan	0	·57	1·0	1·7	∞

How did we fill up the first and last columns?

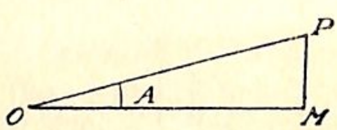


FIG. 8.

Take a very small angle A. Suppose OP gradually gets nearer and nearer OM, PM keeping upright all the time.

Just before it "shuts up" we have—

$$\text{Sin A} = \frac{\text{a very small PM}}{\text{OP}}.$$

$$\text{Cos A} = \frac{\text{OM very nearly} = \text{OP}}{\text{OP}}.$$

$$\text{Tan A} = \frac{\text{a very small PM}}{\text{OM very nearly} = \text{OP}}.$$

When it is quite shut—

$$\text{Sin A} = \frac{\text{O}}{\text{OP}} = 0.$$

$$\text{Cos A} = \frac{\text{OP}}{\text{OP}} = 1.$$

$$\text{Tan A} = \frac{\text{O}}{\text{OP}} = 0.$$

Now let $P\hat{O}M$ be very nearly a right angle.

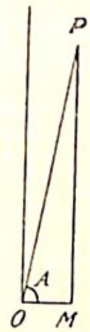


FIG. 9.

Suppose OP gradually opens out till OP and OM are at right angles.

Just before we get A = 90°—

$$\text{Sin A} = \frac{\text{PM very nearly} = \text{OP}}{\text{OP}}.$$

$$\text{Cos A} = \frac{\text{a very small OM}}{\text{OP}}.$$

$$\text{Tan A} = \frac{\text{PM very nearly} = \text{OP}}{\text{a very small OM}}.$$

When A = 90°—

$$\text{Sin A} = \frac{\text{OP}}{\text{OP}} = 1.$$

$$\text{Cos A} = \frac{0}{\text{OP}} = 0.$$

$$\text{Tan A} = \frac{\text{OP}}{0} = \infty.$$

This last requires some explanation.

How can $\frac{1}{0}$ be infinitely great? (∞ = "infinity.")

Let 0 be replaced by "something very very small."

$$\text{Now} \quad \frac{1}{\frac{1}{1{,}000{,}000}} = 1{,}000{,}000.$$

$$\text{So that } \frac{1}{\text{something very small}} = \text{something very large.}$$

$$\text{And } \frac{1}{0} = \frac{1}{\text{something smaller than anything.}} = \text{something larger than anything.}$$

$$= \text{something infinitely large.}$$

$$= \infty.$$

This aspect of tan 90° need not trouble us.

We may notice in any table of tangents that—

tan 89° 0′ = 57·29.
,, 89° 18′ = 81·85.
,, 89° 36′ = 143·2.
,, 89° 54′ = 573·0.

In Fig. 10 we have values of the sine, cosine, tangent, and circular measure of all angles between 0° and 90° shown in the form of curves.

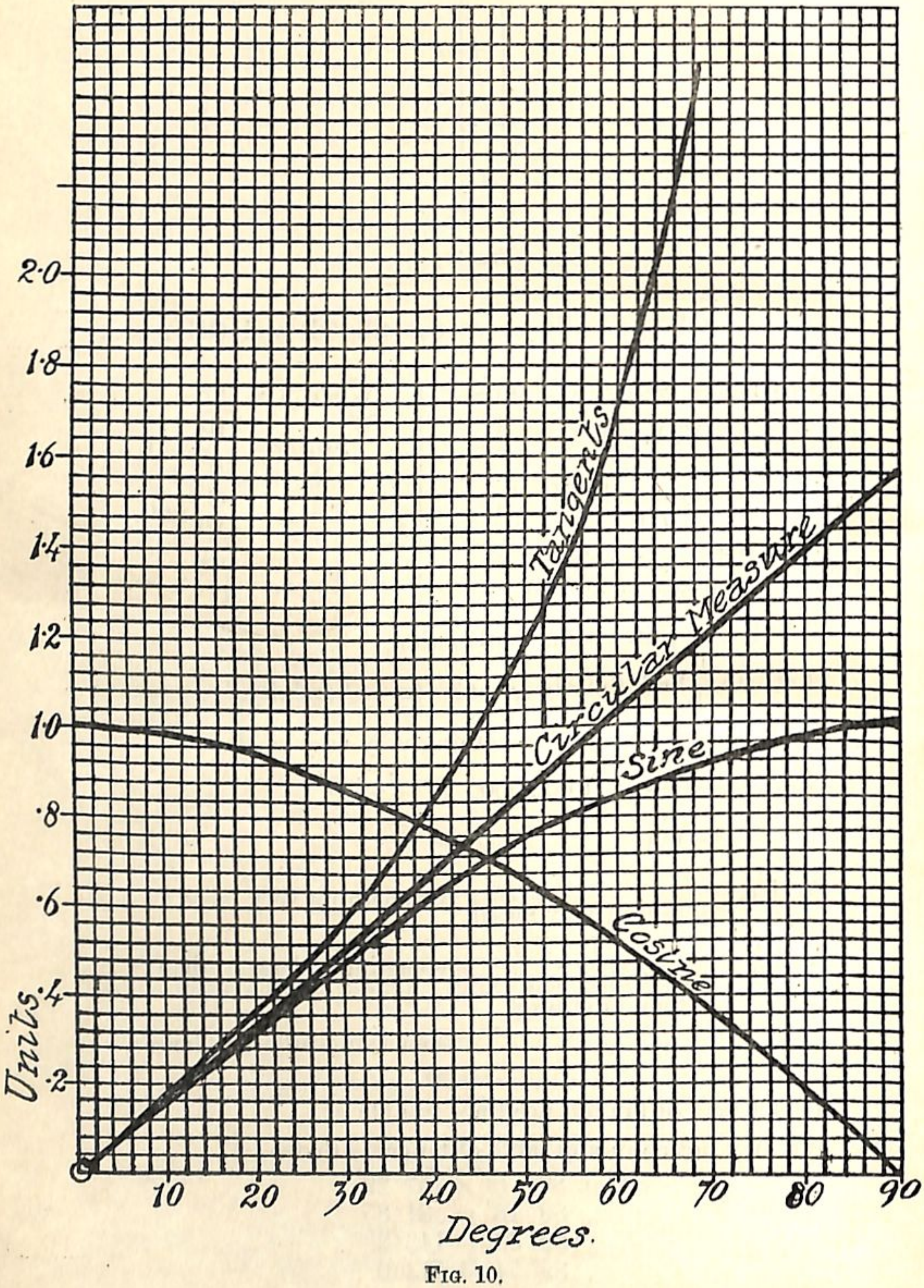


FIG. 10.

It will be seen that for the first few degrees the three curves of sine, $\odot^r$ measure, and tangent values, run together, while further on the sine loses and the tangent gains on the $\odot^r$ measure curve (the latter is a straight line).

Stated mathematically the result is that—

$$\sin\theta = \theta = \tan\theta \text{ when } \theta \text{ is very small.}$$

As θ gets larger we have—

$\sin\theta$, θ, and $\tan\theta$ in ascending order of magnitude.

This is shown as follows :—

Take an angle θ very small with an arc AP, a radius OP and OA, and a perpendicular PM.

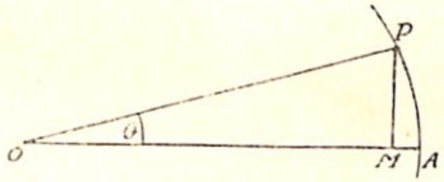


Fig. 11.

$$\text{Now } \sin\theta = \frac{PM}{OP};$$

$$\theta \text{ in } \odot^r \text{ measure} = \frac{\text{arc}}{\text{radius}} = \frac{AP}{OP};$$

$$\tan\theta = \frac{PM}{OM}.$$

It will be seen that PM, the straight line, must always be a little shorter than AP, the curved arc.

Again, OM can never quite = OA, the radius.

As θ gets smaller and smaller, so

PM gets more nearly equal to AP,
and OM gets more nearly equal to OA, the radius.

We have then—

$$\sin\theta = \frac{\text{something nearly} = AP}{\text{radius}};$$

$$\theta = \frac{AP}{\text{radius}};$$

$$\tan\theta = \frac{\text{something nearly} = AP}{\text{something nearly} = \text{radius}}.$$

Looking at these results we see that :—

(1) If θ is very small indeed, $\sin \theta$, θ, and $\tan \theta$ are all equal.

(2) If θ be not inappreciably small, $\sin \theta$ is less than either θ or $\tan \theta$.

(3) Of these two latter, θ is smaller than $\tan \theta$ because OM falls off from OA more quickly than PM does from AP when the angle gets larger. (If denominator gets small, the whole expression increases.)