THE SPARK TRANSMITTER.

1. **The Obsolescence of the Spark Transmitter.**—The radiation of damped wave trains produces interference covering a wide frequency band. Owing to the limited number of available channels of communication in an æther already overcrowded, international regulations have been devised to restrict and, gradually, almost eliminate the use of spark transmission.

At the International Radio Telegraph Convention of Washington, held in 1927, an agreement was reached in the following general terms :—

(*a*) The use of damped wave trains (Type B waves) employing frequencies below 375 kc/s. to be forbidden as from the 1st January, 1930.

(*b*) No new spark transmitting installation to be fitted in a land or fixed station, shore stations being prohibited from using damped waves as from the 1st January, 1935.

(*c*) No new installations for the emission of spark wave trains to be fitted in ships or in aircraft, as from the 1st January, 1930, except when the transmitters working on full power consume less than 300 watts measured at the input of the supply transformer, at audible frequency.

(*d*) Use of spark transmission on all frequencies to be forbidden, as from the 1st January, 1940, except for ship installations, fulfilling the conditions as to power referred to in (*c*).

In the Service, a modern ship installation usually contains :—

(*e*) A spark attachment, for use as a stand-by transmitter in the event of a complete breakdown of the valves or essential components of a valve transmitter. It usually obtains its power supply from the main transformer.

(*f*) An emergency coil, designed for use when power from the ship's mains also fails. It consists of an induction coil and associated simple oscillatory circuits, and it derives its power supply entirely from batteries.

These emergency transmitters are seldom used and are only included in a modern installation in order to provide " a last line of defence."

2. **Methods of Charging up the Condenser.**—In the " oscillatory circuit " chapter of Vol. I we saw that a condenser in series with an inductance and a spark gap, if charged up to a voltage sufficient to break down the insulation of the spark gap, would give a high-frequency oscillatory current in the circuit. This current is damped out at a rate which depends on the losses in the circuit, and by using a suitable type of circuit it may be made to produce an electro-magnetic wave in the æther which carries energy to a distance.

The effective duration of the oscillatory current, and hence of the oscillation in the æther, is very short, and, to render the apparatus effective for communication, it is necessary to have methods by which the condenser may be charged up to discharging voltage at regular intervals. The action mentioned above will then be repeated every time the condenser discharges across the spark gap, and will give a series of wave-trains occurring regularly. It will be seen, when we consider the question of reception, that the most suitable **spark train frequencies** (*i.e.*, the frequencies of the condenser discharges) are those which correspond to the frequencies of easily audible sounds (say, 250 to 1,000 cycles per second), and the various methods of regularly charging and discharging the condenser are designed to work at these frequencies. The methods used, which will be described in this chapter, fall under two headings :—

(1) Direct-current supply methods.

(2) Alternating-current supply methods.

Direct-current methods are only suitable for low-power work, owing to the difficulty of obtaining high-voltage D.C. supplies. They all work on some sort of intermittent make-and-break principle, and will be described in detail under the headings of :—

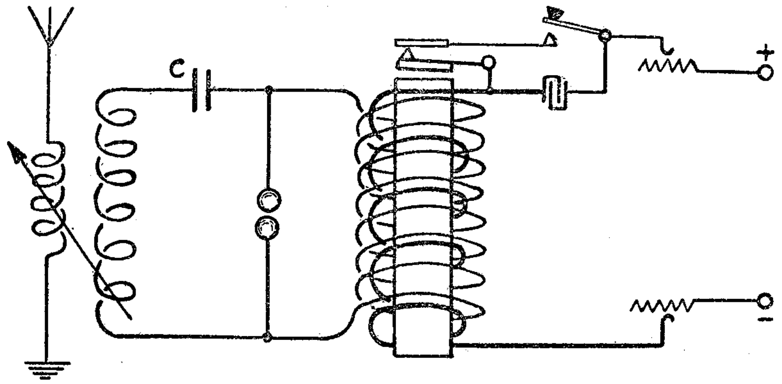
(*a*) Induction coil.
(*b*) Attracted armature buzzer.
(*c*) Motor-driven buzzer.

The second type, using alternating-current supply, is universally used for large power work. The voltage of the alternator is usually stepped-up by a transformer, so that the method is referred to as :—

(*d*) Alternator and transformer method.

3. **The Induction Coil.**—If it is not convenient to run an alternator, owing to there not being a D.C. supply of high enough voltage or power available, or if it is required to work a small set off a low-voltage D.C. supply or accumulator, the induction coil may be used.

The induction coil may be said to convert a D.C. supply into an intermittent current charging the transmitting condenser at a very much higher voltage than that of the supply.



Induction Coil.

FIG. 1.

The induction coil method is used in the Service in some spark transmitters fitted as attachments to continuous-wave transmitting sets for emergency purposes.

4. **Construction.**—An induction coil consists of a **primary coil** of thick wire wound with a number of turns on an iron core composed of a bundle of soft iron wires.

The primary coil is enclosed in an ebonite tube. Outside this again is the **secondary coil,** which consists of some miles of fine copper wire.

It is built up of a number of flat coils or sections, made by winding the wire between paper discs in a spiral form. The coils are joined in series, inner ends and outer ends of coils being joined together alternately, so that the current flows in the same direction in each coil.

By connecting them in this manner, there is no undue potential strain between the end of one section and the end of the next section to which it is joined.

In series with the primary winding is joined the "Interrupter" or "Make and Break."

This consists of a soft iron armature, secured to the top end of a flat steel spring whose tension can be adjusted by means of an ebonite wheel and adjusting screw.

This armature is close to one end of the iron core, the play between the two being about $\frac{1}{16}$-inch.

The armature carries a small platinum contact. Close to the vibrating armature is a fixed standard carrying an adjustable contact with a platinum tip. These contacts are, normally, held together by the tension of the spring.

Suitable terminals are provided to which the sending key should be joined.

A condenser of large capacity is joined across the key and interrupter contacts ; its functions are explained below.

Two resistances are joined in series with the D.C. supply in order to limit the voltage to a value suitable for working the coil.

5. **Action.**—When the key is pressed, a current flows from the main positive lead, through the key, across the interrupter contacts, through the primary winding, through the resistance, and back to negative. The core of the coil is magnetised, and the armature is attracted to it. The contacts of the interruptor are therefore suddenly separated, and the current through the primary falls to zero very rapidly.

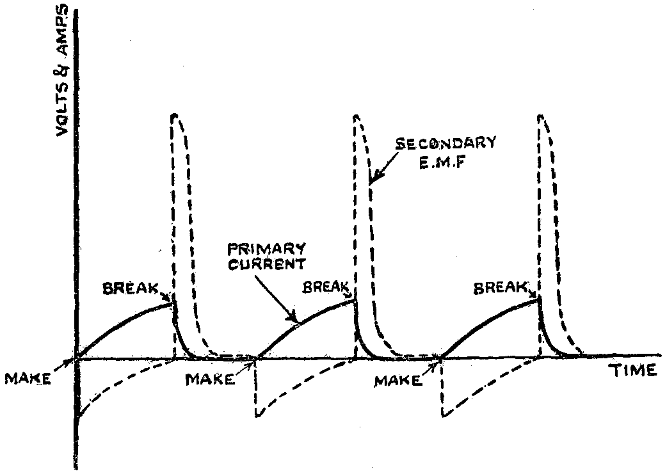
As soon as the primary current has died away, the armature will be released by the core, and will fly back ; and so its contact will make connection again with the fixed contact. The primary current will again start to flow, and the cycle of events be repeated.

6. **Secondary Voltage.**—When the primary circuit is made, as indicated above, the primary current rises comparatively slowly owing to the big self-inductance of the primary coil. There are induced voltages set up in both the primary and secondary windings due to the changing current and changing flux. In the primary the induced voltage is simply the counter E.M.F. of self-induction, the maximum value of which is the value of the impressed voltage (at the beginning of the current flow, when the current is zero, and the applied voltage is entirely balanced by the induced voltage).

The induced voltage in the secondary while the primary current is growing can, therefore, have a maximum value which is N times the primary applied voltage, where N is the ratio of the number of secondary to primary turns. This secondary voltage is small compared with the voltage induced when the primary current is dying away, as we shall see.

When the contacts of the interrupter are separated, the primary current falls to zero. Again there are voltages induced in both the primary and secondary circuits due to changing current and changing flux, but the presence of the large-capacity condenser results in the rate of change of current and flux being much greater than during the period when the current is growing. The secondary E.M.F., being given by the product of the number of turns and **the rate of change of flux,** is therefore much greater than during the growth of current.

7. **Condenser Action.**—(1) The first function of the condenser across the interrupter is to minimise the sparking which tends to occur at the interrupter contacts. When the primary circuit



Primary Current and Secondary Voltage in Induction Coil.

FIG. 2.

is interrupted, the counter E.M.F. of self-induction due to the current decreasing would tend to keep the current flowing across the small gap that forms. Instead of this happening, the counter E.M.F. charges up the shunting condenser which had previously been short-circuited by the interrupter, and which, being of large capacity, does not rise to a high potential. The potential across the gap is therefore limited, and sparking is avoided. The break between the contacts is cleaner and a higher E.M.F. is induced in the secondary.

(2) As the condenser discharges, its discharge current opposes the primary current and helps it to die away. The circuit in which the primary current decays is really a highly damped oscillatory circuit and if the resistance is not too large, a damped oscillation will be set up. In any case, the rate of decay of current and flux is increased.

For these two reasons, the E.M.F. induced in the secondary coil during the period of decay of the primary current is much greater than that induced during the period of growth of the primary current, the determining factor being the rate of change of current.

In both cases, of course, the secondary voltages depend on the amplitude of the primary current and its attendant flux, and the number of turns in the secondary.

A figure is appended, showing the variation of primary current and induced E.M.F. in the secondary circuit.

8. **The Oscillatory Circuit.**—Let us connect the secondary of an induction coil to an oscillatory circuit, consisting of a condenser, an inductance, and a spark gap. When the interrupter breaks the primary circuit, the very high induced E.M.F. in the secondary charges the condenser to such a high voltage that a spark takes place between the balls.

The high resistance of the gap having now been bridged by a spark, the condenser discharges through the inductance and the spark gap, and a high-frequency oscillatory current is set up in the circuit, and energy is radiated.

This action takes place at each break of the interrupter.

The frequency at which wave-trains are radiated is determined by the mechanical constants of the system—the tension of the spring and the position of the armature, etc.

9. **Limitations of an Induction Coil.**—Although an induction coil may produce a momentary voltage of as much as 150,000 volts, yet it is not a very effective means of charging up a condenser for the reason that the **duration** of the high secondary voltage is very short.

The charging circuit consists of a condenser C being charged through a resistance R_s, the resistance of the secondary winding.

It was seen in Vol. I that, in such a case, the time taken to charge up the condenser is proportional to CR_s, the time constant of the circuit.

Since the duration of the high secondary voltage is short, CR_s should be small to enable the condenser to be charged to a high potential. C is fixed by H/F oscillatory conditions, and therefore R_s should be small. The secondary winding must, however, have a large number of turns of fine wire, and so R_s in practice is large. Hence an induction coil is only suitable for charging up a comparatively small condenser ; the energy isolated in the oscillatory circuit for each wave-train is small and the amount of energy radiated is correspondingly small.

This matter may be described somewhat more precisely as follows :—

The energy stored in the field of the primary winding is given by—

$$W = \tfrac{1}{2} LI^2 \text{........where I is the battery current.}$$

At the " break," the field collapses and the stored energy is transferred to the secondary winding within the " period " of the hammer.

It will be assumed that the effect of this is to produce a large charging current " i " that may be regarded as constant for the short time " t," which is governed by the rapidity of the break.

Some of the transferred energy will be dissipated in ohmic losses, and some will go to the condenser, hence

$$W = \tfrac{1}{2}CV^2 + i^2 R_s t.$$

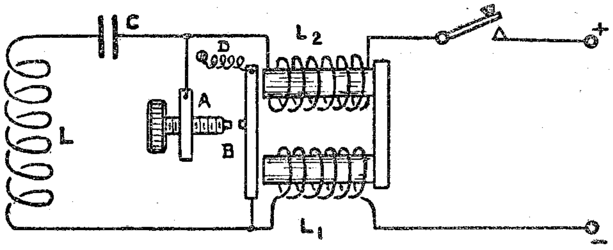
But $i\,t = Q$, the charge in the condenser, and $Q = CV$.

Hence, $$W = \tfrac{1}{2}CV^2 + \frac{C^2V^2R_s}{t}$$

$$\therefore \text{ Energy in condenser} = \tfrac{1}{2}CV^2 = \left(\frac{W}{1 + \frac{2CR_s}{t}}\right) \dots\dots\dots\dots \quad (1)$$

Expressing t in terms of the time constant; if it were $2CR_s$, the energy stored in the condenser would be only half of that available in the primary winding.

10. **The Attracted Armature Buzzer.**—Another method of energising an oscillatory circuit is by means of a buzzer. This is illustrated in Fig. 3.



Typical Buzzer.

FIG. 3.

Here we have a fixed contact A, and a contact B carried on an armature which is free to vibrate. A and B are, normally, held together by a spiral spring D.

Joined to B and A are two coils of high inductance, L_1 and L_2.

This arrangement constitutes the buzzer. A D.C. source of supply is joined to L_1 and L_2, and is made and broken by a signalling key.

Across the make and break AB is joined a circuit, LC.

11. **Action.**—(*a*) When the key is pressed, current flows through L_2, across the contacts AB, and back through L_1. The cores of L_1 and L_2 are magnetised and attract the armature B away from A.

(*b*) When the D.C. circuit is suddenly broken at AB, the current cannot suddenly cease owing to the high inductance of the coils L_1 and L_2, so that the condenser C is charged up by the inductive kick from L_1 and L_2, the right-hand plate being charged positively and the left-hand one negatively.

The energy that was stored in the magnetic fields round L_1 and L_2 is transferred to C when the current in L_1 and L_2 has been reduced to zero.

(*c*) The cores of L_1 and L_2 being demagnetised, the moving contact flies back towards the fixed contact.

When the two contacts are nearly together again, the P.D. between the condenser plates causes a spark to pass across the small gap so formed, and the discharge of the condenser C sets up a high frequency oscillation in the circuit formed by the condenser C, the inductance L and the small spark gap between A and B.

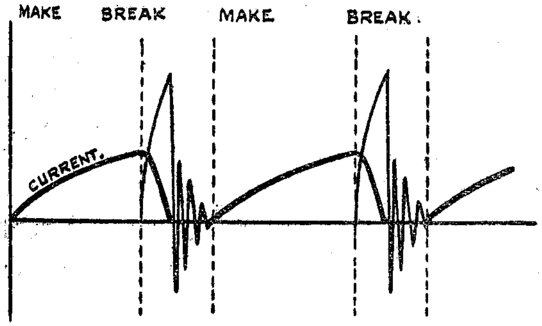


FIG. 4.

(*d*) When A and B touch once more, a direct current will flow through L_1 and L_2, and the operation will continue.

This action may be summarised as in Fig. 4.

The thick line illustrates the slow rise of the direct current through L_1 and L_2 at the moment of "make," because of their self-inductance; and the sudden fall of the direct current at the moment of "break," because of the P.D. across the condenser C at this moment. This is tending to send a current in the opposite direction to that flowing in the inductances and so the latter current decays more quickly than it rose. The condenser in the oscillatory circuit performs, from this point of view, the same function as the shunting condenser used with the induction coil.

The thin line shows the voltage applied to the condenser C at the moment of "break" and the high frequency oscillation set up in the circuit LC.

It is important to arrange the mechanical constants of the circuit correctly, so that, when the two contacts are nearly together and a spark is due to take place, the condenser will be charged up to its maximum voltage.

12. The above method of energising an oscillating circuit has been used extensively :—

(*a*) To energise a transmitting oscillator, when only a comparatively short range is required.
(*b*) To energise receiving circuits for testing or tuning purposes.
(*c*) For laboratory work.

An advantage of this method of energising a transmitting oscillator is that, with reasonably loose couplings, only one wave is emitted from the aerial, and not two waves (due to interaction of primary and aerial circuits) as previously described.

The spark in the primary oscillatory circuit is extinguished in an exceedingly short time because the large mass of metal in its vicinity is very efficient in conducting away the heat which normally sustains the ionisation in the gap. Thus the primary is put on open circuit and no energy is transferred back to it from the aerial circuit. The high-frequency oscillation continues in the aerial circuit alone at the natural frequency of the latter. This type of action is known as "**quenching,**" and will be considered later with respect to a special type of spark gap which effects it very efficiently.

13. **Another Type of Buzzer.**—The circuit is shown in Fig. 5. When the switch is made there is a closed circuit through the oscillatory inductance, buzzer coil and buzzer contacts. The buzzer coil is energised and separates the contacts.

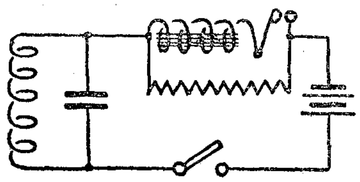


FIG. 5.

At the "break" of the current, the size of the E.M.F. set up across the buzzer coil is limited in value by means of the parallel resistance of 100 ohms. The effect is to produce a small but rapidly quenched spark between the buzzer contacts. The hammer end of the buzzer coil tends to remain at positive battery potential (Lenz's law), and the other end tends suddenly to fall below the potential of the negative end of the battery, thereby causing the condenser to become charged and a damped radio-frequency oscillation takes place in the LC circuit.

It should be noted that the P.D. limiting resistance is short-circuited through the buzzer coil when the contacts are together and, therefore, does not reduce the exciting current from the battery.

14. **The Motor-driven Buzzer.**—A **motor buzzer** is a more efficient method of energising an oscillating circuit than the attracted armature type of buzzer.

It may be illustrated diagrammatically as follows :—

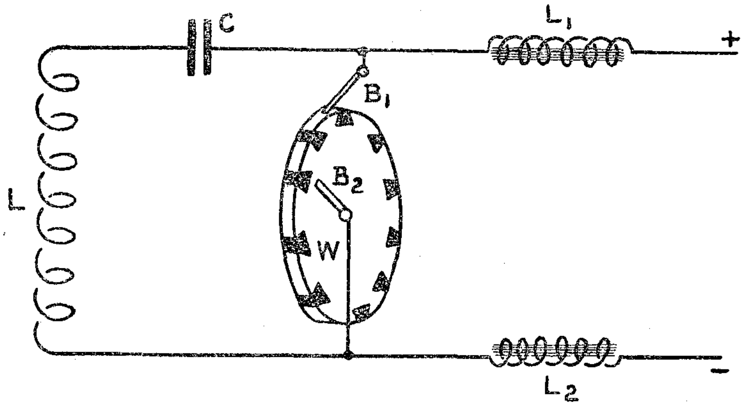


FIG. 6.

W represents a wheel driven round at a high speed by a small motor. In its edge are set a number of insulating segments of mica.

Bearing on its edge and on its side are two brushes, B_1 B_2, across which is joined the oscillating circuit LC.

Joined to the two brushes are two coils of large inductance L_1 and L_2.

A D.C. source of supply, interrupted by a hand key, is connected to the two inductance coils.

15. **Action.**—The action of this type of buzzer is very much the same as that of the attracted armature type previously described.

(*a*) When brush B_1 is bearing on a **conducting** segment of the wheel a steady current will flow through L_1 and back through L_2.

(*b*) When the **insulating** segment on the wheel comes under brush B_1, connection between the brushes is broken. The counter E.M.Fs. of L_1 and L_2 (due to the magnetic fields set up round them by the current) will charge up condenser C.

(*c*) When the gap between brush B_1 and the next edge of the conducting segment is small enough, the condenser C will discharge in a high frequency oscillation, a small spark gap being formed across a portion of the surface of the insulating segment.

This sparking should occur on the under side of the brush. If it occurs above the brush it indicates that the wheel is dirty or that excessive power is being used.

Fig. 4 will serve to illustrate also the action of the motor buzzer. The period marked " make " is that during which the brush is bearing on a conducting segment, and the period marked " break " that during which the brush bears on an insulating segment.

This design of buzzer, like the previous type, produces a **Quenched Wave.**

With this type of buzzer, as with the attracted armature buzzer, it is important to arrange the circuit so that the current falls to zero, and the condenser C is therefore charged up to its maximum voltage, when the gap between the brush and the next conducting segment is small enough for a spark to take place.

During the period of break the circuit L_1, L, C, L_2 is effectively an oscillatory circuit with a steady source of supply ; the current will fall to zero and the condenser charge up, in a period which is about a quarter of the **natural** period of oscillation of **this** circuit. L_1 and L_2 should be so arranged, therefore, that the duration of " break " should be just less than this quarter-period. The condenser will then be at its maximum voltage when the spark is due to take place.

Power may be reduced by inserting series resistances in the supply circuit.

16. The brushes should bear as firmly as possible on the surface of the wheel, and the standards on which they are mounted should have no play in them.

Excessive sparking at the brush, loose brush holders, or a pitted or dirty wheel may cause a bad note and loss of range.

The condenser is charged and discharged every time the brush bears on an insulated segment. Therefore, the number of times per second the condenser is charged, is equal to the speed of the wheel, in revolutions per second, multiplied by the number of insulating segments.

17. **The Alternator and Transformer Method.**—The methods hitherto described for charging up a transmitting condenser are only used under the special conditions referred to.

The almost universal practice for energising spark oscillatory circuits of $\frac{1}{2}$ kW. sets and upwards is to use an alternator or rotary converter and transformer.

It is essential to charge the condenser up to a very high voltage, for otherwise an excessively big condenser would be needed to store up a reasonable quantity of energy (Energy $= \frac{1}{2} CV^2$), which would mean that only large LC values could be obtained in the oscillating circuit. We might produce this voltage directly from some **high voltage alternator,** but such machines are very difficult and expensive to construct, and are not at all efficient; also, the whole circuit would have to be very carefully enclosed to prevent fatal shocks being taken off it.

Fortunately, it is a very easy matter to increase the voltage of an alternating current by utilising a step-up transformer.

Our simplest arrangement is then as shown in Fig. 7, namely, a low voltage alternator (or rotary converter) of a power suitable for the set we are using, delivering its alternating current at a frequency depending on the number of its poles and the speed at which it is run.

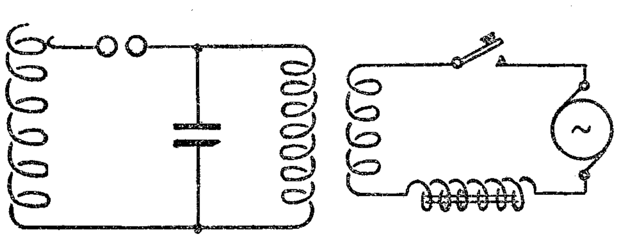


FIG. 7.

The circuit as shown may be divided into—

(*a*) Low Tension circuit, and High Tension circuit.

(*b*) Charging or Low Frequency circuit, and oscillatory or High Frequency circuit.

(*a*) **Low-tension Circuit.**—This includes everything to the right of the transformer in Fig. 7. From the terminals of the alternator, current will flow through the primary of the transformer and across a signalling key of some sort. The impedance coil will be described later.

High-tension Circuit.—This includes the secondary of the transformer and everything to the left of it in Fig. 7. The secondary terminals are connected to the oscillatory circuit, which consists of a condenser, spark gap, and inductance. The current flowing from the secondary terminals of the transformer will be a **small** one at a **high voltage,** and at the same frequency as that of the alternator.

(*b*) **Charging Circuit.**—In Fig. 7 this means the condenser and everything to the right of it.

Oscillatory or H/F Circuit.—This means the condenser, spark gap and inductance.

Note.—As regards the arrangement of the oscillatory circuit, it is a matter of indifference whether we take the transformer leads to each side of the condenser, or to each side of the spark gap, as in Fig. 8.

In the latter case the charging current flows through the transmitting inductance. Both arrangements may be found in practice.

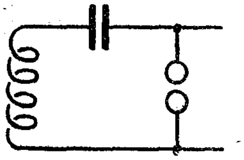


FIG. 8.

18. **The Charging Circuit.**—It has been customary to consider the charging circuit from the point of view of resonance, and to show theoretically that the condenser will be charged up to the maximum voltage if the charging circuit is made resonant to the frequency of the alternator. On this assumption the impedance coil was regarded as a variable inductance which tuned the charging circuit, the latter being considered as a single circuit in accordance with the theory by which inductance or capacity on the secondary side of a transformer can be given an equivalent value and transferred to the primary side (*see* Vol. I). In sets still in use in the Service, however, the LC value of this equivalent single circuit, even with the minimum setting of the impedance coil, is always greater than the CL value which would correspond to the frequency of the supply, so that the theory of resonance of the charging circuit is not borne out in practice. It will be seen that the function of the impedance coil in the practical case is really to act as a regulator of the voltage impressed on the primary of the transformer, and in addition to assist in preventing what is known as " arcing."

19. **Condenser Voltage.**—Let us assume that the circuit is made at the beginning of a cycle of alternator voltage. A current will start to flow in the charging circuit and the voltage across the condenser will start to build up. From the theory at the end of the " Oscillatory Circuit Chapter " (Vol. I) the conditions at first will be " transient " ; in other words, the graphs of current and voltage to begin with will not be sinusoidal, but will be the resultant of a sine wave (representing the final conditions of forced oscillations), and a damped wave at the natural frequency of the circuit (representing free oscillations).

The complete wave form will be of the type shown in Fig. 9.

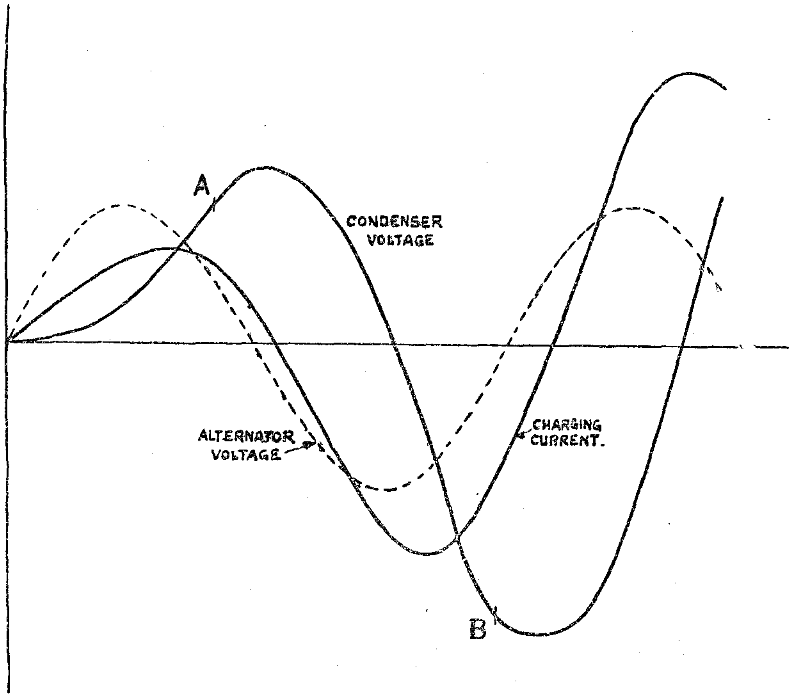


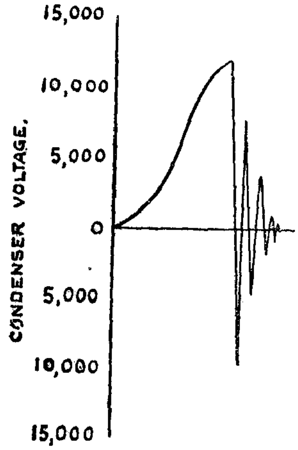
FIG. 9.

When the transient stage is over, the curve representing current will be a sine wave, lagging o the alternator voltage by a definite phase angle, while the voltage across the condenser will also b sinusoidal in form and lagging by 90° on the current.

These final conditions are not, however, of importance, because the spark gap is adjusted s that it breaks down at some voltage less than the final maximum value, for example, at point A i the figure above ; under these circumstances, the transient conditions recur again after the spar gap breaks down, and the initial current and voltage variations are repeated.

20. **Spark Train Frequency.**—Let us consider in detail what happens when a spark occurs We shall take first the simple case of a fixed spark gap. By this is meant a gap in which the plug are fixed relatively to each other while sparking is taking place, but whose distance apart can b varied before the transmitting key is pressed. Let the spark gap be set at such a distance that th voltage across the condenser, and hence across the gap, corresponding to that at point A (Fig. 9) breaks down the insulation of the gap.

An oscillatory action takes place in the high-frequency circuit, the spark gap being now equivalent to a resistance. Energy is transferred by means of the mutual coupling to the aerial circuit, and a certain proportion is radiated into space in the form o electro-magnetic waves. The time during which the oscillator action occurs is very small indeed compared with that of one cycle at the frequency of the alternator, so that the curve representing voltage across the condenser during the charging period and the consequent oscillatory discharge will be somewhat as shown.



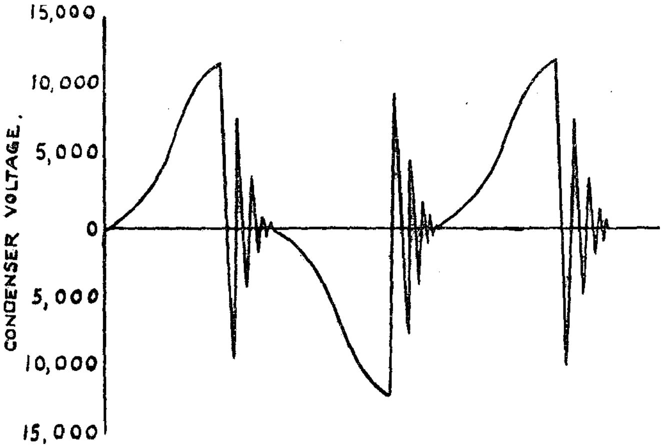
Condenser Voltage under Discharge Conditions.

FIG. 10.

The voltage across the condenser when the discharge is just completed is, of course, zero. If the break-down voltage is so arranged that, at the end of the ensuing discharge, a cycle of alternator voltage is just commencing again, exactly the same sequence of events will be repeated.

The case we have taken, of spark gap breakdown before the condenser voltage had reached its first maximum value, and the completion of the oscillatory action when the alternator voltage is again zero, as at the beginning, will obviously give **one spark per half-cycle** of the alternator voltage.

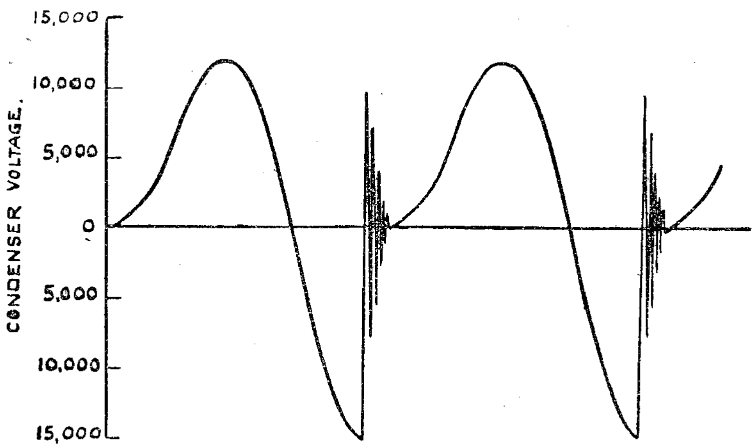
The sequence of events during succeeding half-cycles may be illustrated by the following graph of condenser voltage. Spark trains have been drawn to end where the next half-cycle of alternator voltage is beginning, although this will not in general be the case.



One Spark per Half-cycle.

FIG. 11.

If the spark gap were set at such a distance that the voltage at point B (Fig. 9) was just sufficient to break down its insulation (this voltage being greater than the first peak value), we should get **one spark per cycle** instead of one spark per half-cycle, and the curve representing condenser voltage would be of the form shown in Fig. 12.



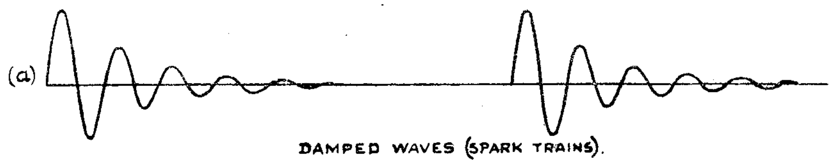
One Spark per Cycle.

FIG. 12.

It is important clearly to understand the difference between the two frequencies involved in a spark transmitter, and to appreciate the shortness of time during which energy is being radiated into space in comparison with the case of (say) a C.W. transmitter.

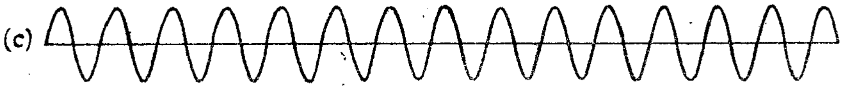
Assume a spark train frequency of one spark per cycle, of numerical value 500 times per second. Assume, also, that the LC value of the oscillatory circuit corresponds to a frequency of 500 kc/s. The condenser receives a charge from the alternator and transformer once in every 1/500 second If we assume that there are 100 complete oscillations in the oscillatory discharge of the condenser, the time taken before the condenser is fully discharged is 100/500,000 second, since each cycle takes 1/500,000 second. The total time of discharge is thus 1/5,000 second, and is therefore only a tenth of the time (1/500 second) between condenser charges.

Thus, for nine-tenths of the time that the key is pressed, no energy is being sent out into space as æther waves, which is one reason for the comparative inefficiency of spark transmission. Fig. 13 (*b*) attempts to show this to scale.



DAMPED WAVES (SPARK TRAINS).

SPARK TRAINS WITH TIME INTERVALS TO SCALE.



UNDAMPED OR CONTINUOUS WAVES.

FIG. 13.

With the type of gap which was in common use in the Service, the asynchronous rotary gap, these curves, which give a regular recurrence of events, have to be modified. This type of gap will be treated later.

21. **Arcing and the Impedance Coil.**—When the insulation of the spark gap is broken down, and the high frequency oscillatory current is flowing across the gap, the intense heat generated by the spark at the moment of discharge is sufficient to volatilise some of the metal of which the spark gap electrodes are made. This volatilised metal forms a conductive bridge from one electrode to the other. So long as a certain minimum current is passing across the gap, this conductive bridge is maintained. Now, when the spark gap becomes a conductor, the current from the alternator, which has hitherto been charging up the condenser, will tend to flow across the gap, maintaining its conductive property and preventing the condenser from being charged up again. It is therefore necessary to take every possible precaution for restoring the insulating properties of the spark gap as soon as the high-frequency discharge is completed.

Apart from mechanical devices for prevention of arcing, such as an air blast, which will be discussed later in dealing with the different types of gap, the inductance of the charging circuit, coupled with that of the impedance coil, tends to prevent charging current flowing across the gap. When the gap becomes conductive, the condenser is short-circuited and the charging circuit may be considered to consist of inductance and resistance only. The high inductive reactance cuts down the current to such an extent that it is insufficient to maintain the conductivity of the gap; the latter being restored, the condenser comes into the charging circuit again and the current charges up the condenser once more.

The **Impedance Coil** is therefore useful as an added inductance in the charging circuit for the prevention of arcing.

A further use of the impedance coil is in controlling the power taken from the alternator. The larger the inductance inserted in the circuit by the impedance coil, the further from resonance are the conditions in the charging circuit; the more is the charging current cut down, and the less is the voltage built up across the condenser. The impedance coil may therefore be looked on as a voltage regulator, controlling the voltage in the condenser and hence the power radiated.

22. **Power taken in Charging a Condenser.**—When a condenser, C farads, is charged up to a discharging voltage of V volts, the amount of energy stored up in it is $\frac{1}{2}CV^2$ joules.

This energy is dissipated in damping losses in the primary and aerial circuits while the condenser is discharging in a high-frequency oscillation across the spark gap.

If we charge up the condenser to a voltage of V volts N times per second (*i.e.*, if N is our spark train frequency), then we shall be expending energy at the rate of $\frac{1}{2}NCV^2$ joules per second. But a joule per second is a watt, the unit of power.

Hence the power required to charge a condenser of C farads to a voltage of V volts N times per second is $\frac{1}{2}NCV^2$ watts.

Expressing power in kilowatts and capacity in jars, the equivalent formula is :—

$$\text{Power in kW.} = \tfrac{1}{2} \times N \times \frac{C}{9 \times 10^8} \times V^2 \times \frac{1}{1000}$$

$$= \frac{NCV^2}{1{\cdot}8 \times 10^{12}}$$

Example.

Find the power required to charge a condenser of 200 jars to a voltage of 15,000 volts, at a frequency of 300 cycles per second, with a spark train frequency of one spark train per cycle.

$$\text{kW.} = \frac{200 \times 15{,}000^2 \times 300}{1{\cdot}8 \times 10^{12}} = 7{\cdot}5.$$

From the above formula, we can deduce that the—

(*a*) greater the size of the condenser charged,
(*b*) higher the sparking voltage,
(*c*) higher the spark train frequency,

the more is the power required to charge the condenser and the more is the power passed to the aerial and radiated away every second, the preponderant factor being V.

In Service sets the condenser in the oscillatory circuit is composed of separate elements, which may be joined in series or in parallel. The parallel setting is used when a high LC value in the oscillatory circuit is necessary, *i.e.*, on long wavelengths or low wave frequencies. In order to keep as much equivalence as possible in the power radiated on different wave frequencies, the voltage to which the condenser is charged up should be smaller the greater the value of C. As the transformer secondary is in two halves, which may also be joined in series or in parallel, the voltage across the condenser can be reduced by using the parallel connection, or increased by using the series connection. This explains the rule employed in these sets :—

Condensers in parallel, transformer secondaries in parallel.

Condensers in series, transformer secondaries in series.

23. **Design of Spark Gaps.**—Charging circuits are very similar in their general arrangement, differing in detail only according to the power of the set and the range of waves required.

It is chiefly in **design of spark gaps** that sets differ.

The objects aimed at may be classified as follows :—

(*a*) **To Prevent Arcing.**—The effect of arcing has been already discussed.

The object is so to cool the conductive bridge that it is extinguished as soon as the oscillatory discharge is over.

Apart from the effect of the inductance in the charging circuit, and the additional inductance of the impedance coil, various methods of preventing arcing are included in the designs of the different types of spark gap.

(*b*) **To Effect Quenching.**—Quenching is effected by devising a very much more rapid method of cooling the spark gap and restoring its insulating properties than any method used for prevention of arcing. It effects this cooling so quickly that not only is arcing prevented, but the interaction and exchange of energy between the primary and aerial circuits is stopped as soon as the energy has been transferred for the first time to the aerial circuit. The theory of quenching will be considered in paras. 27 and 28, which deal with the special type of gap designed to effect this action.

(*c*) **To Produce a High Spark Train Frequency** —The pitch of the note heard in the telephones at the receiving station depends on the spark train frequency of the transmitting station. If a fairly high frequency alternator is used, the conditions of one spark per cycle will give a high note.

If, however, the alternator or rotary converter is a low frequency one, we may increase the spark train frequency by using such a short spark gap as to give one spark per half-cycle or even more.

The higher the spark train frequency the more difficult it is to prevent arcing, because the electrodes become hotter. With one type of gap, the asynchronous rotary gap, the spark train frequency is independent of the alternator frequency, and can be adjusted to any value desired.

The different types of gap employed are :—

(*a*) The fixed gap.
(*b*) The synchronous rotary gap.
(*c*) The asynchronous rotary gap.
(*d*) The quenched gap.

These will now be considered in detail. The last two are the types used in Service sets.

24. (*a*) **The Fixed Spark Gap.**—By this is meant a gap in which the plugs are fixed relatively to each other while sparking is taking place, but can be set to any required distance apart before the transmitting key is pressed.

Various shapes are illustrated in Fig. 14.

Such gaps are quite suitable for low power, or for low sparking frequencies, and are simple, requiring little attention beyond a periodical cleaning.

Two waves are emitted from the aerial circuit, the amount by which their frequencies differ depending on the coupling between the primary and aerial circuits.

The gap electrodes should be constructed of non-arcing material.

During the time the gap is conductive its resistance should be low, therefore the distance apart of the electrodes must not be too great. If, however, the distance apart is too short, the tendency towards arcing will be greater. The sparking surfaces should be parallel and clean, otherwise the spark will jump across at the same point, causing the surfaces to be burnt away.

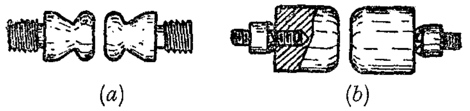


FIG. 14.

For higher powers or higher spark train frequencies a **Blower** is often provided to prevent arcing troubles. This is an arrangement for forcing a stream of cooling air between the electrodes. In relatively low power work, a comparatively low pressure stream provided by a fan will usually be found to be sufficient; at higher powers, it has sometimes been the practice to drill a cylindrical hole through one of the electrodes, and blow air through it at a pressure of several atmospheres in order to effect very rapid quenching.

25. (*b*) **The Synchronous Rotary Gap or Discharger.**—A **Synchronous Rotary Gap** denotes a form of design in which a metal wheel carrying a number of studs or spokes projecting from its edge rotates between two fixed electrodes, the rotating wheel being rigidly fastened to the alternator shaft. When the studs are opposite the fixed electrodes, the spark jumps from one electrode to the wheel stud, through the wheel, and back through the second gap to the other electrode.

As the speed of the wheel and the alternating frequency both depend on the speed of revolution of the motor driving the alternator, the number of times per second at which the condenser voltage reaches a peak value and the number of opportunities it has of discharging can be made equal, and the position of the studs arranged so that these conditions occur simultaneously.

As the number of cycles per revolution of the alternator is equal to the number of pairs of its poles, and as in one revolution of the spark wheel the number of opportunities of sparking is equal to the number of studs on the wheel, it follows that to get **one spark train per half-cycle** the wheel should have as many studs as the alternator has poles.

The position of the fixed studs can be altered relatively to the moving studs by mounting them on a rocker which can be moved in one direction or the other. The condenser can thus attain its peak value of voltage when the studs are exactly opposite each other, and the gap separation is adjusted for the breakdown to occur just before this happens.

Arcing is prevented by the increasing separation of the electrodes as the wave train takes place, and also by the fanning and cooling caused by their rapid motion.

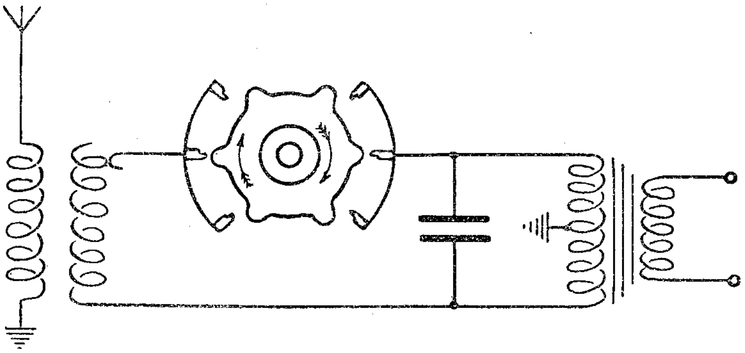
In larger sets, air blasts are also used to cool the electrodes and prevent arcing.

It should be noted that the motor buzzer wheel, as previously described, is only a special variety of a synchronous gap. As the supply is a direct-current one, the spark train frequency is entirely dependent on the speed of revolution.

26. (*c*) **The Asynchronous Rotary Gap.**—This is the type of gap used in some spark sets in the Service.

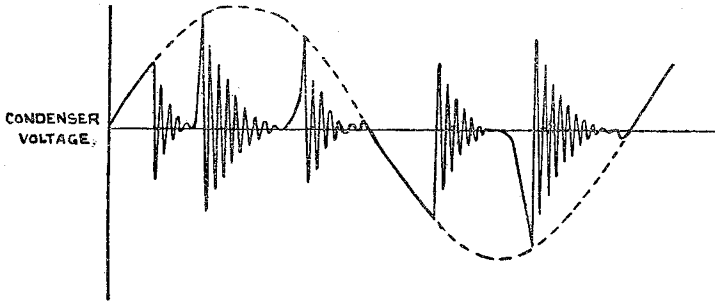
The principle of the rotating wheel with studs, and the fixed electrodes between which it rotates, is exactly the same as for the synchronous gap, the essential difference in the action being that the **speed of rotation of the wheel is entirely independent of the speed of the alternator.** The wheel is driven by a separate motor. The word " asynchronous," which means " out of time with," refers to this independence of speed of rotation.

The gap between the fixed and moving electrodes is adjusted to be as small as possible. A spark will occur whenever the gap between a fixed electrode and the point approaching it is small enough for the condenser voltage to force a spark across it. The great advantage of the asynchronous gap is that it is possible to produce a high spark train frequency from a low frequency supply. This being the case, it is obvious that there may be several sparks during one cycle of alternator supply, and consequently these occur at different points in the cycle. The conditions are not exactly repeated each time as in the case of the synchronous spark, because the charging current from the alternator is charging up the condenser during different parts of its own cycle of variation, and hence neither the voltage to which the condenser is charged nor the voltage of breakdown is constant. Since the gap is adjusted to be as small as possible, there will be a discharge each time the studs come opposite each other unless the condenser voltage is very small. Sometimes, however, this condition holds and a spark is missed.



Asynchronous Rotary Gap.

FIG. 15.



Condenser Voltage with Asynchronous Rotary Gap.

FIG. 16.

Not only is it possible to miss a spark altogether, but the interval between sparks is not absolutely constant. If the charging current after one breakdown is such that the condenser voltage before the next discharge is greater than usual, the spark will take place over a longer gap, *i.e.*, when the studs are a little further apart than usual. If the condenser voltage is less than its average value, the spark will take place a little later than usual.

In addition, the energy stored in the condenser and the proportion radiated in the separate wave-trains is variable.

The disadvantages of this type of gap—the possibility of a spark being missed, irregular time-intervals between sparks, and irregular amplitudes of wave-trains—result in the note heard at a receiving station being impure.

The great advantage is the high spark train frequency which can be got from a low frequency supply, giving more energy radiation and a high and easily readable note at the receiver.

Arcing is prevented, as in the synchronous gap, by the mechanical separation of the electrodes and the draught of air. If necessary, an air blast may be fitted in addition.

A figure is given which shows the way in which the condenser voltage may be considered to vary during one cycle of low-frequency alternator supply, several spark discharges taking place during this period.

27. (*d*) **The Quenched Gap—Theory of Quenching.**—The **Quenched Gap** is designed to put out the spark much more quickly than any of the methods used for prevention of arcing. It was seen in the Chapter on the " Oscillatory Circuit " (Vol. I) that when the primary oscillation has transferred its energy to the aerial, the aerial re-transfers it to the primary, and the energy is transferred and re-transferred backwards and forwards between the two circuits until it has been entirely expended in various damping losses, as illustrated thus :—

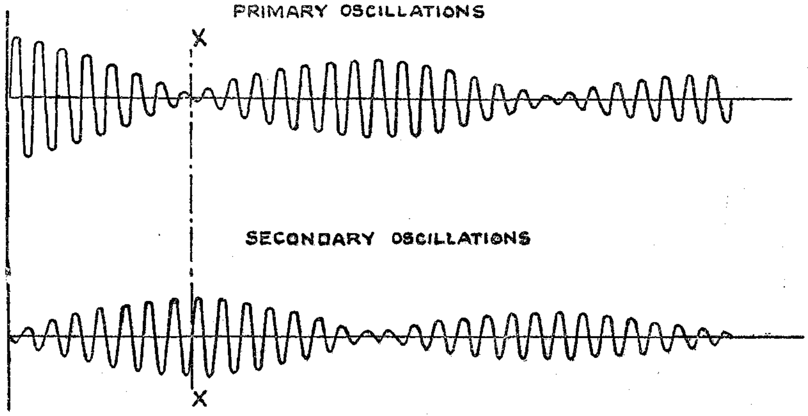


Diagram of Primary and Aerial Currents in Ordinary Coupled Circuit.

FIG. 17.

This transfer and re-transfer of energy produces two harmful results :—

(*a*) The heavy damping in the spark gap is wasting the energy of the high-frequency oscillation during the whole time of transmission.

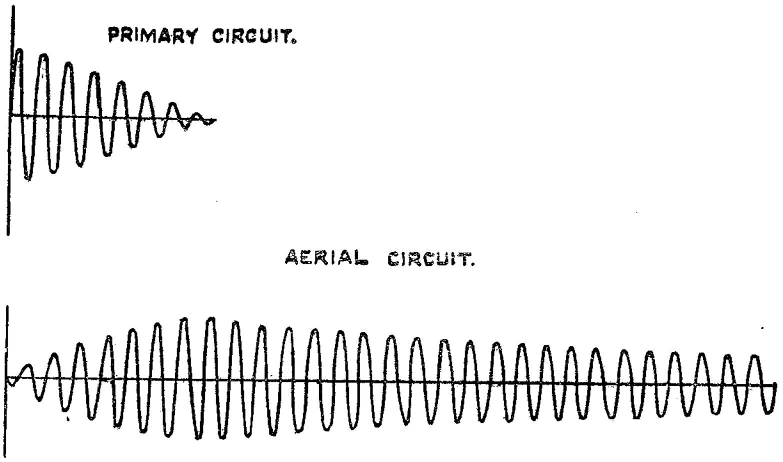
(*b*) Two waves are emitted which interfere with ships working on other waves of different frequency.

If, in some way, we can manage to put the spark out at the moment X in Fig. 17 (when the primary energy is at a minimum), then the conditions are entirely changed.

As soon as the whole of the energy has been transferred to the aerial the conductivity of the gap is destroyed and the energy which is now in the aerial cannot return to the primary, and will therefore continue to oscillate in the aerial circuit until the whole of it has been radiated in the form of electro-magnetic waves or lost unavoidably in resistance in the aerial circuit.

The coupling between the circuits can be increased, and more energy transferred from the closed to the open circuit. After the spark is " quenched," the aerial circuit oscillates at its own natural frequency, and it is only for a comparatively small period during the transfer of energy that two-wave frequencies are being radiated. These are both considerably different from the natural frequency of the single circuit, especially with the tight coupling employed, and cause interference at the beginning of the wave-train. The tight coupling causes the aerial current to build up very rapidly, causing a shock effect by setting up free oscillations in neighbouring aerials.

A diagram of the current oscillations in the two circuits is as shown in Fig. 18.



Primary and Aerial Currents in Quenched Gap Circuit.

FIG. 18.

The upper diagram represents the oscillations in the primary circuit until the spark is "quenched" at the moment X (*see* Fig. 17), and the lower diagram those in the aerial circuit. The advantages and disadvantages of quenching may be summarised as follows :—

Advantages.

(*a*) Only one wave frequency radiated for the greater part of the wave-train.

(*b*) No tendency to arc. The time involved in quenching is probably that corresponding to 3 or 4 cycles of high-frequency oscillation, which is very small compared with the time in which anti-arcing devices become efficient. One spark per half-cycle can therefore be obtained quite easily with the quenched gap.

(*c*) The comparatively high resistance of the gap is in circuit for a very short time. As the unwanted power loss in the aerial circuit can be made considerably less than that in the primary circuit, a greater proportion of the energy input is converted to radiation energy.

(*d*) Tight coupling (up to 20 per cent.) can be used, and therefore rapid transference of energy is ensured. The tighter the coupling the less is the time of transference and the less are the losses in the primary circuit.

Disadvantages.

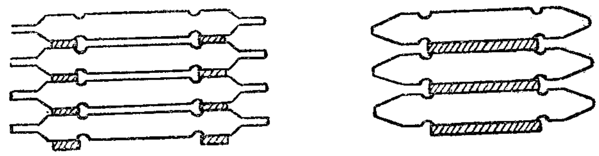
(*a*) The tight coupling causes the aerial oscillation to start with a very rapidly increasing amplitude which shocks neighbouring aerials into oscillation.

(*b*) During the period of interaction two wave frequencies are radiated, each differing from the frequency of free oscillation of the aerial.

Quenching is achieved by the use of the special design of gap called the **Quenched Gap,** which will now be considered in detail. The rapid mechanical rotation of the motor buzzer is sometimes considered to give a quenching action.

28. (*a*) **The Quenched Gap—Construction.**—The Quenched Gap, as now described, is used in spark attachments to main valve transmitting sets in the Service. Quenching is simply a matter of cooling the spark path rapidly enough.

A method of accomplishing this is to make use of the property metals have of conducting heat. In the quenched gap, the spark gap is broken up into a number of very short gaps in series with each other. The electrodes are made of copper, plated with silver, these metals being good heat conductors. In addition, large cooling or radiating fins are provided, so that there is a large mass of metal surrounding the gap and plenty of metal surface exposed to the surrounding air. In addition, it may be necessary in some cases to employ an air blast to cool the fins sufficiently. The gaps are so short that no part of the air dielectric is far from the metal of the electrodes. There are two methods of building up a quenched gap, shown in Fig. 19 (*a*) and (*b*).



Internal Spark Gap.

(*a*)

External Spark Gap.

(*b*)

FIG. 19.

In Fig. 19 (*a*), the gap consists of a number of metal discs with circular grooves cut in them The discs are separated by washers of mica, about 0·2 mm. in thickness, which are inserted betwee the discs at the outer edges and extend a little way across the circular grooves. The sparkin surface in the centre of the discs is thus completely shut off from the surrounding air.

In Fig. 19 (*b*), the mica washers are placed between the electrodes inside, and just extendin into, the space between the circular grooves. The sparking takes place between the edges of th electrodes. This is the type used in the Service.

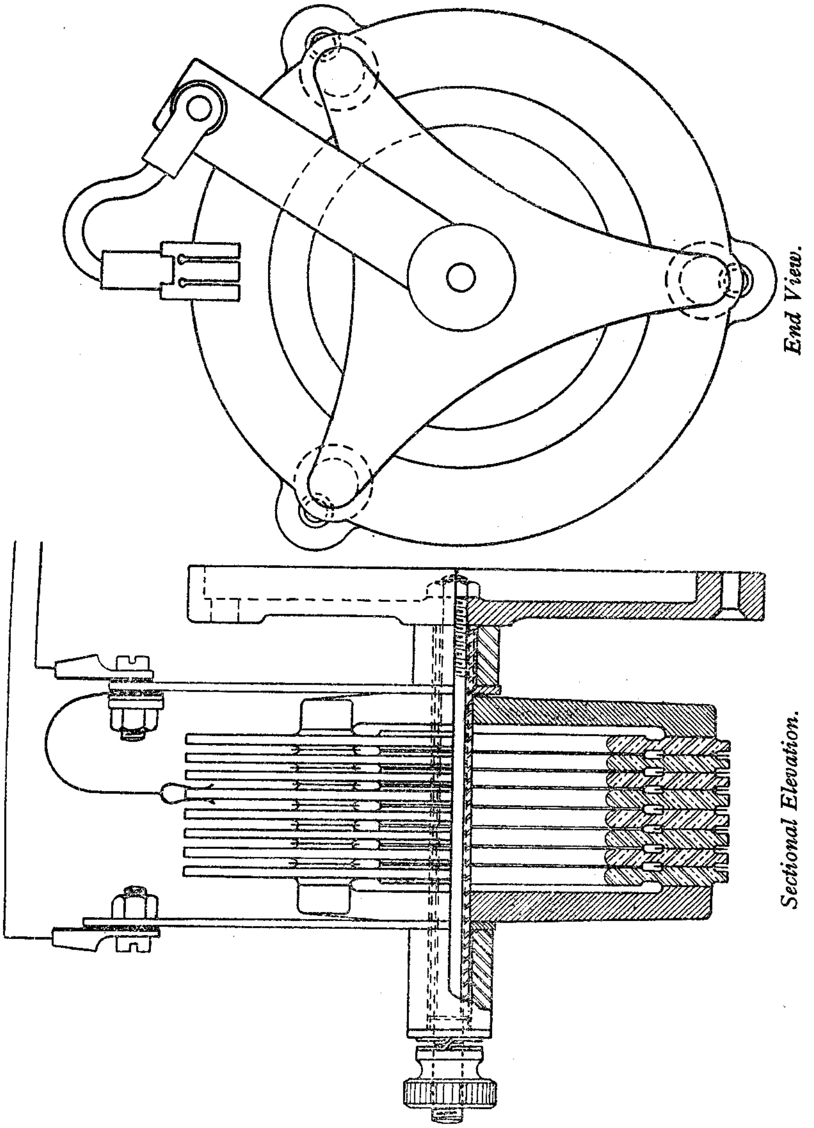
In both cases the spark is rapidly extinguished because of the adequate cooling properties o the gap, and because the mutual repulsion of the ions in the ionised air between the electrodes forc the spark to the outer edges of the sparking surface, where it becomes lengthened across the circula groove. In the "internal" gap it is probable that the removal of the oxygen in the gap by oxidatio of the electrodes is an important factor in assisting its quenching properties.

Fig. 20 shows a complete quenched spark gap as used in the Service. The number of sing gaps used in series can be varied by short-circuiting the others by a spring clip, which is attache to one terminal of the spark gap by a length of conducting wire and can be fastened to any one the radiating fins. The number is varied according to the condenser break-down voltage, th voltage for each individual gap being about a thousand volts.

29. **The Charging Circuit Complete.**—We are now in a position to discuss broadly th general requirements of a Spark Transmitting installation (*see* Fig. 22).

Power Supply.—The alternating current will be supplied from either a motor alternator a rotary converter.

Duplicate machines are generally supplied in H.M. ships, placed in separate watertight co partments, and fed through duplicate starters from either side of the ring main system.



Quenched Gap:

FIG. 20.

Normally, the machine in use should be fed from the section of the ring main on the disengaged side in action.

With both motor alternators and rotary converters a **Starter** will be necessary, with a no-volt-release coil, and some arrangement to prevent an excess current being taken from the mains. This may take the form of a fuse in the lead from one main, or of an overload release coil on the starter.

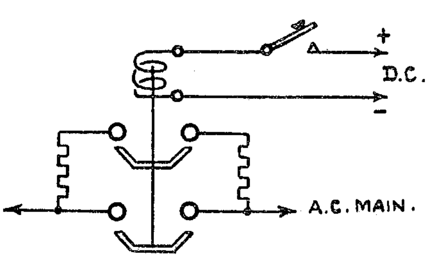
A Motor Field Regulator will be provided for varying the speed, and therefore the alternating frequency. (As previously explained, the voltage of the alternating current supplied by a **rotary converter** will always remain about 65 per cent. of the supply voltage, whatever the speed.

An **A.C. Ammeter** and a **Frequency Meter** will also be provided. With a motor alternato a **D.C. Ammeter** and an **A.C. Voltmeter** will be supplied ; also an **Alternator Field Regulato** in order to vary the voltage of the alternating current.

From the slip rings of the machine in use come the A.C. mains, in series with which we shal have the Signalling Key, an Impedance Coil, a safety arrangement of some sort, and, finally, th primary of the step-up transformer.

30. **Signalling Key.**—If the alternating current is small and its voltage is low, signalling ma be effected by making and breaking the alternating current circuit by means of a hand key.

If, however, the current is too great, or the voltage of a dangerously high value, a **Magneti Key** will be used. This consists of a single-pole break between two contacts, which is short-circuite by a moving contact. The key is energised by direct current being supplied to the bobbin of a solenoid when a hand key is pressed, as illustrated in Fig. 21.



Magnetic Key.

FIG. 21.

When the low-tension current is too great to be interrupted conveniently, the magnetic key may be placed in th high-tension circuit, but special precautions must then b taken about its insulation.

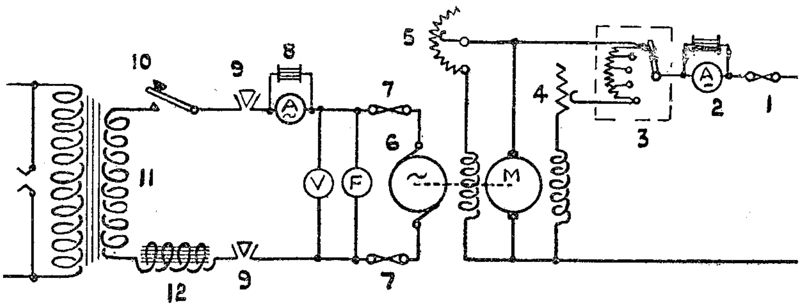
The drawback of this arrangement is that, even whe the key is not pressed, the secondary terminals of th transformer are alive.

It is used in certain high-power shore stations.

31. **Safety Arrangements.**—It is necessary to prevent the operator from accidentally receiving a fatal shock.

For a shock to prove fatal, about one-eighth to one-sixteenth of an ampere of direct or low frequency alternating current will be necessary, one ampere being certainly enoug to kill a man ; far heavier currents at high frequency, however, can be safely withstood.

The resistance of the human body varies in different individuals and with the degree of moistur of the skin. The greater part of the body resistance is in the skin and, normally, the resistance of a man from one hand to the other is about 20,000 ohms ; if the subject is in a perspiring state—a common occurrence in the tropics—the resistance will be reduced very much below this figure. It is also obvious that the resistance presented will be inversely proportional to the area of skin in contact with the live terminals ; for example, a very much worse shock will be experienced if th live terminals are firmly grasped with the hands, or held in a pair of pliers, than if they are onl touched with the finger tips.



Typical Low-tension Circuit.

FIG. 22.

Any voltage above 1,250 volts direct or low-frequency supply will probably prove fatal, and voltages of 500 and above are dangerous. It is sometimes customary to consider that sources o supply at pressures of the order of 220 volts can be touched with impunity ; this is a great mistak for, with good contact and wet hands 220 volts can be—and has been—fatal. Moreover, should the skin become broken by (say), scratching against 220 volt terminal contacts, the resistance becomes so low that a serious electrical burn may be produced, which might take several months to heal and even produce fatal shock effects.

In modern practice, it is customary to enclose all of the dangerous components within a cage, arranging that the cage cannot be opened without breaking the supply circuits at one point at least. It is better if both mains are broken, one by each of two cage doors. Thus, if the key is pressed when either cage door is open, nothing will happen.

32. **Low-tension Circuit.**—Fig. 22 represents a typical arrangement of a Low-tension Circuit.

1 is a fuse in the positive D.C. main.
2 is a D.C. Ammeter with its shunt.
3 is a starter for the motor of the Motor Alternator (6).
4 is the Motor Field Regulator.
5 is the Alternator Field Regulator.
6 is the Motor Alternator. (If a Rotary Converter is supplied in lieu, then the Alternator Field Regulator (5) and field magnet winding will be omitted.)
7/7 are A.C. fuses, one in each A.C. main.
8 is the A.C. Ammeter with its shunt.
V and F are, respectively, the A.C. Voltmeter and Frequency Meter.
9/9 are the breaks in the low-tension A.C. circuit, completed when the cage doors are closed.
10 is the hand key for signalling. If the A.C. current is large, this is replaced by a magnetic key.
11 is the Transformer.
12 is the Impedance Coil.

If power is obtained from a Rotary Converter, then the A.C. Ammeter and Voltmeter may be omitted.

33. **High-tension Circuit.**—The high-tension circuit comprises the secondary of the transformer, the leads to the primary oscillating circuit, and the oscillating circuit itself, made up of primary condenser, primary inductance and spark gap.

In this circuit it is necessary to protect the transformer and condenser against excessive strains on their insulation, which may arise in several ways.

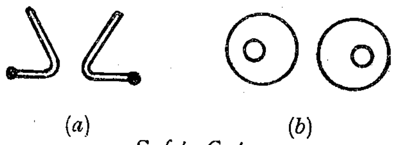
These risks, and the methods of guarding against them, are as follows :—

34. **Safety Gaps.**—The transformer is protected against any excessive rise in its own voltage by having safety gaps fitted across its terminals.

The gap is so arranged that if the terminal voltage of the secondary rises above its normal working limit, then an A.C. metallic arc will form across the gap.

Typical safety gaps are shown in Fig. 23.

Fig. 23 (*a*) consists of two bent pieces of copper wire. Fig. 23 (*b*) consists of two brass discs, mounted eccentrically so that the gap length can be adjusted by rotating them.


(*a*) (*b*)

Safety Gaps.

FIG. 23.

The arc will rise, on account of its own heat, sliding along the wires. The higher it rises the longer becomes the gap which it must bridge, so that it automatically breaks down.

The gap must be kept set at the exact distance laid down in the Handbook for the set in question.

In the same way, the transmitting condenser is fitted with safety gaps to prevent it being punctured by any abnormal rise of voltage.

It is commonly the practice, where several sections of a condenser are employed in series, to earth the centre point of the central sections.

This equalises the capacity to earth of each element of the condenser.

35. **Back Oscillations.**—When the condenser discharges across the spark gap it is quit possible that some of the high-frequency oscillatory current, instead of flowing across the spar gap, will try to flow back through the secondary of the transformer.

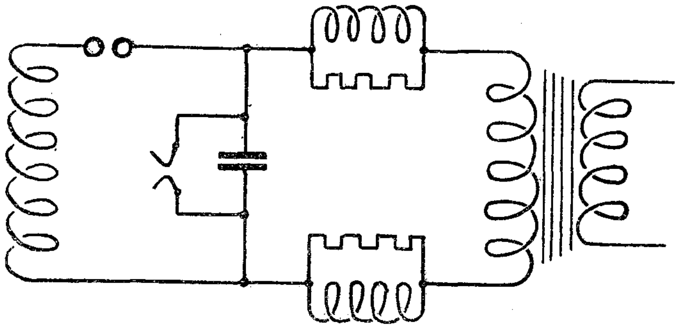
This is a form of trouble known as " Back Oscillations."

If this high-frequency oscillation is applied directly to the secondary turns of the transforme it will set up a big inductive voltage to earth across the end turns, and the insulation of the transformer might easily be broken down.

To prevent this, coils of wire, termed " Protecting Coils," of about 200 to 300 mics inductanc are sometimes placed in series with each main (Fig. 24).

The back E.M.F. of these 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.

On the other hand, when the **high-frequency discharge** tries to send some of its current bac along the high-tension mains, the reactance of the protecting coils becomes so large that the practically form insulators to high-frequency currents. (The insulation of these coils may b punctured, but they can easily be re-wound on board.)



Protecting Coils and Resistances.

FIG. 24.

Now, protecting coils alone, under certain circumstances, have proved worse than useless.

Being mounted on a baseboard, the two coils have a certain small capacity effect between them ; also, each coil has a certain self-capacity of its own.

This capacity, combined with the inductance of the two coils, forms an oscillatory circuit which may happen to have the same LC value, and therefore the same natural frequency as that of the primary oscillator.

Should this happen, then resonant currents will be set up in the protecting coils, and 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.

To avoid this, the protecting coils are shunted with non-inductive resistances in the shape of **Carbon Rods,** upon which the energy of the high-frequency currents is expended.

The high-frequency current sets up a big P.D. across the inductance, which consequently tries to force a big current through the resistance, and the back oscillation is damped out.

Fig. 25 represents the high tension circuit of a modern spark attachment. The oscillatory circuit is connected to the secondaries of the transformer through a resistance " R " ; connected across the output of the transformer are two condensers " C." The " protecting condensers " C serve to by-pass any R/F oscillations which may be fed backwards, thereby preventing the building up of high R/F voltages across the secondary of the transformer. The resistance R is of the order of 600 ohms and is there in order to prevent the two protecting condensers from acting as integral components of the main oscillatory circuit ; the ratio of R to the equivalent reactance of condensers C, determines the extent of their influence on the frequency.

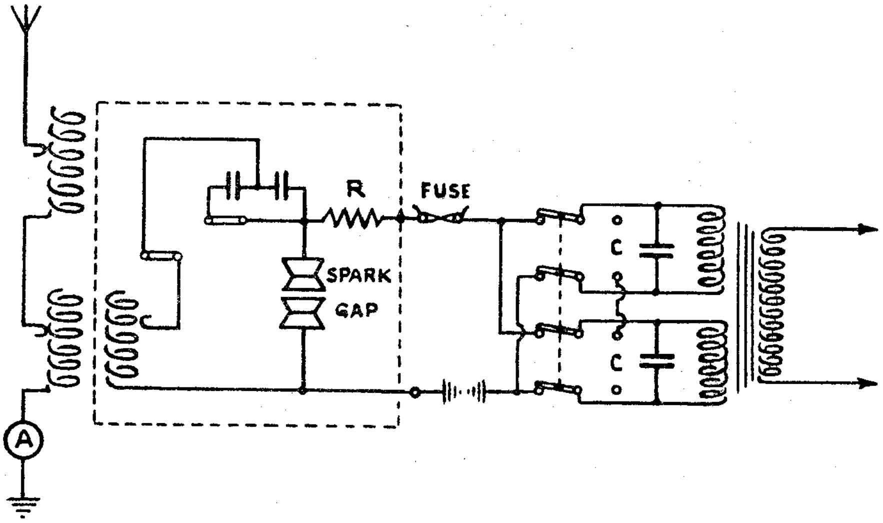


FIG. 25.

36. **The Design of the Oscillatory Circuit.**—The oscillatory circuit must be arranged so as to provide a certain range of LC values, according to the purpose for which the set is designed.

For example, a set might be required to give a range of all LC values between 50 and 1,200, which would give a range of frequencies between 676 kc/s. and 140 kc/s.

This might be arranged by having a condenser of 50 jars and an inductance which could be varied between 1 mic and 24 mics, but this would be bad electrical practice for the following reason :—

The energy stored in a condenser of C farads when charged up to a discharging voltage of V volts is $\frac{1}{2}CV^2$ joules.

From this it follows that, the larger the condenser, the smaller the voltage required to store a given amount of energy. (*See* para. 22.)

A high condenser voltage would mean a long spark gap, which would have a heavy damping effect. Also, the higher the voltage, the greater do insulation difficulties become.

Consequently we want to use the largest possible condenser and the smallest possible inductance.

A much better arrangement would be to provide a condenser composed of two elements of 100 jars each, which could be joined in series, giving a capacity of 50 jars, or in parallel, giving 200 jars. This arrangement is generally used in practice.

A primary inductance which could be varied between one and six mics would give a range of LC values from 50 to 300 in the series position, and from 200 to 1,200 in the parallel position.

37. **The Condenser.**—The condenser must be made with adequate dielectric strength to stand the greatest sparking voltage that is likely to be used. For instance, if the condenser referred to above is required to stand an eight-millimetre spark, and if one sheet of the dielectric used in it

will only stand two millimetres safely, it would be necessary to make up the two elements of 50 j each by joining four sections of 200 jars each permanently in series. It would therefore be compo as follows :—

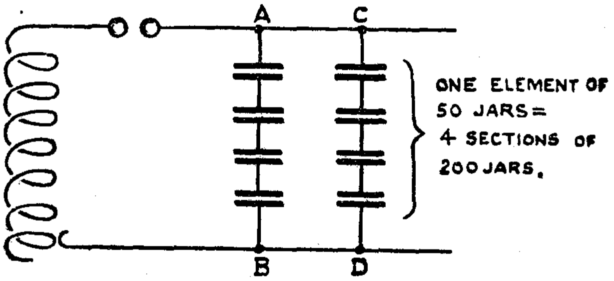


FIG. 26.

To join the two elements in series, connect terminals B and C together.

To join the elements in parallel, connect A to C and B to D.

The dielectrics generally used in the Service for spark transmitting condensers are eboni glass or mica.

The elements and sections composing the condenser are contained in an iron tank, which kept brimful of oil, to prevent brushing over the plate edges, and to keep the condenser cool.

However efficient a condenser is made, certain losses in it are unavoidable. These losses we referred to in Vol. I under the general heading of "Hysteresis Losses."

When a condenser is being charged up and discharged, it gradually gets hotter and hotter a result of these losses.

Arrangements have to be made for this heat to be radiated away, and also for the oil to expa without forcing its way under the edge of the lid.

38. **The Primary Inductance.**—This is a coil of copper tubing or flat copper strip, of lar surface area, in order to obtain low resistance to high-frequency currents with a given requir inductance and mechanical rigidity. It must have a surface of adequate area for the maximu oscillatory currents it will be required to carry.

The turns must be spaced sufficiently far apart to prevent sparking over between adjace turns.

An adjustable connection, of very low resistance, must be provided so that the inductance circuit can be varied gradually from the minimum to the maximum value, in order to give a required LC value between the limits for which the circuit is designed.

39. **The Aerial Circuit.**—This circuit, illustrated in Fig. 27, comprises the following :—

Aerial, Feeders and Deck Insulator, which are fully dealt with in Section "R."

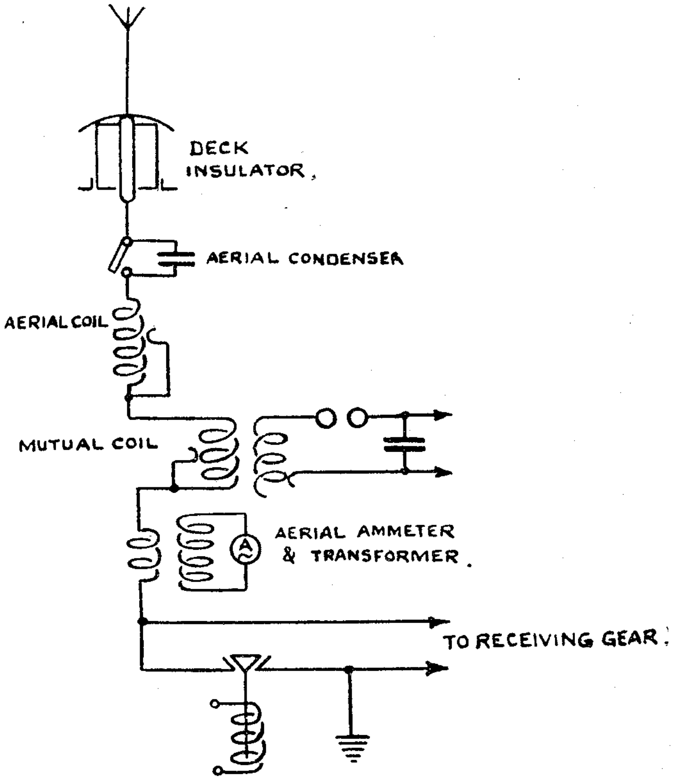
(*a*) **The Aerial Coil.**—The aerial coil is provided in order to increase the LC value of t aerial circuit when transmitting waves longer than the fundamental wave of the aerial.

In spark transmitting circuits it is made of stout copper wire, the turns of which are wound a former of insulating material, and spaced sufficiently wide apart to prevent sparking over betwe adjacent turns.

An important point is whether the idle turns of the aerial coil, *i.e.*, those not required for t particular frequency in use, shall be short-circuited, as in Fig. 28 (*a*), or left on open circuit, as Fig. 28 (*b*). This question has already been discussed in Vol. I.

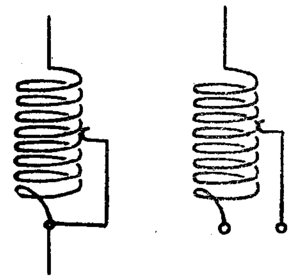
The general practice is to short-circuit the idle turns of coils used in spark transmitting sets.

When making a tuning connection on the aerial coil, it is important to remember that all the current of a received signal has to pass through it, and therefore a thoroughly clean and tight connection should be made.



Typical Aerial Circuit.

FIG. 27.



(*a*) (*b*)

FIG. 28.

(*b*) **The Mutual Coil.**—The mutual coil is provided in order to transfer into the aerial circuit the high-frequency oscillations generated in the primary.

Its distance from the primary is made adjustable in order to allow the coupling to be varied. In some circuits its inductance is also made adjustable.

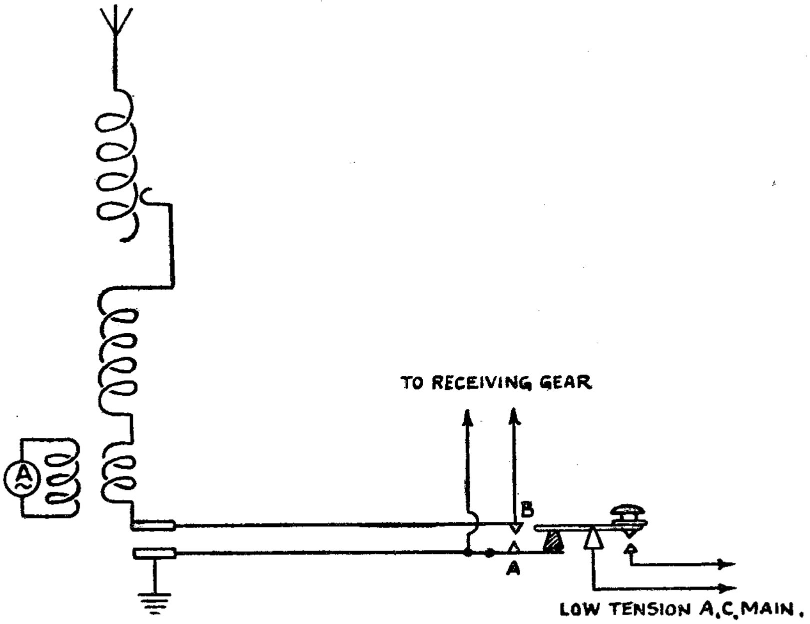
The loosest possible coupling consistent with giving readable signals to the receiving stat should always be used.

It is better to use a long spark and a loose coupling than a short spark and a tight coupling

(*c*) **The Aerial Condenser.**—For transmitting waves shorter than the fundamental wave the aerial, a **series condenser** is generally used, being short-circuited with a link when not requir

40. (*d*) **The Aerial Ammeter.**—In order to enable an operator to tell that his circuits correct, a hot-wire ammeter, termed the "Aerial Ammeter," is provided.

If joined directly in series with the aerial, it would have to be unduly large to carry the aerial current in most aerial circuits. It is therefore usually joined across the secondary of a toroi transformer.



"Listening Through" Device

FIG. 29.

41. (*e*) **Send-Receive Contact.**—This consists of a make-and-break in the earth lead, acr which the receiving gear is joined.

When the transmitting key is pressed this break is short-circuited, thus short-circuiting receiving gear, and connecting the mutual coil to earth for transmitting purposes.

When the transmitting key is released the break is opened, thus putting the receiving circ in series with the aerial.

This allows for what is termed "listening through," *i.e.*, listening between the Morse signals one's own message to see whether anyone else is transmitting at the same time.

The requirements of the break are :—

(*a*) It must make before, and break after, the low-tension charging circuit, to obviate the risk of sparking into the receiving gear.

(*b*) It must either be very close to the earth connection or be joined to it by a non-inductive lead. If there were a long inductive lead between it and earth the voltage across it would be considerable, and the break would have to be a long one to prevent sparking taking place across it as it was made and broken.

A suitable arrangement is illustrated in Fig. 29. Here were have a hand key, fitted with two " back contacts," A and B. Contact A is carried on a flexible springy piece of copper.

A and B are connected to aerial and earth by a non-inductive lead of concentric cable, and across them is joined the receiving circuit. When the key is at rest, an ebonite thimble on the toe of the key is bearing on the end of the copper strip that carries contact A. The aerial is then connected to the receiving gear.

When the key is pressed, however, its first motion allows A and B to make contact, and thus to complete the aerial circuit to earth, and to short-circuit the receiving gear before the " heel " contacts make.

Its further motion closes its " heel " contacts, and completes the low-tension A.C. circuit.

EXAMINATION QUESTIONS ON SPARK TRANSMITTERS.

1. Sketch the circuit of a simple spark transmitter. Explain the action of the protecting coils, the carbon rod resistances, and the safety gaps.
   (Qualifying for P.M.G. II Cert. H.M. Signal School, 1934.)

2. Describe and explain the action of a synchronous spark system of wireless telegraph transmission.
   (I.E.E., Oct., 1927.)

3. Draw a circuit diagram of a rotary spark transmitter of about $1\frac{1}{2}$ kW. input, assuming that a D.C. supply is available. Indicate the usual switches, fuses, and transmitting key.
   (C. & G., I., 1928.)

4. Describe, with sketches, three types of spark gap used on spark transmitters and state the advantages and disadvantages of each type.
   (C. & G., I., 1930.)

5. Describe, with a diagram, the construction and working of a $\frac{1}{4}$ kW. spark transmitter suitable for marine use. What are the advantages of spark sets over I.C.W. sets for marine emergency purposes?
   (C. & G. Preliminary, 1934.)