TEXT-BOOK ON WIRELESS TELEGRAPHY

NEW EDITION IN TWO VOLUMES

VOLUME I

GENERAL THEORY AND PRACTICE

BY

RUPERT STANLEY, B.A., M.I.E.E.

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TEMP. MAJOR R.E., AND CHIEF WIRELESS INSTRUCTOR IN THE B.E.F., FRANCE

WITH ILLUSTRATIONS

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1919

WIRELESS TELEGRAPHY

SENATORE GUGLIELMO MARCONI, G.C.V.O., LL.D., D.SC., ETC.
Inventor of Radio-signalling.

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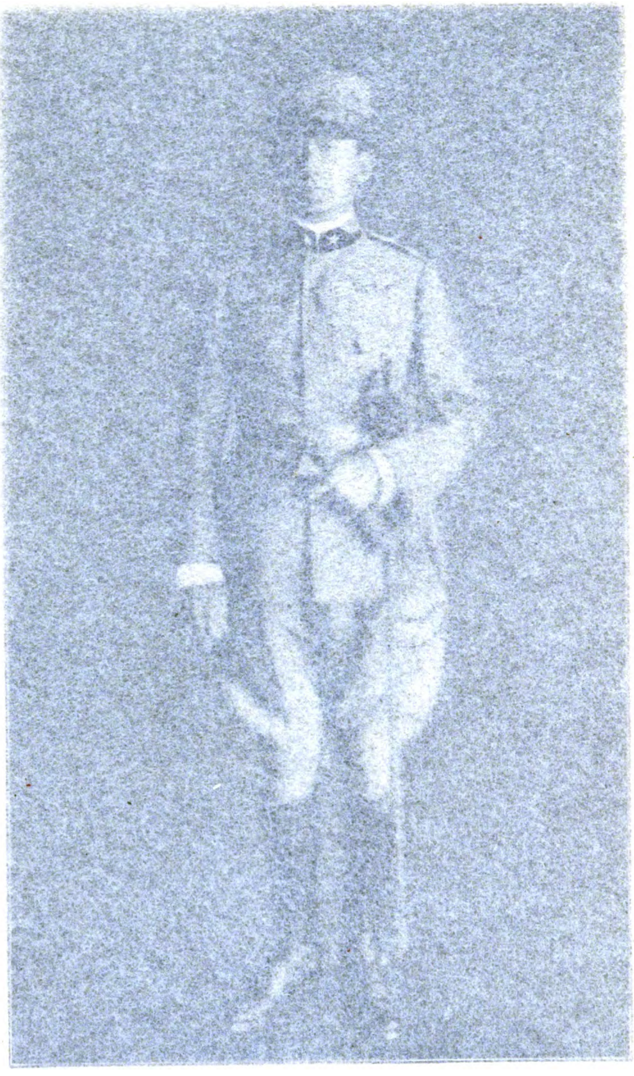

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PREFACE TO THE NEW EDITION

The first edition of this book was in the hands of the printer when the great world war broke out and the author had already joined up for military service. As a consequence many errors remained uncorrected, including much faulty grammar and punctuation. In spite of this the book has evidently been of some service to the class for whom it was written, judging by its distribution, and the author regrets that owing to his military duties he has been unable heretofore to revise it.

In the Edition now presented many chapters have been almost entirely rewritten, the subject matter rearranged, and new diagrams added. More mathematical proofs and formulæ have been included though it is not intended to be a mathematical treatise on the subject. Books dealing with the subject in a mathematical manner have been written by eminent scientists and are already available for those who can appreciate them; four years exclusively spent at specialised wireless work by the author have confirmed him in the idea that the ordinary student can and will make most of the necessary measurements by simple experimental means. In this respect the class of student for whom the book was written has been already defined in the Preface to the First Edition.

The practice of radio-signalling has been revolutionised during the last four years by the advent and development of the hard vacuum valve and valve apparatus generally; the author has been fortunate in holding an appointment which brought him intimately in contact with this development. Instead of increasing unduly the size of the present volume the whole subject of Valves and Valve Apparatus, Continuous Waves, and Wireless Telephony has been dealt with in a companion volume—Volume II. of the Text Book. In the present volume additions have been made to the questions appended to the end of each chapter; these questions are designed to help the student in self-examination and are not meant to be of a problematical character. A new chapter has been added on secondary cells and batteries.

RUPERT STANLEY.

FRANCE,
May, 1919.

PREFACE TO FIRST EDITION

Many of those attending classes with the intention of becoming wireless operators have little, if any, preliminary knowledge of electrical matters, or indeed of scientific phenomena in general. Many amateurs, who are quite expert in the ordinary manipulation of radio apparatus, miss much of the fascination of this interesting hobby because they do not understand the fundamental principles on which it is based.

In the course of writing this Text-Book on Wireless Telegraphy the author has always kept before his mind the special requirements of such students.

Several excellent treatises on Radio-Telegraphy are at present available; as a general rule, however, these deal with theoretical considerations in a manner which can be thoroughly understood only by those who have already become acquainted with the theory of electrical science, and who understand, to some extent, the significance of the technical terms associated therewith.

Time after time the author has been requested by students of this subject to recommend to them an elementary text-book on Electricity and Magnetism. It has always been with great reluctance that the author has made any recommendation, and that for several reasons:—

In the first place our elementary text-books are, for the most part, hopelessly out of date; they juggle with one fluid, two fluid, and atomic theories; they labour over Faraday's crude though pioneer experiments, and fog the practical student with long dissertations on potential gradients or moments of complex arrangements of magnets.

In the second place our elementary text-books are written to serve as a preliminary to the study of general electrical engineering, and are not at all adapted to the elucidation of the principles of energy radiation.

Lastly, no elementary text-book on magnetism and electricity adequately introduces some of the most important phenomena applied to radio-telegraphic circuits, such as self-induction, mutual induction, oscillatory currents, and the true significance of magnetic or electric lines of strain in the all-pervading ether.

Therefore, in the opening chapters, the author has tried to introduce the subject of radio-telegraphy by demonstrating its place in the natural order of things, and its intimate relation to other branches of science.

The electron theory has been used; on it has been based all theoretical considerations, the author believing that this theory, modern, simple, direct, and well established, will present fewer difficulties to the student than the vague fluid theories which it has replaced.

In dealing with the technical portion of the subject, calculations and formulæ have been made as simple as possible, while long accounts of historical developments and researches have been avoided. Only the best types of modern radio apparatus have been fully described, and the author has tried, at each point, to explain fully the theory governing each system of connection or the development of each design.

The author has been indebted to the Marconi Wireless Telegraphy Co. and to Captain R. Sankey, C.B., for much valuable information on Marconi apparatus, also for the loan of blocks and photos for the purposes of illustration, on which the value of such a text-book materially depends. A like remark applies to Messrs. Siemens Bros. & Co., who placed at the disposal of the author blocks, photos, and many particulars concerning the Telefunken System; to the Compagnie Universelle de Télégraphie et de Téléphonie sans Fils for photos and particulars of the Goldschmidt apparatus. To Messrs. The Electrical Co., Ltd., Messrs. The Cambridge Scientific Inst. Co., Messrs. Isenthal & Co., Messrs. The Union Electric Co., and to Mr. S. G. Brown like acknowledgments are due. The author has also to thank Prof. J. Earls and Mr. W. J. McCracken, B.A., B.L., for much assistance and advice in the compilation of the work. Lastly, the author wishes to place on record how much he is indebted to Mr. James Craig, Sirocco Works, Belfast, for preparing all the diagrams with which the book is illustrated. There are undoubtedly many literary faults in the text, perhaps many descriptions and explanations which are vague and insufficient; it is therefore hoped that any failings of this description may be outweighed by the merit of the help which Mr. Craig has given to the author.

In conclusion a word of advice may be given to those who wish to obtain an intimate knowledge of this engrossing subject.

When they have mastered the fundamental principles of radio-telegraphy they will only be in a position to really appreciate the interest which further reading will open up to them. Valuable information can then be gained by reading the papers and contributions of such well-known authorities as Signor Marconi, Dr. J. A. Fleming, Dr. W. Eccles, Dr. Erskine Murray, Dr. Austin, and many others.

Reprints of these papers, contributed to such learned institutions as the British Association and the Physical Society, can constantly be found in the pages of *The Electrician*, *The Wireless World*, and other well-known periodicals.

It is hoped that this text-book may serve as an introduction to a full appreciation of the work of scientists who have done, or are doing, so much to elucidate the outstanding problems of radio-telegraphy.

RUPERT STANLEY.

BELFAST,
July, 1914.

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TEXT-BOOK ON WIRELESS TELEGRAPHY

CHAPTER I

THE EARTH, THE ATMOSPHERE AND THE ETHER

In its first state the earth was a mass of gaseous matter, or "nebulæ," at a very high temperature, revolving round the sun. Through the æons of time it was gradually cooling down, until about 200,000,000 years ago, as calculated by Lord Kelvin, it began to be solid on the outer surface, just as the surface of water turns into ice when cooled. This solidification of the earth's surface continued until it became an irregular solid mass, in the aggregate shaped nearly like a sphere; but the surface is all uneven with high ridges and points called mountains and deep depressions where the seas and oceans have collected. The cooling of the earth is going on continuously and the surface is cooler than the interior as can be easily proved by taking the temperature when one descends a mine. The lower we go the more the temperature rises, and volcanic eruptions show us that the middle of the earth is still at a very high temperature.

The earth is a ball 8000 miles in diameter and is surrounded by a mixture of gases called the atmosphere. The principal gases in the atmosphere are nitrogen and oxygen. This atmosphere covers the earth as a chamois skin covers a tennis ball, and forms a layer probably about 200 miles thick. It is most dense at the surface of the earth and gets lighter and lighter until the gases which compose it fade away into nothing; just as a vertical column of smoke which is dense at the bottom gradually spreads out, becoming less dense as it ascends.

In the atmosphere of the earth float clouds and vapours formed from dust, water vapour, and gases which have risen from the earth's surface; the highest of these is never much farther than 4 or 5 miles from the earth's surface.

The earth and its atmospheric envelope is always spinning round on its axis and at the same time it is travelling round the sun in a circle whose radius is about 93 millions of miles. These rotations of the earth are similar to those of a spinning top which spins on the floor and at the same time travels round and round in a circle on the floor. The spinning of the earth on its axis causes night and day, and the rotation of the earth round the sun causes winter and summer.

Now we must not forget that the earth is only a very small portion of the universe; there are many other planets travelling in circles or in elliptical orbits round the sun. We have to ask ourselves: what fills all the space of the universe in which these planets move? Is there anything in that space? The fact that we can see nothing in it does not justify us in assuming that there is nothing. We cannot see the air, *i.e.* the atmosphere, but we know it is there, and we know many facts concerning it.

There is indeed another medium which pervades the whole universe. Evidence of the existence of this medium will accumulate as we proceed, but for the present we will consider one or two very elementary facts which show that such a medium does exist. We know that light and heat come to us from the sun; they travel millions of miles before they reach our atmosphere, and then they travel through the atmosphere until they affect our eyes or sense of touch. We know that light and heat travel in the form of lines or rays: if we let the light come through a hole in a shutter into a darkened room we see it in the form of what are called rays of light, traced out in the dust particles of the room. It is well established that light and heat are forms of energy, and transference of energy from one place to another implies the existence of a medium to convey it, not only that, but the medium is strained in so doing. Thus when energy is conveyed from a steam engine to a loom or other machine there must be a medium in the form of belting, or shafting, or gearing to convey the energy, and the medium is strained while it is conveying the energy. In the same way the fact that light and heat come to us from the sun across interplanetary space implies the existence in that space of a medium which can be strained. This medium must also exist in our atmosphere, and many elementary scientific phenomena demonstrate to us that the medium pervades all forms of matter—solid, liquid, or gas, as well as the interplanetary space.

The Dutch philosopher Huyghens first propounded the theory of the existence of an all-pervading medium, now called the ether, through which heat and light travel with a definite velocity of 300,000,000 metres per second, or roughly 186,000 miles per second.

All the accumulated evidence of modern science confirms the theory that such a medium does exist, and the demand for a rational explanation of many phenomena in nature makes it easier to believe in such a universal ether rather than to believe that interplanetary space is void or entirely empty.

Let us first consider the air which is a familiar medium through which sound energy is conveyed in all directions. The vibrations of a sounding body set up waves in the air, the length of the waves depending upon the number of vibrations per second made by the sounding body. A number of sounding bodies may all be vibrating at different frequencies, setting up waves of different wave lengths in the air, and the ear will detect that there are different sets of waves arriving at it. Also we know that a body may vibrate so slowly, setting up long air waves, or so fast, setting up short wave lengths, as to cause no impression on the ear; in other words the air waves may be too long or too short for the ear to detect them. Thus one can set up waves in the air of all wave lengths; all exactly identical in character, but our sense of hearing can only detect a certain limited range of them.

It is believed that heat and light are radiated from the sun owing to violent electrical disturbances at its surface caused by its very high temperature. These disturbances set up strains in the ether medium which spread out through it in all directions, analogous to the spreading out of sound waves in air.

We do not believe that heat and light are shot from the sun through space, like a bullet shot from a ship to disturb a target; but rather that disturbances in the sun set up harmonic strains or waves in the ether medium. These waves excite our senses of touch and sight, in the same way as a ship by violent movement might set up waves in the water to disturb a distant target. And just as the sense of hearing can only detect a limited range of air waves, so our sense of touch can only detect ether waves of lengths which lie within a limited range, *i.e.* the heat waves; and our sense of sight detects ether waves of another range, *i.e.* the light waves. But some waves seem to affect our sense of touch and our sense of vision, which leads us to conclude that light waves and heat waves are identical in nature and only differ in the lengths of the waves. This conclusion is verified by the fact that they have many other properties in common; for example each can be reflected, refracted, dispersed, and polarised. Also, just as it is possible for air waves to be too long or too short to affect the sense of hearing, so there are ether waves too long or too short to affect either our sense of touch or our sense of vision.

Air waves from $\frac{1}{8}$ inch long to 12 or 13 yards long affect the sense of hearing, ether waves 36×10^{-6} cms. long give the sensation of violet light, 45×10^{-6} cms. long the sensation of blue light, and as they increase in length we receive the different colours of the spectrum until waves 80×10^{-6} cms. long give the sensation of red light; ether waves longer than these do not affect the eye. If waves of all these different lengths arrive at the eye together we get the sensation of white light, as in sunlight, whilst waves from 80×10^{-6} cms. to 80×10^{-4} cms. long give the sensation of heat. Ether waves longer than 80×10^{-4} cms. or shorter than 36×10^{-6} cms. do not affect the human senses of sight and touch, at the same time ether waves shorter than violet light waves have chemical effects, and can act on photographic plates. These waves are commonly called the chemical or actinic rays, whilst waves 2×10^{-8} cms. long are known as X rays, discovered by Sir Wm. Crookes.

Thus we see that just as waves of varying lengths can be set up in air, so in the all-pervading ether medium various lengths of waves can be set up, and are being continually set up by natural means; also that we can detect many of these waves by their direct effect on the human senses of touch and sight, and we can detect others by chemical or photographic results.

The problem of Wireless Telegraphy is simply to make and arrange apparatus so that long waves will be set up in the ether, and to make and arrange other apparatus to detect these waves, for they are far too long to be detected by the senses of sight or touch. Waves in any medium are caused by setting up strains in the medium, and we must first study how strains can be set up in the ether, and how they can be combined to cause a wave motion.

QUESTIONS ON CHAPTER I.

1. How would you demonstrate the difference in the natures of light waves and sound waves?
2. What is the evidence for the existence of an all-pervading medium in the universe?
3. What range of ether wave lengths can be received, using the eye as a detector?
4. If waves are set up in the ether shorter than those which affect the eye, how can they be detected, and what use is made of them?
5. Describe the changes which take place in the ether disturbances set up round an iron ball as the latter is slowly heated from a cold state to a white heat.

CHAPTER II

MATTER AND ELECTRICITY

UNDER normal conditions of temperature and pressure some kinds of matter may be known to us as solids, others as liquids, and others as gases, but all the different forms of matter in the universe can be catalogued under two main headings, *i.e. Elements* and *Compounds*.

An *Element*, as the name implies, is a simple or elementary substance which may enter into combination with other substances but which by itself cannot be decomposed by any chemical or physical action to form one or more new substances. If, for example, a quantity of copper unites with any other substances to form copper sulphate it is not possible to carry out a decomposition of the suphate which will not yield the same quantity of copper again ; neither more nor less.

There are about eighty such elements known to us at present, including the metals, miscellaneous elements such as silica and carbon, and gases such as hydrogen, oxygen, chlorine, etc.

All elements differ from each other in weight and physical properties; gold is much heavier than hydrogen; iron has magnetic properties possessed by no other elements to the same extent, and radium has radio-active properties at ordinary temperatures which are shared by few other substances.

The smallest portion of an element which can exist or enter into combination with other elements is called an "ATOM"; for example, a piece of copper contains millions of elementary particles, or atoms, of copper; all absolutely identical and none of them divisible into new atoms which have properties different from those of copper.

A compound is a combination of two or more elements; such compounds comprise far the greatest number of the forms of matter with which we are familiar.

The smallest particle of a compound is called a "MOLECULE."

and a molecule is always made up of a whole number of atoms of each elementary substance present; thus a molecule of water is made up of a combination of two atoms of hydrogen and one atom of oxygen; a molecule of sulphuric acid similarly consists of a combination of two atoms of hydrogen, one of sulphur, and four of oxygen. In the same way molecules of salt, sugar, alcohol, coal, rubber, or any other compound consist of different combinations of atoms of different elements.

An alloy, such as brass, german silver, solder, or platinoid, is simply a mixture of atoms or molecules of two or more elements or compounds. Thus a study of all the phenomena connected with matter can be based on such knowledge as we possess concerning the comparatively few fundamental elements; if, for example, we consider samples of iron, copper, hydrogen, and radium we are led to ask ourselves why are they all different as regards their physical and chemical properties. This difference is apparent even in the smallest samples, and the smallest samples possible are atoms of these substances. We must come to the conclusion that the atoms are in some way different from each other and thus the investigation resolves itself into a study of atomic structure.

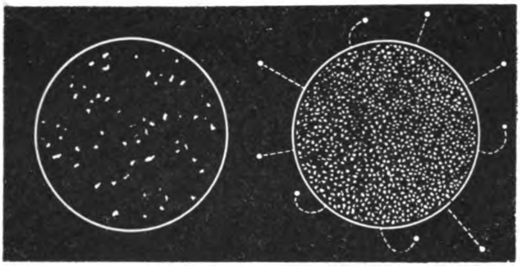
Unfortunately an atom of any substance is far too small to be seen under the most powerful microscope, and there are billions of them in one cubic centimetre of the substance. In ancient times atoms were considered to be hard like miniature pellets of shot; as Dr. Preston wrote:—"The hard atom was conceived by the Greek philosophers Democritus and Leucippus, and was subsequently glorified in the poetry of Lucretius."

There is a form of fine dust which can be taken from the bed of the ocean called globigerina; it looks like a very fine powder and a few particles of it cannot be seen by the naked eye. Yet if put under a powerful microscope each particle is seen to be a beautiful structure, in appearance like a miniature sea-shell. Is an elementary atom then simply a small hard particle or has it got an elaborate structure unsuspected like that of the globigerina?

Fortunately, although we cannot see an atom, the brilliant work of such scientists as Crookes, J. J. Thomson, Rutherford, H. A. Wilson, Pierre and Madame Curie has cleared up many points concerning atomic structure, and has established the fact that electricity is a fundamental constituent of the atoms and molecules of all forms of matter. From the researches of these and other scientists we learn that an atom of any substance contains still smaller things, which by Sir J. J. Thomson were called "Corpuscles," but by many scientists "Electrons." We shall speak of them as electrons in this treatise.

It is indeed very probable that an atom of matter contains a number of electrons vibrating in the atom about a central nucleus. Those who chiefly realise the fact that atoms are far too small to be seen may find it difficult to believe in the existence of electrons and be very sceptical about their movement in the atom. But the appreciation of this movement of electrons in an atom may not be difficult to the student of science who knows that the atoms or molecules of a substance are in constant vibration, the rate of vibration depending on the temperature of the substance.

By brilliant researches on the discharges of electricity through rarified gases contained in vacuum tubes Sir J. J. Thomson has probably done more than any other scientist to establish the electronic structure in an atom, to show why elements differ from each other in physical and chemical properties, and to demonstrate the fact that electricity is a fundamental constituent of matter, and therefore of the universe.



(*a*) Fig. 1. (*b*)

Thus an atom of an element might be represented as in Fig. 1 (*a*), where the white specks represent electrons, though their number and arrangement will be different for different forms of matter. A surface atom of radium might be represented as in Fig. 1 (*b*), in which electrons are seen to be flying off the atom; some escaping into the space around, others being pulled back into the atom by the attracting force which acts toward its centre. An atom of radium is very heavy and it is probable that it contains many electrons.

Fig. 2 shows a glass globe exhausted of air, with a glass stem holding a small plate of platinum at the centre, and two electrodes sealed through the glass. If wires from an induction coil which is generating a very high electric pressure, or difference of potential measured in volts, are joined to the electrodes, the negative wire to the top terminal and the positive wire to the bottom, a discharge of electrons will be driven from the top terminal and will strike against the platinum plate.

The plate will be seen to become red hot. This proves that the electrons, though so small as to be quite invisible, yet travel in such numbers and with such velocity that their bombardment heats the platinum.

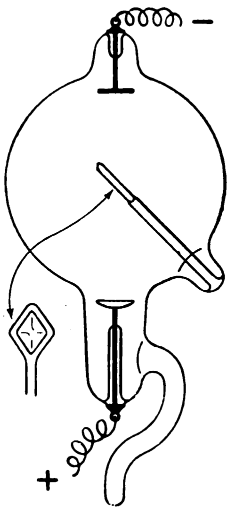


Fig. 2.

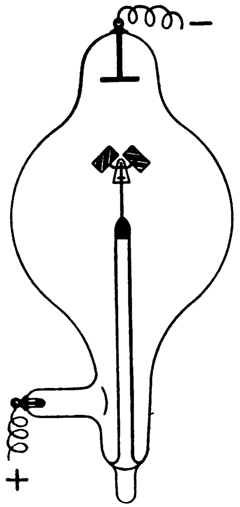


Fig. 3.

In like manner one might heat a target by bombarding it with a rain of bullets; the energy of the high-velocity bullets would be turned into heat on the target, though here again one does not see the bullets.

Fig. 3 shows another vacuum tube with electrodes, and in the centre is pivoted a small wheel with very light vanes. If the electrodes of this tube are suitably joined to a source of high electrical pressure the discharge of electrons will be seen to turn the little wheel rapidly and at the same time make its vanes phosphoresce.

Fig. 4 shows another such vacuum tube, having at the centre a plate covered with barium sulphide. When electrons are made to discharge across it and strike the plate the latter is seen to give off a brilliant light. Indeed in all these experiments the glass of all the vacuum tubes is seen to glow with phosphorescent light. Since light is due to waves of definite length set up in the ether we have here a proof that a sudden stoppage of electrons may so disturb the ether that there is set up in it those small ripples or waves which give the sensation of light ; the length of the waves, in other words the colour of the light, depending upon the form of matter (whether glass, barium sulphide, etc.) that contained the ether in which the waves were started.

These experiments are carried out in vacuum tubes, *i.e.* in tubes in which the air is very attenuated, or at a very low pressure, because the electrons are so tiny that their motion would be quickly stopped in air at ordinary pressure unless very high voltages were used, and even then they would heat up the air so much that it would itself become incandescent, thus obscuring the other light effects.

Lightning is a discharge of electrons, generally from one cloud which is highly negatively charged to one highly positively charged. The electrical pressure or voltage is so great as to make the electrons burst their way through the resistance of the air, and raise it to a white heat as they pass through it. An electric spark discharge from an induction coil is similarly a discharge of electrons ; a current of electricity through a wire is a steady flow of electrons through the wire.

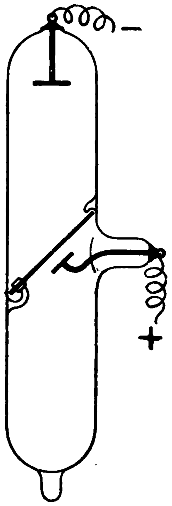


Fig. 4.

The diameter of an electron, its mass, its velocity, and the charge carried by it, have been measured.[1] Its mass is $\frac{9}{10^{28}}$ gram or is about $\frac{1}{1845}$ of that of a hydrogen atom, which is the lightest atom of all the elements ; its diameter is less than $\frac{1}{3 \times 10^{12}}$ cm. ; its velocity depends on the positive potential of the anode or plate which attracts it and can attain a value of 50,000 kilometres per second in a high voltage tube. Its charge corresponds

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[1] See note at end of Chapter.

to about $\frac{1}{63 \times 10^{17}}$ coulomb, and a substance with a surplus of electrons has properties identical with those possessed by bodies which in former times were said to be negatively electrified. The charge cannot be separated from the electron; it *is* the electron—the fundamental unit of electricity. It is probable that the mass of an electron is due to the magnetic disturbances which it causes in the ether medium; the luminescence and fluorescence, and heat caused by it in gas, and glass, and other substances are due to similar etheric disturbances. In fact all the physical properties of all forms of matter may be due to the movements of the electrons, or units of electricity, which are a fundamental constituent of them.

The electrons are identical no matter what substance they may issue from; thus the atoms of all elements contain electrons, and the difference between different elements is probably due to the electronic structure in the atom. Gold differs from lead because an atom of gold contains a certain number of electrons arranged in a certain way, an atom of lead contains a different number of electrons arranged in a different way. Each little atom has its electrons in it, like seeds in a fruit, but there are reasons to suppose that the electrons may be moving about in the atoms so that it is more like a little universe with its planet electrons moving around a central nucleus. By the application of electrical pressure, or voltage, one or more electrons may be torn out of an atom so that we get a kathodic discharge in a vacuum tube. Sir J. J. Thomson has shown that as many as eight electrons can be torn out of an atom of mercury. Some substances, such as radium, actinium, and uranium, emit electrons spontaneously from their atoms at ordinary temperatures and are said to be radio-active.

We do not know how many electrons there are in an atom of any substance but it is reasonable to suppose that the number increases with the weight of an atom. Thus the atomic weight of hydrogen is 1 and its atom is supposed to contain one electron —the atomic weight of radium is 226 and its atom probably contains a great number of electrons.

Mendélejeff first drew attention to what is now known as the Law of Periodicity; if the atoms of the different elements are arranged in the order of their atomic weights it is found that atoms of similar characteristics occur periodically like octave notes on a piano. Thus lithium (atomic weight 7) has properties not shared by the substances which succeed it in the atomic scale until we come to sodium (atomic weight 23), and they disappear again until potassium (atomic weight 39) is reached. In a similar way helium (4), neon (20), and argon (37·9) have similar characteristics, as have glucinum (9·1), magnesium (24·3), and calcium (40·1); in fact so regular is this periodicity that the existence of unknown elements was shown by gaps in the series; this has led to the discovery of some of these elements such as gallium and germanium. Spectroscopic results also demonstrate the fact that there is a definite similarity between elements which follow each other at regular intervals in the periodic series.

To account for this peculiar periodicity Sir J. J. Thomson considers that an atom consists of electrons, or negative charges, surrounding a central nucleus of positive charge. When the number of electrons in an atom is from 1 to 8 they are arranged symmetrically on a circle or sphere round the central nucleus; when the number is from 9 to 16, the ninth, tenth, etc., will lie on a new circle or sphere concentric with the first. Similarly with 17 electrons a third circle or sphere would be commenced with the seventeenth, and so on. Thus the similarity of properties of certain substances will correspond to the number of electrons on the outer circle or sphere

The ring diameter changes with the atomic weight so that the atomic volume diminishes as we pass through an octave to rise again when a new ring, or an octave, is started. Some doubt still exists as to the nature of the nucleus in an atom; it may be ether, or it may be something corresponding to what we have previously called positive charge. On the other hand positive charge may simply correspond to a deficit of electrons. The fact that an atom contains a positive as well as a negative charge would seem to have been proved by the experiments which P. Curie carried out with certain crystals.

Owing to the difficulty of explaining the fact that hydrogen gives two spectra, although its atom is supposed to consist of 1 electron and 1 nucleus, Sir J. J. Thomson has presented the idea that an atom may also contain a third constituent whose nature is at present unknown.[1]

It may be thought that if an atom of an element loses one or more electrons it thereby changes into an atom of something

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[1] Lectures by Sir J. J. Thomson at the Royal Institution, commencing February 16th, 1918. In his 1919 Lectures he states that the different spectra may be due to a difference of electron position in the atom.

else, and consequently by taking an electron discharge from a substance the latter should slowly change. Up to the present the physical and chemical properties of most substances have not been found to change owing to a discharge of electrons from them, but in the case of radio-active substances it is thought that new substances of distinct individuality are produced. The radiations from thorium are supposed to bring about a very slow formation of a new substance called Thorium X; much research remains to be done on these lines.

Now physical science teaches us that the molecules of a compound and the atoms of an element, which may be called monatomic molecules, are in constant movement; the extent of the movement of any molecule depending on the temperature of the substance. This molecular movement is small in solids, more free in liquids, and still more free in gases; in fact it is this which distinguishes solids from liquids and gases. The pressure of a liquid or gas against the sides of the containing vessel is due to the constant bombardment of the molecules; as they move hither and thither a definite number of them are always striking against the side of the vessel.

Evaporation from the surface of a liquid is due to the fact that some of the molecules in their movement arrive at the surface with such a velocity that they fly off into the air or other fluid medium above the surface. As the temperature of the substance is increased the molecules move with greater velocity; as it is decreased the molecular movement diminishes, and at absolute zero of temperature, *i.e.* − 273° C., all the molecules of a substance are at rest.

In all pieces of elementary substances it is believed that there are not only the atoms of the element which formed the substance, each containing a definite number of electrons, but also a great number of free electrons, and that the electrons as well as the atoms are in constant movement. Thus a piece of copper wire consists of an aggregate of atoms of copper and a number of free electrons all moving hither and thither, the atoms being definite constellations of electrons which give the piece properties by which we distinguish it as copper. Also it must not be overlooked that ether pervades the copper since this medium pervades everything.

Similarly a piece of gold wire consists of a number of atoms or constellations of electrons, and a number of free electrons all moving continually in all directions; but the constellations in this case consist of a different number of electrons, differently arranged to those in copper, and so gold differs from copper, or iron, or hydrogen, or other elements in its physical characteristics.

In a metal it is computed that there are 10^{23} free electrons per centimetre cube of the substance, a number approximating to the number of complete atoms in the same volume.

From the definite results of modern research we are led to conclude that electricity is a constituent of all forms of matter; that it has mass and by its motion can convey energy; that a unit of negative charge is an electron, and a unit of positive charge is either the nucleus of an atom round which the electrons in it are grouped, or is the atom itself when it has lost an electron and the remainder have not rearranged themselves into a new group corresponding to an atom of another substance.

It is possible that the whole universe may consist of two essentials only :—ether and electrons.

QUESTIONS ON CHAPTER II.

1. Define "matter," "atom," "electron," "radio-activity."
2. Deduce some evidence of the fact that electrons have mass.
3. Write a short account of the structure of the atoms of matter.
4. On the electron theory how does an atom of copper differ from an atom of hydrogen ?
5. If the electron theory is taken as the correct one, what is electricity ?

HISTORICAL NOTE.

In the middle of the eighteenth century Franklin propounded the existence of an electrical fluid as a constituent of all forms of matter, and started what has since come to be known as the "One Fluid Theory." Any body which had more than a normal amount of the fluid was said to be positively electrified, one with less than the normal amount was negatively electrified. This arbitrary use of the terms "positive" and "negative" has led to much confusion in the light of modern scientific results.

Later, a Two-Fluid Theory came into existence and held the field for a long time, until Faraday's experiments on Electrolysis suggested that at least a definite amount of electricity was associated with each atom of matter. G. Johnstone Stoney read a paper at Belfast in 1874 in which he spoke definitely of a unit quantity of electricity and proceeded to deduce its value. In 1891 Stoney first suggested the name "Electron" for this unit but implied that there were positive and negative electrons in each atom of matter. Afterwards the word "Electron" came to mean a unit of negative charge, though several modern writers, including Sir J. J. Thomson, still write of positive and negative electrons. As a positive unit of charge is always associated with atomic mass, never less than that of an atom of hydrogen, it is apparent that the negative unit is more fundamental, and the term "Electron" might well be reserved to denote the fundamental unit of electricity. Fournier gives the mass of an electron as $\frac{6{\cdot}1}{10^{28}}$, its diameter as $\frac{1}{5 \times 10^{12}}$ cm., and its charge as $\frac{1}{88 \times 10^{17}}$ coulomb.

LIST OF THE ELEMENTS WITH INTERNATIONAL ATOMIC WEIGHTS FOR 1911.

O=16.

(See F. W. Clarke, "A Recalculation of the Atomic Weights," 1910.)

Element.	Symbol.	Atomic weight.	Element.	Symbol.	Atomic weight.
Aluminium	Al	27·1	Neodymium	Nd	144·3
Antimony	Sb	120·2	Neon	Ne	20·2
Argon	A	37·88	Nickel	Ni	58·68
Arsenic	As	74·96	Niobium	Nb	93·5
Barium	Ba	137·37	Nitrogen	N	14·01
Beryllium	Be	9·1	Osmium	Os	190·9
Bismuth	Bi	208·0	Oxygen	O	16·00
Boron	B	11·0	Palladium	Pd	106·7
Bromine	Br	79·92	Phosphorus	P	31·04
Cadmium	Cd	112·40	Platinum	Pt	195·2
Cæsium	Cs	132·81	Potassium	K	39·10
Calcium	Ca	40·09	Praseodymium	Pr	140·6
Carbon	C	12·00	Radium	Ra	226·4
Cerium	Ce	140·25	Rhodium	Rh	102·9
Chlorine	Cl	35·46	Rubidium	Rb	85·45
Chromium	Cr	52·0	Ruthenium	Ru	101·7
Cobalt	Co	58·97	Samarium	Sa	150·4
Copper	Cu	63·57	Scandium	Sc	44·1
Dysprosium	Dy	162·5	Selenium	Se	79·2
Erbium	Er	167·4	Silicon	Si	28·3
Europium	Eu	152·0	Silver	Ag	107·88
Fluorine	F	19·0	Sodium	Na	23·00
Gadolinium	Gd	157·3	Strontium	Sr	87·63
Gallium	Ga	69·9	Sulphur	S	32·07
Germanium	Ge	72·5	Tantalum	Ta	181·0
Gold	Au	197·2	Tellurium	Te	127·5
Helium	He	3·99	Terbium	Tb	159·2
Hydrogen	H	1·008	Thallium	Tl	204·0
Indium	In	114·8	Thorium	Th	232·0
Iodine	I	126·92	Thulium	Tm	168·5
Iridium	Ir	193·1	Tin	Sn	119·0
Iron	Fe	55·85	Titanium	Ti	48·1
Krypton	Kr	82·9	Tungsten	W	184·0
Lanthanum	La	139·0	Uranium	U	238·5
Lead	Pb	207·10	Vanadium	V	51·06
Lithium	Li	6·94	Xenon	Xe	130·2
Lutecium	Lu	174·0	Ytterbium	Yb	172·0
Magnesium	Mg	24·32	Yttrium	Y	89·0
Manganese	Mn	54·93	Zinc	Zn	65·37
Mercury	Hg	200·0	Zirconium	Zr	90·6
Molybdenum	Mo	96·0			

Beryllium or Glucinum (Gl). Niobium or Columbium (Cb).

CHAPTER III

CHARGED BODIES AND ELECTRIC STRAIN IN THE ETHER

IF an ordinary ebonite ruler is rubbed with a piece of fur or flannel and the rubbed part held near light objects, such as small pieces of tissue paper, the latter will be attracted to the ebonite. A dry glass rod rubbed with silk shows the same phenomena, and a like result can be obtained with an amber mouthpiece of a pipe, or a stick of sealing-wax rubbed on the sleeve of a coat. These bodies are then said to be electrified.

When a rod of brass, or of any metal, is held in the hand and rubbed in a similar way it evinces no such property of electrification; however, if we mount the brass or other metal on a support of ebonite, amber, or sealing-wax, and flick it with a piece of fur we find it has now the property of attracting light substances; in other words it is electrified. Thus bodies can be divided under two headings: those in which the electrified portion remains isolated or insulated, termed "Insulators," and those over which the electrification passes freely, and can pass into other similar bodies in contact with them, termed "Conductors."

Ebonite, sealing-wax, amber, silk, shellac, dry glass, and air are good insulators; metals and alloys, the human body, and most vegetable matter are good conductors.

A brass rod held in the hand is electrified by friction, but the electrification can spread all over the brass into the body through the hand, and into the earth through the body, so that no signs of electrification appear; when the brass is insulated the electrification can spread all over the brass but it cannot spread any farther, so that the brass as a whole shows signs of electrification.

If one electrified ebonite rod is suspended at the centre by a thread and another electrified ebonite rod is brought near the electrified end of the suspended one the latter is seen to be repelled. But if a glass rod, electrified by rubbing it with silk, is brought near the suspended electrified ebonite the latter will be attracted and move round towards the electrified glass rod. The rubbed glass and the rubbed ebonite will each attract light neutral bodies; they are each electrified but there is evidently some difference in their electrification. If the fur which rubbed the ebonite rod had been insulated it would have attracted the electrified ebonite rod as the glass did; and, indeed, it can be easily proved that if two insulators, or insulated conductors, are rubbed together they both become electrified to exactly the same extent but with different states of electrification, one repelling another electrified body, the other attracting it with exactly the same force. Franklin tried to explain this, in his "One Fluid Theory," by saying that when two bodies are rubbed together one loses something which the other gains; one was negatively electrified and the other positively electrified, the negative and positive electrifications being necessarily equal.

Charged Bodies.—If an excess of electrons can be put on any substance it is no longer in a normal, or neutral, condition; the ether which pervades it will be strained and this strain is communicated to the ether around it so that it has an effect on other substances in the neighbourhood. On the electron theory when a rod of ebonite is rubbed with fur an excess of electrons goes to the ebonite from the fur, the ether round the ebonite is strained and on account of this strain light substances near the ebonite, such as bits of paper, are attracted to it.

In older text-books ebonite rubbed with fur was said to be negatively electrified so that an excess of electrons on a body corresponds to what was formerly known as a "Negative" charge. This is perhaps a little confusing and is entirely due to the conventional manner in which the terms "Positive" and "Negative" were adopted by the older scientists when the nature of electricity was not understood.

Similarly when a dry glass rod is rubbed with silk some electrons go out of the glass on to the silk; the glass has now a deficit of electrons and is in an abnormal condition; the ether in and around it is strained and so it attracts light neutral substances. The glass was formerly said to be "Positively" electrified, so that a positive charge in the older theory corresponds to a deficit of electrons in the modern theory.

Generally then it may be said that properties of electric charge, or of electrification, are evinced by any substance when it has either an excess or deficit of electrons compared with the number in a normal piece of the substance ; this abnormal condition has set up a strain in the ether which pervades the body and, since ether is a perfectly elastic medium, this strain extends into the ether around it conveying forces to neighbouring substances.

The fur which rubbed the ebonite lost electrons to the ebonite ; the fur was thus charged positively. But the fur and the hand which held it are both conductors, through which electrons can easily pass, so that, when the ether in them is strained, electrons flow from the general mass of earth and the body to the fur to make up the deficit until the strain on the ether is removed. Instantaneously, therefore, the fur loses its abnormal or electrified condition. If it had been supported on a substance through which, or over which, electrons cannot easily pass, *i.e.* an insulator, it would have remained electrified and the positive electrification of the fur would have equalled the negative electrification of the ebonite. Similar reasoning applies to all conductors ; they allow electrons to pass easily over them from or to the great earth conductor unless they are isolated or "Insulated" from it, in which case they can be easily electrified, positively or negatively, like ebonite, glass, amber, or any other insulator.

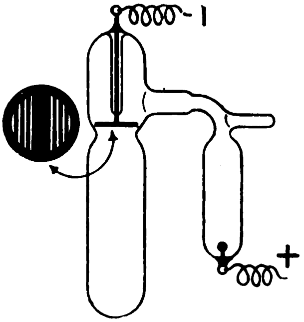


Fig. 5.

Some bodies are more easily electrified than others ; this will depend upon the structure of the atom, how many electrons it contains, and how the electrons are arranged in the atom. Sir J. J. Thomson has shown that from some atoms only one electron can be freed, from others two, and so on. The difference between electrons and the positively charged residue of the atoms from which the electrons are obtained is beautifully shown by experiment with a special form of vacuum tube similar to that in Fig. 5.

There are two plates or electrodes in the tube, one of which is joined to a source of great positive electrical pressure, the other is joined to a source of great negative pressure. This may be effected by joining the terminals to the secondary wires of an induction coil. The negative electrode plate is cut in the form of a grid, with horizontal slits or openings in it.

When joined to a sufficiently great difference of electrical potential, or pressure, a discharge will take place between the electrodes in the tube; electrons will be torn out of the atoms of gas in the tube near the negative electrode, and shot with great velocity towards the positive electrode. They will be like little invisible pellets flying across this space in the tube, and will make it phosphoresce with the usual yellowish-green coloration.

Now when a shot is fired from a gun the gun itself recoils, and similarly in this case when electrons fly forward from atoms the robbed atoms themselves fly backward; they will pass through the openings in the negative electrode and there will be seen behind it rays of quite a different colour to those due to the flying electrons in front. These rays will be of a reddish colour and are due to the positively charged atoms flying backwards from the recoil.

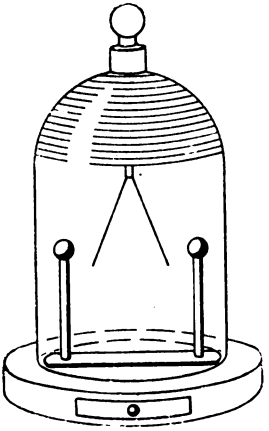


Fig. 6.

One insulated conductor can be charged by bringing it into contact with another charged conductor, or by joining them together with a conducting wire. A simple little instrument for studying effects of electrical charges is the Gold Leaf Electroscope (Fig. 6).

It consists of two little gold leaves hanging side by side on a metal bar connected by a metal rod to a disc, and the whole well insulated by ebonite, paraffin wax, or glass, from a case which surrounds the leaves, the case having glass windows through which the leaves can be seen; it may be of glass and wire netting.

If the electroscope is charged the leaves will stand apart, for being electrified in a similar sense (both positively or both negatively charged) they repel each other. Thus if joined to a conductor and the conductor is charged the leaves stand apart.

If the electroscope is charged, say positively, and another charged conductor is brought near it, the leaves will collapse if the conductor has a negative charge but will stand still further apart if the conductor is positively charged. This instrument can only be used for dealing with very small charges as the little gold leaves would be torn off if the effects are too strong; we shall use it later in studying the action of condensers.

A body charged positively or negatively attracts neutral bodies; a body charged positively attracts a negatively charged body but repels another positively charged one. In the case of very light bodies free to move these forces of attraction or repulsion will actually make them move towards or away from each other as the case may be. This movement implies a force conveyed from the one to the other by some medium in the space between them; the medium is not the air as the effect can take place in a vacuum, it must therefore be the invisible ether medium, or rather the strains set up in the ether by the abnormal condition of the charged body or bodies.

If a brass ring is insulated and has attached to it some little balls of pith by light threads, as shown in Fig. 7, and if the ring and balls are electrified it will be found that the balls will rise in the air and remain supported well away from the ring. An invisible force is supporting them against the action of gravity similar to the action of the invisible force which acts on neutral bodies, or across space between electrified bodies, in the experiments already described. No force can be conveyed from one place to act at another place without a medium, and in conveying the force the medium is always strained. Power from a steam engine is conveyed to a loom or lathe by the medium of a belt, or a shafting, or a rope drive, and in conveying the force the belt, or the shaft, or the rope is strained.

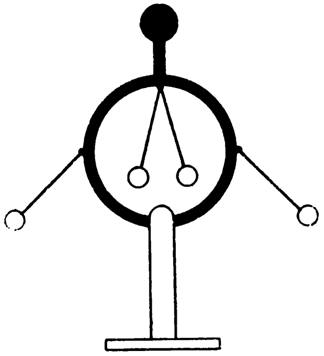


Fig. 7.

As already explained the ether must be the medium in the case before us and the force is conveyed by a state of strain in the ether medium. Since it is usual to denote a force by a line we picture to ourselves this ether strain in all directions round a charged body as lines of strain; since it is set up by what is called a state of electrification in the body we call this "Electric strain" in the ether, and represent it in a picture by "Lines of electric strain." Each line represents a unit of strain force in the ether.

Since we are accustomed to represent forces as acting in a definite direction it is convenient to assume the direction of an electric line of force in the ether as that in which a positive charge would be urged, *i.e.* out from the positively charged bodies and into the negatively charged ones.

Each electric line of force or strain in the ether starts at a unit of positive charge and ends at a unit of negative charge; they issue out and enter conductors always at right angles to the surfaces of the conductors, and their shape in space depends on the arrangement of charged bodies in the vicinity.

Thus if an insulated metallic sphere is isolated from other conductors and charged, the electric lines of strain in the ether round it are as shown in Fig. 8 (A). The arrows on the lines show the direction of the strain.

If two insulated spheres are charged, one positively and the other negatively, and placed near each other, the electric lines of strain in the ether will be shown in Fig. 8 (B). Note that though the lines are curved between the spheres, yet they are at right angles to the surfaces of the spheres where they enter or leave.

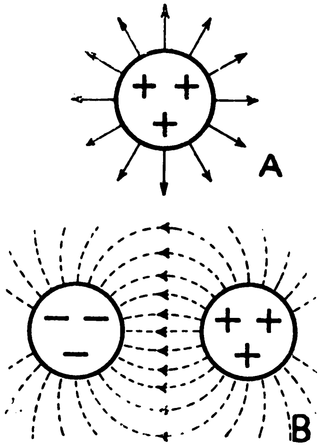


FIG. 8.

If an insulated metal plate A is charged positively and a similar metal plate B is charged negatively and placed near A the electric lines of strain between the plates will be as shown in Fig. 9. In this case the electric lines are straight except near the edges, and are uniformly distributed in the space between the plates; that is to say there are a uniform number of lines per sq. cm. in the space between the plates. This is an example of what is called a "uniform electric field." In each of the cases described only a few electric lines are drawn, the actual number which exist in the ether space will depend upon the amount of the positive or negative charges on the bodies which are causing the strain. The electric field is the space in which the ether is strained, the strength of the field being measured by the number of strain lines per sq. cm. at any point. We cannot have free electrons without having atoms which have lost electrons, and electric lines of strain which start from positive charges, due to

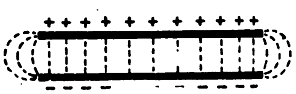


FIG. 9.

atoms which have lost electrons, end on negative charges which are the complementary number of free electrons. We can thus see why a neutral body is attracted by a charged body; some lines of ether strain stretch from the positively charged body in Fig. 10 to the neutral body; each line issues from an atom which has lost an electron, or at least from a state of deficit of one electron on the charged body, and where it enters the neutral body there is a free electron constituting a negative unit of charge. In other words the electric strain in the ether has disturbed some of the electrons of the neutral body accumulating electrons to that side of it nearest the charged body; then the lines of strain being like elastic strings tend to shorten, and if their number is great enough this force of contraction will pull the neutral body up to the charged body. Thus we see that before a neutral body is attracted by a positively charged body it is really negatively charged on the nearest side by the influence of the electric lines of force set up in the ether, and then the positive charge attracts the negative charge. The attraction of a negatively charged body for a neutral body is explained in a similar manner.

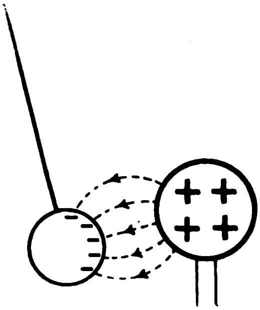


FIG. 10.

The forces of attraction and repulsion round bodies electrically charged are therefore due to the strain set up in the ether around them.

Current of Electricity.—The molecules and electrons in a substance are always in a state of vibratory movement, the rate of vibration depending directly on the temperature; at the absolute zero of temperature (— 273° C.) all vibratory molecular movement has ceased.

If, in addition to this vibratory movement, there is set up a regular drift of electrons from one end of the substance to the other, that would constitute what is commonly called a current of electricity. How is this drift to be set up? It has been noted that electric strains in the ether are set up by an accumulation of electrons at one side and a deficit of electrons at the other, and that if possible electrons will move, or positive and negative charges will attract each other and combine, so as to remove the strain. Positive and negative charges can combine if the ether is strained in a conducting path. Thus if we have a good conductor, such as copper wire, and put an electric strain on the ether in and around the wire, electrons will move along it tending to remove the strain.

Consider the simple case of a primary cell. When zinc is put in contact with a solution of sulphuric acid, or in a solution of sal-ammoniac as in a Leclanché cell, the zinc becomes negatively charged, *i.e.* has an excess of electrons, the solution is positively charged, *i.e.* has a deficit of electrons. The ether in the vicinity is electrically strained between the positive solution and the negative zinc. If a piece of copper wire is now made to connect the zinc to the solution the ether in the copper is strained, and, copper being a conductor, electrons will flow along it tending to remove the strain. The moment this displacement of electrons occurs in the wire and cell a chemical action sets up between the solution and the zinc, keeping up the negative charge on the zinc and the positive charge in the solution. Thus the flow of electrons along the copper wire will be kept up and this continuous flow of electrons is called a current.

As remarked before a unit of positive charge may be the nucleus of an atom round which the electrons are arranged and round which they may be moving in circular orbits, or it may be the residue of an atom which has lost one or more electrons. In either case the positive units may be pulled by the ether strain along the conducting wire from the solution to the zinc at the same time as the electrons move in the opposite direction to meet them. Since, however, an electron is very much smaller than an atom, or the residue of an atom, it is likely that electrons can pass much more easily along a conductor than the unit of positive charge which is of atomic size. In gases and liquids the movement of positively charged particles or " ions " often constitutes a current, but in the general case a current of electricity may be taken to mean a flow of electrons from the negative ends of ether strain lines to the positive ends ; this is at variance with the teaching of the older text-books in which electricity was always supposed to flow from positive to negative, following the analogy of water which flows from a high level to a low level. Here again the discrepancy exists because bodies which were formerly said to be negatively electrified are now found to be those on which there is an excess of electrons.

A flow of electricity will always take place in a conductor when the ether in it is electrically strained, and if this strain is kept up the flow will be continuous. If two or more Leclanché or other cells are connected in series the electric strain in the ether will be greater than that obtained with one cell; it will in fact be equal to the sum of the strains set up by each cell, and the resulting displacement or current in a conducting wire attached to the battery will be correspondingly greater. As in a water analogy one might have a tank on each floor of a house with pumps sending water up from tank to tank; the rate of water current in a pipe leading from the top tank back to the bottom one will increase with the number of pumps thus employed in series; the greater the number of pumps the greater the water pressure set up. Similarly the chemical action in each cell acts like a pump, each keeping up a certain pressure or strain in the ether, and the resulting strain depends on the number of cells in series. The ends of each wire on the armature of a dynamo when it is kept revolving have positive and negative charges and therefore an electric strain is set up in the ether by them; as a number of the wires are connected in series the resulting ether strain is the sum of all the strains due to the several wires

Thus a battery of cells or a dynamo can be used as a source of ether strain for getting a current of electricity to move through a conducting circuit.

Potential.—The electric strain in the ether available for making an electric current flow through the medium in which the ether is strained is called the electric pressure, or potential, and is measured in units called "Volts." When a body is charged the ether in and around it is strained and it is then said to have a certain positive or negative potential, according to the nature of the charge. If one body is charged positively and another negatively there is said to be a difference of potential between them; if two bodies of the same size are charged equally with positive or negative electrification there is no difference of potential between them. If two zinc plates are placed in the same acidulated water both will be charged negatively and no current will flow along a copper wire connecting them. The method of measuring difference of potential in volts or smaller scientific units will be explained in Chapter V.

Resistance.—With a given electric strain exerted on the ether in and around any substance the resulting movement of electrons through it as a current or discharge will depend upon the nature, length, and cross-section of the substance. For example, with a given ether strain, or voltage, applied there will be a more rapid movement of electrons in copper than in iron or tungsten, and it will take a comparatively great ether strain to cause any movement at all of electrons through mica or ebonite; copper is therefore said to have less resistance than iron, iron has less resistance than tungsten, and tungsten has much less resistance than ebonite. Different forms of matter, solids, liquids and gases, can thus be arranged in a series according to the apparent resistance they offer to the passage of electricity through them; those of comparatively low resistance are called "*Conductors*," those which allow electricity to pass through them only when a great electric strain is applied to the ether in them are called "*Insulators*." Silver is the best conductor we have; the next best is copper, and iron has roughly seven times the resistance of copper; mica, ebonite, paraffin oil, and glass are good insulators. It is natural to expect that when the ether in a piece of any substance, say copper, is electrically strained, the thicker it is the more electrons would pass a given cross-section of it per second, and the longer it is the less electrons will pass from one end to the other per second through the intervening maze of atoms and electrons in vibration. It is indeed found to be the case that the resistance varies inversely as the thickness and directly as the length.

When a discharge or current passes through a substance the substance is heated to a degree depending on the square of the current, and on the resistance which the substance offers; that is to say, the regular movement of electrons from one end to the other is accompanied by a speeding up of the vibratory movement of all the atoms and electrons in the substance. The substance now radiates heat, and if heated sufficiently may radiate light; it is interesting to note that light and heat are due to harmonic wave disturbances in the ether of very short wave-length, and that they can be set up by electrical means.

A great ether strain is required to cause a discharge across air which is therefore a good insulator, a difference of potential of from 3000 to 4000 volts being necessary to cause a discharge across one millimetre of air. When such a discharge takes place the air is heated and we see the discharge as a spark, or a succession of sparks. The conductivity of any substance depends on its temperature, decreasing in metals as the temperature rises. If a metal is cooled to a very low temperature, near the absolute zero, its resistance becomes so low that a current of electrons once started in a ring of the metal will continue flowing for a considerable time after the starting force or strain has ceased to exist.

Capacity.—When a tank is filled with water the resulting water pressure depends not only on the quantity of water put in, but also on the size and shape of the tank. Thus if equal water quantities are put into the vessels A and B (Fig. 11) the pressure at the tap in A is greater than that at the tap in B, and there may be a greater pressure in A than in B though the charge of water in A is less than in B.

Similarly when a conductor is charged, negatively or positively, the density of ether strain, or the electrical potential of the conductor depends not only on the amount of the charge but also on the size of the conductor; to some extent on its shape; and, unlike the water analogy, on the proximity of other conductors. These considerations qualify what is called the "Capacity" of the conductor so that the potential depends on the amount of charge put on the conductor and on the capacity of the conductor. For example, in the electrostatic units of measurement, a sphere of 1 centimetre radius has 1 unit of capacity and 1 e.s. unit of charge would raise it to unit potential; if 1 e.s. unit of charge were put on a sphere of 5 cms. radius its potential would only be $\frac{1}{5}$ e.s. unit of potential for its capacity is 5 times greater than that of the sphere of 1 cm. radius. For our purposes the practical unit of capacity is the microfarad which is equal to 900,000 e.s. units.

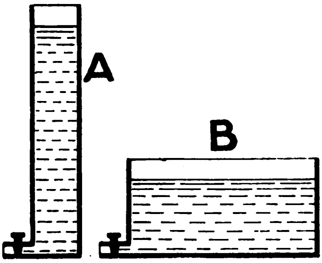


Fig. 11.

We will conclude this Chapter by emphasising the fact that when a body is electrically charged, positively or negatively, the ether around it is electrically strained. *This strain is represented as lines of electric strain force which issue out of conductors at right angles to the surface at any point.* The density of this strain, or number of lines per square cm., depends directly on the charge and inversely on the capacity of the body; in practical work it is measured in units called volts, and the density at any point is called the electrical potential at that point. A little consideration of Figs. 8 and 10 will show that the electrical potential at a point close to or on the surface of a charged conductor is greater than at a point farther away, except in cases where there are other charged or neutral conductors in the vicinity such as the example given in Fig. 9. *In radio-telegraphy transmitters our main purpose in charging up circuits and wires with electricity is to produce this electric straining of the ether around them.*

QUESTIONS ON CHAPTER III.

1. Explain the difference between positive and negative electrification.
2. Mention some good insulators ; in what way do they differ from conductors ?
3. What is meant by the "electrical potential" of a charged conductor ? On what two things does it depend ?
4. "Around an electrified body a state of strain is set up in the ether ;" what experimental facts support this statement ?
5. What is meant by the direction of an electric line of force ?
6. What is meant by joining cells in series ? If the difference of potential between the plates of a cell is 2 volts what is the difference of potential between the terminals of a battery consisting of 10 such cells in series ?
7. What is a "uniform electric field" ?
8. What is meant by "voltage" and "potential" ? When a body is electrified how does the potential of it depend on its size ?

CHAPTER IV

MAGNETISM AND MAGNETIC STRAINS IN THE ETHER

THE ether around charged bodies is electrically strained and this strain exists until a current or discharge takes place which will bring the charged body to a neutral or normal condition. The current may flow through a conducting wire, it may be a discharge across an air gap, or it may be a flow through a conducting liquid; the nature of the current may be a passage of electrons (units of negative charge) in one direction, or a passage of positive units of charge in the opposite direction, or a combination of both. It may be repeated that the direction of the electric strain force in the ether at any point near a charged conductor is at right angles to the surface of the charged conductor.

Now if there is a movement of electricity in any path a new kind of strain is set up in the ether round that path. This strain will not have any effect of attraction or repulsion on neutral or charged bodies but it will affect compass needles and magnets, iron and other magnetic substances—so that it is called a "Magnetic strain" in the ether.

A simple demonstration of this magnetic straining of the ether can be made as shown in Fig. 12 (*a*); a wire carrying a current is passed through a sheet of cardboard, soft iron filings are sprinkled on the cardboard and the cardboard lightly tapped; it will be found that the iron filings arrange themselves in whirls or concentric circles round the wire. Some invisible force has pulled the iron filings into these positions; it is not a strain in the air, since the experiment can be carried out in a vacuum, therefore it must be a strain effect in the invisible ether medium, pictured to us by iron filings, just as we can picture lines or rays of light in the dust of a darkened room through which a beam of light is set up. The distance to which this strain effect extends out from the wire will depend on the strength of the current in it.

If a small pivoted compass, or magnetic, needle is placed on the cardboard it will not now necessarily point magnetic North and South, but will set itself as a tangent to the magnetic strain circle at the point where it happens to be placed; in other words, the force which ordinarily makes the needle point magnetic N. and S. has been overcome by the force of the magnetic strain in the ether near the current-carrying wire.

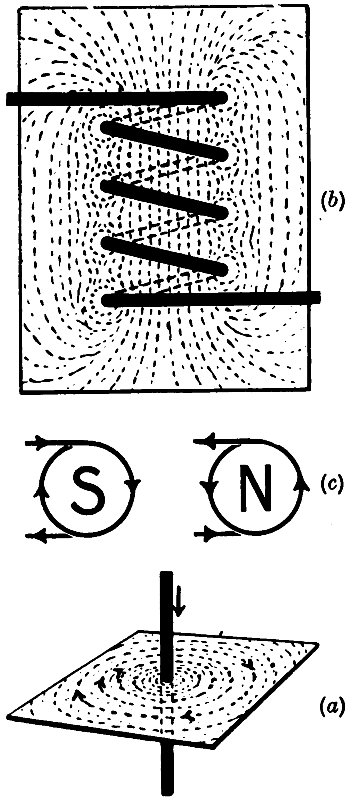


Fig. 12.

If a long piece of insulated wire is made into a cylindrical coil and a current is passed through the coil it will behave like a magnet. If pivoted at its centre and free to move it will turn round until it points in the magnetic N. and S. direction; if a sheet of cardboard is fixed on its axis and iron filings sprinkled on the cardboard they will arrange themselves as shown in Fig. 12 (*b*), showing the nature of the magnetic strain in the ether through and around the coil. Such a coil is called a *Solenoid,* and the effect on a compass needle placed near it will depend on the strength of the electric current flowing in the coil and on the number of turns of wire per cm. length of the coil; it will not depend on the kind of wire or insulation used.

It is curious that this effect can only be demonstrated with iron filings or with a compass needle which is made from steel or hard iron. Iron is the most abundant metal in the world, and it is interesting to realise that it is practically the only metal which can be magnetised, also that if it is hard iron or steel it will retain its magnetic properties when magnetised. To a slight extent bismuth, antimony, and manganese can be magnetised, or are affected by magnetic strain in the ether, but the results obtained with these metals are very small compared with those obtained when iron is employed.

Referring again to the current-carrying solenoid mentioned above, if its core is filled with iron, instead of simply air, or wood, or glass, or any non-magnetic substance, on investigating the magnetic strain set up in the ether round it by the use of iron filings or compass needles it will be found that the strain is now greatly intensified, and extends out to a great distance around the coil. With a given current in the coil the presence of an iron core increases or multiplies very greatly the magnetic strain effects set up in the ether; evidently it is easier to set up magnetic strain in ether when it is contained in iron than when it is contained in any other substance. Iron is thus said to be very "Permeable" to magnetic strain effects, or to have small "Reluctivity"—a term corresponding to "Resistance" which is used when speaking of the passage of electricity through substances. Further study shows us that the increased magnetic strain effects obtained when an iron core is used are not only due to the fact that iron is more permeable than other substances, but are to a large extent due to the fact that, when the ether in iron is magnetically strained, a physical change takes place in the iron which creates new magnetic strains, and thus multiplies the effect of the current in the coil. But first let us consider the method of measuring or comparing magnetic strain effects in the ether. It is evident that, like electric strain effects, they represent forces, therefore in a diagram we should represent them by lines or curves. Iron filings and compass needles show us approximately the shape of these magnetic forces, and since they act on the poles of a magnet it is convenient to assume their direction as that in which the N. pointing pole of a magnet would be urged along them. One line representing unit magnetic strain in the ether would mean that a magnet pole of unit strength was acted upon by unit force; for example, when a certain current flows in a certain coil with an air core we may speak of the strength of the magnetic strain at the axis of the coil as 20 lines per square cm., and when the core is filled with iron the magnetic strain may be now 10,000 lines per square cm., showing the multiplying effect or permeability of the iron.

The *permeability* of iron depends :—

(1) On the quality of the iron,

(2) On the extent to which the ether in it has been magnetically strained,

(3) On its temperature.

It has been already remarked that a solenoid carrying a current of electricity behaves like a magnetic or compass needle; if suspended through its centre of gravity and free to move it will point magnetic N. and S. When fitted with a soft iron core the effect will be much stronger, and it will always be found that there is a definite relation between the direction of the current in the coil and the end which points N.; thus if the current is reversed the coil will reverse, the end which was before pointing N. will now point S. The ends which point to the magnetic poles of the earth are called the North Seeking Pole and South Seeking Pole respectively, or more often the shorter terms N. Pole and S. Pole are employed.

To ascertain the N. and S. poles of such a coil the following rule can be applied:—Look at one end of the coil; if the current is flowing round that end in the same direction as the hands of a watch move that end is a S. pole; if the current is flowing in the opposite direction the end is a N. pole. This rule is illustrated in Fig. 12 (*c*), and assumes positive direction of current, *i.e.* that the current is a positive one flowing from the + potential end of the coil through the coil to the — potential end. The rule is true whether the coil has an iron core or not.

If a hard iron or steel core is employed with a current-carrying solenoid it will be found that after the current is stopped or the iron taken out, the latter will retain its magnetic properties for a considerable time. That is to say the ether round it will remain magnetically strained. It is now a *magnet*, not an ordinary piece of iron. If pivoted through its centre of gravity it will point in the magnetic N. and S. direction; either pole, or end, of it will attract small pieces of iron or steel but there is no property of attraction at its centre. If the N. Pole of another magnet is brought near the N. pole of the suspended magnet, the latter N. pole will be repelled and will move away; if a S. pole is brought near it will be attracted. "Like poles repel each other, unlike poles attract each other." Let us fix our attention on the fact that while the approaching magnet pole is still a distance of perhaps a foot or more from the suspended magnet the latter moves. Some force is causing it to move, a force no doubt due to the approaching magnet, but there must be some medium conveying the force. If it is desired to move something it may be pushed with a rod or pulled with a rope, but there must always be some connecting medium between the force applied and the thing moved; also in every case the rod or the rope or other medium is strained while conveying the force.

In the case of our magnets the ether must be the medium, since the experiment will work equally well in a vacuum, and the ether conveys the force from one magnet to the other because it is strained. How is the ether strained round a magnet so that it will attract iron and cause a motion of other pivoted magnets near it? Let the magnet be placed under a sheet of thick paper and iron filings be sprinkled on the paper; the filings will arrange themselves in definite symmetrical lines and curves as in Fig. 13, so that it is possible to see the peculiar state of magnetic strain in the ether round the magnet.

Thus round a magnet there exists a state of magnetic strain in the ether, and it will be found that the extent of this strain depends on the degree to which the steel has been magnetised, or on what is called the strength of the magnet. The lines of strain stretch from one pole to the other in every plane outside the magnet and no doubt the ether in the magnet is also strained.

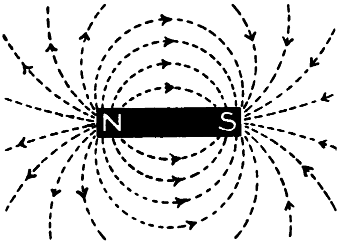


Fig. 13.

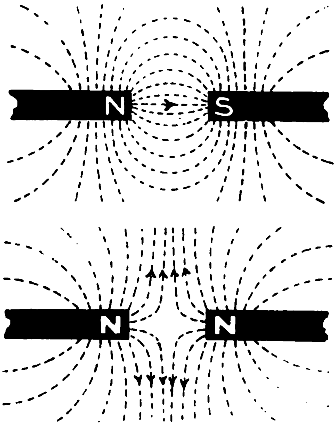


Fig. 14.

Since the direction of a line of strain is taken as that in which the N. pole of a magnet would be urged, and since we know that a N. pole will be repelled by a N. pole and attracted by a S. pole, the lines of magnetic force therefore issue from N. poles of magnets and enter at S. poles as shown by the arrow heads in Fig. 13.

If it is desired to see why two like poles repel each other and two unlike poles attract each other, the experiment with a sheet of paper and iron filings can be repeated with two magnets arranged as in Fig. 14, when the ether strain lines will be as there shown. The lines of magnetic strain set up in the ether are always tending to shorten themselves; for that reason the S. pole of one magnet is pulled towards the N. pole of another near it, as if they were connected by invisible elastic strings. The lines never cross each other, for if poles are placed in any position near each other the lines peculiar to each disappear and new irregular curves of ether strain take their place, just as in mechanics a number of forces gives a resultant force which has the same effect.

The lines of magnetic strain are self-repellent, therefore those farthest out in what is termed the "MAGNETIC FIELD" are pushed into curves by those inside them in the field. The "strength of a magnetic field" at any point in air, or other non-magnetic substance, is measured by the number of magnetic lines which cross a square centimetre at that point, the square centimetre being taken at right angles to the direction of the magnetic lines. This strength of field is usually denoted by the letter H.

We must now consider the difference between an ordinary bar of iron and one which is magnetised. They may be alike in appearance but the latter has got properties of attraction and repulsion not possessed by the former. The difference is in the arrangement of the atoms of iron in the bar; in an ordinary bar of iron the atoms are all massed together without any order; in a magnetised bar some of the atoms are arranged in definite lines or chains along the bar, and the more of these chains formed the stronger is the magnet. The bar would be completely magnetised, or as we say "saturated," if all the atoms were arranged in definite lines. It is much the same as the difference between an irregular heap of bricks and a brick wall, or another heap of bricks in which at least the outside ones were arranged in definite order.

Again we must remember that an atom of iron contains electrons in motion, the motion being in definite directions in each atom, and when the atoms are rearranged in magnetising a bar they are not only arranged in definite lines but are also arranged so that the electronic movements in the atoms synchronise with each other. We cannot say how electrons revolve or move round the centre of an atom, but a chain of atoms in a magnetised bar of iron may be compared with a row of pulleys on a long shaft. When driven the pulleys all revolve in the same sense, and from them a line of belts will move in the same direction conveying forces to machinery placed beneath.

The scientist Ampère many years ago propounded the idea that each atom of iron had electric currents flowing round it. Before magnetisation the atoms were in disorder and hence the currents moved irregularly; but when magnetised some of the atoms become parallel to each other and are arranged in chains along the bar so that the currents round these atoms are flowing round in the same direction or sense. Thus order is established out of disorder and the magnetic properties appear. We see how well this hypothesis agrees with the more definite knowledge we have obtained in later years regarding the constitution of an atom. Fig. 15 illustrates this conception of the magnetisation of iron, and the student is referred to works on Magnetism and Electricity, where experiments are described which go to prove the correctness of this explanation.

Let us now consider how iron can be magnetised, in other words how some of the atoms in an ordinary bar of iron can be properly rearranged so that the bar evinces magnetic properties, and magnetic lines of strain are set up in the ether around it. This can be done by simply laying the bar or rod of iron on the table and drawing a pole of a magnet along the bar from end to end, taking care always to rub along the bar in one direction. The more we rub the more strongly will the bar become magnetised, and we shall find that the end where we leave off rubbing is of opposite polarity to the pole used for rubbing, in consonance, as it were, with the rule that unlike poles attract each other. Note that nothing goes out of the magnet into the bar of iron. It is simply that the magnetic lines of strain in the ether at the pole of the magnet affect the atoms of iron in the bar so that some of these atoms are turned into definite directions along its length, in line with the path of the ether strain lines of force.

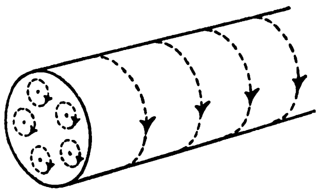


FIG. 15.

A more satisfactory method of magnetising iron or steel is that of putting it into a current-carrying solenoid and this is the method adopted commercially. It will be found that soft iron can be easily magnetised and is very effective as a core in a solenoid, but it loses its magnetism very easily. On the other hand hard iron and steel are more difficult to magnetise, their permeability is not so great, but once magnetised they retain their magnetism for a considerable time. Apparently it is difficult to rearrange the atoms in a bar of steel where they are very compact and pressed together: once rearranged they are not easily susceptible to disarrangement.

Some kinds of iron ore evince magnetic properties when dug out of the ground; the best known of these is called magnetite (Fe_3O_4), now found principally in Sweden but in ancient times it was found in a province of Asia Minor called "Magnesia," hence the derivation of the words "magnet," "magnetism," etc.

Now let us briefly review and consider the general conditions under which electric and magnetic strains may be set up in the ether medium. If a body is electrically charged, positively or negatively, the ether round it is electrically strained; if two neighbouring bodies are charged, one positively and the other negatively, the ether between them is electrically strained and invisible lines of force extend from the one body to the other. As long as the body, or bodies, retain any charge so long will some electric strain remain in the ether. *Thus electric straining of the ether is associated with charges on bodies,* i.e. *electricity at rest.*

It has already been shown that when electricity moves along a wire or other path the ether round the path is magnetically strained. *Thus magnetic straining of the ether is associated with discharges or current,* i.e. *electricity in motion.*

Again, a state of electric strain exists in the ether round a charged body; if the charge disappears the electric strain will disappear, but for the charge to disappear there must be a flow of electrons to or from the charged body; this flow of electrons constitutes a discharge or current, round the path of which the ether is magnetically strained.

Hence we see that when an electric strain in the ether disappears a magnetic strain is set up in it.

Now, taking a simple case as an example, if an electric strain in the ether is due to positive and negative charges the direction of the electric strain will be as shown in the upper diagram of Fig. 16; if a discharge passes across the air gap from the one body to the other, or if they are connected by a wire to obtain a discharge through the wire, a magnetic strain is set up whose direction is as shown in the lower diagram. It will be seen that the magnetic strain acts in planes at right angles to those of the electric strain which it replaces.

Thus electric lines of strain owing to a charge or charges act at right angles to the magnetic lines of strain which replace them when a discharge takes place.

To further illustrate this point let the copper wire A in Fig. 17

be negatively charged and the metal plate B underneath positively charged. The ether near the wire and plate will be electrically strained as shown by the full line curves in the Fig., the lines of force issuing out of the plate at right angles to its surface and entering the wire at right angles to its surface, each line of force having a positive unit of charge at one end and a negative unit of charge at the other end. Now suppose a discharge to take place between the wire and plate; the electric strain will disappear, but during the discharge a magnetic strain is set up in the ether round its path. This magnetic strain is in the form of circular lines of strain round the discharge path, a few of which are shown by dotted circles in the Fig. It is evident that the magnetic strains are acting at right angles to the electric strains which they have replaced.

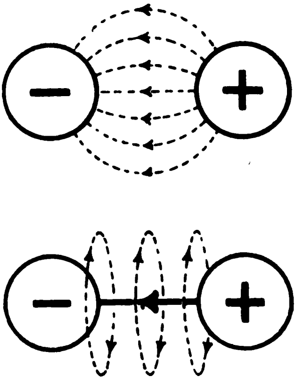


Fig. 16.

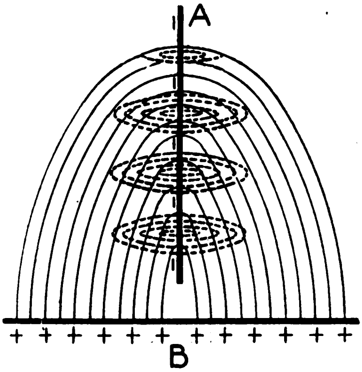


Fig. 17.

This fact is of the greatest importance because if we can get charge and discharge to follow each other consecutively we shall have electric and magnetic strain effects alternately in the ether, acting at right angles to each other; not only at right angles in space as shown, but also as regards time, for the one will be a maximum when the other is zero.

When two strains alternate with each other in this way in any medium a harmonic wave motion is set up in it and energy is spread out through the medium by this wave motion.

Water is a familiar fluid medium in which wave motion can be set up; familiar because we can see it and can see the waves. Large waves in water are caused by wind and gravity but let us consider the case of ripple motion in water. Suppose someone gently plunges a stick up and down in the water at the centre of a large pond; ring ripples or waves will be set up, will spread outwards, and will continue for some time. What causes the water at any point to rise to a crest and fall to a trough alternately? There is an attraction between the molecules on a surface of water which gives to the surface what is called a "Skin effect." Because of this attraction, or surface tension, or skin effect, it is possible to float a needle on the surface of water.

Now when water is heaped up into a crest, as shown in Fig. 18, the surface is stretched and the force of surface tension tends to pull the molecules close together again. Therefore this force, shown in the Fig. by arrows marked ST, tends to flatten down the water, and it does move downwards. When the surface has arrived at AB the surface tension is again normal and the motion should cease were it not for the fact that during the motion of the water downwards a new force is created—that of inertia of motion, which makes the water swing too far. Just when the extra surface tension is zero at AB the force of inertia is a maximum, so that the water goes on downwards and the surface becomes a trough, as at CD. Here the force of inertia has died out, but the surface is again strained and a force of surface tension again set up, tending to shorten the surface and bring it up to AB. During its motion upwards the extra surface tension dies out, but again inertia of motion upwards is called into play. With small ripples or waves the force of gravity need not be considered as it is practically constant.

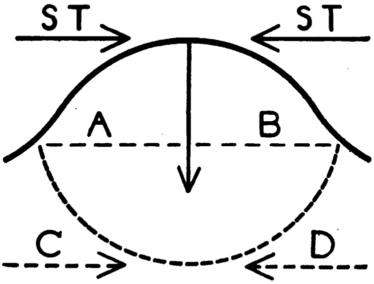


Fig. 18.

Thus we see that the up-and-down motion of water is caused by two forces acting at right angles to each other as regards space and time. Water being an elastic medium the strains are communicated from one alternate crest and trough to the water beyond, and the ripple motion spreads outwards through it. How do we know that this ripple or wave motion conveys energy? Suppose there is a piece of wood floating near the edge of the pond. When the ripple motion arrives to the water at the wood the latter will alternately rise and fall. Now the wood has weight, no matter how small, and to raise it against the pull of gravity implies that energy has been exerted on it—this energy comes from the ripple motion in the water. There may be lots of pieces of wood floating in the water all round the pond and each will be periodically raised a little by the wave motion when it arrives. Thus some of the energy applied in plunging the stick up and down in the middle of the pond has been carried out in all directions by the wave motion set up in the water, and it can be made to do work on, or apply forces to, bodies near the edge of the pond. Two kinds of strains set up in the water at right angles to each other implies a radiation of energy through the water, and this is true for any other elastic medium.

The student will therefore appreciate the importance of the electric and magnetic strains which can be set up in the ether medium by electrical means; if charge and discharge can be made to follow each other rapidly these strains will follow each other alternately in the ether, and will act at right angles to each other. Energy will thus be radiated through the ether medium and will affect substances at some distance from the source of ether strains.

As far as Radio-Telegraphy is concerned we must concentrate our attention on the existence of these ether strains; we must realise that bodies are electrically charged to set up an electric strain in the ether, and discharges or currents are produced so that the ether may be magnetically strained.

EXPERIMENTS ON CHAPTER IV.

1. Suspend a magnet by its centre of gravity, and try the effect of bringing a pole of another magnet (*a*) near its N. pole, (*b*) near its S. pole.

2. Place a bar magnet under a sheet of white cardboard. Dust soft iron filings lightly over the cardboard; tap the cardboard lightly with a pencil and note how the iron filings map out magnetic lines.

3. Place two magnets in a line with their N. poles opposite each other and about two inches apart. Repeat experiment 2 and note how the magnetic lines show why N. poles repel each other.

Repeat experiment with two S. poles opposite each other, and with a N. pole opposite a S. pole; note why unlike poles attract each other.

4. Fill a glass tube loosely with hard iron filings; proceed to magnetise it as if it were a bar of iron, using a pole of a magnet; note how the filings rearrange themselves, see if the tube has magnetic properties. Shake up the tube and test again.

5. Carry out the experiments described in this chapter with a current-carrying wire, and a current-carrying coil.

QUESTIONS.

1. What are "magnetic lines"? What is meant by the direction of a magnetic line?

2. Explain how a current-carrying coil of wire sets up a magnetic strain in the ether.

3. Draw an iron core wound with insulated wire; show the direction of a current of electricity through the coil and the resulting N. and S. poles of the iron.

4. Show how a coil could be wound and a current passed through it so that it would have a N. pole at each end of the coil and a S. pole in the middle ?

5. The magnetising force of a current-carrying coil is $\frac{4\pi}{10} \times \frac{CT}{l}$; if a coil, 10 inches long, has 200 turns of wire, and the current flowing in it is 0·6 ampere, what is the magnetising force of the coil ? In the formula given C is the current in amperes, T is the number of turns in the coil, and l is its length in cms. 1 inch = 2·54 cms.

6. What is necessary in order to obtain a harmonic wave motion in an elastic medium possessing inertia ?

7. How can a wave motion of strain be set up in the ether medium ?

CHAPTER V

ELECTRICAL MEASUREMENTS AND CALCULATIONS

All units of measurement used in electrical calculations are based on the Metric, or, as they are usually called, the C.G.S. units. In this system of units the centimetre is the unit of length, the gramme is the unit of mass, and the second is the unit of time—hence the name—C.G.S. units.

Force.—In the British system of units, a unit of force is the force which would give a mass of 1 lb. an acceleration of 1 foot per second every second. In the C.G.S. system the unit is that force which would give a mass of 1 gram an acceleration of 1 cm. per second every second. This is called a "*dyne.*"

A *weight of* 1 *gram exerts a force of* 981 *dynes, i.e.* gravity would give a mass of 1 gram in falling an acceleration of 981 cms. per second every second.

Work.—Work is always done or energy is expended when a force is moved through a distance, and the work is measured by the *product of the strength of the force and the distance through which it has been moved.* Thus if a force of 1 lb. is moved through 1 foot, the work or energy is said to be 1 ft.-lb.; if a cubic foot of water (weighing 62½ lbs.) is raised 20 feet the work done is 62½ × 20 ft.-lbs. = 1250 ft.-lbs.

Similarly in the C.G.S. system if a weight of 2 grams is raised through 6 cms. the work done is 12 gram.-cms. and the unit of work is the work done when unit force (1 dyne) is moved through unit distance (1 cm.), that is to say, the unit of work is a *dyne-cm.*; this is called an "*erg.*"

Hence unit of work or energy = 1 *erg* = 1 *dyne-cm.*

Ten million ergs (10^7 *ergs*) *is called a joule.*

Power.—Power is the rate of doing work—in British units we measure power by the number of *ft.-lbs. of work done per second:*

if there are 550 ft.-lbs. of work done per second, we call that a horse-power. Thus power $= \frac{\text{work done in ft.-lbs.}}{\text{seconds of time it took to do it}}$

and horse-power $= \frac{\text{work done in ft.-lbs.}}{\text{seconds taken} \times 550}$

In the Metric System power is also measured by the number of units of work done per second.

Hence power unit = 1 erg per second.

In electrical calculations a larger unit is adopted. If work is being done at the rate of 10 million ergs (10^7 ergs), or 1 joule per second, we say the power is 1 watt.

$$\text{Watts} = \text{joules per second} = \frac{\text{ergs per second}}{10^7}$$

Thus there are the " absolute " units and, in general, larger units based on them which may be used if found more practical.

Length.—absolute unit—a centimetre.
larger units—metre = 100 cms.; Kilometre = 1000 metres.
Time.—absolute unit—a second.
Mass.—absolute unit—a gramme.
Force.—absolute unit—a dyne.
larger unit—weight of 1 gramme = 981 dynes.
Work.—absolute unit—an erg.
larger unit for electrical purposes—a joule = 10^7 ergs.
Power.—absolute unit—an erg per second.
larger unit for electrical purposes—a watt = 10^7 ergs per second = 1 joule per second.

The units used for electrical and magnetic measurements are based on the above; unfortunately there are two sets of absolute units in use called the electro-static and electro-magnetic units: there are also practical units used for ordinary commercial applications.

For our purpose it will be sufficient to consider the absolute or C.G.S. electro-magnetic units and their relation to the practical units.

Current.—When a current of electricity flows round a circle of wire magnetic lines of strain are set up as already described, and it will deflect a magnetic needle placed at the centre of the circle. When the circle is in the first place parallel to the needle the current acts on the needle with a certain force, which can be measured in "dynes," and which will depend directly on the strength of the current and inversely on the radius of the circle. (See Fig. 19.) Current is quantity of electricity flowing per second, and it is found by experiment that the force in dynes with which the current acts on the magnet is given by the formula

$$\text{F dynes} = \frac{2\pi . \text{C} . m}{r}$$

where m = strength of magnet's pole, r = radius of the circle, and C is the current.

Now if $m = 1$, $r = 1$ cm., $\text{C} = 1$, then $\text{F} = 2\pi$ dynes, or 1 dyne for each centimetre of the circumference (which $= 2\pi$ cms. when $r = 1$ cm.).

Thus we see that *unit current is that current which, flowing in a circle of unit radius, acts on unit magnet pole placed at the centre with one unit of force per each unit of length in the circle.*

It is evident why the unit is called an electromagnetic unit for its definition is based on the magnetic effects of a current in a wire.

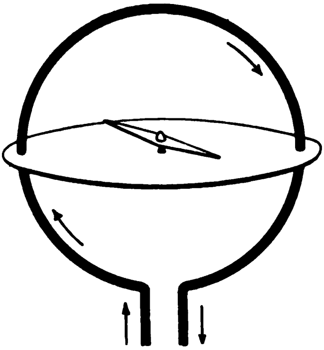


Fig. 19.

There is no special name given to this absolute or C.G.S. unit of current, but, being too large for ordinary purposes, one-tenth of it is used as a practical unit, and is called an "ampere." One-millionth part of an ampere is called a "microampere."

Quantity or Charge.—A current is quantity per second, or discharge per second; thus the C.G.S., or absolute unit of current, is the C.G.S. or absolute quantity of electricity flowing per second, and a current of 1 ampere is $\frac{1}{10}$th of an absolute unit of quantity or charge per second. This practical unit of quantity is called a "coulomb." For some purposes a much smaller unit is required, and the millionth part of a coulomb is called a "microcoulomb." Just as a current of water is measured in gallons per second, so a current of electricity is measured in coulombs per second, but a coulomb per second is called an ampere.

Potential and E.M.F.—When water flows through a pipe the force causing it to move is the water pressure, which might be called the "water motive force"; in the same way a current of electricity flows when a difference of potential is applied to a circuit, and this *difference of potential is called the Electro Motive Force, or, shortly, the E.M.F.*

When water flows through a pipe we know that for a given rate of flow, or current, the work which can be done by the water depends on its pressure; thus, if the current is at the rate of 1 lb. of water per second and it flows with a force which is due to a difference of level of 20 feet, then the water-flow can do $1 \times 20 = 20$ ft.-lbs. of work per second. If the force is due to a difference of level of 50 feet, the work done by a current of 1 lb. of water per second is 50 ft.-lbs.: thus, the work done per second by what might be called unit strength of water current is a measure of its pressure, or the difference of level which constitutes the force acting on it: 20 ft.-lbs. of work on unit current represents 20 feet difference of level, 50 ft.-lbs. of work on unit current represents 50 feet difference of level.

In a similar manner the height to which a quantity of water is raised may be measured by the work done on each lb. of water per second.

An analogous method is adopted in electrical science for measuring difference of potential: the units of work here used are ergs and the C.G.S. unit of current is one C.G.S. unit of quantity per second.

If one erg of work is done by one C.G.S. unit of current in flowing from one point to another we say that the difference of potential between the two points is one absolute, or C.G.S. electromagnetic, unit of potential. This is much too small a unit of potential for practical purposes, and one hundred million of these units (or 10^8 ergs) are used to form the practical unit of difference of potential or E.M.F., which is called a *volt*.

Thus, if the difference of potential between two points in a circuit is 1 volt it means that on each C.G.S. unit of current flowing between the points 10^8 ergs of work are done; since an ampere $= \frac{1}{10}$ C.G.S. unit, on each ampere of current flowing between the two points 10^7 ergs of work are done.

Thus a volt represents 10^7 ergs of work done per second on each coulomb of charge or discharge, it being always remembered that "Coulombs per second" means the same thing as "amperes."

Electrical Work.—The C.G.S. unit of work is, of course, the erg, and it has been shown that this is the work done by the

C.G.S. unit of current when it flows from one point to another between which unit difference of potential exists.

A larger unit is 10^7 ergs, called a joule; it is the work done by one ampere of current in flowing between two points, A and B, when the difference of potential between A and B is one volt.

Now V volts represent V joules of work by each ampere of current, therefore if the current is C amperes the work done per second is VC joules, and if the current flows for t seconds the total work done equals VCt joules.

Thus, if an electromagnet takes 2 amperes of current when 8 volts are applied to it and the current is kept up for ten minutes (600 seconds), the total electrical work done, or energy expended on the coil is—

$$VCt = 8 \times 2 \times 600 = 9600 \text{ joules}$$
$$= 9600 \times 10^7 \text{ ergs.}$$

The flow of electricity (2 amperes) = 2 coulombs per second
$= \frac{1}{5}$ C.G.S. unit per second.

Electrical Power.—Power is the rate of doing work; the C.G.S. unit is 1 erg per second, so that the power in C.G.S. units is the ergs of work done divided by the time in seconds taken to do it. The practical unit of work is a joule, and therefore of power is a joule per second.

The *joules per second* are obtained by multiplying the volts and amperes together, and a joule per second has been given a name, *i.e. a watt,* which is therefore the practical unit used for measuring electric power.

$$\text{Thus watts (W)} = VC = \text{volts} \times \text{amperes}$$
$$= \text{joules per second.}$$

A larger unit—the kilowatt = 1000 watts.

Electrical Resistance.—When water flows through a pipe the resistance it meets with depends directly on the length of the pipe, inversely on the cross section of the pipe, and directly on the conditions of the pipe, that is the number of bends in it and how much obstruction there is in it due to leaves, roughness, or other cause.

When a difference of potential is applied to any electrical circuit a current flows through the circuit, and the ratio of the volts applied to the current that flows, $\left(\frac{V}{C}\right)$, is called the resistance of the circuit measured in units called *ohms*. Thus if 10 volts are applied and 2 amperes of current flow, the resistance (**R**) is $\frac{10}{2} = 5$ ohms. An ohm is therefore the practical unit of electrical resistance ; it is the resistance of a circuit through which 1 ampere will flow when 1 volt is applied, or 6 amperes will flow when 6 volts are applied, etc.

As in the water analogy it is found by experiment that the electrical resistance of a circuit depends—

(1) Directly as its length—the greater the length the greater is R.

(2) Inversely as its cross section—the greater the cross section the less is R.

(3) Directly on the conditions of the circuit, that is to say on the materials of which the circuit is made, for different materials allow electrons to pass along them at different rates.

The resistance effects of different materials are compared by calculating, from experiments, the resistance of a piece of each material 1 inch long and 1 sq. inch section (or 1 cm. long and 1 sq. cm. section in some Tables). The resistance of such a piece of a material is called its *specific resistance.* Thus to find the resistance of any piece it is only necessary to multiply the specific resistance by the length in inches (or cms.) and divide by the cross section in sq. inches (or sq. cms.), using the English or metric units according to the system on which the specific resistance is calculated.

$$\left.\begin{array}{l}\text{Thus the specific resistance}\\\text{of copper}\end{array}\right\} = 0{\cdot}00000066 \text{ ohm per inch cube}$$

$$\rho = 0{\cdot}00000066 \text{ ohm}$$

$$\text{Then } R = \frac{\rho \times l}{A} \text{ ohms.}$$

The resistance of a piece of copper wire 100 yards long and 0·02 sq. inch section is

$$R = \frac{0{\cdot}00000066 \times 100 \times 36}{0{\cdot}02} = 0{\cdot}1188 \text{ ohm.}$$

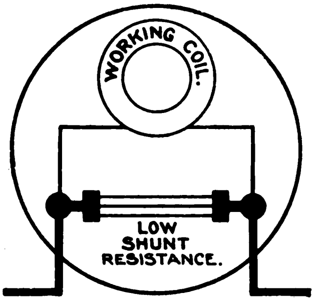
The specific resistance of German silver is 0·00001181 ohm, of iron is 0·000003569 ohm ; the values for any materials can be found in electrical pocket-books and text-books.

It will be pointed out in a later chapter that the above method of calculating resistance is only applicable when steady currents are used ; with oscillating discharges or currents the resistance will be higher than for steady currents.

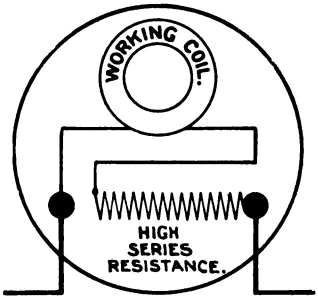
Resistance in Series.—When resistances are connected in series the resulting resistance is the sum of their resistances;

$$R = (r_1 + r_2 + r_3 + \text{etc.}) \text{ ohms}$$

and the current will be of the same strength in all parts of the series circuit. If a long thin wire is joined in series with a short thick one and an E.M.F. applied across the terminals the current will be of the same strength in both wires, just as a water current must be of the same strength in a row of pipes joined in series no matter how their diameters may vary. But the volts used up in the first resistance is $C \times R_1$ and in the second resistance is $C \times R_2$; these are called the drops of potential across the resistances, and we see that *the drop of volts (or volts required) to send a current through a resistance is directly proportional to the current and to the resistance, and is equal to their product.* ($V = CR$.) This relationship is known as Ohm's Law.



AMMETER.



VOLTMETER.

Fig. 20.

The current flowing in a circuit is measured by an ammeter, which is joined in series with the apparatus or circuit, just as a gas meter is joined in series with the pipes through which the gas flows. A gas meter offers little resistance to the flow of gas, so that not much pressure is wasted in it; similarly an ammeter has a very low resistance so that the drop of volts in it will be very small even if the full current is flowing. It usually consists of two parts, a shunt of manganin strip through which most of the current flows and a small working coil joined in parallel with the shunt through which a definite fraction of the current flows, the current dividing between them inversely as their resistances, or—

$$\frac{\text{current in coil}}{\text{current in shunt}} = \frac{\text{resistance of shunt}}{\text{resistance of coil}}$$

The resistance of the shunt is low and depends on the current to be carried; thus if the ammeter measures up to 5 amperes the resistance of the shunt part of it might be about 0·0145 ohm. The coil has a small resistance of not more than 2 ohms, and, as the coil and shunt are joined in parallel, it is easily seen that the resistance of the whole instrument is very small.

A voltmeter is very similar in design to an ammeter but is a high resistance instrument: its coil works exactly in the same manner as that of an ammeter, but instead of being shunted with a low resistance it is joined in series with a very high resistance, which usually consists of a long thin insulated manganin wire wound on a frame which is fixed at the back, inside the instrument. Thus a Weston voltmeter to measure up to 220 volts may have a resistance of 16,000 ohms, of which 3 ohms is the resistance of the little working coil and the remaining 15,997 ohms is the resistance joined in series with it. A voltmeter is never joined into the main circuit but is always joined across the points in any circuit whose difference of potential it is desired to measure. It is made to have a high resistance because in measuring a difference of potential we wish to do so with an instrument which takes the least possible current. One does not measure the steam pressure going to an engine by diverting a lot of the steam and bringing it to the steam gauge: if this were done the pressure in the engine cylinders would be seriously reduced. A small pipe leads a small quantity of the steam to the steam gauge, and for a similar reason a voltmeter has a high resistance so that very little current will be used in it when measuring the voltage; the wires connecting the voltmeter to the points desired can therefore be of small diameter. The difference between an ammeter and a voltmeter is shown in Fig. 20.

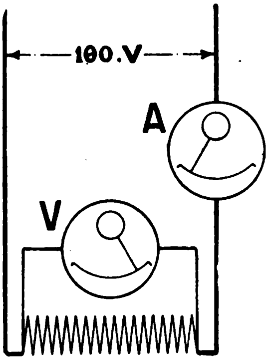


Fig. 21.

An ammeter is joined in series with the circuit or apparatus, a voltmeter in shunt across it as shown in Fig. 21. If an ammeter is joined in shunt across a circuit by mistake it is likely to be burnt out. Thus in Fig. 21 suppose there are 100 volts applied to the apparatus and that the ammeter, of 0·03 ohm resistance say, is joined across the circuit instead of the voltmeter, then by Ohm's

Law the current which flows through it $=\frac{V}{R}=\frac{100}{0\cdot03}=3333$ amperes, which would burn it out.

If a voltmeter is joined by mistake in series in a circuit, nothing would happen, for it has such a high resistance that only a very small current would flow.

The author has seen a student join an ammeter to a battery, nothing else being in the circuit, to see what the current of the battery was! Naturally the current was that which flowed through the low resistance ammeter and promptly burnt it up.

It is not intended to describe here the different designs of ammeters and voltmeters as these can be studied in any electrical engineering text-book; a special design much used in radio-telegraphy, known as the hot-wire ammeter, will be described in Chap. XXI.

When resistances are joined in parallel the combined resistance can be found from the formula:—

$$\frac{1}{R}=\frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3}+\frac{1}{r_4}+\text{etc.}$$

where R is the combined resistance.

Thus, suppose A and B, in Fig. 22, are two mains which are at a difference of potential V volts, and are joined by three resistances, r_1, r_2, and r_3 in parallel.

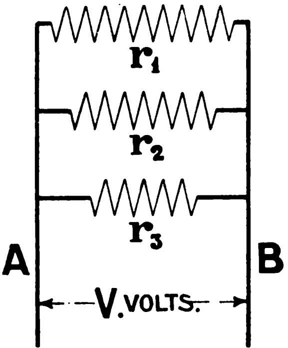


FIG. 22.

Then by Ohm's Law

$$\text{Current in } r_1=\frac{V}{r_1}$$

$$\text{Current in } r_2=\frac{V}{r_2}$$

$$\text{Current in } r_3=\frac{V}{r_3}$$

$$\text{Total current}=\frac{V}{r_1}+\frac{V}{r_2}+\frac{V}{r_3}$$

$$C=V\left(\frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3}\right)$$

But if R is their combined resistance by Ohm's Law we have also $C=\frac{V}{R}=V\left(\frac{1}{R}\right)$.

$$\therefore \frac{1}{R}=\frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3}.$$

It is very usual to have two resistances in parallel, in which case

$$\frac{1}{R}=\frac{1}{r_1}+\frac{1}{r_2}=\frac{r_1+r_2}{r_1\times r_2}; \text{ or } R=\frac{r_1\times r_2}{r_1+r_2}$$

Thus, if $r_1=5$ ohms and $r_2=50$ ohms $R=\frac{5\times 50}{5+50}=\frac{250}{55}=4\frac{6}{11}$ ohms.

It will always be found that the combined resistance is less than the least of the resistances in parallel: if 1 ohm is joined in parallel with 10,000 ohms, the combined resistance

$$=\frac{1\times 10{,}000}{1+10{,}000}=\frac{10{,}000}{10{,}001}\text{ ohm}$$

which is less than 1 ohm.

If a number of equal resistances are joined in parallel the combined resistance is that of one divided by the number in parallel. Thus if a Tungsten Lamp has 1600 ohms resistance and ten such lamps are joined in parallel the resulting resistance

$$=\frac{1600}{10}=160\text{ ohms.}$$

Again, if two resistances are joined in parallel the main current divides between them into two parts which are inversely proportional to their resistances, or—

$$\frac{\text{current in } r_1}{\text{current in } r_2}=\frac{\text{resistance of } r_2}{\text{resistance of } r_1}$$

When a current C flows through a resistance R the drop of potential across the resistance (V) $=$ CR, thus the watts used up in the resistance $= VC = CR \times C = C^2R$ and the joules expended in it in t seconds $= C^2Rt$.

Therefore, watts in any circuit or portion of a circuit equals current × volts drop across it, or equals $(\text{current})^2 \times$ its resistance.

Joules of work expended in any circuit equals volts across it × current × time in seconds, or equals $(\text{current})^2 \times$ its resistance × time in seconds.

In order that the student may become familiar with the methods of working electrical calculations a few examples will now be given :—

1. A current of 5 amperes is required to drive a 100 volt motor; what is the power given to the motor, the total energy used in half an hour, and, if the efficiency of the motor is 80 per cent., what is its horse-power ?

Power given to motor in watts = VC = 100 × 5 = 500 watts.

Watts are joules per second, therefore energy used in half an hour equals 500 × 30 × 60 = 900,000 joules = 900,000 × 10^7 ergs.

Power given out by motor is 80 % of 500 watts

$$\frac{500 \times 80}{100} = 400 \text{ watts} = \tfrac{400}{746} \text{ H.P.} = 0{\cdot}53 \text{ H.P.}$$

2. If 2 amperes of current flowing in a circuit do 600 million ergs of work per second in that circuit, what is the applied voltage ?

600 million ergs = 600 × 10^6 = 60 × 10^7 ergs. Now 1 volt represents 10^7 ergs of work (1 joule) done per second per ampere of current, therefore 2 × 10^7 ergs on 2 amperes : thus voltage applied $= \frac{60 \times 10^7}{2 \times 10^7} = 30$ volts.

3. If 300 microcoulombs of electricity flow per minute in a circuit across which a difference of potential of 100 volts exists, what is the electric power in the circuit, and the electrical work done in each minute ?

300 microcoulombs per minute = 5 microcoulombs per second therefore the current is 5 microamperes.

Power = VC = 100 × 5 = 500 microwatts.

Work done per minute = VCt = 100 × 5 × 60 = 30,000 microjoules $= \frac{30{,}000}{10^6}$ joules $= \frac{3}{10^2} \times 10^7$ ergs = 300,000 ergs.

4. If the resistance per 1000 yards of a 7/22 S.W.G. copper cable is 5·672 ohms, what is the resistance of (*a*) 350 feet of it, (*b*) four lengths of 350 feet joined in parallel ?

Resistance is directly proportional to length,

$$\therefore \frac{\text{Res. of 350 ft.}}{5{\cdot}672} = \tfrac{350}{3000} = \tfrac{7}{60}$$

∴ Resistance of 350 feet of $\frac{7}{22}$ S.W.G. = 5·672 × $\frac{7}{60}$ = 0·6617 ohm.

Resistance of four such lengths in parallel

$$= \frac{0{\cdot}6617}{4} = 0{\cdot}1654 \text{ ohm.}$$

5. What is the combined resistance of three resistances in parallel, these being of 5, 10, and 100 ohms respectively ?

$$\frac{1}{R} = \tfrac{1}{5} + \tfrac{1}{10} + \tfrac{1}{100} = \frac{20 + 10 + 1}{100} = \tfrac{31}{100}$$

$$\therefore R = \tfrac{100}{31} = 3{\cdot}226 \text{ ohms.}$$

6. The working coil of an ammeter has a resistance of 2 ohms and can safely carry $\frac{1}{20}$ ampere. What must be the resistance of its shunt if the instrument is to measure up to 15 amperes ?

When the maximum current is flowing through the instrument, *i.e.* 15 amperes, the current through its coil is not to be more than $\frac{1}{20}$ ampere, therefore the current in its shunt must be $14\frac{19}{20}$ ampere.

$$\therefore \frac{\text{Res. of shunt}}{\text{Res. of coil}} = \frac{C_c}{C_s} = \frac{\frac{1}{20}}{14\frac{19}{20}} = \tfrac{1}{299}$$

$$\therefore \text{Resistance of shunt} = 2 \times \tfrac{1}{299} = \tfrac{2}{299} \text{ ohm.}$$

7. How could the above instrument be arranged to measure up to 30 amperes ? By changing its shunt to one of lower resistance, $\frac{1}{20}$ ampere going through the coil when $29\frac{19}{20}$ amps. goes through shunt.

$$\therefore \text{Resistance of new shunt} = 2 \times \frac{\frac{1}{20}}{29\frac{19}{20}} = \tfrac{2}{599} \text{ ohm.}$$

EXERCISES ON CHAPTER V.

1. A lamp of 400 candle power takes 1·5 watts per candle power; how many amperes of current flow through it if the applied voltage is 220 ?

2. Find the combined resistance of four wires connected in parallel, their resistances being 6·25, 8, 20, and 100 ohms respectively.

3. If a current of 10 amperes flows along a wire of 0·015 ohm resistance to an instrument of 20 ohms resistance, find the drop of volts across the wire, across the instrument, and across the whole circuit.

4. If the voltage applied to a potentiometer wire of uniform section is 4 volts what is the drop of volts across $\frac{1}{8}$th of the wire ?

5. An oscillating current of 10 microamperes effective flows in a receiver aerial of 25 ohms resistance; find the watts used up in the resistance.

6. When a volt is applied across a carborundum crystal the current flowing in it is found to be 8 microamperes; what is the resistance of this crystal ? Draw the connections of ammeter and voltmeter to make the above measurements.

7. What is the resistance of 1200 yards of a conductor $\frac{1}{8}$th inch diameter if the resistance per mile of a wire of the same material $\frac{1}{4}$ inch diameter is 2 ohms ?

8. If 300 watts are used in a transmitter find the joules of work done in half an hour, and the ergs of work done in $\frac{1}{100}$ second.

9. Two points A and B are at a difference of potential of 5000 volts. How many ergs of work are done on each coulomb of electricity passing between A and B, and how many joules of work are done per second if the quantity per second is 5 coulombs ?

10. Calculate the resistance of 220 yards of a copper cable made of 7 strands of No. 22 S.W.G. wire, the cross section of No. 22 wire being 0·006 sq. inch.

11. Define a volt, a watt, a coulomb, an erg, and specific resistance.

12. What is the relation between the C.G.S. electromagnetic units, and the practical units of (*a*) current, (*b*) potential, (*c*) work, (*d*) power, (*e*) quantity or charge ?

13. If two resistances are connected in series in a circuit and you change them so that they are now connected in parallel how will the current be changed if the same E.M.F. is applied ?

14. How can you find in which direction a current is flowing along a wire or coil ?

CHAPTER VI

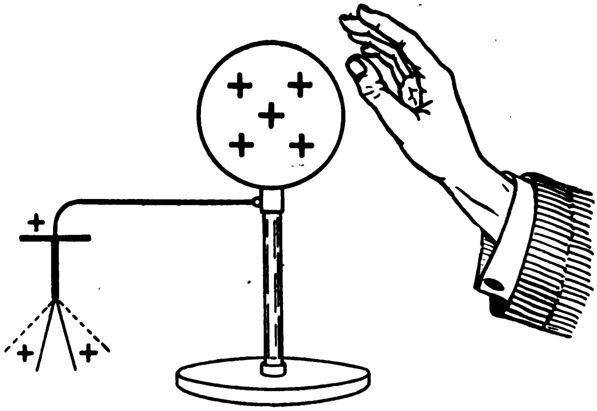
CAPACITY EFFECTS—CONDENSERS

Capacity Effects.—When a vessel is filled with water the pressure in the vessel depends on how high the level of the water is raised ; the pressure will be directly proportional to the quantity of water put into the vessel, and inversely proportional to its size and shape. The size and shape will qualify what we might call the capacity of the vessel. If the vessel is connected to a tank containing water a discharge will flow into it until the levels or pressures are the same in both, and the greater the capacity of the vessel the more water will flow in to equalise the pressures.

Similarly, if we have an insulated conductor, with no other conductors near it, and we proceed to charge it, connecting it by contact or by a wire to a charged conductor, a charge will flow into it until the two are at the same potential. Every conductor has a certain electrical capacity depending on its size and shape, and the larger this capacity the more charge is required to bring it to a given potential. Thus the potential is directly proportional to the charge, and inversely proportional to the capacity, as in the water analogy ; in symbols $V = \frac{Q}{K}$, where V = potential, Q = quantity or charge and K = capacity.

Unit capacity would be that of a conductor which is raised to unit potential by unit charge. The practical unit of capacity is called a *farad* (after Faraday). A conductor whose capacity is 1 farad would be raised to a potential of 1 volt by a charge of 1 coulomb. Unfortunately a farad is far too large a unit for ordinary purposes, so a millionth part of it is used as a working unit, and is called a *microfarad* (10^6 microfarads = 1 farad). Thus a capacity of 1 microfarad is charged to a potential of 1 volt by 1 microcoulomb of electricity. There are, of course, scientific or absolute units of capacity, based on the C.G.S. units of measurement. In these units a sphere of 1 cm. radius has a capacity of 1 unit and 900,000 of these scientific units equal 1 microfarad. Since all formulæ for calculating capacity are based on the centimetre as a unit of length, and give the capacity in absolute units, we shall have to divide by 900,000 when it is desired to express the capacity in microfarads.

If a conductor is positively charged and there is brought near it another body negatively charged, or even a body at zero potential such as the hand, the potential of the first body is immediately lowered. This can easily be seen by experiment. Attach an insulated conductor to a gold-leaf electroscope by a wire and charge the whole system, gradually raising its potential and noting its value by the increasing divergence of the gold leaves (Fig. 23). Having raised it to a certain potential bring the hand close to any part of the charged system and note that immediately the divergence of the leaves is decreased. If the system is positively charged bring near it a negatively charged body; the effect is seen to be still greater. If the negatively charged body is taken away the potential rises to its former value but if left there the potential is permanently lowered.



SHEWING HOW A NEUTRAL BODY BROUGHT NEAR LOWERS THE POTENTIAL OF A CHARGED BODY, DOTTED LINES SHEW POSITION OF LEAVES IF HAND IS TAKEN AWAY

FIG. 23.

To bring it to its former potential while under the influence of the negatively charged body we would have to put a greater positive charge on it, therefore *its capacity is greater than it was* *before.* As an analogy suppose a tank is filled with water up to a certain level or pressure, and that on account of some strain the bottom and sides of the vessel bulged outwards; to get the same water pressure as before more water will have to be put into the tank. It must be remembered that a charged conductor is surrounded by a strain in the ether in the shape of electric lines of force; if the conductor is of symmetrical shape the strain in the ether round it will be symmetrical, the electric lines leaving the conductor everywhere at right angles to its surface. But if another conductor is brought near the charged conductor the ether between the two will be more strained than that around other parts of the charged conductor. Thus if the charged conductor is a plate and another plate joined to earth is brought parallel to it and near it almost all the ether strain will exist in the space between the two conductors; that is to say this space will be filled with electric lines of force, as shown in Fig. 24. This condensing of the electric lines into a smaller space is accompanied by a fall of potential for a given charge, or, what is the same thing, an increase of the capacity of the system. This change will be greater the smaller the distance across the space. It is found that the effect also depends on the insulating material filling the space between the conductors. So far we have only considered the case of air but if this space is filled with ebonite, or glass, or paraffin wax, we shall find that the capacity is increased by using one of these substances.

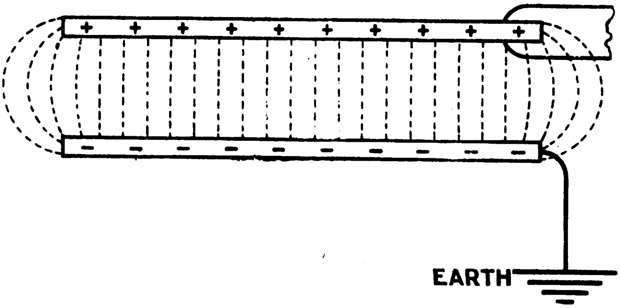


Fig. 24.

Dielectrics.—An insulator used in this way is called a "*dielectric,*" and the ether strain set up by the system, and therefore the capacity of the system, depends on the material in which the ether is strained or the electric lines of force set up; in other words it depends on the dielectric used. Thus the capacity of a conductor depends—

1. On its size.
2. On the presence of other conductors.
3. On the dielectric in which the electric lines are set up between the charged conductors and neighbouring conductors.
4. On the distance between the charged conductor and the neighbouring conductors—that is on the thickness of the dielectric; the thinner it is the greater the effect.

If we experiment with the effects of ebonite and air as dielectrics we shall find that an ebonite dielectric increases the capacity 2·5 times as much as air. This number is called the "specific inductive capacity" or "dielectric constant" of ebonite.

The "dielectric constant" of a substance is therefore its effect when used as a dielectric as compared with an air dielectric.

Taking the dielectric constant of air as 1 that of glass is from 6 to 9, depending on the kind of glass used, that of paraffin oil is 2 and of mica 8; other dielectric constants are given in the table at the end of this chapter.

Condensers.—Conductors placed parallel to each other and separated by a suitable dielectric constitute a "condenser"; it usually takes the form of one metallic plate, or set of plates joined together, separated from a similar plate or set of plates by glass, ebonite, paraffin oil, air, or other dielectric. The plates may be flat rectangular or circular sheets, or may be in the form of tubes.

If $A =$ area in sq. cms. of one set of plates or surfaces,
$k =$ dielectric constant, or specific inductive capacity, of the dielectric used,
$t =$ thickness of the dielectric between the plates or surfaces measured in cms.,

then the capacity of the condenser—

$$K = \frac{A \times k}{4\pi \times t \times 900{,}000} \text{ mfds.}$$

A simple form of condenser is the Leyden jar; it consists of a glass jar, coated to about halfway up the sides both inside and out with tinfoil, the inside coating being connected to the circuit by a metallic rod ending in a small sphere above the jar, and fitting into an ebonite cover on the jar which aids the insulation of the rod and inside coating. The glass above the coatings is generally coated with shellac for the same reason. To apply the above formula to a Leyden jar—A is the area of one of the tinfoil coating in sq. cms., k has a value varying between 6 and 9 depending on the quality of glass, and t is the thickness of the glass measured in cms.

A Leyden jar of what is known as pint size has a capacity of about 0·001 microfarad, a quart size has a capacity of about 0·0017 microfarad. Special tubular forms of Leyden jar condensers are used in wireless telegraphy, as shall be described hereafter, but ordinary Leyden jars can be used as condensers for obtaining oscillatory discharges.

Another form of condenser much used for ordinary electrical purposes consists of sheets of tinfoil separated by thin sheets of paper well soaked in melted paraffin, alternate sheets being joined together to form as it were one large sheet, and the other alternate sheets joined together to form the other large sheet, with the paraffined paper as dielectric. The whole is inclosed in a hard wood or ebonite box. In this way a condenser can be made to have a comparatively large capacity though its bulk is quite small. Such condensers are only suitable for charging to comparatively low potentials.

A transmitter condenser might be made of zinc plates separated by sheets of glass, the glass sheets being much larger than the zinc plates, so as to avoid any likelihood of a discharge taking place round the edges of the glass. Suppose each zinc plate has an area of A sq. cms. and that the condenser consists of 2 zinc plates joined together, separated by the glass sheets from 3 similar zinc plates joined together as shown in Fig. 25. Now it must be noted that the total active area is 4A sq. cms. for each side of the two zinc plates is acting as a surface separated by the dielectric from a similar surface. Thus if each zinc plate is 5·4 cms. by 6·5 cms. and the glass is 0·4 cm. thick (it would be about 11 cms. by 10 cms. in area), then taking the dielectric constant of glass as 8 we would have for the capacity of the condenser—

$$K = \frac{4 \times 5{\cdot}4 \times 6{\cdot}5 \times 8}{4\pi \times 0{\cdot}4 \times 900{,}000} \text{ mfd.} = 0{\cdot}000248 \text{ mfd.}$$

The best kind of glass is flint glass and lead glass should be avoided. In some types of tubular Leyden jars the plates consist of electrolytic copper deposited on silver which has previously been deposited by chemical means on the glass.

In medium-sized Wireless Transmitter Circuits the Marconi

Company employ condensers with plates of zinc or copper separated by glass sheets, the whole being contained in a vessel which is filled with transformer oil. The oil aids cooling and prevents brush discharge; it has a specific inductive capacity of about 2·4 and a dielectric strength of about 70,000 volts per cm. If spark discharges puncture the glass and pass across the oil in the condenser the oil will flow in and insulate the circuit again, but sparking will gradually deteriorate the oil. The oil must have no trace of moisture as this greatly lowers its dielectric strength.

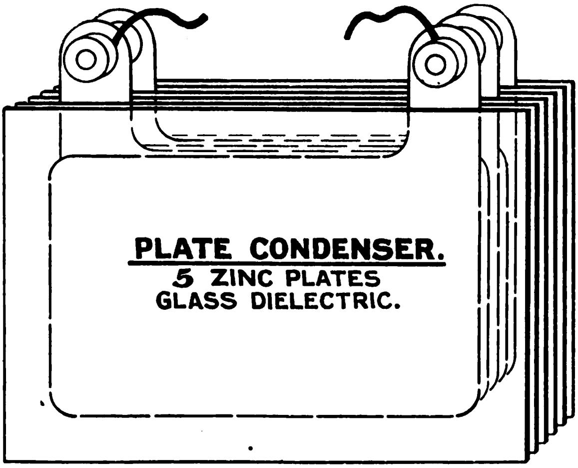


Fig. 25.

Moscicki Condensers are long thin tubes of the Leyden jar type in which the inner plate consists of a deposit of electrolytic copper connected to a terminal on the ebonite or porcelain cap of the condenser by a spring contact. The dielectric is of glass which is thickened at the top, *i.e.* at the edges of the plates where the greatest electric strain takes place. The outer coating is copper and the whole jar is contained in a copper or brass tube, connected to the outer coating by a terminal spindle, and also by a mixture of glycerine and water which fills the tube. The ebonite or porcelain cap which carries a terminal connected to the inner coating closes the tube, and a rubber gland is fitted beneath it so that it is watertight. The standard size of a Moscicki condenser has a capacity of 0·0014 mfd.

The Telefunken Company use condensers of the Leyden jar type in their transmitters; these are specially suitable for use in tropical climates where the heat is liable to warp or deteriorate wooden or ebonite cases, and deteriorate wax or oil fillings.

Dubilier Condensers have tinfoil plates with mica dielectrics; in order that they should stand comparatively high voltage strains they are made up in sections which are really condensers in series with each other, so that the applied voltage is distributed along them. The use of mica as a dielectric enables the condenser to be made very compact; a Dubilier condenser of 0·0025 mfd. capacity, and capable of being charged to 20,000 volts, has tinfoil plates 4½ cms. × 6½ cms. with mica dielectric 0·25 mm. thick. It is made up in 10 sections as shown in Fig. 26, the sections being separated by several thicknesses of mica so that there are really 10 condensers in series and when 20,000 volts are applied the strain across any unit is only 2000 volts. The whole is embedded in melted beeswax and contained in a hard wood box 6 in. × 3½ in. × 5¼ in. with an ebonite top on which the terminals are mounted.

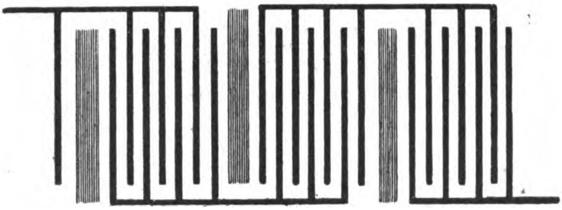


Fig. 26.

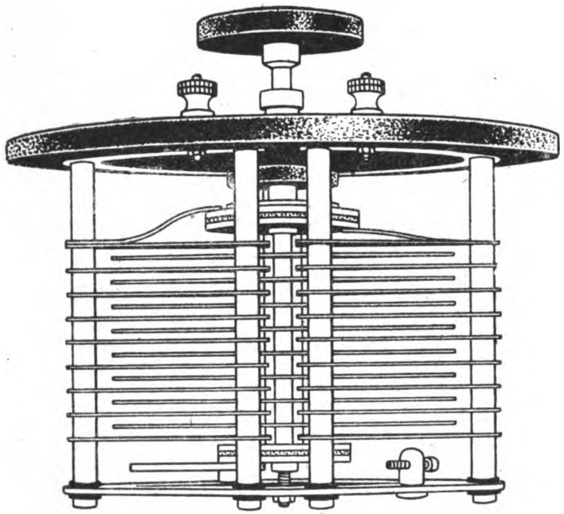
Reference will be made later in the chapter to the fact that there is energy loss in mica when employed as a dielectric, but with a distributed voltage, as in this case, the energy loss is not important.

Small condensers, used as shunts across telephone receivers, may be made with tinfoil and paraffined paper embedded in paraffin wax, and enclosed in wooden boxes with ebonite tops, on which are mounted the terminals to which the two sets of plates are joined.

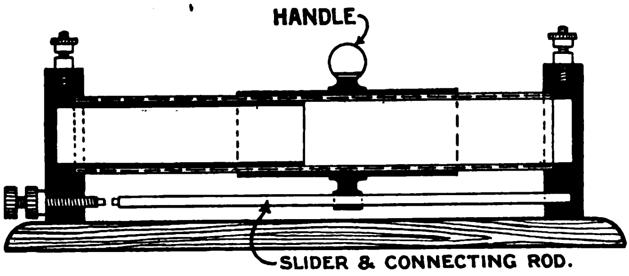
Thin mica sheets whose dielectric constant is 6·7 would be preferable to paraffin paper as a dielectric; thus a small condenser having 41 plates joined in groups of 20 and 21, each 2 cms. × 4·35

cms. and separated by mica 0·1 mm. thick, would have a **capacity**—

$$K = \frac{40 \times 2 \times 4{\cdot}35 \times 6{\cdot}7}{4\pi \times 0{\cdot}01 \times 900{,}000} = 0{\cdot}029 \text{ mfd. (approx.)}$$



MOVING VANE VARIABLE CONDENSER.



TUBULAR VARIABLE CONDENSER.

Fig. 27.

In making plates for condensers it is well to round off the corners of the plates slightly, as an accumulation of electric strain always takes place at sharp points or corners on charged conductors, and in all electrical apparatus which have to be charged to high potentials it will be noted that sharp corners, points, or edges are always avoided.

Condensers whose capacity may be varied consist of sets of semicircular fixed and movable plates, separated by air, paraffin oil, glass, ebonite, or mica. The movable plates are mounted on a spindle, so that by rotating it the whole or only a portion of the movable plates may be placed opposite the fixed plates. Such a condenser is shown in Fig. 27. Another form is a tube of metal over which is fixed a tube of ebonite and on the ebonite another tube of metal slides, having fixed to it an insulating handle. By sliding the outer tube over the ebonite more or less of its surface can be made to cover, or be opposite, the fixed tube inside, and thus the capacity can be varied. The capacity K per unit length is $k \div 2 \log_\epsilon \frac{r_2}{r_1}$, where k is the dielectric constant and r_1 and r_2 are the radii of the inner and outer cylinders. The tubular condenser shown in Fig. 27 is fitted with an adjustable safety spark gap at the bottom left-hand side.

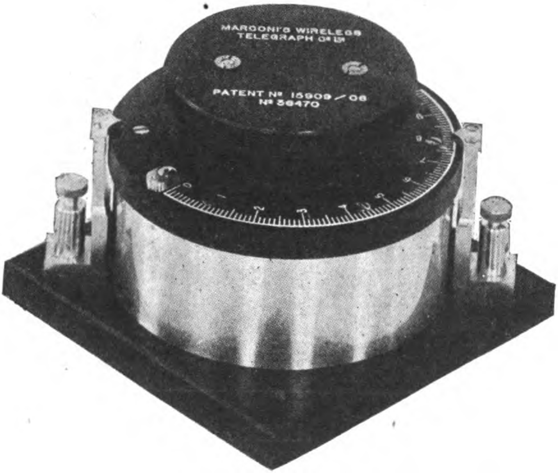


Fig. 28.—Marconi variable condenser for receiver circuits.

Fig. 28 shows a variable condenser patented by the Marconi Company for use in wireless receiver circuits. It has two sets of semicircular movable plates on the same shaft and corresponding to these two sets of semicircular fixed plates. This gives more capacity effect for a given bulk of condenser than that obtained by the condenser shown in Fig. 27. The advantage is further increased by using thin ebonite sheets as dielectric instead of air; not only has ebonite a higher dielectric constant than air but its use enables a thinner spacing between the fixed and movable plates without the risk that they may touch or become shortened by dust or damp.

Returning to the consideration of the capacity of a condenser we note that the thinner the dielectric, everything else being equal, the greater the capacity. But we must not make the dielectric too thin or we shall be limited in the potential to which we can charge it. If we raise the potential too high a discharge will take place through the dielectric, puncturing it, and thus the plates would no longer be efficiently insulated from each other. In much the same way a great potential strain between two clouds charged with electricity of opposite kinds breaks down the insulation of the dielectric (air) between them, and we see a discharge, in the form of lightning, forcing its way through the air. Similarly when a great difference of potential exists across a spark gap the insulation of the air dielectric between the spark balls breaks down, and a spark passes. The breaking down potential for any dielectric depends on its thickness as well as on the material; consequently the thickness of the dielectric which must be used in a condenser depends on the potential strain it will be required to stand, also on the material used as a dielectric. Thus the *dielectric strength* is measured by the voltage which will break down the insulation of unit thickness of the material. For instance, 3000 volts will discharge across 1 mm. of air, but it would take 200,000 volts to discharge across 1 mm. of mica, and about 50,000 volts to discharge across 1 mm. of ebonite. These values vary according to the shape of the electrodes between which the dielectric is placed. Thus, while capacity is increased by decreasing the thickness of the dielectric, for a given potential there is a certain minimum thickness for each dielectric that may be used, and the best dielectric has not necessarily the highest dielectric strength.

Another important consideration in choosing a dielectric for a condenser is the loss due to *dielectric hysteresis*. If a charged Leyden jar is discharged and left undisturbed for, say, 30 seconds a second small discharge can be got from it, and sometimes even a third one. This is due to the fact that when charged the strain across the dielectric causes the charges to leave the plates and really settle on the surface of the dielectric, through which they are tied by the electric lines of force, or ether strain, in the dielectric. When the opposite sets of plates are suddenly discharged through a circuit joining them, such as a piece of wire or a spark gap, the flow of electrons rushing round the circuit neutralises the positive and negative charges, but some are still left straining across the dielectric, trying as it were to get across that way instead of taking the easier path that has suddenly been provided for them; thus the dielectric does not entirely recover from the strain when the discharge takes place. Some of the energy of charge is not reproduced as energy of discharge and the loss of energy is called the dielectric hysteresis loss.

We must now obtain an expression for the amount of energy stored in a condenser. The energy of a flow of water is determined by the product of the quantity of water that flows and the pressure at which it flows; thus the power of a waterfall is the product of the quantity of water flowing per second and the pressure of the water, calculated from the height of the fall. If W lbs. equals the weight of the water discharged per second, and h equals the height of the fall in feet; the energy per second $= Wh$ lb.-feet, and 550 ft.-lbs. per second equals one horse-power.

Again, if a tank is filled with W lbs. of water to a height of h feet, and the water is allowed to flow out at the bottom, the quantity of water discharged is W lbs., but the pressure of the water is due to a height of h feet at the commencement of the discharge, and falls to 0 when the discharge is complete, so that the average pressure is that due to $\frac{1}{2}h$ feet of water. Thus the total energy of the discharging water is $W \times \frac{1}{2}h$ lb.-ft., and this must be a measure of the energy stored in the tank before the discharge. Similarly when a condenser is discharged its potential at the commencement of discharge is V volts, at the end is zero, therefore the average potential is $\frac{1}{2}V$ volts, and thus if the quantity of electricity is Q coulombs the total energy of discharge is $\frac{1}{2}QV$ joules. This must also equal the energy stored in the circuit before the discharge, neglecting dielectric hysteresis.

In a circuit charged to V volts with a charge of Q coulombs the energy stored $= \frac{1}{2}QV$ joules.

If the charge is Q microcoulombs this equals $\frac{Q}{10^6}$ coulombs.

$$\therefore E = \frac{1}{2}\,\frac{Q_{\text{mc.}}\,V_{\text{volts}}}{10^6}\text{ joules.}$$

Now 1 microfarad is charged by 1 microcoulomb to a potential of 1 volt.

∴ K mfds. is charged by K microcoulombs to a potential of 1 volt.

∴ K mfds. is charged by KV microcoulombs to a potential of V volts.

∴ If a condenser of K mfds. is charged to V volts, the charge $Q = KV$.

$$\therefore E = \tfrac{1}{2}\,\frac{Q \times V}{10^6} = \tfrac{1}{2}\,\frac{KV \times V}{10^6} = \tfrac{1}{2}\,\frac{K_{\text{mfds.}} \times V^2_{\text{volts}}}{10^6}\ \text{joules.}$$

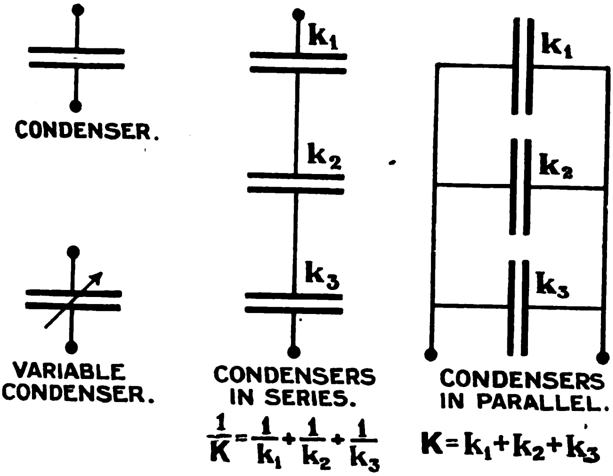


Fig. 29.

In diagrams a condenser is usually denoted as shown in Fig. 29; if its capacity is variable an arrow is generally drawn across it.

If we join condensers in parallel, as shown in the Figure, the combined capacity is equal to the sum of their capacities; $K = K_1 + K_2 + K_3$.

It is easily seen that by joining them in parallel we are simply adding the size of their plates together if they are similarly constructed, and has just the same effect as if we had increased the size of the plates of one of the condensers to the same extent. If three condensers of 1 mfd. each are joined in parallel the resulting capacity is 3 mfds.

If condensers are joined in series, as shown in the figure, the capacity of the series is less than that of one alone, and is given by the formula :—

$$\frac{1}{K}=\frac{1}{K_1}+\frac{1}{K_2}+\frac{1}{K_3}.$$

If each has a capacity of 1 microfarad the capacity of the three in series is obtained thus :—

$$\frac{1}{K}=\frac{1}{1}+\frac{1}{1}+\frac{1}{1}=\frac{3}{1}$$

$$\therefore K=\tfrac{1}{3}\text{ mfd.}$$

Thus the capacity of any system of electrical conductors for storing electrical energy can be decreased by joining a condenser in series with the system. We shall see later that the capacity of an aerial circuit in radio-telegraphy is often thus decreased.

If a condenser of 0·02 mfd. capacity is joined in series with one of 0·04 mfd. capacity the resulting capacity is given by—

$$\frac{1}{K}=\frac{1}{0{\cdot}02}+\frac{1}{0{\cdot}04}=\frac{0{\cdot}04+0{\cdot}02}{0{\cdot}02\times 0{\cdot}04}=\frac{0{\cdot}06}{0{\cdot}0008}=\frac{6}{0{\cdot}08}$$

$$K=\frac{0{\cdot}08}{6}=0{\cdot}0133\text{ mfd.}$$

It is seen that this is less than the capacity of either condenser.

Every circuit or wire has some capacity, and while that of wires or isolated conductors is very small compared with a condenser arrangement yet in wireless telegraphy they must be taken into consideration. For instance there are circumstances when we may wish to increase the number of turns in a coil to increase what is known as the inductive effect, yet by so doing we are increasing the capacity of the coil; for this reason it may be better to attain our object by some other means. We shall discuss these circumstances later in connection with Wireless Telegraphy Receivers.

The capacity of a straight vertical wire, far removed from other conductors,—

$$=\frac{l}{4{\cdot}6052\log\frac{2l}{d}\times 900{,}000}\text{ mfds.}$$

where l is its length in cms. and d its diameter in cms.

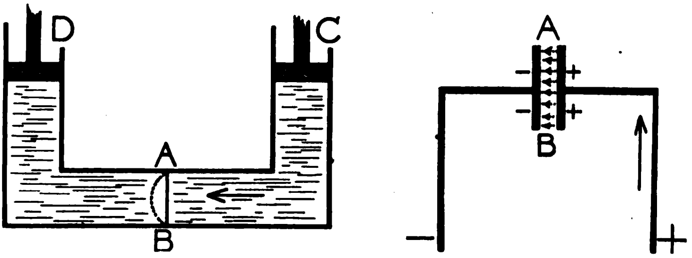
The capacity of a straight horizontal wire, raised high above the earth and not close to other conductors,—

$$= \frac{l}{4{\cdot}6052 \log \frac{4h}{d} \times 900{,}000} \text{ mfds.}$$

where l and d are its length and diameter in cms., and h is its height in cms. above the earth.

If two or more such wires are joined in parallel, their combined capacity is not quite the sum of their capacities, but no simple formula can be given for the resultant capacity since it depends very largely on how close they are together, and on local circumstances such as the presence of other conductors near them.

An aerial, or antennæ, used in radio-telegraphy, consists of one or more wires stretched horizontally, with vertical wires leading down from each, all connected together at the bottom, and to apparatus which either charges the aerial or through which it may discharge. A ship's aerial of ordinary dimensions would have a capacity of the order of about 0·0012 mfd.



(*a*) **Fig. 30.** (*b*)

Students are sometimes puzzled as to the reason why an oscillating or alternating current can pass through a condenser while a direct current cannot do so. This may be best explained by a well-known water analogy as shown in Fig. 30 (*a*). Here a water pipe is fitted with two pistons at C and D and an elastic diaphragm at AB.

Now if a difference of pressure is put on the pistons so that the larger pressure is on C, tending to make the water move through the circuit in the direction shown by the arrow, the water can only move until the elastic diaphragm is strained to the full effect of the difference of pressure, and then all movement of the water will be stopped. This is presuming that the strain put upon the elastic diaphragm, *i.e.* the difference of pressure on C and D, is not sufficient to burst it. If, on the other hand, the greater pressure is put alternately on C and D the water will be displaced backwards and forwards in the pipe just as if AB were not present, as long as the latter has enough elasticity to yield to the strains put upon it.

Similarly, if a condenser has applied to it a difference of potential acting in one direction only, as shown in Fig. 30 (*b*), a displacement of positive and negative charges will take place until one side is charged positively and the other negatively to the full difference of potential, and the dielectric AB between the plates is strained. Then all displacement of electric charges will cease. Thus with a unidirectional voltage applied to a condenser only a charging current will flow, and this is completed in a very small instant of time. On the other hand, if an alternating difference of potential is applied to C and D, at one moment positive charges will flow to C and negative charges to D; as the voltage dies down the charges will flow back to neutralise each other; when the voltage rises in the reverse direction charges will again flow to C and D but they will now be reversed charges.

Thus it is seen that while the voltage alternates, or oscillates, alternating or oscillating movements of charges flow to the plates of the condenser CD. No electricity passes across the dielectric AB, just as in the water analogy no water passes through the diaphragm AB, but this does not prevent an alternating or oscillating movement of electricity in the remainder of the circuit. In the water analogy if too great a pressure is applied the diaphragm will burst; similarly if the difference of potential, or voltage, applied to the plates of the condenser is too great the strain on the ether in the dielectric AB will be too great, and a discharge will pass across it.

QUESTIONS AND EXERCISES.

1. A condenser has a capacity of 0·002 microfarad. If the number of the plates was doubled and the thickness of the dielectric also doubled what would be its new capacity?

2. If the above-mentioned condenser were charged to 10,000 volts what would be the energy stored in it?

3. What is meant by the "dielectric constant" and the "dielectric strength" of a material? What are their values for air?

4. If an aerial has a capacity of 0·0015 mfd. what is the new value of capacity when a condenser of 0·0004 mfd is joined in series with it?

5. The capacity of a condenser used in the primary circuit of a Marconi half

kilowatt transmitting set is found to be 0·0074 mfd. It has 16 pairs of plates and the dielectric is glass 2 mms. thick. Taking the dielectric constant of glass as being 8, what is the size of each zinc plate ?

6. An aerial consists of two wires each raised 120 feet vertically and then 300 feet horizontally, the diameter of the wires being 2·743 mms. If the capacity of the two wires is 40 per cent. greater than that of one used alone find the capacity of the aerial ?

7. A condenser has a capacity of 10,000 cms.; what is its capacity in microfarads?

8. Calculate the capacity of the earth in farads, taking its diameter as being 8,000 miles.

9. To shorten the wave lengths of an aerial a condenser can be connected in series with it, thus reducing the capacity effect. Would a large condenser thus used decrease the wave length more than a small one ? Give reasons for your answer.

10. What is a dielectric ?

11. If we apply 15,000 volts to a condenser of 0·002 mfd. capacity :—

(*a*) What charge is stored in it ?

(*b*) How much energy is stored in it ?

DIELECTRIC CONSTANTS AND STRENGTHS.

Dielectric.	Dielectric constant.	Dielectric strength (volts per cm. thickness).	Remarks.
Air	1	39,000 to 40,000	For any dielectric the dielectric strength will depend on the shape and condition of the surfaces and the suddenness with which the voltage strain is applied.
Compressed air	Little more than 1	Increases almost in proportion to pressure	
Flint glass ..	6·6	300,000	
Glass plate ..	8·4	250,000	
Mica	8	590,000 to 600,000	
Ebonite ..	2·01 to 2·76	500,000	
Paraffin oil ..	2·0 to 2·6	60,000 to 100,000	Dielectric constants of liquids decrease as the temperature rises.
Paraffin wax ..	1·977	130,000 to 270,000	
Vaseline ..	2·2	90,000	
Castor oil ..	4·78		

CHAPTER VII

INDUCTION EFFECTS

We have already seen in Chapter IV. that when a current of electricity flows along a wire the surrounding ether is subject to a magnetic strain; in other words the wire is surrounded by magnetic lines in the form of concentric circles, and if the wire is coiled up the magnetic lines pass along the axis of the coil, their number and direction depending on the strength and direction of the current in the coil. An iron core will greatly increase the number of magnetic lines through the coil for a given current.

There is a converse effect which we shall now proceed to study. If a wire is surrounded by ether in a magnetic state of strain and that magnetic strain suddenly changes in value electrons will flow along the wire, and one end of it will momentarily be at a higher electrical potential than the other end. A wire surrounded by magnetic lines of force, or placed in a magnetic field of lines of force, is said to be interlinked with the magnetic lines, so that we can describe the above phenomena in this way:—if a wire is interlinked with a magnetic field and the number of magnetic lines interlinked with the wire changes a momentary difference of potential is set up between the two ends of the wire.

If the magnetic field interlinked with the wire continues to change the difference of potential set up in the wire will continue, and *its value at any moment will depend upon the rate of change of the magnetic field at that moment.* We can insure this continuity by having a magnetic field which is not uniform in strength across which the wire can be moved; if it moves from a position where the field is weak to one where the field is stronger the induced difference of potential will increase, and *vice versa.* If we keep the wire stationary and move the magnetic field we obtain just the same effect. It is not sufficient simply to make the wire move through magnetic lines, for if the wire is interlinked with the same number of magnetic lines every instant there would be no difference of potential in the wire. The wire must be interlinked with a magnetic field, and one or other must move in such a way that the number of magnetic lines interlinked with the wire, cut by the wire, or cutting through the wire, is changing.

There may be a number of such wires all interlinked with magnetic lines, and moving in such a way that an E.M.F. or difference of potential is induced in each wire ; if then all the wires are properly joined in series with each other an E.M.F. is obtained which is the sum of their individual E.M.F.'s.

This explains what happens in a dynamo or generator ; in it we have a magnetic field of ether strain between the N. and S. poles of one or more electromagnets and constrained to act in the space between the poles by filling the centre of the space with a core of soft iron, so that between this core and each pole there exists a field of invisible magnetic lines. Copper wires are made to move through this field between the core and the poles, the method adopted being to fasten the wires on the surface of the core and make it revolve, carrying the wires with it, therefore making them cut through the magnetic lines. Such an arrangement is shown in Fig. 31. The core with its wires is called the armature of the machine. Consider any wire A ; at the moment shown it is not cutting any magnetic lines, but as it revolves it begins to cut them in a slanting manner, the angle at which it cuts them getting steeper and steeper until it cuts them at right angles, as at B, after which the reverse action takes place.

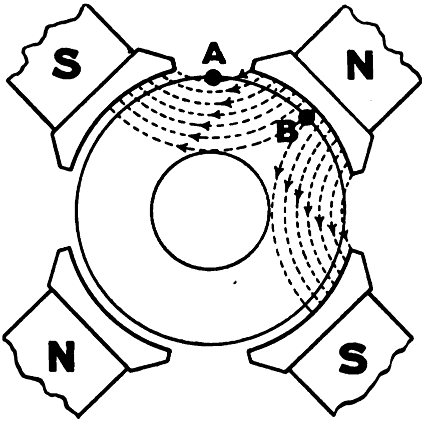


FIG. 31.

Thus we see that the number of magnetic lines cut through by the wire is continually changing, therefore the induction of an E.M.F. in the wire will be continuous, but its value will rise and fall. When a number of such wires are suitably joined in series with each other the resultant E.M.F. will be increased, so that a maximum value of 200, or 400 volts, or whatever value is desired, can be easily obtained. The free ends of the two wires (at the ends of the series) are joined to two insulated conducting rings on the shaft of the revolving armature, and the circuit (through which a current is required) is connected to these rings by sliding contacts of copper or carbon, called brushes; thus the E.M.F. obtained by induction effects can be utilised, just as we use the E.M.F. of a battery of cells.

Now the question at once arises—which is the positive and which is the negative end of a wire which cuts through a magnetic field? A simple experiment will help us to answer it: Connect a wire to the terminals of a galvanometer, or, better still, a number of wires in series with each other in the form of a coil, so as to increase the effect; make the wires of one side of the coil cut *down* through the magnetic field between the poles of a horseshoe magnet. Immediately it will be seen the galvanometer deflects to one side, showing that a current has flowed through the galvanometer coil, and therefore an E.M.F. must have been applied to the circuit. This was the E.M.F. induced in the wires in series with each other which cut through the magnetic field. The deflection is only a momentary one; therefore the current and the E.M.F. induced are only momentary.

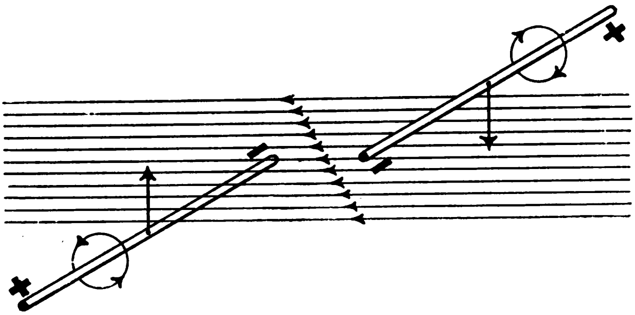


Fig. 32.

Now make the wires cut *up* through the magnetic field; again the galvanometer deflects, but this time in the opposite direction, therefore the current is flowing in the opposite direction, and thus the E.M.F. is induced in the opposite direction. So that the direction of induced difference of potential in a wire depends on the relative directions of the motion of the wire and of the magnetic lines. Fig. 32 shows the result when the wire cuts down through the field there shown, the direction of induction is such that the front end is negative, and when it cuts up through the field the front end is positive. To find the current direction, imagine the magnetic lines to bend round the wire as it cuts through them as shown in Fig. 33, and imagine a corkscrew to be turned in the same direction as the curve of the magnetic line shows. Then the positive direction of current along the wire is in the same direction as the corkscrew would move in a cork if screwed as shown. In the Figure the current flows from front to back; therefore the current goes to the outside circuit from the back, which is thus the positive end of the wire.

In the armature wires of a dynamo the E.M.F. is induced in one direction when they pass through the magnetic lines coming out of a N. pole and in the opposite direction when they pass through the magnetic lines going into a S. pole. Thus the resulting current in the wires and outside circuit will be continually reversing its direction; this is called alternating current, and the E.M.F. an alternating E.M.F. If the current is required to flow only in one direction in the outside circuit this can be accomplished by connecting it through brushes, not to two insulated rings on the shaft, but to a number of insulated contacts joined to the wires, which constitute what is called the commutator. In this way we get what is called direct current, making the machine a direct-current generator.

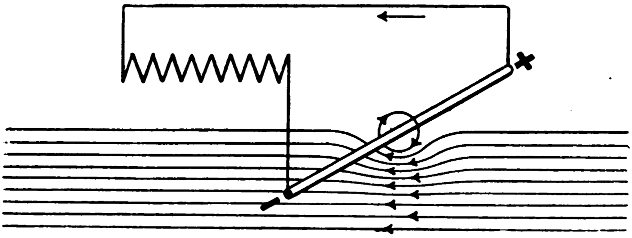


FIG. 33.

Returning to our experiment with the galvanometer, if the side of the coil in the magnetic field between the poles of the horseshoe magnet is not moved there will be no deflection on the galvanometer, so that it is not enough to put a wire, or wires in series, in a magnetic field. Only when the wires are moved into or out of the field is an induced E.M.F. obtained; the wires must interlink with the magnetic field, and the number of interlinkages must change per instant of time. The wires may move from a stronger field to a weaker one or *vice versa*, or the strength of the field may increase or decrease to produce the effects.

The experiment can be repeated by joining a stationary coil of wire to the galvanometer, and bringing near it, or inserting in it, a pole of a magnet. When the pole is inserted or brought up, induction takes place in one direction, when it is taken out or removed induction takes place in the opposite direction. A N. pole will set up induction in one direction, a S. pole will set up induction in the opposite direction, because the direction of induction depends on the direction of the magnetic lines with respect to the wires of the coil; magnetic lines come out of N. poles, they go in to S. poles.

Again it will be noted that the strength of the induced E.M.F. as shown by the deflections, depends on how quickly the magnet pole is moved; the faster the magnetic lines interlink with the coil the stronger the E.M.F. induced. Thus the E.M.F. induced does not depend on the strength of the magnetic field but on the rate of interlinkage; for example there will be a greater E.M.F. set up in a wire which cuts through 100,000 magnetic lines in $\frac{1}{20}$ second than in one which cuts through 1,000,000 magnetic lines in 1 second. In the first wire the interlinkage is at the rate of 2,000,000 lines per second, in the second it is only at the rate of 1,000,000 per second.

The absolute electromagnetic unit of potential difference, or E.M.F., corresponds to an interlinkage of 1 line per second, but this is far too small a unit for commercial purposes and the practical unit is the "volt" which is the potential difference between the ends of a wire interlinking with magnetic lines at the rate of 100,000,000 or 10^8 interlinkages per second.

Thus if the number of magnetic strain lines interlinked with a wire *changes at the rate of* N *lines per second* the voltage induced in the wire is $\frac{N}{10^8}$ volts. If there are T wires, or turns of wire, in series with each other, each experiencing this rate of interlinkage, the potential difference at the terminals of the series or coil is $\frac{NT}{10^8}$. Note carefully that N is not the number of magnetic lines which has interlinked with the coil, but is the change per second of the number of magnetic lines so interlinked. For example, suppose there are Z wires in series on the armature of a dynamo, that the total number of magnetic lines from N. poles to S. poles is M, and that the armature revolves at a speed of n revs. per second. Then each wire cuts through the M lines n times per second, so that the rate of interlinkage — $N = Mn$; as there are Z wires in series the voltage or P.D. at the terminals of the armature winding $= \frac{NZ}{10^8} = \frac{MZn}{10^8}$ volts.

Self-Induction.—A wire carrying a current is surrounded by magnetic lines in the form of concentric circles all along its length; forget for a moment what causes these magnetic lines, that is to say think only of the magnetic lines and the wire. The magnetic lines interlink with the wire, therefore any change in their number will induce an E.M.F. in the wire; if their number decreases, in other words if some of the magnetic strain in and round the wire collapses, an E.M.F. will be induced in it in one direction, but if they increase an E.M.F. will be induced in the wire in the opposite direction, and this will happen no matter what causes the decrease or increase of the magnetic lines. A decrease or increase of current in the wire will decrease or increase the number of magnetic lines interlinked with it, *thus any change of current in a wire will induce in it an E.M.F.* If there is no change of current there will be no induction. This effect produced in a circuit by a change in its own current is called *self-induction.*

The self-induced E.M.F. will always be in such a direction as to oppose the change of current which produces it; if the current decreases, the induced E.M.F. will be in the same direction as the E.M.F. applied to the circuit, helping it as it were so as to stop the decrease of current. If the current is increasing the induced E.M.F. is in the opposite direction to the applied E.M.F., thus tending to decrease the effective E.M.F. and stop the increase of current.

Self-induction in electricity is like *inertia* in mechanics; if a truck is moving along a set of rails and we try to decrease its velocity, or rate of displacement, its inertia will tend to make it go on just as before, and the inertia will have to be overcome before any decrease in its velocity can be accomplished. If the truck is at rest, or moving only slowly, and we desire to increase its velocity, its inertia will oppose the change and must be overcome before the velocity can be increased. But once the inertia is overcome, once the truck is started and moving with a uniform velocity, there will be no inertia. So it is with self-induction.

if the current, or rate of displacement of electricity, is flowing steadily there is no self-induction, for there is no change in the number of magnetic lines interlinked with the circuit; but if the current is decreased or increased, stopped or started, then an inductive effect is set up.

Self-induction effects are only produced with direct current at switching on or off, or when the current is increased or decreased; but with alternating current, which is not only flowing backwards and forwards in the circuit but is also continually rising and falling in value, self-inductive effects are also continually rising and falling, and reversing in direction as the current reverses; always opposing the change of current. Oscillating currents or discharges are alternating currents changing at a very high rate, so that with these also self-induction effects are ever present, and have an important bearing on the electric conditions of the circuit.

If a wire carrying a current is made up into a coil the magnetic lines which were strung out along the wire are now congregated together, threaded along the axis through the coil, and the magnetic lines due to the length of one turn will not only interlink with that turn, but with others near it, so that any change of current in the coil will set up a greater E.M.F. of self-induction than would be the case if the same length of wire were stretched out straight. The presence of an iron core in a coil greatly increases the number of magnetic lines through it for a given current, therefore will cause an increased change in the number of magnetic lines interlinked with the coil if the current changes.

Thus the self-induction effect in a coil of wire is much greater than that of the same length of wire stretched out straight; also the presence of an iron core in a coil greatly increases its self-inductive effect, except in the case of a coil carrying a current or discharge oscillating at a very rapid rate. With rapidly oscillating currents an iron core does not increase the self-inductive effects to any great extent.

The amount of self-induction effect set up in a wire or coil depends on the rate of change in the number of magnetic lines interlinked with it, either decreasing or increasing; this depends on the rate at which the current is changing since the number of magnetic lines depends directly on the strength of the current. Thus, if the current is changing at the rate of one ampere per second in any wire, coil, or circuit, there will be a certain amount of self-induction effect, or as it is sometimes called inductive effect, depending on whether it is a wire, or a coil, or on the shape of the circuit. In order to compare the self-induction effects in different circuits, we calculate, or find by experiment, *the voltage induced in any circuit when the current is changing at the rate of one ampere per second and call this " The Coefficient of self-induction " or the " Inductance "* of the circuit. The coefficient of self-induction is measured in units called *henrys*—if a circuit has a " coefficient of self-induction " of 1 henry, it means that when the current in the circuit is *changing* at the rate of 1 ampere per second there will be induced in that circuit an E.M.F. of 1 volt. If the circuit consists of one turn of wire, the change of magnetic lines would in this case be 100,000,000 or 10^8 per second, if it consists of a coil of T turns the change in the number of magnetic lines is $\frac{10^8}{T}$ per second.

With direct current it is difficult to change the value of the current at a predetermined rate, but if an alternating current of C effective amperes is flowing in a circuit at a frequency of f cycles per second the rate of change of the current is known to be $2\pi f C$ amperes per second. Thus, if we measure the inductance effect of a circuit with alternating current changing at a rate of $2\pi f C$ amperes per second, it is easy to calculate what the effect would be when the current changes at the rate of 1 ampere per second and so determine the coefficient of self-induction of the circuit.

It may appear confusing that an induced voltage effect should be measured in units called henrys, but a comparison with resistance may make this clear.

If a current of 1 ampere flows in a non-inductive circuit and the drop of potential across the circuit is then found to be 10 volts, we say that the resistance of the circuit is 10 ohms, for $C = \frac{V}{R}$, and the symbol used for resistance is the letter R. Similarly, if the current in a circuit is changing at the rate of 1 ampere per second and it is found that the back E.M.F. of self-induction set up is 10 volts, we say the " Inductance " of the circuit is 10 henrys, and the symbol used for inductance is the letter L.

Thus if a coil of T turns has an inductance of L henrys and the current in it is changing at the rate of A amperes per second, the volts induced in it by the change of current is LA, and the magnetic lines interlinked with it are changing at the rate of $\frac{LA \times 10^8}{T}$ lines per second.

In wireless work, where straight wires and coils without iron cores are so much employed, the henry is too large a unit for practical purposes, so that smaller units have been adopted such as the millihenry, the microhenry, and the centimetre—the latter being the absolute or scientific unit, which has, perhaps unfortunately, the same name as the metric unit of length.

$$\begin{aligned} 1 \text{ henry} &= 1{,}000 \text{ millihenrys or } 10^3 \text{ millihenrys,} \\ &= 1{,}000{,}000 \text{ microhenrys or } 10^6 \text{ microhenrys,} \\ &= 1{,}000{,}000{,}000 \text{ centimetres or } 10^9 \text{ centimetres,} \end{aligned}$$

thus 0·02 henry = 20,000 microhenrys = 20,000,000 cms.

Similarly 800,000 cms. = 800 microhenrys = 0·0008 henry.

Where coils with iron cores are employed the inductance is usually stated in henrys, but for straight wires and air-core coils it is usual in wireless work to state the inductance in centimetres. The inductance of a straight wire l cms. long and d cms. diameter

$$L = 2l\left(2{\cdot}3026 \log_{10} \frac{4l}{d} - 1\right) \text{ cms.}$$

The inductance of a coil, or helix, of one layer of D cms. diameter, l cms. long, and having n turns *per cm.*—

$$L = (\pi D n)^2 l\left[1 - 0{\cdot}424\left(\frac{D}{l}\right) + 0{\cdot}125\left(\frac{D}{l}\right)^2 - 0{\cdot}0156\left(\frac{D}{l}\right)^4\right] \text{ cms.}$$

If the coil is long compared to its diameter, its inductance is approximately $L = (\pi D n)^2 l$ cms.

The inductance can also be calculated to within 1 per cent. by the formula given by Prof. Nagaoka :—

$$L = \pi^2 D^2 n^2 l k \text{ or } = \frac{L_1^2}{l} k$$

where L_1 = total length of wire on the coil in cms., D, n, l, have the significance given above, and k is a constant whose value is a function of $\frac{D}{l}$ and can be obtained from tables or a curve. A table is given at the end of this chapter.

A greater accuracy than 1 per cent. is not necessary, for with high-frequency currents the self-capacity of a coil has to be considered; in any case most coils used in wireless circuits are provided with tappings, by means of which they can be adjusted to the value of inductance required.

As regards the inductance of flat spiral coils let D cms. be the mean of the diameters of the various turns, n the number of turns, and l the width from inner to outer turn, then the above formula can be applied if the result is increased by 3·5 per cent. For such spiral coils Spielman has shown that if D is the external diameter of the spiral in cms., d the diameter of the internal aperture and n the number of turns, the inductance is given by a formula of the form:—$L = \frac{n^2 D}{2} \times f\left(\frac{d}{D}\right)$ cms. If the diameter of the central aperture equals the breadth of the winding, $f\left(\frac{d}{D}\right) = 14$: if there is no central aperture and $d = 0$ then $f\left(\frac{d}{D}\right) = 7$. In practice nothing is gained by winding the spiral right to the centre, and a good design is to make the diameter of the internal aperture equal the breadth of the winding.

In designing coils to obtain inductance effects it must not be forgotten that every electrical conductor has some capacity, and the capacity of a coil will depend on its design. It will be seen later that coils used in wireless circuits are designed to have a minimum capacity effect and a maximum inductance effect for the length of wire used.

Mutual Induction.—If some or all of the magnetic lines set up by the current in one circuit are made to interlink with a second circuit in such a way that inductive effects are produced in this circuit there is said to be *mutual induction* from the first to the second circuit. The coefficient of mutual induction is generally denoted by M; it is measured by the induction produced in the second circuit when the current in the first circuit is changing at the rate of 1 ampere per second. Mutual induction coefficient is measured in the same units as self-induction, *i.e.* henrys, microhenrys, or centimetres. The mutual induction effect on a circuit may be added to or opposed to its own inductance effect, so that the total inductance effect is measured by $(L + M)$ or $(L - M)$ respectively.

A changing magnetic field of one circuit interlinking with a second circuit will induce a voltage in it and this voltage may cause a current to flow in the second circuit; thus watts of energy, measured by the product of the volts induced and amperes of current, are by mutual induction transferred from the first circuit to the second. Examples of this will be discussed later when dealing with coupled circuits. To measure the mutual induction between two coils, fixed in a certain position, connect them in series and measure their total inductance by experiment; and call this L_1. Then reverse the connections of one coil and measure the total induction again; call this L_2, then $M = \frac{L_1 - L_2}{2}$.

QUESTIONS AND EXERCISES.

1. What is meant by the "coefficient of self-induction" of a circuit? If a coil has 20 turns and a coefficient of self-induction of 0·001 henry, what is the change in the number of magnetic lines interlinked with it when the current flowing in it is changing at the rate of 1 ampere per second?

2. Find the coefficient of self-induction of a coil consisting of 375 turns of enamelled copper wire; the diameter of the coil being 6·5 cms. and its length 36 cms.

3. In question 2 calculate the change of magnetic lines in the coil when the current changes at the rate of 10 amperes per second.

4. Describe how a coil used to give inductance effects with rapidly changing oscillatory currents differs in design from one used with alternating currents at ordinary low frequencies.

5. The coil of a wavemeter has a coefficient of self-induction equal to 150 microhenrys. What is its value in—

(*a*) Millihenrys?
(*b*) Centimetres?

6. Design a flat spiral coil which will be suitable for carrying currents of the order of 1 microampere and which will have an inductance of $L = 5 \times 10^6$ cms.

SPIELMAN'S TABLES FOR FLAT SPIRAL COILS.

$$L = n^2 D f\left(\frac{r}{D}\right) \text{ cms.}$$

Where n = number of turns, D = external diameter, r = radius of aperture.

$\frac{r}{D}$	$f\left(\frac{r}{D}\right)$	$\frac{r}{D}$	$f\left(\frac{r}{D}\right)$
0	6·9676	0·35	14·1916
0·05	7·7158	0·40	15·6458
0·10	8·5558	0·45	17·2340
0·15	9·4876	0·50	18·9740
0·20	10·5125	0·90	45·7434
0·25	11·6340	1·00	~
0·30	12·8578		

VALUES OF k IN NAGAOKA'S FORMULA.

$$L = \pi^2 D^2 n^2 l K.$$

$\frac{D}{l}$	k	$\frac{D}{l}$	k	$\frac{D}{l}$	k	$\frac{D}{l}$	k
0·1	0·9588	1·2	0·6475	3·2	0·4145	5·5	0·3015
0·2	0·9201	1·4	0·6115	3·4	0·4008	6·0	0·2854
0·3	0·8838	1·6	0·5795	3·6	0·3882	6·5	0·2711
0·4	0·8499	1·8	0·5511	3·8	0·3764	7·0	0·2584
0·5	0·8181	2·0	0·5255	4·0	0·3654	7·5	0·2469
0·6	0·7885	2·2	0·5025	4·2	0·3551	8·0	0·2366
0·7	0·7609	2·4	0·4816	4·4	0·3455	8·5	0·2272
0·8	0·7351	2·6	0·4626	4·6	0·3364	9·0	0·2185
0·9	0·7110	2·8	0·4452	4·8	0·3279	9·5	0·2106
1·0	0·6884	3·0	0·4292	5·0	0·3198	10·0	0·2033

For a given length of wire on a single layer coil the inductance will be a maximum if $D = 2{\cdot}4l$ approx.

CHAPTER VIII

INDUCTION COILS, ALTERNATORS, AND TRANSFORMERS

A Spark Induction Coil used in conjunction with a direct-current supply of comparatively low voltage provides us with a method of generating pulses of high voltage. Its core consists of a bundle of soft iron wires over which is wound in layers a *primary coil* of insulated copper wire; the primary is then covered with an insulating layer of mica, micanite, or ebonite, and on this is wound a *secondary coil* which has many more turns than the primary, is made of smaller gauge insulated copper wire, and is wound in a particular manner to prevent its insulation from breaking down under the voltage strains induced in it.

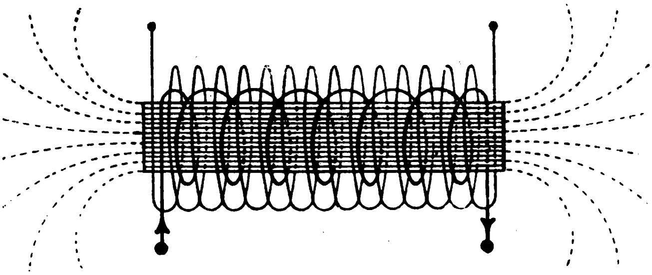


FIG. 34.

When current is started in the primary coil by connecting it to a battery magnetic lines of ether strain are set up in the iron core; when the current is stopped by disconnecting the battery the magnetic strain lines collapse out of the ether. From Fig. 34 it will be seen that magnetic lines set up or collapsing by the starting or stopping of current in the primary coil will interlink with the turns of the secondary coil, and it has already been shown that when the number of magnetic lines interlinked with a turn of wire changes an E.M.F. is induced in the turn, its value depending on the rate of change of the magnetic lines. This rate of change depends on their number, that is to say on the current in the primary coil, and on the rapidity with which they are set up or made to collapse.

All the turns in the secondary are in series with each other so that the induced E.M.F.'s are added together; thus by putting a great many turns in the secondary coil a great difference of potential can be obtained at its terminals when the magnetic lines are changing in number. Each time the magnetic lines are set up in the core an E.M.F. will be induced in the secondary in one direction, and when they collapse the induced E.M.F. will be in the opposite direction. Various methods are employed for rapidly making and breaking the primary current; Fig. 35 illustrates the one which will be most frequently met with in wireless work. The battery current passes through a switch to a metal bracket which supports a metal screw with a platinum or tungsten tip. This tip rests against a platinum or tungsten contact, mounted on a strip of spring metal which carries at the top end a piece of soft iron; this piece of soft iron is called the armature and is arranged to be fairly close to the soft iron core of the coil. When the primary current is switched on the resulting magnetisation of the iron core attracts the soft iron armature, pulling it over so that the contact on the spring support is pulled away from the contact on the end of

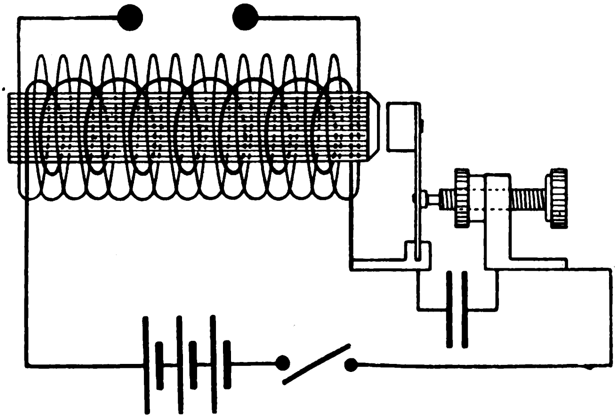


FIG. 35.

the screw and the circuit is thus broken. When the circuit is broken the primary current stops, the magnetisation of the core collapses so that it no longer attracts the armature, the armature and spring fall back, the contacts come together again, and thus the primary current starts again. It will be seen that this make and break of the primary circuit will continue with a rapidity which largely depends on the elasticity and inertia of the combination of spring and armature.

As a matter of fact the magnetic lines in the core of a spark induction coil collapse much more suddenly than they start up, therefore the voltage induced in the secondary at the break of the primary current is very much greater than that induced at the make. So much is this the case that we may neglect the induction effect at the make and simply say that *a high E.M.F. is induced in the secondary each time the primary circuit is broken.*

To understand this we must consider the effect of the magnetic lines on the primary coil itself, for they interlink with it as well as with the secondary. Each time the primary current starts the magnetic lines in building up interlink with the primary coil, and set up in it an E.M.F. of self-induction which is opposed to the current; this prevents the latter from rising quickly to its full value. Thus the magnetic field builds up comparatively slowly, and its induction effect on the turns in the secondary is consequently not very considerable. If C is the steady value to which the current will eventually rise, its value a fraction of time t after switching on is given by the formula :—

$$C_t = C\left(1 - \epsilon^{-\frac{R}{L}t}\right)$$

where R and L are the resistance and inductance of the circuit. The ratio $\frac{L}{R}$ is called the *time constant* of the circuit. The time required for the current to rise to n per cent. of its steady value with steady D.C. voltage applied is :—

$$T = 2{\cdot}3\,\frac{L}{R}\log_{10}\frac{1}{\left(1 - \frac{n}{100}\right)}$$

Again, when the primary circuit is broken and the current stops the collapsing magnetic lines induce in the primary coil an E.M.F. which tends to prevent the current stopping, acting in the same direction as the battery and of very much greater value than the battery voltage. Taking for granted that the break at the interrupter is complete the current must stop suddenly in spite of this E.M.F. so that the collapse of the magnetic field occurs suddenly and a high E.M.F. is induced thereby in the secondary coil. As a matter of fact, unless special precautions are taken, the current will not stop suddenly, for the extra E.M.F. induced in the primary when the current tends to stop will tend to make the current persist in the form of an arc across the break at the interrupter. This arc consists of metal vapour, formed by the heating effect of the current passing across the increasing resistance of the break between the platinum contacts; metal vapour is more or less a conductor, so that if this arcing is allowed to exist the circuit is never properly broken at all, and the decrease of magnetic field is neither sudden nor complete. Under these circumstances a high voltage would not be induced in the secondary coil. The simplest method of preventing this arcing at the interrupter is to connect a suitable condenser across the interrupter contacts as shown in Fig. 35. When the break occurs the extra voltage induced in the primary, instead of making the current arc across the break, will send charges on to the plates of the condenser; as this extra voltage dies away the condenser will send an oscillatory discharge round the primary and battery circuit in the opposite direction, thus helping to complete the collapse of the magnetic lines in the core. The very fact that a charge current has to flow into the condenser will limit the rise of voltage across the interrupter contacts and thus prevent the arcing.

The effect of the condenser can be easily seen by noting the lengths of sparks obtained from the secondary with and without the condenser across the interrupter.

The condenser may be made up with sheets of tinfoil separated by paraffined paper. For one inch Spark Coils it should have a capacity of the order of 1 microfarad; it can be designed by applying the formula, $K = \frac{Ak}{4\pi t \times 900{,}000}$ mfds. For the interrupter contacts tungsten, or an alloy of tungsten and molybdenite, wears better than platinum, and can be of smaller cross-section; there are various designs for giving a high rate of interruption per second, and the most suitable design will depend upon the size of the coil and energy dealt with. The Wehnelt electrolytic and the mercury jet interrupter are suitable for use with spark coils used for X-ray work; they are not much employed in radio-telegraphic work and therefore will not be described.

Spark coils for radio-telegraphic transmitters have to be specially designed because the voltage induced in the secondary is required to send a charging current into a condenser. It will be found that a coil which will ordinarily give a 10″ spark across its secondary will give a very short spark when a condenser is connected across its secondary terminals. The condenser must first be charged, and the voltage to which it is charged is that which is available for sending a spark across the discharge gap.

Now the voltage induced in the secondary at the break of the primary rises very suddenly, but it also falls quickly to zero again; the charging current which it sends into the condenser has to flow through the resistance of the secondary winding and connecting wires, and so takes some time to build up the condenser potential. Suppose the voltage induced in the secondary rises to 100,000 volts; this would instantly send a discharge across a long spark gap under ordinary circumstances, but if it has to send a charging current into a condenser the current has to flow through the secondary resistance, and the drop of volts (CR) in this resistance, coupled with the fact that the condenser takes an appreciable time to charge up, means that the impulse of voltage is over before the condenser has been charged to more than about 8000 volts in this case. Under these circumstances unless a spark gap across the condenser is of such a length that 8000 volts can cause a discharge no spark will pass across it. It can be shown that if V is the voltage applied to a condenser K_1 and the current has to flow through a secondary coil of resistance R, the voltage to which the condenser is charged after time t seconds is $V_1 = V\left(1 - \epsilon^{-\frac{t}{K_1R}}\right)$; by taking logarithms it follows that $t = 2{\cdot}3026K_1R\,\{\log V - \log(V - V_1)\}$. Thus the voltage of discharge will be less the greater the capacity of the condenser.

This demonstrates two things:—

(1) That the secondary under these circumstances must be wound with comparatively thick wire so that the current encounters little impedance against its rush into the condenser before the volts drop away.

(2) That the condenser must not be too large for the given size of coil, else the current from the secondary will not charge it up to a sufficient voltage.

If the resistance of the secondary is high, or the condenser charged by it too large, the discharge voltage will be low, and the spark gap will have to be comparatively short.

The secondary coil consists generally of double silk covered copper wire, and should be wound in sections as shown in Fig. 36.

Each section consists of a spirally wound coil on a thin ring of paraffin-paper, brushed over with hot paraffin so that it sticks to the paper. All these sections are then threaded over the insulating cover on the primary, connected with each other in series as shown, pressed close together and hot paraffin run in to impregnate the whole mass. It is important that the connections should be made as shown so that the currents will flow in the same direction round each section, and that there will be no undue potential strain between the turns of wire lying contiguous to each other.

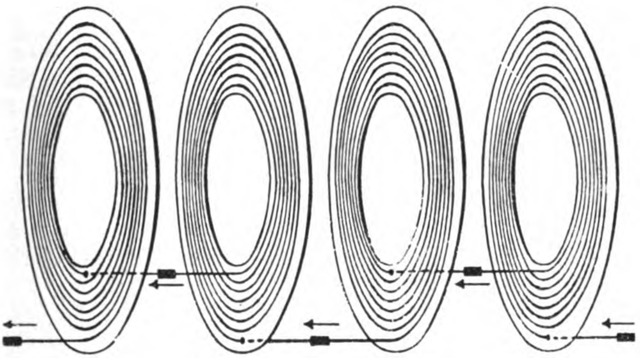


Fig. 36.

This is a much safer construction than simply winding the coil in layers one on top of the other ; for example, if we wind a layer of 500 turns forward, and a similar layer of 500 turns back over it, we have 1000 turns in series and the potential difference between the first and last turn when induction takes place may be very great, yet they are placed close to each other. This would be very much like arranging a 500-volt battery of cells so that the positive terminal on the first cell is dangerously close to the negative terminal on the last one.

The primary should be wound with good conductivity copper wire with double cotton covering ; its resistance should be kept low so as to keep the ohmic drop of volts to a minimum.

Instead of a vibratory interrupter a rotary one may be employed, and it can be driven by a little motor which derives its driving current from the same battery as supplies the primary coil; if possible it is better to have an independent battery for the motor. One style of rotary interrupter consists of a cylinder of ebonite with bars of copper dovetailed into its surface; a pair of brushes fixed in line on a spindle, but insulated from each other, press on the cylinder, and the circuit is closed each time a copper bar comes under the two brushes. The disadvantages of this type of rotary interrupter are:—

(1) The necessity of keeping a proper pressure on the brush contacts without having undue wear on the brushes or the cylinder.

(2) The fact that the ebonite and the copper on the cylinder surface do not wear away evenly so that the copper bars become loose in course of time.

(3) Dust and moisture on the rotating cylinder cause sparking, with consequent metallic deposit on the ebonite between the bars, and deterioration of the clear make-and-break effect.

One of the great advantages of the rotary interrupter is the fact that the rate of interruption can be easily determined by fixing the speed of the motor and the number of bar contacts on the rotary cylinder; obvious improvements in the design will suggest themselves to the student.

The efficiency of a spark induction coil designed for, and used with, wireless apparatus is not more than about 50 per cent.; it differs from a similar coil designed for X-Ray work, or other work of a like nature, in that the ratio of secondary turns to primary turns is lower and the secondary is wound of thicker wire than usual. The constants of a Marconi Co. 10-inch spark induction coil are: primary resistance 0·20 ohm, primary inductance 0·015 henry, secondary resistance 6500 ohms, secondary inductance 625 henrys, capacity of shunt condenser 1·5 mfds., magnetic leakage 0·33, and ratio of transformation 160 : 1.

Alternators.—An alternator is a machine in which the difference of potential, or voltage, induced has not a constant value, as in an ordinary direct current generator, but rises and falls and reverses in direction many times per second. Let us consider the potential changes in any wire, W, on the armature as the armature rotates. Fig. 37 shows some of the poles, and magnetic lines coming out of N. poles, passing through the armature iron core, and going into S. poles; we will suppose the armature to rotate in the direction of the arrow, so that the wire W cuts through these magnetic lines.

Starting from the position shown, as the wire passes to A the voltage induced in it will rise to a maximum value : this is represented on the curve below by the height of the line V_m ; when the wire goes on from A to B, passing out of the magnetic field the voltage dies away to zero again, as shown at V_0 on the curve. Then, as it goes on from B to C, the voltage will rise in it again to a maximum, but since the magnetic lines are going up into the S. pole, whereas they were coming down from the N. pole, the voltage is now induced in the opposite direction along the wire ; this is shown by drawing the voltage below the line instead of above it. As the wire passes on from C to D, out of the magnetic field, the voltage dies away to zero again as shown on the curve. From D, as it goes on in front of another N. pole, a new wave of voltage is started exactly similar to that drawn, so that in each wire we get a complete wave of voltage for every pair of poles on the machine.

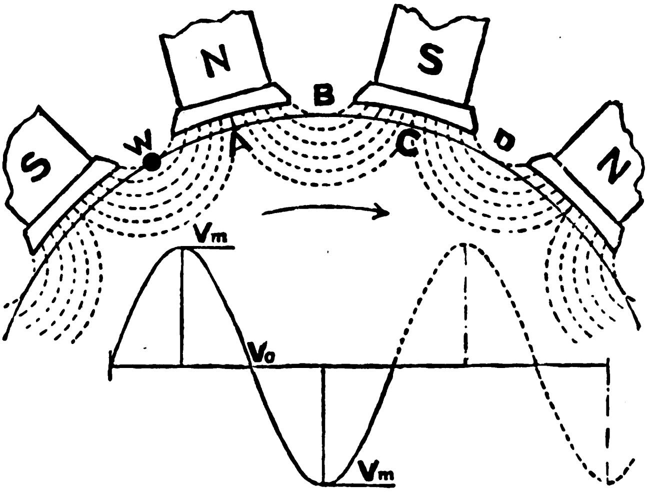


FIG. 37.

There are a great many wires on the armature, and induction is taking place simultaneously in each of them ; they are all connected properly in series with each other, so that all their voltages are added together like that of cells in a battery. Thus between the end terminals of the armature we get a big wave of voltage as the wires pass in front of each pair of poles, and in this way an alternating voltage of 100, or 200, or 5000 volts is obtained, depending on the number of magnetic lines per pole, the speed at which they are cut by the wires, and the number of wires in series.

If there were only two poles on the machine the distance from W to D would represent one complete revolution or 360°, therefore the distance along the horizontal line corresponding to a complete cycle of voltage represents 360°.

The end wires are connected to two insulated rings on the shaft, and connection with the outside circuit is made to these through brushes bearing on them. Direct current must be used in the coils on the poles of the alternator to provide the magnetic field: this may either be obtained from a battery, or some of the alternator's own armature current may be led to a commutator mounted on its shaft, and so turned into direct current for use in the pole coils. The latter are generally connected all in series with each other.

Since the voltage is at one moment a maximum and the next moment zero, a question at once arises as to what is meant by saying the voltage is 100, or 200, or 500. These values denote the effect which the voltage will have on a voltmeter, or lamp, or other apparatus to which it is applied; this effective value of the voltage is 0·707 of the maximum value; *i.e.* $200 \text{ volts} = 0{\cdot}707\, V_m$, so that if the voltmeter reads 200, the maximum value of the voltage wave is $200 \div 0{\cdot}707 = 283$ volts.

When voltage is applied to a circuit the watts of energy in the circuit equal $V \times C$, but $C = \frac{V}{R}$, $\therefore$ watts $= \frac{V^2}{R}$, *i.e.* the effect in the circuit is proportional to the square of the volts. In the case before us the volts are varying in accordance with the shape of the curve shown in Fig. 37; this is called a sine curve, for at any moment the volts induced in a wire on the armature are found to be proportional to the sine of the angle through which the wire has moved. Thus if V_m is the maximum value the instantaneous values at the terminals of the machine at various instants of time are—

$$V_m \sin 5^\circ,\ V_m \sin 10^\circ,\ V_m \sin 20^\circ,\ \ldots\ V_m \sin 360^\circ$$

The effect at any instant will be proportional to the square of the voltage at that instant, and the average effect will be proportional to the average square of all the above voltages. It is easily seen that this depends on the average values of the square of the sines of all angles between 0° and 360°; this is known to be $\frac{1}{2}$, thus the average effect is proportional to $\frac{1}{2}V_m^2$ and the effective voltage is therefore $\sqrt{\frac{1}{2}V_m^2} = \frac{1}{\sqrt{2}}V_m = 0{\cdot}707\,V_m$.

It is important not to overlook the fact that the voltage we read in a voltmeter on an alternating circuit is not the maximum voltage which is applied to the circuit, thus if the voltmeter reads 10,000 volts we must not forget that the maximum strain on the insulation is due to 14,100 volts, which is the maximum value in this case.

Referring again to Fig. 37 it is seen that a complete wave of voltage is obtained for each pair of poles on the machine; such a complete wave is called a *cycle* and the number of cycles per second is called the *frequency* of the machine or circuit in which its current flows.

It is very easy to calculate the frequency, for if there are p pairs of poles, there are p cycles in each revolution, and if there are n revolutions per second, there are pn cycles per second, which is the frequency. Thus if an alternator has 8 poles and runs at 1500 revolutions per minute, there are 4 pairs of poles and 25 revolutions per second, therefore there are 4 cycles per revolution, or 100 cycles per second—the frequency is 100. Alternators for ordinary commercial work in this country are usually made for a frequency of 50, but when used for radio-telegraphy they are designed for a frequency of 100–500.

Alternators used for radio-telegraphy generate from 200 to 2000 volts; these voltages are much too low to charge condensers in order that the latter may discharge across spark gaps. As already mentioned it requires about 3000 volts to spark across 1 mm. of air. Therefore the voltage is transformed up by a step-up transformer, which is in some respects similar in design to an induction coil; the alternator is connected to the primary coil of the transformer, and as the secondary coil has a great many more turns in it than the primary the voltage obtained from the latter will be an alternating one, but very much higher than that applied to the primary. In this way from 20,000 to 70,000 volts can be obtained for charging condensers, and provides the method of excitation usually adopted for all Wireless Telegraphy Transmitters from size $\frac{1}{2}$ KW. upwards.

It will be remembered that with an induction coil the high voltage was induced every time the primary circuit of the coil was broken; if the interrupter vibrates at the rate of 100 per second we get a high voltage to charge the shunted condenser 100 times per second, and thus obtain a spark discharge 100 times per second.

With an alternating generator and transformer *we obtain a high voltage twice in each cycle,* therefore if there are 200 cycles per second we have a maximum of voltage 400 times per second, which can give 400 sparks per second, if the spark gap is arranged so that a spark takes place only when the generator voltage is a maximum; this is called " synchronous " sparking rate.

If the inductance and capacity effects in the circuit connected to the alternator terminals are negligible the resulting current in the circuit will rise, fall, and reverse in step with the volts; it is an alternating current of the same periodicity as the voltage and of similar sine wave form, its value at any moment being given by Ohm's Law; *i.e.* $C = \frac{V}{R}$. *The current and volts are then said to be in phase with each other.* Considering the effect of the current in the circuit we know that the watts of energy in the circuit can be written C^2R, since watts $= V \times C$ and $V = CR$; thus the effects are proportional to the square of the current. But the current is continually changing; like the volts, its values lie on a sine curve, therefore the average square of current equals the square of the maximum value of current multiplied by the average square of the sines of all angles between 0° and 360°.

$$\text{Thus (effective current)}^2 = C^2_{\text{max.}} \times \tfrac{1}{2}$$

$$\therefore \text{ Effective current} = \frac{1}{\sqrt{2}} C_{\text{max.}} = 0{\cdot}707\, C_{\text{max.}}$$

This is what will be read in an ammeter connected in the circuit, and is what is meant when we say that the alternating current is so many amperes.

Lag and Lead.—If the circuit has appreciable inductance effects the current will rise to its maximum and pass through its zero values later than the similar changes in the voltage; the current is then said to *lag* behind the volts. At the same time the value of the current will be less than it would have been had the inductance effect been absent. To understand this it must be remembered that inductance in electricity corresponds to inertia in mechanics; its action is always to oppose any change of current value, and its effect will be greatest when the current is changing at its greatest rate. An inspection of a sine curve of current will show that the current change is steepest when it is passing through its zero value, hence at this point the back E.M.F. of self-induction is greatest. If f is the frequency, L the inductance of the circuit, and C the effective current, the effective value of the back E.M.F. is $2\pi f$LC volts. The relation between the current and the back E.M.F. will be as shown in Fig. 38.

Since one complete cycle AB represents 360°, the distance

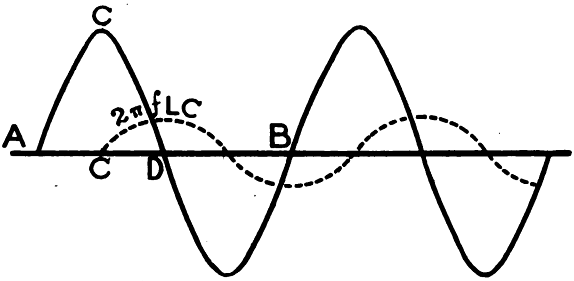


Fig. 38.

CD represents 90°; in other words the back E.M.F. is at right angles to the current. Now to get the current through the circuit we must apply a voltage CR to drive it through the resistance and a voltage $2\pi f$LC, equal and opposite to the back E.M.F. of inductance; also the latter component of voltage must be at right angles to the former.

The required voltage can therefore be obtained by putting

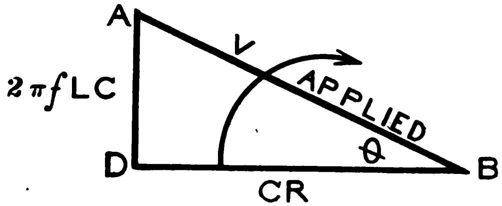


Fig. 39.

these two components at right angles to each other as shown in Fig. 39, and getting their resultant which is represented by the hypotenuse of the right-angled triangle. This is called a vector diagram. The current will be in phase with the ohmic component CR, therefore is out of phase with the applied volts by the angle θ. It is easily seen that if the inductance of the circuit is very large compared to its resistance $2\pi f$LC will be large compared to CR, most of the applied volts V are used up in overcoming this back E.M.F., the current will be relatively small, and the angle θ by which the current is lagging behind the volts will be nearly 90°. Also, since in a right-angled triangle $AB^2 = AC^2 + CB^2$, it is seen that $V^2 = (CR)^2 + (2\pi fLC)^2$, or $V = C\sqrt{R^2 + (2\pi fL)^2}$. If $L = 0$, $2\pi fL = 0$, and $V = CR$, that is the current is in phase with the volts and obeys Ohm's Law when the inductance is negligible. The phase relationship of the voltage, current, and back E.M.F. will be as shown in Fig. 40, the current lagging behind the volts by an angle θ which is represented by the distance *ab* along the base line in this diagram.

Now if there is a capacity effect in the circuit it will tend to neutralise the reaction of inductance so that the current does not lag so much behind the volts; indeed, if the capacity effect preponderates the current may even *lead* the volts; that is to say after the first surge in the circuit the current will rise to its maximum before the volts are a maximum and pass through zero value before the volts are zero. The student may find it difficult to realise that, for example, the current could be a maximum before the applied potential attains its maximum value; this difficulty is removed if one remembers that capacity effects in electricity correspond to elasticity in mechanics. Making use of Dr. J. Fleming's famous analogy, suppose there is a railway truck on a pair of rails in front of a wall to which the truck is attached by a strong spring, and that an alternating force is applied to make the truck move backwards and forwards. When a force is applied and the truck moves backwards it compresses the spring and the effect of this will be that the spring drives the truck forward even before a forward force is otherwise applied. A forward force is

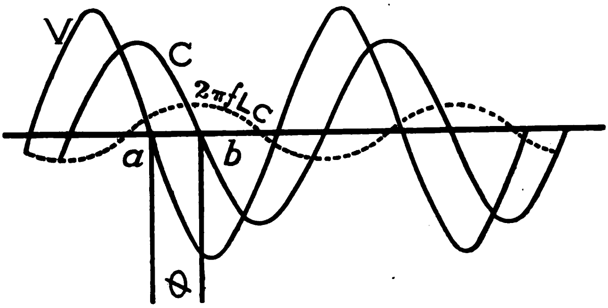


FIG. 40.

now applied which rises to a maximum and dies away to zero; the truck moves forward and by the time it comes to rest the spring is extended, tending to pull the truck back even before a backward force is applied. Similarly in an electric circuit containing capacity effect, the capacity is charged up by the applied potential, and when the latter dies away to zero the discharge from the capacity starts a current flowing in the opposite direction before the potential applied to the circuit has built up in the reverse direction.

In the truck analogy inertia of movement of the truck will act in opposition to the spring's effect; similarly in the electrical circuit inductance effects act in opposition to capacity effects.

Finally, the displacement of the truck for a given force applied will vary inversely as its weight, so in the electric circuit the displacement, or current, of electricity for given applied volts varies inversely as the resistance.

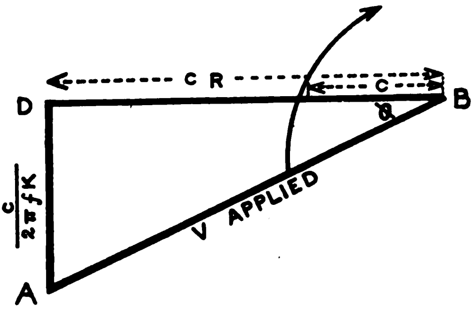


FIG. 41.

The reactance of a capacity effect of K mfds. to an alternating current flowing at a frequency of f cycles per second is $\frac{1}{2\pi fK}$ ohms, and the back E.M.F. set up by this capacity reaction is $\frac{C}{2\pi fK}$ volts. This back E.M.F., like that due to inductance, acts at right angles to the current; if a circuit contains resistance and capacity, with negligible inductance, the voltage required to send an alternating current through the resistance and against the capacity reactance can be found by a vector diagram as shown in Fig. 41. It is seen to be similar to that already given for an inductive circuit, but in this case the current leads the volts by an angle θ instead of lagging.

From the Fig. it can be realised that if R is small and $\frac{1}{2\pi fK}$ large, CR will be small compared with $\frac{C}{2\pi fK}$. AB would then be nearly equal to AD, the angle of lead θ will be nearly a right angle, and most of the applied volts V will be employed in setting up the capacity reaction volts, $\frac{C}{2\pi fK}$.

Later it will be seen that in spark wireless transmitters an alternating voltage is applied to a condenser circuit in which the inductance and resistance effects are relatively low, so that the resulting current flow may lead the applied volts by an angle of nearly 90°, as shown in Fig. 42. Also, when dealing with the Marconi disc discharger, it will be shown that an alternator circuit can be periodically broken when the condenser voltage is a maximum without sparking at the contacts, because the alternator current is zero at the moment of break.

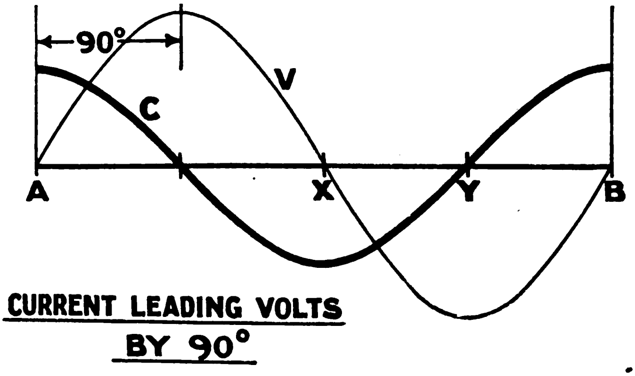


FIG. 42.

The general case would be a circuit containing inductance, capacity, and resistance, the vector diagram of which would be as shown in Fig. 43. Lay out a line AB to represent the current in phase and value. Multiply C by R and get the line AD which represents CR—the volts required to send the current through the resistance. DE represents the inductance back E.M.F. $= 2\pi fLC$, acting at right angles to the current, and DF the capacity back

E.M.F. $= \frac{C}{2\pi f K}$, also acting at right angles to the current but in opposition to the inductance back E.M.F. Subtract DF from DE and get DG, which is the resultant back E.M.F., then AG represents the volts required to be applied to the circuit since it represents the resultant of AD and DG. It is easy to see that AG $= \sqrt{AD^2 + DG^2}$, or

$$V = C\sqrt{R^2 + \left(2\pi f L - \frac{1}{2\pi f K}\right)^2}$$

The square root factor in this equation is called the *Impedance* of the circuit, $2\pi f L$ is the ***reactance of induction***, and $\frac{1}{2\pi f K}$ is the ***reactance of capacity***, all measured in ohms when L and K are in henrys and farads respectively.

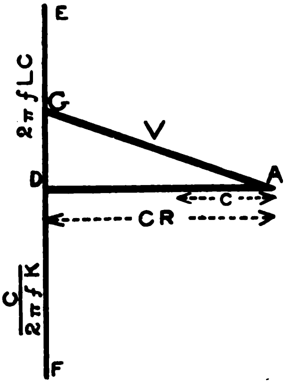
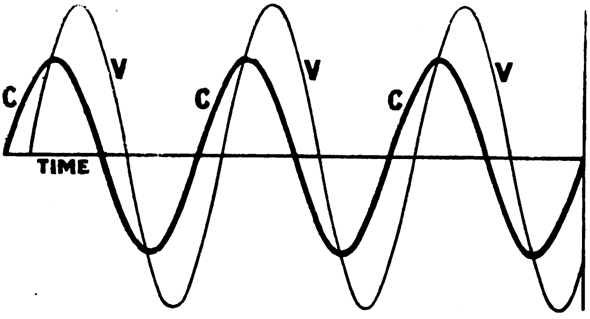


Fig. 43.

Fig. 44 is an example of the current leading the volts in a circuit where the capacity effect preponderates over the inductance effects.



THREE CYCLES OF A "LEADING" CURRENT.

Fig. 44.

Transformers.—The function of an interrupter on an induction coil is to make and break the magnetising current in the primary, so that the magnetic lines set up in the iron core would collapse through the secondary, inducing impulses of high voltages in it at a speed of, say, 100 impulses per second. An alternating current is one which rises to a maximum, falls to zero, reverses its direction, falls to zero, and so on, at a rate which depends on the frequency, or number of cycles per second; if such a current is available the magnetic lines in the core rise and fall without an interrupter, and so generate high voltages in the secondary coil. Such an arrangement of coils for use with alternating currents is called a transformer; the construction of a closed iron core transformer will be here briefly described.

An iron core, made of thin sheets or laminations of iron averaging about 0·012 inch thick, is built up; each sheet being slightly japanned or oxidised. On this core is wound a coil of double cotton-covered copper wire, called the primary, through which the alternating current will flow. The primary is covered with good insulation—micanite, presspahn, or mica; and over this again is wound the secondary coil which is of smaller wire than the primary, but consists of a great many more turns if it is desired to obtain a high voltage from it. The ends of the secondary are brought to two terminals heavily insulated with ebonite or porcelain. If the transformer is a small one, dealing with energies up to 5 KW., it is put in a perforated iron case and is then said to be air-cooled; a large transformer is enclosed in a cast-iron case which is filled with special transformer oil. The core and coils of a transformer get hot when in use, and the oil serves to convey the heat from them to the iron case from which it is radiated away.

With very large transformers an air blast may be blown through for the same purpose.

The design of a transformer differs from that of an induction coil in that the magnetic lines have a complete iron circuit or path. The magnetic lines of an induction coil, issuing from one pole of the core, have to pass through the air to the other pole as they do in the case of an ordinary bar magnet; in a transformer the iron path is continuous so that the magnetic lines, set up in the core on which the coils are wound, continue their paths in the iron which connects, as in Fig. 45, one end of the core to the other. This arrangement ensures that magnetic strain lines are set up easily in the iron, and that more magnetic lines are set up by any given value of primary current than would otherwise be the case, thus ensuring high efficiency.

When the alternating current flowing into the primary rises to a maximum the resulting magnetic lines in the core will induce a voltage in the secondary coil which also rises to a maximum.

When the current dies away and rises to a maximum in the opposite direction the magnetic lines die away and new ones are set up in the opposite direction, so that a voltage is now induced in the secondary coil in an opposite direction to that induced at first.

Thus it can be seen that the secondary induced voltage will be alternating, having the same frequency as the applied voltage and current. If the applied voltage goes through 100 complete cycles per second the voltage induced in the secondary will do likewise, and as in each complete cycle there are two maximum values in opposite directions, we see that a frequency of 100 cycles per second means 200 maximum values of voltage per second. With an induction coil we only get a secondary high voltage at each break of the primary current; with a transformer we get a secondary high voltage twice in each cycle of primary current.

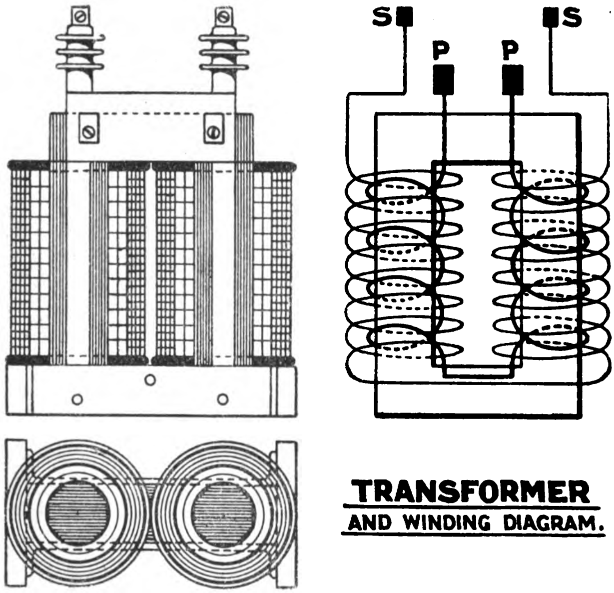


Fig. 45.

If the core of an induction coil, or of a transformer, were made of solid iron, voltages would be induced in the iron (which is a conductor of electricity) by the changing magnetic field in it, and currents would flow in it which cannot be used and would only heat up the core. This explains why the cores are built of iron wires, or iron laminations, japanned or oxidised—the japanning offers resistance to these currents so that their values are small. Such currents are called *eddy currents.*

With iron of inferior quality the magnetic field in the core lags behind the primary current, thus when the current is zero the field is not yet zero and some of the energy of the current going in the reverse direction will be used up in sweeping out the remanence of magnetism. This is called *hysteresis effect,* and the energy loss due to it is hysteresis loss. It can be made almost negligible by employing iron of good quality for the core, such as the special one called Stalloy. Eddy current loss and hysteresis loss combine to give what is called the *iron loss* in the transformer.

The current in the primary flows through its resistance and consequently there is $C_p{}^2R_p$ loss of watts ; similarly when current is taken from the secondary there is a $C_s{}^2R_s$ loss of watts in the secondary. These two combined represent what is called the *copper loss ;* it can be made very small by using sufficient section of wire in the coils, thus keeping their resistance low, and the gauges of wire should be chosen so that on full load the losses in the primary and secondary are approximately equal.

Well-designed transformers will have an efficiency of over 90 per cent. even in small sizes, and a 1000 KW. transformer can have an efficiency of 99 per cent. Roughly one may say that the more iron and copper allowed in the design per KW. of energy to be handled the higher will be the efficiency of the transformer.

If M is the maximum value of the number of magnetic lines set up in the core, T_p the turns in the primary, V_p the voltage applied, and f the frequency ; we have the following relation :—

$$V_p = \frac{4{\cdot}44M \,.\, T_p \,.\, f}{10^8}$$

Thus if the voltage, frequency, and number of turns in the coil are known we can find the number of magnetic lines set up in the core. A similar formula holds for the secondary coil—

$$V_s = \frac{4{\cdot}44M \,.\, T_s \,.\, f}{10^8}$$

Transformers designed for radio-transmitter purposes are made to give a secondary voltage of from 20,000 to 70,000 volts.

From the above formula it can be seen that the ratio of voltage induced in the secondary to the voltage applied to the primary is the same as the ratio of the number of turns in the respective coils—

$$\frac{V_s}{V_p}=\frac{T_s}{T_p}$$

If the slightly erroneous assumption is made that the efficiency of the transformer is 100 per cent., and that as many watts are obtained from the secondary as are put into the primary, then $V_sC_s = V_pC_p$, or

$$\frac{C_s}{C_p}=\frac{V_p}{V_s}=\frac{T_p}{T_s},$$

that is to say the ratio of the currents is roughly the inverse ratio of the numbers of turns in the coils.

Alternating Current Power and Power Factor.—If V is the effective value of an alternating voltage applied to a circuit, and C the effective value of the resulting current, the effective watts in the circuit = VC only when the volts and current are in phase. Obviously if the current is zero when the volts are a maximum, or *vice versa*, the power will be zero, and even when they are not so much as this out of phase the power will be something less than that given by the formula VC, whether the current is lagging or leading. As Dr. Stienmetz said, in an analogy, a workman will make his maximum effort when he has a full kit of tools and at the same time a maximum desire to work. But if he is lacking in tools just when he is keen to work, or has a full supply of tools without a full desire to work his output will be reduced.

To obtain an expression for the power in an alternating circuit when the current lags behind or leads the volts we must multiply the current, not by the volts, but by the component of voltage in phase with the current.

In Figs. 39 and 41 it will be seen that the component of voltage in phase with the current is the ohmic or CR volts represented by the line BC. Now BC = AB cos θ, $\therefore$ the CR volts = V cos θ. Thus if C is the amperes in the circuit, V the volts applied, and θ the angle of lag or lead, then the power = VC cos θ watts. Cos θ is called the *power factor*. If C is in phase with V, $\theta = 0$, and cos $\theta = 1$; then power = VC and the circuit obeys Ohm's Law; if θ is nearly 90°, as it would be in a circuit containing either high inductance or high capacity effects compared with the resistance, $\cos 90° = 0$, therefore the power $VC \cos \theta = 0$ no matter what the values of the current and voltage may be.

The amount of copper in the circuit depends on the value of the current to be carried by it; if this copper is to be as remunerative as possible the power for a given current should be as great as possible; thus every precaution should be taken to ensure that the current is as nearly in phase with the volts as we can get it, making θ very small and the Power Factor ($\cos \theta$) nearly unity.

Resonance Effects.—In the general case it was shown that the formula $C\sqrt{R^2 + \left(2\pi f L - \frac{1}{2\pi f K}\right)^2}$ gives the voltage required to drive an alternating current through a circuit containing inductance and capacity effects. $\sqrt{R^2 + \left(2\pi f L - \frac{1}{2\pi f K}\right)^2}$ is called the *impedance* of the circuit, and for a given resistance of circuit the impedance will be least when the part enclosed in the bracket is zero; *i.e.* when $2\pi f L - \frac{1}{2\pi f K} = 0$

$$2\pi f L = \frac{1}{2\pi f K}$$

$$f = \frac{1}{2\pi \sqrt{LK}}$$

When the frequency has this value the circuit is said to be in a state of resonance.

Under these conditions $V = C\sqrt{R^2 + 0} = CR$; the effects of inductance and capacity neutralise each other, the current is in phase with the volts, the power factor is unity, and the power is a maximum for a given V and C.

When a circuit is in a state of resonance the current and volts may be of moderate values and yet excessive strains may be set up across the inductive and capacity portions of the circuit which are balancing each other. Thus it is quite possible to arrange an alternating circuit with resistance, capacity, and induction to give the conditions shown in Fig. 46; the voltage required to send the current through the resistance is only 10 volts, yet the alternating current flowing through the induction coil may set up a self-induced E.M.F. in it of 1000 volts and this is balanced by a similar reaction voltage across the condenser portion of the circuit.

The induction coil and the condenser are each experiencing a strain of 1000 volts though only 10 volts are applied to the circuit.

The student will remember that, although only 6 to 10 volts may be applied to the primary of a spark induction coil, the back E.M.F. of inductance set up in it may make the current spark across the break of the interrupter, and will administer a very nasty shock if the metal parts of the interrupter are touched. Similarly when an effective alternating voltage V is applied to a condenser oscillating circuit the voltage to which the condenser is charged is $\frac{\pi}{2} \times \sqrt{2}\text{V}$; this will be referred to again in Chap. XIII.

In long land lines carrying alternating electric power for distances of 100 or 200 miles, of which there are many examples in America, the working frequency is such that a dangerous condition of resonance is not likely to occur, but very special precautions have to be taken against lightning discharges, for these may start surges in the line at a frequency such that $2\pi f\text{L} = \frac{1}{2\pi f\text{K}}$, and thus set up breaking strains of voltage.

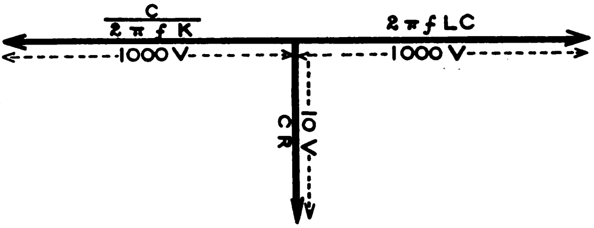


Fig. 46.

Similarly in wireless work where alternators and transformers are employed the working frequency will not set up excessive strain, but precautions must be taken to prevent high frequency oscillating currents from getting back through them, as resonance effects may be set up by the high frequency currents and break down the insulation of the end turns of the transformer or alternator. We shall see later that choke coils and lamps are employed for this purpose.

As a matter of fact the low frequencies used in the generating circuit of a wireless transmitter are not such as will set up resonance effects likely to break down the insulation, and resonance is really encouraged because it improves the power factor. Thus the voltage from a transformer secondary is used to charge a condenser, K, and the impedance of this circuit is least when $2\pi f L_s = \frac{1}{2\pi f K}$ or $L_s = \frac{1}{4\pi^2 f^2 K}$, but

$$\frac{L_p}{L_s}\text{ approx.} = \frac{T_p}{T_s}$$

$$\therefore L_p = \frac{T_p}{T_s}L_s = \frac{T_p}{T_s}\,\frac{1}{4\pi^2 f^2 K}$$

$$\therefore \frac{T_s}{T_p} = \frac{1}{4\pi^2 f^2 L_p K}$$

Now $\frac{T_s}{T_p}$ is fixed by the step up of voltage required, therefore this equation shows us that with a given frequency (f) and condenser (K) the transformer primary should have an inductance (L_p) if resonance, a good power factor, and maximum energy of output for a given current and voltage of machine are to be attained.

If the primary in itself has not this value of inductance a small auxiliary and adjustable inductance coil can be connected in series with it, as is done in some Marconi transmitters described later. In a circuit arranged for resonance the voltage will build up with each swing of the current if a discharge is not allowed to take place in the meantime. By setting the spark gap fairly long this property may be used to obtain high voltage effects, but the sparking rate will be reduced. The voltage may thus rise to a maximum at the end of four or five cycles so that a spark discharge then takes place. One pulse of energy is drawn from the machine and one spark discharge takes place at every fourth or fifth cycle. The question of resonance and resonance transformers will be further dealt with in Chaps. XIV. and XV.

QUESTIONS AND EXERCISES.

1. Why is the core of a transformer made of japanned laminations instead of solid iron?
2. Explain the function of a condenser when joined across the make and break contacts of an induction coil.
3. Why is the secondary of an induction coil used for wireless telegraphy purposes made of thicker wire than usual?
4. A transformer is supplied with alternating current at a voltage of 100, and a frequency of 50 cycles per second. If it has got 400 times as many turns in

the secondary as are in the primary, what voltage will be induced in the secondary, and how many times in a second will this voltage rise to a maximum ?

5. If an induction coil has 300,000 volts induced in its secondary what is the approximate length of spark it will give in air ?

6. If a condenser is joined across the secondary terminals of an induction coil why is the spark obtained very much shorter than if the condenser were not connected ?

7. An alternator has 8 poles: at what speed must it run to generate voltage at a frequency of (*a*) 100, (*b*) 200 cycles per second ?

8. What is meant by saying that an alternating current is not in phase with the volts ? Draw curves of alternating voltage and current in which the current leads the volts by 45°.

9. If the voltage of an alternator is 400, what is the maximum value to which the voltage wave rises twice in each cycle ?

10. If the current in the primary coil of a spark induction coil is flowing clockwise in what direction is the current in the secondary flowing ?

11. What would be the result of making the core of a transformer of steel instead of annealed soft iron ?

12. What is meant by resonance and how is it obtained in an alternating circuit ?

CHAPTER IX

OSCILLATORY DISCHARGES

It has been shown that an electric strain is set up in the ether round or near conductors charged with electricity, its extent depending on the amount of charge, on the capacity of the charged system, and on the nature of the dielectric in which the ether is strained. A disappearance of electric strain in the ether sets up in it a magnetic strain, round the wire or circuit through which the discharge takes place.

The amount of electrification and of electric strain can be increased by using condensing effects, and will increase as the difference of potential applied is increased. Large differences of potential can be obtained by using an induction coil or a transformer, and the amount of charge is equal to the product of the potential applied and the capacity of the system charged; $(Q = VK)$.

The amplitude of discharge varies directly as the difference of potential across the circuit in which it takes place, and inversely as the Impedance effects present in the circuit. Inductive effects always oppose any change in the rate of discharge; these effects will depend upon the shape of the circuit and the rate at which the current, or discharge, is changing. The energy of charge depends on the potential applied and on the capacity of the charged system; the rate and nature of the discharge depends on the potential, capacity, resistance, and self-induction in the discharging circuit.

In 1838, Prof. Henry, of Princeton University, discovered that when a condenser is discharged across a small spark gap the discharge is not simply in one direction across the gap, but oscillates backwards and forwards across it; what appears to be a single discharge spark is really a rapid succession of sparks. They follow each other so rapidly that we cannot distinguish between the separate sparks with the eye. Fig. 47 shows the record obtained when the discharge from an oscillating condenser circuit is made to act on an oscillograph. If the spark is photographed on a plate rapidly falling in front of it

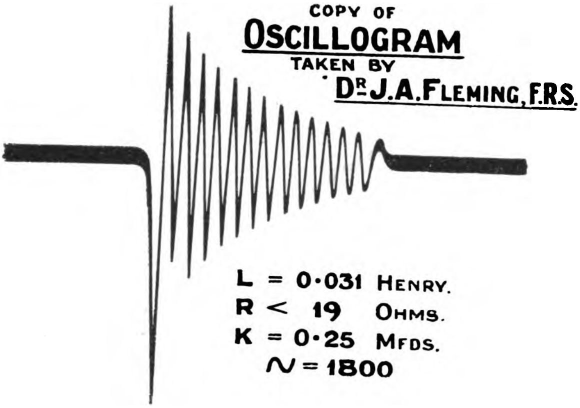


FIG. 47.

the photograph will show that it is not one single flash but a rapid succession of flashes.

We can find an exactly similar action in a water analogy

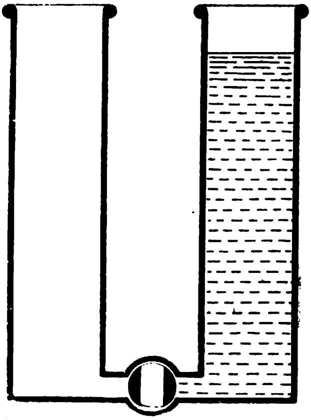


FIG. 48.

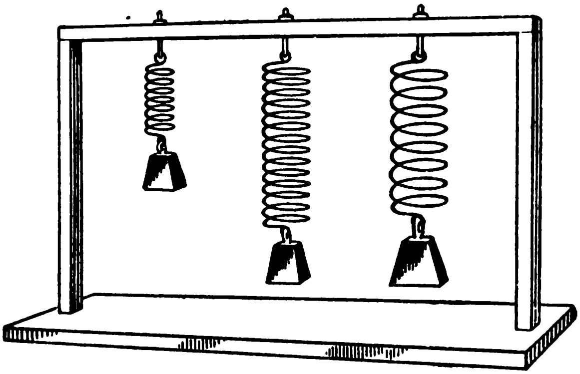
when two long glass tubes are connected by a pipe whose bore is not too small, and fitted with a stop cock. The tubes are filled with water coloured so that it can be easily seen, and one tube is filled to a greater height than the other one. If the tap is suddenly opened the water will flow, or discharge, along the pipe from the tube in which the greatest pressure exists to the other one. We might expect that the flow would take place in the one direction until the water stands at the same height in both tubes, but it will be found that under suitable conditions this is not the case. The water will overflow into the second tube, raising the level in it too high; it will then surge back again into the first tube to produce the same effect in it; thus we shall see the water surging backwards and forwards between the tubes several times. The surges will gradually die down and the water will settle at the same level in each tube, so that the oscillating movement of the water in the connecting tube will cease.

This is analogous to the action occurring when a condenser is discharged under suitable conditions; the discharge surges backwards and forwards across the spark gap in the circuit, its amplitude decreasing until it ceases when the remaining difference of potential is not sufficient to send a further discharge across the gap. Some interesting questions at once arise in connection with this phenomenon;—what are the suitable conditions, what bearing has the inductive action of the circuit on the surges, and how does the resistance of the circuit control the effects?

Before answering the questions let us turn our attention to a similar phenomenon in mechanics. Make three or four springs of steel wire wound loosely, about 2 or 3 inches diameter, and, say, 6 inches long; the springs should be made of different gauges of wire, in which case the elasticity, or what we might call the springiness of each spring, will depend upon the gauge of the wire. As shown in Fig. 49, suspend the springs from a beam and attach a weight to the bottom of each. If one of these springs is, as it were, charged, either by pressing the weight up or pulling it down, and then discharged by letting go, we shall find the weight does not simply return to its original position but oscillates up and down past it; the oscillations gradually dying down until the weight is again settled in its original position. If we do this experiment with all the springs we shall find that, in each case, the resulting motion is oscillatory, but that the *rates of oscillation are all different.* Now there are two forces which are causing the oscillatory motion—the springiness of the spring and the force of inertia; the rates of oscillation are different with the different springs because the forces of elasticity, or of inertia, or of both, are different for the different springs.

It is exactly the same in the electric circuit; capacity effects are analogous to the springiness of the spring, inductive effects are analogous to the inertia of the moving system; the discharge will be oscillatory owing to the capacity and inductive effects, and the rate at which the oscillations take place will depend upon the values of the capacity and inductive effects present in the circuit.

What are the conditions necessary for a discharge to be oscillatory, and what is the effect of the resistance of the circuit? Returning to the weighted springs if we gradually increase the weight on one of them we shall find the result is to lessen the number of oscillations which will take place after it is charged: the extent of the motion of each oscillation, or as we call it the amplitude of the oscillations, will rapidly decrease, and the number of oscillations made before the system comes to rest will be less than before. That is to say the greater the weight the greater is the damping effect on the oscillations, decreasing the amplitude of each successive oscillation and decreasing the number of oscillations. If we go on increasing the weight we shall finally arrive at one which will entirely prevent oscillations taking place, so that if the weight is greater than a certain value there will be no oscillations.



DIFFERENT SPRINGS AND WEIGHTS
HAVE DIFFERENT PERIODS OF OSCILLATION.

Fig 49.

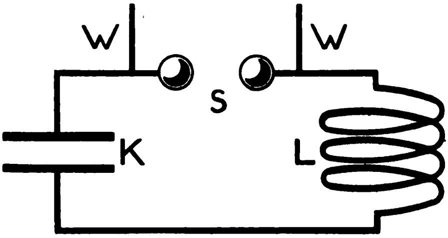
Similarly, in the electric circuit, the resistance of the circuit determines the damping effect on the amplitude and number of oscillations in the discharging current; if the resistance effect exceeds a certain value the discharge will not oscillate at all, but will simply be a direct discharge of a single movement of electricity across the circuit. In our analogy of water flowing from one vessel to another through a connecting pipe, if the pipe is of small diameter, or is obstructed by sand, leaves, etc., it offers a resistance to the flow of water; this will therefore take place at a small and steady rate, raising the pressure in the second vessel until it is equal to that in the first without any oscillatory motion taking place.

Thus the suitable conditions are that the resistance be of a low value; we know that the resistance of a circuit is directly proportional to its material and its length and inversely proportional to its cross section, whether the circuit be a wire, a liquid, a vacuum tube, or the air between two spark balls. Thus the discharge will be oscillatory if the materials of the circuit are good conductors, and of good cross section, and *if the spark gap is not too long.* Where discharges take place across a spark gap most of the circuit resistance is in the gap, because air is a very bad conductor; hence to keep the resistance low we must have a low spark gap resistance, *i.e.* the gap must be comparatively short.

There cannot be an oscillating spring system that has not some weight, nor an electric circuit that has not some resistance; but if the weight is kept small in the one case and the resistance kept low in the other their damping effect on the oscillations will be small, and there will be a greater number of oscillations at each discharge.

It is, however, necessary to point out that the spark gap must not be too short, because the discharge would then take place before the capacity had been charged to any great potential; also it is probable that with a short gap it would be an arc discharge instead of a true spark discharge. An arc discharge can be distinguished from a spark by the fact that it is more like a flame and yellowish in colour, whereas a good spark discharge is white, sharp, and, as it were, vicious in its action.

In the oscillating spring system the damping of the oscillations will depend not only upon the weight but also on the amount of energy communicated from the oscillating system to its surroundings. The air near the spring will be set in wave motion, and motion of anything, even of air, implies that energy has been given to it; in this case the energy has been taken from the oscillating spring system, and a loss of its energy means that its own state of motion will be decreased. We know that if the spring oscillated in water instead of air it would come to rest sooner; water is heavier than air, hence to set water in motion more energy will be abstracted from the spring. If the spring oscillated in treacle its oscillations would be still more quickly damped. Thus the damping also depends on the rate of loss of energy communicated to, or, as we might say, radiated to the surrounding medium. Similarly with an oscillatory discharge in an electric circuit the damping of the oscillations may be partly caused by and dependent on the resistance of the circuit, but it will also depend on the rate of radiation of energy to the surrounding medium; the medium in this case being the ether. In wireless telegraphy, as we shall see later, the object of an oscillatory discharge is to radiate energy in the form of strains in the ether, *i.e.* ether waves; transmitter circuits are so designed that a certain proportion of the energy is radiated from each oscillation of the discharge. Again, an oscillating spring system can lose energy by giving it to another spring system, which it strikes against at each oscillation. The second spring system would thus start oscillating with energy taken from the first one. In a similar manner oscillating electric energy in a circuit may be decreased by inducing oscillations in a second circuit placed near it, an effect which is much used in wireless telegraphy. This transfer of energy constitutes a third damping effect on the oscillations, and Chapter XI. will show that it may be the principal damping effect on the oscillations in the discharge circuit of a wireless transmitter. Thus damping, or loss of energy, can be summed up under three headings:—(1) Resistance; (2) Radiation; (3) Transfer. Fig. 50 is a diagrammatic view of a simple oscillatory discharge circuit, K being



OSCILLATORY DISCHARGE CIRCUIT

FIG. 50.

the condenser, L representing the inductance effect, and S the spark gap, while the wires WW lead to the source of charging potential.

We must now consider in detail what actually happens when an oscillatory discharge takes place across a spark gap.

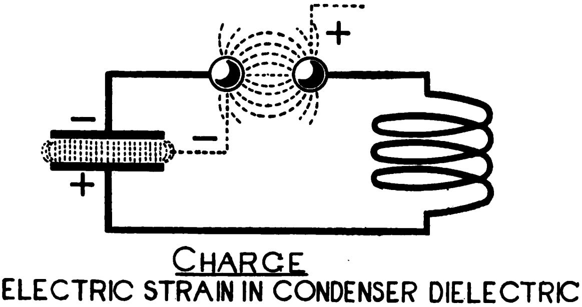


Fig. 51.

I. Let the circuit be charged up by an impulse of voltage from a spark induction coil until a great difference of potential exists across the spark gap; one electrode will be at positive potential the other at negative potential, as shown in Fig. 51, and the ether between the condenser plates, in the spark gap, and generally all round the circuit will be in a state of electric strain.

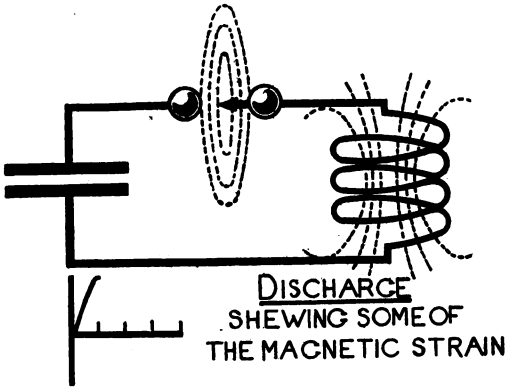


Fig. 52.

II. As the charge is completed the difference of potential becomes so great that the insulation of the air in the spark gap breaks down and a discharge starts, gathering strength as it goes on. This discharge from one side to the other tends to equalise the potentials and decrease the ether strain. After a small fraction of time the discharge will have equalised the potentials and the electric strain will have disappeared. But the flow of electrons across the gap will set up a magnetic strain in the ether, which strain takes the form of whirls of magnetic lines round the path of the flow. At the end of this small interval of time the conditions will be as shown in Fig. 52, and the rate of discharge will have risen in value to a maximum as shown in the curve below the Figure, just as the motion of a spring system is a maximum when it is passing through its position of rest, where it ought to stop.

III. Now, just as the spring system swings too far owing to inertia, so the discharge of the circuit persists owing to induction; when it tends to die out the consequent collapse of the magnetic strain lines on the circuit induces a voltage which prevents a sudden stoppage. This induction makes the discharge flow on, though gradually decreasing, and by the time it has come to zero value a difference of potential is again built up in the opposite direction to that existing before; the side which was at positive potential is now at negative potential and *vice versa.* When this state is attained the discharge has fallen to zero, the magnetic strain has disappeared, and an electric strain again exists in the ether, the conditions now being as shown in Fig. 53. The time taken by the discharge in dying down from its maximum value to zero is equal to the time taken from its start to attain its maximum value.

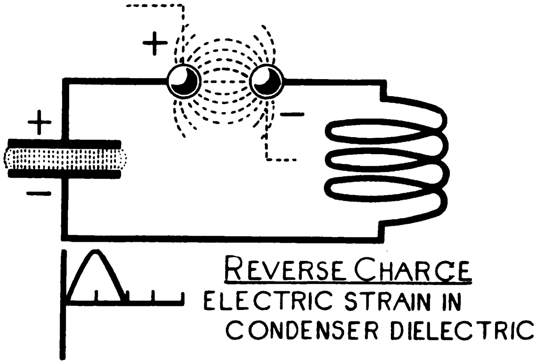


Fig. 53.

IV. The difference of potential is thus again built up and again the circuit discharges across the spark gap, but this time in the opposite direction to the first discharge. As before, after an interval of time the difference of potential and the electric strain will have disappeared, the discharge has risen to a maximum, and a magnetic strain exists in the ether round it as in Fig. 54. The discharge being in the opposite direction to the first one we represent this by drawing the curve below the axis of time as shown in the Fig.; also owing to loss of energy the maximum current in this second discharge will be a little less than that in the first, so that the curve of current is a little smaller.

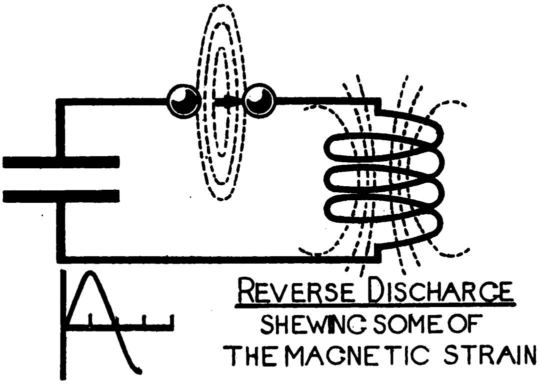


Fig. 54.

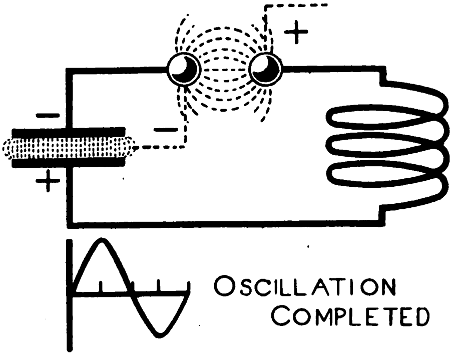


Fig. 55.

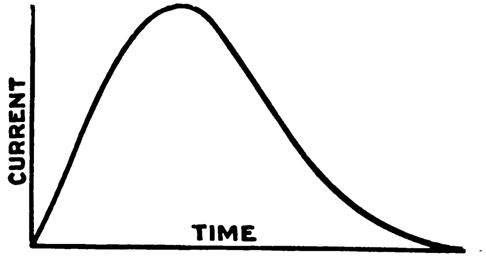
V. The reversed discharge builds up a difference of potential again, similar to that with which we started, at the same time the discharge itself dies away as shown in Fig. 55. The magnetic strain in the ether gives place again to an electric strain.

VI. The whole procedure is repeated several times in exactly the same manner and we thus get a series of discharges, oscillating backwards and forwards, just as the spring system oscillates up and down. Each discharge has a maximum value a little smaller than the one preceding it; of the original energy in the circuit, which is equal to $\frac{1}{2}\frac{V^2_{\text{volts}}K_{\text{mfds}}}{10^6}$, joules, a part is used up in the resistance of the circuit including that of the spark gap (this part being turned into heat as is evident in the spark gap), and a small part sets up the strains in the ether. At each swing of the discharge portions of the energy will be lost in these forms, so that the swings gradually die down.

The time taken by the circuit to pass from a condition as shown in Fig. 51, until it comes again to a similar condition, as shown in Fig. 55 (*i.e.* while it discharges completely, first in one direction and then in the opposite direction), is called the "time of a complete oscillation" or the "**periodic time.**" *All the oscillations take equal times,* the small ones near the end of the discharge taking the same time as the large ones at its commencement, just as in the case of an oscillating pendulum or spring. Thus a complete oscillatory discharge might be represented as shown in Fig. 69, in which the *amplitude* or maximum values of the current is seen to gradually die away owing to the energy lost at each oscillation.

If the loss of energy is too great, in other words if the resistance of the circuit is too large, there will be no oscillations, but the circuit will discharge itself only in one direction, as shown in Fig. 56; this is called a "uni-directional discharge" and is obtained when, for instance, the spark gap is too long.

Now from the analogy of the weighted springs it may be realised that the time of an oscillation depends on the amounts of capacity effect and inductive effect in the discharging circuit; in 1853 Lord Kelvin proved that, if the resistance of the circuit is small, the number of oscillations per second was approximately equal to $\frac{1}{2\pi\sqrt{L \times K}}$, where L is the coefficient of self-induction of the circuit measured in henrys and K is the capacity of the circuit measured in farads. The number of oscillations per second is called the "frequency" (n), and we see that the time taken for one oscillation, or the "Periodic Time" $T = 2\pi\sqrt{L_h K_f}$. The



DIRECT DISCHARGE WHEN RESISTANCE OF CIRCUIT IS TOO GREAT.
FIG. 56.

quantity $\sqrt{LK}$ is called the "oscillation constant" of the circuit.

As it is more usual in wireless work to measure inductance in centimetres (1 cm. $= \frac{1}{10^9}$ henry) and the capacity in microfarads (1 mfd. $= \frac{1}{10^6}$ farad) we shall find it more convenient to deduce the following formulæ :—

$$\text{Frequency } (n) = \frac{1}{2\pi\sqrt{\frac{L_{\text{cms.}}}{10^9} \times \frac{K_{\text{mfds.}}}{10^6}}} = \frac{\sqrt{10^{15}}}{2\pi\sqrt{L_{\text{cms.}}\, K_{\text{mfds.}}}}$$

$$= \frac{\sqrt{1000} \times 10^6}{2\pi\sqrt{LK}} = \frac{5{\cdot}033 \times 10^6}{\sqrt{LK}}$$

$$= \frac{5 \times 10^6}{\sqrt{L_{\text{cms.}} \times K_{\text{mfds.}}}} \text{ approximately.}$$

$$\text{Periodic time} = \frac{\sqrt{L_{\text{cms.}} \times K_{\text{mfds.}}}}{5 \times 10^6} \text{ second.}$$

$$\text{Oscillation constant} = \sqrt{L_{\text{cms.}} \times K_{\text{mfds.}}}$$

The periodic time is proportional to the product of capacity and the inductance in the circuit ; as regards the individual effect of each :—increase of capacity will increase the amplitude of the discharge while increase of inductance will diminish the amplitude but increase the momentum of discharge : the analogy with the similar effects in an oscillating spring system is left to the student for consideration.

Now let us turn our attention to the damping of the oscillations, and study the conditions under which the discharge will be uni-directional.

Lord Kelvin's complete formula for oscillation frequency is $\frac{1}{2\pi}\sqrt{\frac{1}{LK}-\frac{R^2}{4L^2}}$, which decreases in value with increase of the resistance (R) of the circuit. If $\frac{R^2}{4L^2}=\frac{1}{LK}$ the oscillation frequency is zero; in this case $R^2=\frac{4L}{K}$ or $R=2\sqrt{\frac{L}{K}}$. Thus the number of oscillations is reduced by increasing R, and there will be no oscillations at all if R is equal to or greater than $2\sqrt{\frac{L_h}{K_f}}$.

Capacity and inductance are necessary to make the discharge oscillate; resistance damps out the amplitude and number of the oscillations. From Kelvin's formula we see that increase of resistance will greatly increase the damping; it may be here noted that an increase of capacity decreases the resistance of the circuit, while an increase of inductance increases the resistance. These effects are, however, slight compared to the resistance effects in other parts of the circuit, particularly in the spark gap.

If L is measured in millihenrys and K in microfarads the critical value of the resistance is given by:—

$$R=2\sqrt{\frac{\frac{L}{1000}}{\frac{K}{10^6}}}=\left(2\sqrt{\frac{1000\ L_{\text{mhys.}}}{K_{\text{mfds.}}}}\right)\text{ ohms.}$$

High frequency currents, such as these oscillatory discharges, do not flow uniformly through the cross section of a wire, but are most dense near the surface, owing to inductive effects which are proportional to the frequency. Hence the resistance of a conductor to oscillatory discharges is reduced, not necessarily by increasing its diameter, but by increasing its surface. The surface may be increased by increasing the cross section of the conductor; without increasing the effective cross section we may increase the surface by making the conductor in the form of a tube, or by making it of several strands of wire instead of one single thick wire. The fact that a wire has a greater resistance to oscillatory currents than to direct currents is called the "skin effect"; the oscillatory currents flow mostly on the outer layers of the wire, so that the cross section of the wire is, as it were, reduced to them. At very high frequencies a hollow tube would have just the same resistance as a solid tube of the same section, because the current is practically all flowing on the surface. The effect will be greater with iron wires than with copper ones because the induction effects are greater. In wireless telegraphy apparatus we shall find coils made of copper tubes and copper strip, giving a greater surface area than round wires of the same effective cross section, and we shall find that conductors are made up of many strands rather than one thick single strand.

Lord Rayleigh has shown that if the resistance of a wire to uni-directional currents is R_c, its resistance to oscillatory currents of high frequency is $R_o = R_c \times \frac{\pi d}{80}\sqrt{n}$ approximately, d being the diameter of the wire in cms., and n the frequency.

A No. 22 S.W.G. copper wire has a resistance of 0·0431 ohm per metre length for a direct current, but its resistance is 0·1207 ohm per metre length for a current oscillating at a frequency of one million ($n = 10^6$).

Damping Decrement.—Fig. 47 shows how the successive current amplitudes in an oscillatory discharge diminish in size until eventually the discharge ceases. The oscillations are said to be damped and this is caused by the energy losses in resistance, radiation, and transfer. It is very important to know the extent of this damping of the oscillations in a wireless circuit, and it is measured by taking the *logarithm of the ratio of successive current amplitudes in the same direction.* This is called the "*Logarithmic Decrement,*" or simply the "*Decrement,*" of damping; its value does not vary over a complete train. It is usually denoted by the symbol δ; if A_n and A_{n+1} are successive amplitudes in the same sense, *i.e.* both upwards or both downwards (see Fig. 69), then :—

$$\frac{A_n}{A_{n+1}} = \epsilon^{\delta} \text{ and } \delta = \log_{\epsilon}\frac{A_n}{A_{n+1}}$$

where ϵ is Napierian base. Since the Napierian logarithm of any number is 2·303 times its ordinary logarithm to the base 10 this may be written :—

$$\delta = 2{\cdot}303 \log_{10}\frac{A_n}{A_{n+1}}$$

As a matter of fact the spark resistance increases as the oscillations die out, so that the amplitudes of the oscillations do not follow a logarithmic curve, and the decrement increases towards the end of the train. However for purposes of calculation it is generally assumed that δ is constant.

Dr. Fleming has shown that if δ is the decrement of a train of oscillations the number of complete oscillations in the train will be $\frac{2{\cdot}303 + \delta}{\delta}$. If the damping were due to resistance effect alone then δ would be equal to $\frac{R}{2fL}$.

Another expression sometimes employed is the *Damping Factor* which is the product of the logarithmic decrement and the frequency. By means of it we can calculate the amplitude of an oscillation after time t if we know the initial amplitude; thus if d is the damping factor ($=f\delta$) and A_t and A_0 are the above amplitudes respectively, $A_t = A_0 \times \epsilon^{-dt}$.

Effective and Maximum Currents.—If a low resistance hot-wire ammeter were included in the oscillatory circuit its reading would give the effective, or root mean square (R.M.S.), value of the discharging current, but the maximum value to which the current rises will be very much greater than this. If s equals the number of sparks or discharges per second, f the oscillating frequency, and δ the decrement, then the relation between the effective and maximum values of the current is approximately given by the equation :—

$$C_{\text{eff.}} = C_{\text{max.}} \times \sqrt{\frac{s}{4f\delta}} = C_{\text{max}} \times \sqrt{\frac{s}{4d}}$$

Thus taking the case of a large oscillator where $s = 600$, $f = 500{,}000$, and $\delta = 0{\cdot}2$, if the effective current is 20 amperes the maximum value of the current will be 516 amperes approximately. A proof of this formula is given in a footnote at the end of this chapter.

Power in Discharge.—The joules of energy at each discharge of the condenser $= \frac{\frac{1}{2}K_{\text{mfds.}}V^2}{10^6}$, and if there are s sparks per second the watts of energy $= \frac{\frac{1}{2}K_{\text{mfds.}}V^2 \times s}{10^6}$, where V is the potential in volts to which the condenser is charged, the value of which will be deduced later.

Current and Voltage.—In large oscillators where most of the static energy stored in the condenser is turned into kinetic energy in the induction coil at the discharge, it is approximately true that:—

$$\tfrac{1}{2}\mathrm{L}\mathrm{C}_{\mathrm{max}}{}^2 = \tfrac{1}{2}\mathrm{K}\mathrm{V}_{\mathrm{max.}}{}^2$$

Thus if the values of L and K are known the oscillating current can be calculated when the applied voltage is known.

It will be seen later that much of the pioneer work in radio-telegraphy was carried out with damped oscillations, that damping effects other than radiation are avoided in aerial circuits, and that the value of its damping decrement is never left out of consideration when designing such circuits. The most modern systems of radio telegraphy and telephony employ oscillating currents which are quite undamped.

NOTE.—If C_1, C_2, C_3, etc., are *successive* maximum current amplitudes in a train of n oscillations their (effective values)^2 are equal to $\tfrac{1}{2}\mathrm{C}_1{}^2$, $\tfrac{1}{2}\mathrm{C}_2{}^2$, $\tfrac{1}{2}\mathrm{C}_3{}^2$, etc. Since they are *successive* amplitudes we have $\mathrm{C}_2 = \mathrm{C}_1\epsilon^{-\frac{\delta}{2}}$, $\mathrm{C}_3 = \mathrm{C}_1\epsilon^{-\delta}$, etc.

Therefore average—

$$\mathrm{C}^2_{\mathrm{eff.}} = \frac{\tfrac{1}{2}\mathrm{C}_1(1 + \epsilon^{-\delta} + \epsilon^{-2\delta} + \ldots \text{ to } n \text{ terms})}{n} = \frac{\tfrac{1}{2}\mathrm{C}_1(1 - \epsilon^{-\delta n})}{n(1 - \epsilon^{-\delta})}$$

Since $\epsilon^{-\delta n}$ is very small $1 - \epsilon^{-\delta n} = 1$; also $1 - \epsilon^{-\delta} = \delta$ approx.

$\therefore \mathrm{C}^2_{\mathrm{eff.}} = \dfrac{\mathrm{C}_1{}^2}{2n\delta}$, but $n = \dfrac{2f}{s}$ since we are dealing with the amplitudes of successive half oscillations.

$$\therefore \mathrm{C}_{\mathrm{eff.}} = \mathrm{C}_1\sqrt{\frac{s}{4f\delta}}$$

In some books the log decrement δ_1 is taken for successive amplitudes without regard to direction; the value of this δ_1 is then half that of δ as defined above and

$$\mathrm{C}_{\mathrm{eff.}} = \mathrm{C}_1\sqrt{\frac{s}{8f\delta_1}}$$

QUESTIONS AND EXERCISES.

1. Under what circumstances will the discharge from a condenser be oscillatory?
2. In an oscillatory discharge circuit, how will the periodic time be modified—
    (*a*) By an increase in the capacity?
    (*b*) By an increase in the inductance effect?
    (*c*) By an increase in the resistance?
3. A circuit made up for oscillatory discharges consists of a condenser with 5 zinc plates, each 5·4 cms. × 6·5 cms., separated by glass plates, each 0·4 cm. thick; also a coil of copper tube, 18 cms. long and 10·5 cms. mean diameter, consisting of 11 turns. A spark gap is joined across the condenser.

Calculate (*a*) The capacity of the condenser.
(*b*) The inductance of the coil.
(*c*) The oscillation constant of the circuit.
(*d*) The number of oscillations per second in a discharge.

4. In Question 3, if only 3 turns of the coil are used in the oscillatory circuit, find the number of oscillations per second in the discharge.

5. Under the conditions given in Question 4, find the maximum value of the resistance of the circuit which would allow of the discharge being oscillatory, assuming radiation loss to be negligible.

6. Why is the coil in the above-mentioned oscillatory circuit made of copper tube rather than of solid copper wire of same section ?

7. A piece of No. 22 copper cable has a resistance of 4·31 ohms for direct currents. Calculate by the Raleigh formula its resistance to currents oscillating at a frequency of 500,000. The diameter of a No. 22 wire is 0·07 cm.

8. In an oscillatory discharge the amplitude of an oscillation is 0·9 of the amplitude of the one preceding it in the same sense. Find the "decrement of damping" of this discharge.

9. How many oscillations take place in the discharge of Question 8 before it is complete ?

10. In the oscillatory discharge circuit of a Telefunken transmitter the number of complete oscillations in each discharge is about 5. What is the decrement of damping of this circuit ?

11. Distinguish between "damping decrement" and "damping factor."

CHAPTER X

HISTORICAL DEVELOPMENT OF RADIO-TELEGRAPHY

In the last chapter we have seen that part of the energy initially stored up in a condenser was transformed into ether strain energy when an oscillatory discharge took place. Two strain effects are set up and act harmonically in the surrounding ether, the resultant is a wave of strain energy which spreads outwards through the ether in all directions, representing energy radiated from the oscillating discharge. Comparatively little energy is thus radiated from a closed oscillatory circuit such as that dealt with in the last chapter; if more energy can be transformed or radiated in these wave strain effects the presence of such waves in the ether will be detected at great distances from their source.

The development of radio-telegraphy, from the fundamental fact that under certain circumstances an electric discharge will oscillate at a high frequency, may best be explained by treating it in a historical manner. In order that the student shall not be wearied by dates, and by details of experimental methods which are now obsolete, only important steps in the development will be mentioned, and only those experiments described which bear directly on the development.

As already pointed out **Prof. Henry** in **1838** (and later Fedderson in 1857) discovered that under suitable circumstances the discharge of a Leyden jar, or condenser, would be oscillatory, and would oscillate at high frequency. **Kelvin (1853)** proved the laws under which these oscillations took place; showed that the time of oscillation depended on $\sqrt{LK}$, and that the effect of resistance was to damp the oscillations. The conception of electric and magnetic strains in the ether was due to Faraday; but Faraday, whilst a brilliant experimentalist, was not a mathematician and thus did not foresee the far-reaching results of some of his experiments. Faraday died in 1867.

In **1863 Clerk Maxwell**, by mathematical reasoning, formulated the theory that light and radiant heat were electro-magnetic phenomena, caused by strains set up in the all-pervading medium, similar to the electric lines and magnetic lines which we have already discussed. He said that electro-magnetic disturbances travelled in the ether at a definite velocity, that is to say the known velocity of light and radiant heat—186,000 miles, or 300,000 kilometres, per second. Clerk Maxwell was a mathematician, not an experimentalist, and his theories lacked experimental proof for 24 years.

However in **1887 Heinrich Hertz,** a young German Professor, issued the results of his experiments, which proved conclusively the correctness of Maxwell's theory. Hertz had set up electro-magnetic wave disturbances in the ether, had detected them, had proved that they possessed all the properties of light and radiant heat. They could be reflected, refracted, and polarised, and their velocity was 300,000 kilometres per second.

It will be remembered that when an electrical discharge takes place in an oscillatory circuit a portion of the oscillating energy is communicated to the surrounding ether in the form of electric and magnetic strains, producing in it a wave motion. With a closed oscillatory circuit the energy thus conveyed to the ether is a very small portion of that oscillated, and before the experiments of Hertz no method of detecting the ether energy was known.

Hertz increased the relative amount of radiated energy by arranging the capacity effect in the circuit, with plates or spheres separated widely from each other on each side of the spark gap; in other words he opened out the condenser. Of course the capacity of such an arrangement was not so great as when the plates were close together, but by making the plates large enough it was sufficient for the purpose.

Thus the arrangement of circuit made by Hertz was the first *open type of oscillator*. It consisted of a spark gap on each side of which were copper rods, 30 cms. long, terminating in large square brass plates of 40 cms. side, or round discs of copper, brass, or zinc. Such a Hertzian oscillator is shown in Fig. 57. Each side of the spark gap is joined to the high potential terminals of an induction coil, by which the oscillator is charged; the plates provide a suitable amount of capacity effect in the circuit; inductance effect is present in every circuit, even with straight wires. Using a suitable length of spark gap the discharge of this Hertzian open circuit is oscillatory. When the capacity plates are close together the greatest ether strain, on charge, occurs between the plates;

when they are separated far apart on each side of the circuit, it follows that the volume of strained ether is increased, and the electric lines of force are longer since they stretch from plate to plate.

Hertz detected the presence of ether disturbances, or ether energy, in the space around his apparatus by using what he called a "resonator," corresponding to a receiver in radio-telegraphy. It simply consisted of a stout copper wire circle, of about 35 cms. radius, with a very small spark gap in the circle. When he held this circle parallel to his oscillator, in such a way that the small spark gap was turned towards it, he obtained minute sparks across the resonator gap.

By placing his oscillator, (made smaller for the purpose), and his resonator in parabolic mirrors he proved that the ether waves set up by the oscillatory discharge could be reflected, refracted, polarised, and had, in fact, all the properties of light and radiant heat. He reflected the waves from a large conducting surface, and by the interference of the advancing and reflected waves set up stationary waves. This is analogous to the apparently stationary waves which can be set up in a stretched string when it is bowed anywhere along its length; the string will be seen to vibrate in loops, and points along it, called *nodes*, appear to be at rest. The distance between two consecutive nodes is half the wave length of vibration of the string.

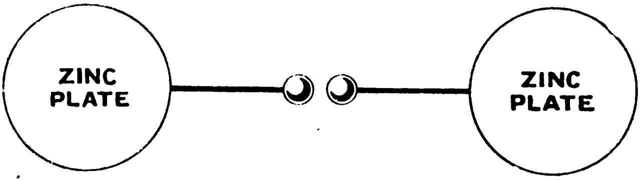


FIG. 57.

Hertz, experimenting with the stationary waves, measured the distance between two consecutive nodes, or between two consecutive *antinodes*, which are points of maximum disturbances. He thus measured the wave length. Knowing the frequency of the oscillations he calculated the velocity with which these ether waves travelled, for velocity = frequency × wave length ($v = n.\lambda$); no matter what frequency or wave length was used he found the velocity to be 300,000 kilometres, or 3×10^8 metres, per second.

The experiments of Hertz proved the accuracy of Clerk Maxwell's theories, set at rest all doubts as to the existence of an all-pervading invisible medium, and opened up a new and delightful field of scientific investigation.

It may be here remarked that the Maxwell theory of the nature of light does not satisfactorily explain all the phenomena connected with it; thus photo-electric effects cannot be satisfactorily explained on this hypothesis alone.

Ether waves similar to light waves had thus been set up by electric means and many scientists devoted themselves to a study of these new waves. The shortest ether waves set up by Hertz's small oscillator were about 60 cms. long, while the longest light wave is about $\frac{8}{10^5}$ cm. long, and the longest radiant heat wave measured is only 0·0025 cm. It is interesting to note that the scientists who first followed Hertz devoted their efforts to the construction of apparatus which would set up and detect waves shorter than his, hoping to produce and detect ether waves more nearly approaching in length those already known in the form of heat and light. Following this idea Professor Chundar Bose, by a development of apparatus, produced and detected ether waves 0·6 cm. long.

Thus, as far as radio-telegraphy was concerned, the progress at first was all in the wrong direction; we realise now that the longer the waves the greater the distance at which they can be received.

Before the work of Hertz was published **Professor Hughes** in **1879** had proved it was possible to send signals to some distance, using an induction coil as oscillator and a microphone as resonator. Unfortunately his scientific friends persuaded him that this was due to inductive effects, such as we have when one magnet acts on another at a distance. For this reason Hughes did not follow up a discovery which, had he been encouraged as to the true significance of it, would have given him a share in the fame of this great scientific and commercial development.

Sir Oliver Lodge had also made discoveries which were of vast importance in their application of radio-telegraphy, and no doubt his syntonic Leyden jars experiment was known to Hertz.

In this experiment an oscillatory discharge is made to take place across a Leyden jar whose inside and outside coatings were connected by a rectangle of wire; the knob of the inside coating and the knob at the end of the wire formed the spark gap, as shown in Fig. 58. At a short distance from this is placed a resonator, consisting of a Leyden jar with a similar circuit of wire, whose length could be adjusted by moving the bridging-piece AB. A very small spark gap is arranged across the second jar.

When the circuits are placed parallel and the resonating circuit is suitably adjusted a small spark is obtained in the latter when a discharge takes place in the oscillating circuit. As the bridging-piece AB is moved about it is found that for one position only would the small spark discharge appear; this was called by Sir O. Lodge the position of syntony, *i.e.* the two circuits were syntonised or tuned to each other.

Moving the bridging-piece AB changed the inductance, L, of the second circuit, and its position when the sparks appeared was that which gave this circuit the same oscillation constant as the oscillating circuit; in other words the inductance was changed until it had a value L_2, such that $\sqrt{L_2K_2} = \sqrt{L_1K_1}$. This experiment was carried out with a closed oscillating circuit which is always a poor radiator so that further development did not come until Hertz demonstrated how to make and use an open oscillator.

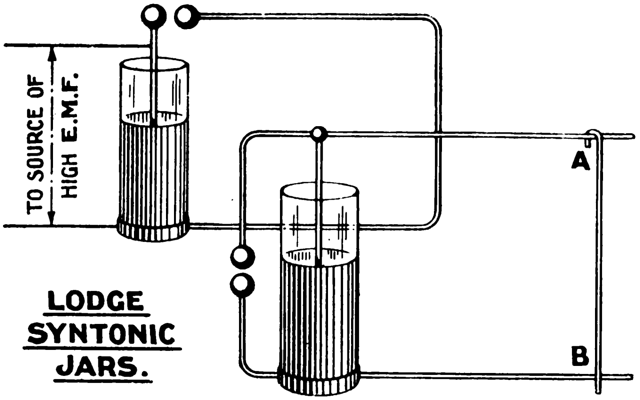


FIG. 58.

When the account of Hertz's work was published many scientists took up the research; as far as radio-telegraphy is concerned the next important development was in the detector of the ether waves. The small spark gap of Hertz in his circle of wire, and that of Lodge in his syntonic jars, were very crude detectors, making manifest etheric disturbances only at very short ranges.

Prof. Branly, in **1890,** found that a coherer was sensitive to ether wave disturbances. A coherer consists of a short gap in an electric circuit which is filled with metal filings; under ordinary conditions the coherer will not conduct a small current, such as would ring a bell or make a galvanometer deflect. When, however, it is connected in a resonating circuit, taking the place of the little spark gap, and ether waves act on the resonator, the coherer becomes a conductor. Fig. 59 explains the action; the coherer is shown in a circuit which contains a galvanometer and a battery, but under ordinary circumstances no current will flow for the coherer is nearly a non-conductor. Branly showed that if the coherer is made part of an open resonating circuit, placed close to an oscillating discharge circuit, the resistance of the coherer is broken down when ether waves strike the resonator and it now conducts the battery current through the galvanometer. This was really only a rediscovery as the same effect had been noted by Munk in 1839. When the ether waves are set up the metal filings seem to cling together, or cohere, (hence the name); the circuit is no longer broken by the little films of gas or air between the filings, and thus the local circuit is a closed one.

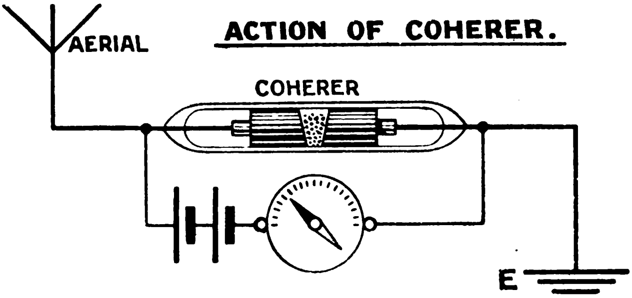


FIG. 59

Branly did not use the coherer for receiving signals. When it coheres and closes the local circuit it remains cohered until it is shaken up, and it probably never occurred to Branly that a coherer might be used to receive a succession of signals. The next important development was that of **Prof. Popoff,** of Kronstadt, who conceived the idea of making a resonator with one side taking the form of a wire raised high into the air. By this arrangement his resonator or receiver responded to ether waves caused by lightning storms, and thus recorded such disturbances. We first hear of his work in **1895,** and in that year **Marconi,** encouraged, no doubt, to investigate this new field by Professor Righi, made rapid progress in the application of Hertzian waves to radio signalling of a commercial value. He was the first to make one side of the oscillator consist of a wire stretched upwards into the air, and the first to join the other side of the oscillator to earth. By so doing he found that, with the same oscillating energy, he could detect the ether waves at much greater distances than had hitherto been accomplished.

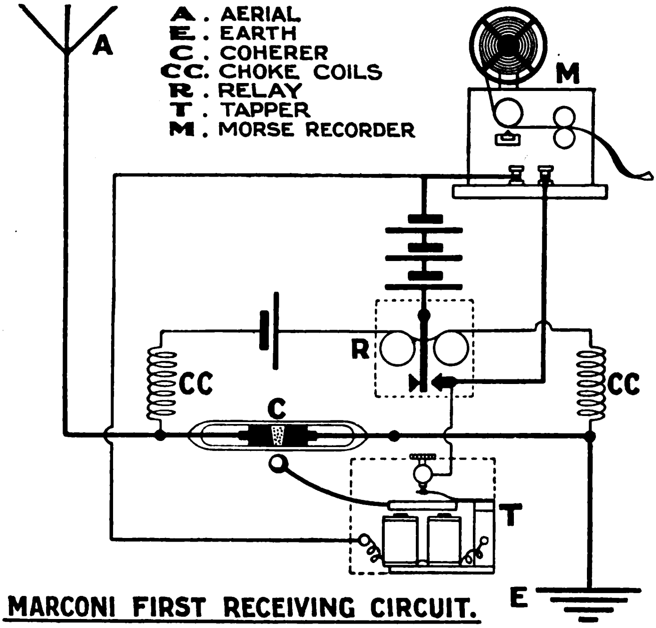
He also improved the coherer, and was the first to devise a scheme for sending intelligible signals by the ether waves, using for this purpose a decohering arrangement.

As already described, when the ether waves act on a receiver with a coherer in its circuit the coherer closes the local circuit attached to it, and the latter will remain closed unless the coherer is shaken up. Marconi included in the local circuit a little electro-magnet, so that when the local current flowed the magnet attracted an armature of soft iron to which was attached a little hammer; this hammer striking against the coherer caused it to decohere so that it was ready to be again affected by another impulse, or train of ether waves. The time of action could be made long or short according to the length of time the oscillator switch was closed; thus a scheme of signals, such as the Morse Code, could be used. The connections of Marconi's first receiver are shown in Fig. 60.

In 1896 Marconi, then only twenty years of age, came to England, and was sympathetically received by Sir Wm. Preece. Engineer-in-Chief of the Post Office Department, who encouraged him in his work, and allowed him to carry out experiments on the premises of the General Post Office.

Preece had for years been experimenting in methods of signalling without wires by conduction through water or by induction effects. These methods had been started by Morse in America in 1842 and Lindsay in Dundee in 1843; they did not lead to much progress, for in 1882 the range attained by Graham Bell on the Potomac river was only 1½ miles. It can be easily understood that under these circumstances, and having regard to his official position, Preece would readily welcome one who could demonstrate to him that wireless signalling across much greater ranges than had been accomplished heretofore was definitely possible.

Marconi, backed by influence and capital, rapidly developed his wireless system and signalled over greater and greater distances ; he enlarged on the theories of Hertzian wave action and developed ideas for tuning or syntonising his circuits. Returning to Italy in 1897 he signalled over 18 kilometres in the presence of the King and ministers of state ; in 1898 the Italian Navy had established two stations 72 kilometres apart. Marconi had by this time discovered that the distance of transmission was increased by increasing the height of the aerial wire, (or antenna), and in 1901 signalled from Cape Lizard to St. Katherine's, a distance of 200 miles, with antennæ only 300 feet high. The significance of this result was that the curvature of the earth, which raises its surface high up between these two stations, was no barrier to the ether waves. Fig. 61 shows the first form of a Marconi Transmitter. Now a single wire has a very small capacity, therefore not much energy could be stored in it ; when the distance of transmission was increased the energy required in the oscillator, or radiating circuit, had to be increased ; hence the aerial, instead of being a



MARCONI FIRST RECEIVING CIRCUIT.

Fig. 60.

single wire, developed into a number of wires in parallel, by which construction its capacity was increased. Thus more energy could be oscillated in it at a given charging voltage, since the energy in it $= \frac{1}{2}KV^2$, therefore varies directly as its capacity. This was known as a fan aerial, and we must note that by increasing the capacity the wave length as well as the oscillating energy was increased.

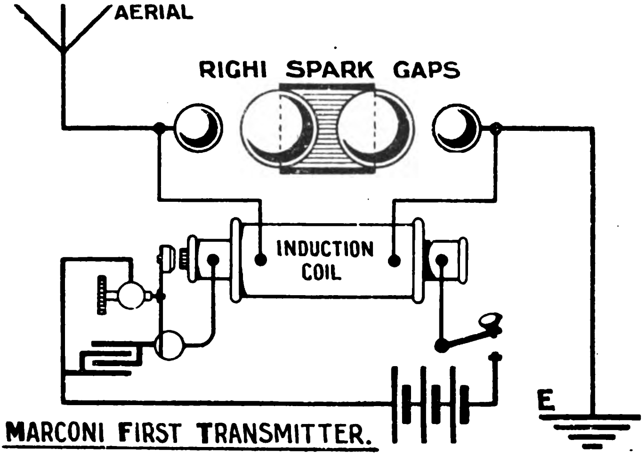


FIG. 61.

The wave length (λ) multiplied by the number of waves per second must equal the velocity of propagation (v).

Thus—$v = n\lambda$; also $v = 300{,}000{,}000$ metres per second,

$$\text{and } n = \frac{5{\cdot}03 \times 10^6}{\sqrt{L_{\text{cms.}}\,K_{\text{mfds.}}}}$$

$$\therefore 300{,}000{,}000 = \frac{5{\cdot}03 \times 10^6}{\sqrt{L_{\text{cms.}}\,K_{\text{mfds.}}}} \times \lambda$$

$$\therefore \lambda = 59{\cdot}6\sqrt{L_{\text{cms.}}\,K_{\text{mfds.}}} \text{ metres.}$$

In 1901 Marconi was able to signal from his large station at Poldhu in Cornwall to Glace Bay, Cape Breton, at night; his aerial at Poldhu consisted of 400 wires and the wave length (λ) employed was 3600 feet.

In the meantime an officer in the Italian Navy had discovered that a drop of mercury between two steel or carbon plugs in a small glass tube acted as a coherer: this decohered itself when a signal ceased so that no tapping arrangement was necessary.

Soon after Poldhu station was completed Marconi evolved his magnetic detector which also was a self-restoring device, much more reliable and delicate in its action than the coherer. It will be described in a later chapter.

Early in 1900 Marconi adopted magnetic or "jigger" coupling between the closed and aerial circuits of his transmitter, and no longer connected the aerial and earth across the spark gap. This was the subject of his now famous patent, British No. 7777; it involved syntonic tuning as well as coupling. With his new arrangement he demonstrated that it was possible to transmit or receive two messages of different wave lengths simultaneously on the same aerial without any confusion due to mutual interference.

His first station at Poldhu employed 20 KW.s of power, and though, after his apparatus was more perfected, he could signal from Cape Cod to Poldhu (a distance of 2669 miles) with 5 KW.s of energy *at night*, yet he soon found that for a satisfactory and reliable service during daylight much greater power was necessary. He therefore built larger stations at Clifden, Ireland, and at Glace Bay, Cape Breton, equipping them with plant of 370 KW.s (500 H.-P.); it was, however, possible to use only 150 KW.s efficiently, and in 1914 the average power used in these stations was about 80 KW.s.

In 1905 he patented the horizontal directional aerial by means of which a maximum amount of the total radiated energy can be sent in any desired direction. From experiments made by Dr. Austin, U.S.A., in 1912, it would appear that the directional aerial increases the radiation in the maximum direction about five times, so that this invention proved to be a great step forward in the solution of the problem of long distance transmission.

With his Clifden and Glace Bay stations Marconi studied the effect of daylight in absorbing the radiated energy. As stated by him before the House of Commons Select Committee, 1913, he found that in the morning and evening, when darkness only extended part of the way across the ocean, the received signals were at their weakest, and the variations seemed to be less in a north-southerly direction than in an east-westerly one.

In 1907 Marconi patented his high-speed disc spark discharger, by means of which trains of waves at high frequency and good regularity could be transmitted. This invention was one of the first to open up the possibilities of high-speed signalling.

Radio-telegraphy was thus firmly established on a commercial basis, largely by the genius and enterprise of Marconi. At the same time there were other investigators whose labours have contributed much to its development. Sir Oliver Lodge and Dr. Muirhead perfected many pieces of apparatus, including a self-decohering device and an automatic transmitter.

Sir O. Lodge did not adopt the arrangement of earthing one side of the transmitter, but worked on a symmetrical oscillator such as was used by Hertz. His aerial consisted of a network of wires, placed horizontally and high in the air, with the other side of his transmitter joined to a similar network raised about a foot above the ground. Such an arrangement is shown diagrammatically in Fig. 62.

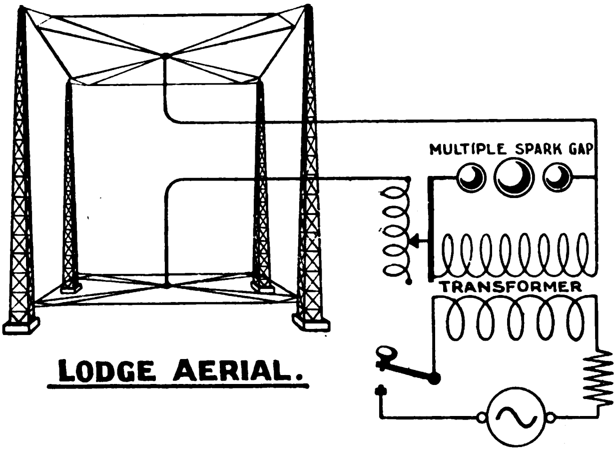


Fig. 62.

Dr. Braun, of Berlin, developed a system for Messrs. Siemens and Halske; **Count Arco** and **Prof. Slaby** developed the Arco-Slaby system. These systems have now been combined into one system known as the **Telefunken** system. **Dr. Lee De Forest,** U.S.A., did much good pioneer work, and brought out a new form of electrolytic detector which is not now employed.

In 1903 **V. Poulsen** had patented his arc method of generating undamped oscillations and, with **Prof. Pedersen**, of Copenhagen, developed during the following years the **Poulsen** system, which soon attained a high value of commercial efficiency and reliability.

In 1910 Marconi received messages from Clifden at a distance of 4000 miles by day and 6735 miles by night; in fourteen years he had passed from experiments across the garden to commercial working across the oceans, and had obtained valuable contracts in many countries.

Among other scientists whose work was valuable in the development of wireless signalling during the early years of the present century we may mention **Prof. M. Wien,** whose *Quenched Gap,* adopted by the Telefunken Company for all their standard work, enables greater oscillations to be set up in an aerial circuit without the risk of damping by retransfer of energy; **R. A. Fessenden,** who was responsible for much original work in the system known in America by his name; and **Prof. Rudolf Goldschmidt,** who invented a high frequency alternator by means of which undamped oscillations could be set up in a wireless transmitter.

This brings the history of wireless down to 1914, when the great world war broke out, and perhaps it is no exaggeration to say that during the war developments in radio-signalling have taken place as great, and as revolutionary, as in the twenty-six years which immediately followed the publication of Hertz's work in 1888. To corroborate this statement reference may be made to the development of wireless telephony. Before 1914 the longest recorded range for telephony was 1000 kilometres and reliable commercial range was not much more than 100 miles. On September 28th, 1915, wireless telephony was established across the American continent from Arlington to Hawaii, a distance of 5000 miles, and on October 26th, 1915, from Arlington to the Eiffel Tower, Paris.

This rapid progress has almost been entirely due to the evolution of the hard vacuum valve for use in wireless circuits.

Edison had noted that negative charges were emitted from the hot filament in an ordinary electric lamp; **Dr. J. A. Fleming** was the first to adopt this for wireless purposes in his design of a two-electrode valve detector. In 1913 the **Lieben and Reisz** valve relay with three electrodes was produced, and about the same time **Dr. De Forest** patented a similar thing in the Audion valve. **H. J. Round** designed for the Marconi Company the Round valve with three electrodes; it was superior to either of those which preceded it, and was used to amplify the oscillations in the receiver as well as relaying the resulting signal pulses.

All these were soft vacuum valves, and in 1914 **Dr. Irving Langmuir** evolved the hard vacuum valve, on which **Edwin H. Armstrong** of Columbia University carried out important research work, and was one of the first to really understand the action and possibilities of valve cciruits. Langmuir's valve was known as the Pliotron; on it as a basis many new designs have been developed by the General Electric Co. in the United States. As far as Europe is concerned the best design of Pliotron valve during the first three years of the war was that known as the French valve, made for the French Military Wireless Service under the direction of **Colonel Ferriè** at Paris. This design was adopted or copied by both Allies and enemies for the wireless military services of the war.

By the use of combinations of these hard vacuum valves the practice of wireless transmission and reception has been revolutionised since 1915, and the rapid development of wireless telephony made possible.

The Marconi Co. have succeeded in using radio-telephony across the Atlantic with a transmitter energy of only 500 watts.

CHAPTER XI

COUPLING OF CIRCUITS FOR SPARK TRANSMITTERS

When a current of electricity flows through a coil of wire magnetic lines of force are set up through the axis of the coil; if the current changes the number of magnetic lines interlinked with the coil changes, thus producing an inductive effect in the circuit. If the current is an oscillating one there will be a continuous inductive effect, the magnetic strain lines oscillating backwards and forwards whilst their number varies. We know that this inductive effect helps to make the discharge in a closed circuit, such as Fig. 63, an oscillating one, the frequency of the oscillations being determined by the value of $\frac{5 \times 10^6}{\sqrt{L_1 K_1}}$, the resulting wave length of ether strain being $59{\cdot}6 \sqrt{L_{1\text{cms.}} \, K_{1\text{mfds.}}}$ metres.

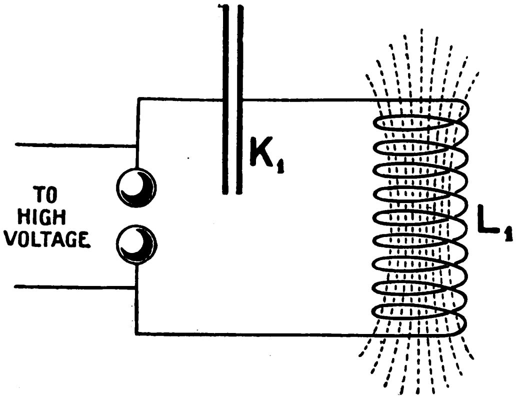


Fig. 63.

Let an aerial and an earth wire be connected to the closed circuit as shown in Fig. 64. When oscillating discharges of the closed circuit go through the portion AB of the coil oscillatory magnetic fields will be set up; if L_1 is the inductance of this portion of the coil the magnetic field will pulse at a frequency of $\frac{5 \times 10^6}{\sqrt{L_1 K_1}}$ per second. It is seen that a great many of the magnetic lines set up through the portion AB of the coil extend through, or interlink with, the remainder of the coil BC, so that the whole coil AC has inductive effects set up in it by the magnetic strains which are produced in a portion of it. Thus, since there are more turns in AC than in AB, and a different number of magnetic lines interlinked with it, (for not all the magnetic lines set up in AB will extend through all the turns AC), the inductance of AC is different to AB,—let us call it L_2.

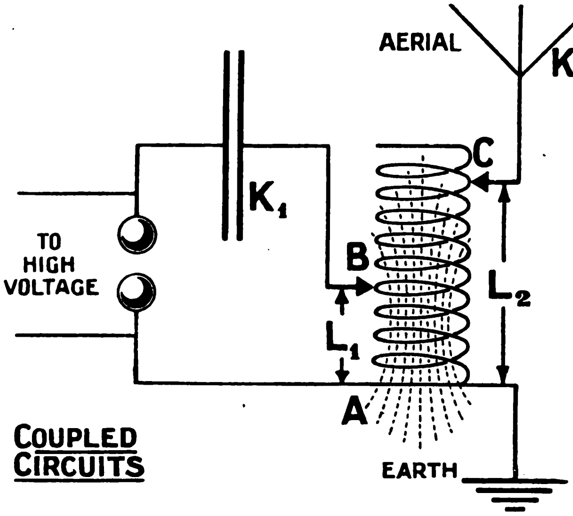


Fig. 64.

Now the effect of magnetic lines interlinking with turns of wire is to induce an E.M.F. in the turns, and if the magnetic field is oscillatory the induced E.M.F. will be oscillatory. In this case the magnetic field is oscillating as fast as the oscillations of the discharge; thus a high frequency, or oscillating, E.M.F. is induced in the coil AC. It is joined to the capacity of the aerial at one side and to the capacity of the earth at the other; hence the oscillating E.M.F.s induced in it will cause oscillating currents to flow up and down the whole open circuit.

If a swinging pendulum is tapped it may be kept in motion in an irregular sort of way, but if the taps are properly timed to hit the pendulum at regular intervals, and always at the same point of its motion, the swings of the pendulum can be made both regular and greater in extent. Similarly with a child's swing; the force applied must be in step or in tune with the swing to realise the full effects of the force, or make the amplitude of the swing motion a maximum. Again, if we uncover the strings of a piano, and sound a tuning fork near them, the resulting air waves will affect, more or less, several of the strings, but that one which has the same vibration frequency as the fork will be most affected. It is said to be in tune, or in unison with the tuning fork, and its induced vibrations may be so great that it will be heard to give out the same note as the latter.

So it is with electrical circuits if we apply oscillating electrical or magnetic forces to them; the effect will be a maximum if the forces are applied at the same frequency as the natural electrical frequency of the circuit; or if the circuit is arranged so that its electrical frequency is the same as that of the forces applied.

In the case before us, if K_2 mfds. is the capacity of the open, or aerial to earth, circuit and L_2 cms. is its inductance, (mostly in the coil AC), then Kelvin's formula shows us that the *natural frequency* of the circuit is $\frac{5 \times 10^6}{\sqrt{L_2K_2}}$. If some impulse of energy starts electrical oscillations in the circuit the oscillations will tend to continue at this frequency, just as a pendulum disturbed from its position of rest swings backwards and forwards at a frequency depending on its length.

If only one impulse is given to the circuit the oscillations which persist at its natural frequency are called "free oscillations." In the case under consideration there are several impulses from the closed circuit, on account of the oscillations in it, and the amplitudes of the oscillations in the aerial circuit, (*i.e.* the maximum values of current in the oscillations), will be greatest if the impulses are timed to synchronise with the natural frequency of the circuit. The frequency of the impulses is the frequency of the closed circuit, so that this should be equal to the frequency of the aerial circuit; $\frac{5 \times 10^6}{\sqrt{L_1K_1}}$ should equal $\frac{5 \times 10^6}{\sqrt{L_2K_2}}$, from which it follows that L_1K_1 should equal L_2K_2. Under these circumstances the circuits are said to be "*in tune with each other*"; the current displacement in the aerial circuit will be a maximum for the given energy employed in the closed circuit, and the oscillations in the aerial will persist longer after the impulses from the closed circuit have ceased; that is to say there will be more oscillations in each train before they die out.

Generally the capacity of the open circuit is less than that in the closed circuit, *i.e.* K_2 is less than K_1; therefore if $L_1K_1 = L_2K_2$ the value of L_2 must be greater than L_1, so that there will be more turns of the coil AC included in the open circuit than there are in the closed circuit.

Irrespective of the length or natural frequency of a pendulum it can be made to oscillate at some other frequency by properly timing the impulses applied to it. Similarly we may set up oscillations in the open circuit of Fig. 64 by impulses from the closed circuit at a frequency $\frac{5 \times 10^6}{\sqrt{L_1K_1}}$, which may not be the natural frequency of the open circuit. Such oscillations are called "*forced oscillations,*" and a circuit in which no attention is paid to tuning effects is said to be "*an aperiodic circuit.*"

The above method of coupling two synchronised electrical circuits is known as "auto-transformer coupling."

There is another method by which the circuits can be coupled; it seems to have been developed and first applied to radio-telegraphic circuits by Dr. Braun. In this method the closed oscillatory circuit of a transmitter is coupled to the open, aerial, or radiating circuit by electro-magnetic effects alone.

Referring to the use of an induction coil for producing high voltages, it was seen how the action of intermittent direct current in a primary winding could induce E.M.F.s in the turns of a secondary winding, due to the sweeping of the magnetic lines out of the iron core every time the current was suddenly reduced to zero. The same action occurs in a transformer, where the currents flowing in the primary are alternating currents of ordinary slow frequency, such as 50 cycles per second.

Nikola Tesla discovered that similar effects could be produced by oscillating discharges of electricity, or high frequency currents, (the frequency of which might be a million cycles per second), and he introduced the oscillation transformer, sometimes called the Tesla Transformer. Its primary consists of a few turns of thick copper wire; the secondary of many turns of much thinner wire, separated from the primary by a thick cylinder of ebonite, or glass, or by an air space. They must be well separated so that there is no possibility of a direct discharge passing from the primary to the secondary. In some cases the whole arrangement of coils is immersed in a glass case filled with purified paraffin oil to increase the insulation. Fig. 65 shows such a transformer. The primary coil forms part of an ordinary oscillating discharge circuit, containing condensers, such as Leyden jars, and a spark gap. High frequency oscillating currents flow in the primary, setting up through it an oscillating magnetic field; this induces a high frequency E.M.F. in the secondary winding, and, as there are many turns on

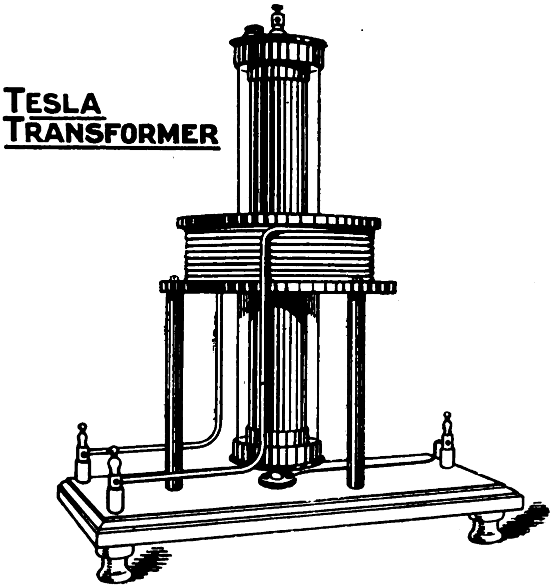


Fig. 65.

this winding, the induced E.M.F. in it can be made to have a very high value, even up to a million volts. Thus it can give powerful brush discharges, and a vacuum tube held near it in the hand will light up. If such a high frequency high voltage circuit is touched it will not be felt, nor have any harmful effects, so that one can grasp the terminals of such a circuit with the hands without feeling any sensation of shock. An iron core would be of no service in such a transformer; rather the reverse, for the oscillating magnetic fields would heat it up seriously. Also, there is no advantage in having more than one layer of winding in either the primary or secondary, as the inductive effects at high frequencies would set up in the inner windings a high impedance to the current. *All coils used for radio-telegraphy transmission on high frequency currents have only one layer of winding.*

Oscillation transformers used in the transmitting circuits of radio-telegraphy are not exactly of the same design as that just described, for reasons which will be apparent later, but their action is much the same.

In Fig. 66 is seen the usual form of closed oscillating circuit, and the time depicted is that at which the discharge current through the circuit and across the spark gap is a maximum, so that a magnetic field is built up through the coil A. Close to A is another coil B joined to the aerial and earth; it is seen that the magnetic lines of A are to some extent interlinked with the coil B, so that the two circuits are coupled together by these magnetic lines, or, as we say, by electro-magnetic induction. Just as in the case of a single coil, when the magnetic lines are set up through or shrink back into coil A they will induce oscillating E.M.F.s in coil B, which will send oscillating currents surging up and down the aerial to earth circuit. The inductive effect in B will depend on the size and number of turns in it, that is to say, on its coefficient of self-induction L_2: and the surges in the open

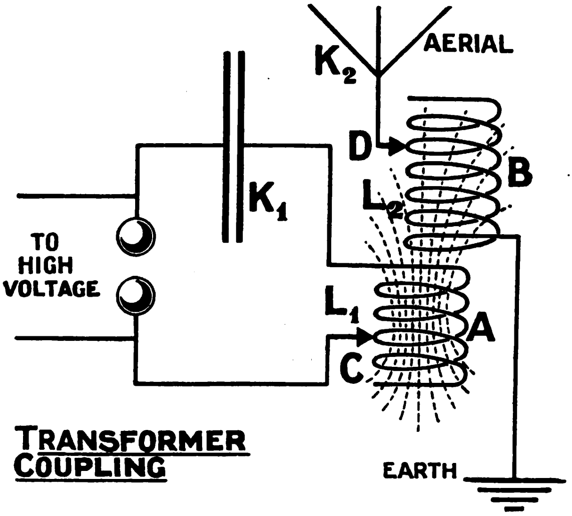


Fig. 66.

circuit will have maximum values when $L_2 \times K_2 = L_1 \times K_1$, *i.e.* when it is in tune with the closed circuit. The two circuits can be brought into tune by changing L_1, or L_2, or both: this can be accomplished by having moving contacts at A and B, so that more or less turns of the coils can be included in the circuits as required. If the frequency or wave length of one circuit is changed that of the other circuit can then be tuned to it, and should be so tuned; with reservations, however, which shall be dealt with later.

In the Marconi system the oscillation or coupling transformer is called the "jigger"; it is employed in all except the smallest of the Marconi equipments for spark telegraphy.

It is evident from the foregoing that energy is conveyed to the opened circuit from the closed circuit by the magnetic lines of strain coupling them, therefore it would seem desirable to use every magnetic line set up in the closed circuit, and make it transfer energy to the open one by coupling the two circuits as closely as possible. Such close coupling is found in an induction coil, in an ordinary transformer, and in an ordinary Tesla transformer; it would be effected in this case by placing the inductance coil of the open circuit so that all the magnetic lines, oscillating in the coil of the closed circuit, interlink with and act upon it.

Thus in the first method of coupling, shown in Fig. 64, this would be accomplished by having as many as possible of the turns in the coil common to both the open and closed circuits; and in the second method of coupling by having the coil B wound over coil A, so that all the magnetic lines oscillating in coil A will act on the turns in coil B.

Now, as a matter of fact, for the purposes of radiating energy from an aerial circuit, such close coupling would be most inefficient, and is never employed in properly designed transmitters. Let us briefly consider all the objects to be aimed at with regard to the aerial circuit. First it must be so arranged that electrical energy can be made to oscillate in it; this object is attained by tuning it and coupling it to the closed circuit, using auto-transformer or Tesla-transformer coupling. Secondly, each time the aerial circuit receives energy from the closed circuit it is desirable that there should be a great many oscillations of current in it, that in fact the current should continue to oscillate in it after the oscillations in the closed circuit discharge have ceased, just as a swing should go on oscillating after we have ceased to impulse it. Thirdly, the oscillations in the aerial should take place at one frequency so that radiation of energy into the ether is made on one wave length only, to which the receiver circuit at the distant station is tuned, so that we are not sending out energy on wave lengths which will not affect the receiver. Fourthly, we must try not to interfere with other stations or systems working in the vicinity on a different wave length.

Now let us discuss the second consideration; if the oscillations in the aerial are to continue freely it means that the damping effect in this circuit must be kept small. Damping is due to resistance loss, radiation loss, and transfer of energy to another circuit. Resistance loss in the aerial circuit can be kept low by using wires and connections of suitable cross section and good surface area, not neglecting the fact that the resistance of the earth connection should be kept low, for it must be remembered that the earth constitutes one half of the circuit, corresponding to one of the plates in Hertz's oscillator.

Radiation loss cannot be avoided since it is our object to radiate energy, but radiation should be slow rather than fast; it is better to have a good many small pulses of energy given to the ether from persistent oscillations than to have a few larger pulses from oscillations that are quickly damped out. Slow radiating aerials can be employed which will help us to attain this object.

As regards transfer loss this will be considerable if the coupling is made tight and an ordinary spark gap employed. Referring to Fig. 66, when currents are oscillating in the aerial circuit they will set up lines of magnetic strain in the ether embraced by coil B; these lines must not be confused with those set up in coil A and interlinking with coil B. The magnetic field of coil B will have a mutual induction effect on coil A, inducing in it a component of E.M.F. If the discharge is still taking place across the spark gap the space between the spark electrodes is filled with metal vapour and is more or less conductive, so that the E.M.F. induced in A will send a component of current round the closed circuit. The E.M.F. multiplied by the resulting current represents watts of energy, *i.e. energy which has been transferred back from the open circuit to the closed one.* In reality there are not two distinct fields of magnetic force due to the currents in A and B respectively and mutually acting on both the coils, but the resultant magnetic field produces the same effect.

If energy is thus retransferred from the aerial, or open circuit, to the closed one the oscillations in the aerial circuit will be quickly damped out; besides which the tuning of both circuits will be upset as shall be presently described.

A wave of energy started in the ether by the first oscillation will require further pulses of energy behind it if it is to be spread out to any great distance; these it can only get if the oscillations in the radiating circuit are not damped out. The more oscillations there are in the aerial at each discharge of the closed circuit the more persistent is the radiation, the more energy will be radiated for each discharge, and the further this wave radiation is likely to penetrate. For a given range less primary energy may be applied to the transmitter, and, as we shall see presently, the radiated energy is heaped up better on one definite wave length.

Thus to avoid excessive damping of the oscillations in the aerial circuit by retransfer of energy loose coupling must be adopted where ordinary spark gaps are employed, so that the mutual induction effect of the aerial current on the closed circuit may be reduced to a minimum. The coupling must be close enough to allow the magnetic field of the closed circuit to act inductively on the coil in the aerial circuit, but loose enough to avoid the back induction from the aerial circuit; this is almost impossible to thoroughly attain, but at least it shows the importance of having a correct coupling adjustment which is comparatively loose.

It has been emphasised that the above refers to closed circuits fitted with ordinary spark gaps; the electrical energy handed back to the closed circuit is measured in watts—the product of the voltage induced in it and the resulting current that flows. If there were no current then no matter what may be the induction of voltage the watts of energy would be zero. Now in general the first oscillation in the aerial circuit is not the largest, but the oscillations build up in amplitude as they receive timed impulses from the oscillations in the closed circuit, and when the discharge in the closed circuit stops oscillating the oscillations in the aerial die away gradually if the damping is small. Similarly the first oscillation of a swing is not the largest, but the amplitude of the swing's motion increases as we push it with four or five timed impulses; then, after the pushes have ceased, its oscillations die down.

Thus suppose that when the oscillations in the aerial are of maximum amplitude, with greatest mutual induction effect on the closed circuit, the discharge in the closed circuit had ceased and the spark gap was non-conducting, then there might be a voltage induced in the closed circuit coil by the magnetic field of the aerial circuit current, but no current would flow in the closed circuit as it is broken at the spark gap. Thus there would be no energy transferred back and no damping due to retransfer of energy. It is possible to arrange the circuits and design the spark gap so that retransfer of energy can be avoided in this way, and it will be described later that such automatic action is claimed for the Marconi Rotating Disc Discharger, and for Quenched Spark gaps such as are employed in Telefunken transmitters. With these it is possible to use comparatively close coupling and yet avoid damping of the aerial oscillations by retransfer of energy.

With an ordinary spark gap and tight coupling the interchange of energy between the open and closed circuits will be as shown in Fig. 67; here the oscillations in the closed circuit build up oscillations in the open circuit, and the transfer of energy damps

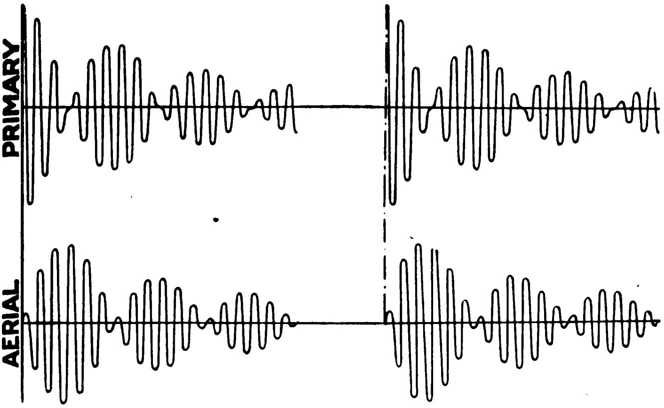


Fig. 67.

down the closed circuit oscillations. But the retransfer of energy from the open circuit damps down its oscillations and revives those in the closed circuit; this swinging of energy from the one circuit to the other occurring several times in a train. This result can be verified by the records of an oscillograph; it damps down the oscillations in the open circuit and reduces the number in each train.

On the other hand when a quenched spark gap is used in the closed circuit the oscillating conditions are as shown in Fig. 68. Here the electric discharges across the gap oscillate only a few times before the spark is quenched, or extinguished, and the circuit becomes non-conducting; these oscillations have built up oscillations in the open circuit but the reaction back from this circuit cannot start a current in the non-conducting closed circuit. Thus no current flows in the closed circuit and therefore no energy is retransferred to it from the open circuit, even with comparatively tight coupling. Therefore this damping effect does not exist in the open circuit, and its oscillations go on swinging, with small decrement, so that there are a great number in each train.

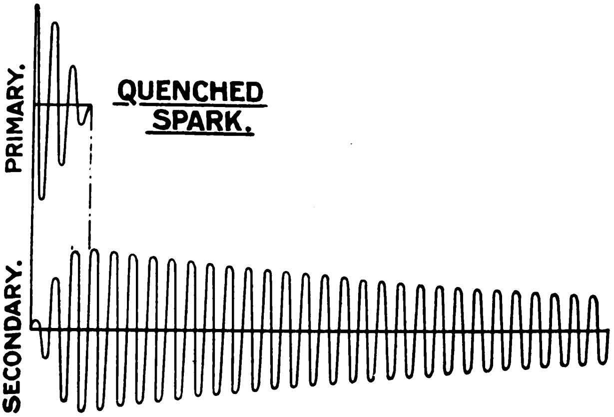


FIG. 68.

Damping.—The effects which produce damping of electrical oscillations were explained in Chapter IX., also the method of measuring the damping of the oscillations by obtaining the decrement of damping. With regularly damped oscillations such as shown in Fig. 69 :—

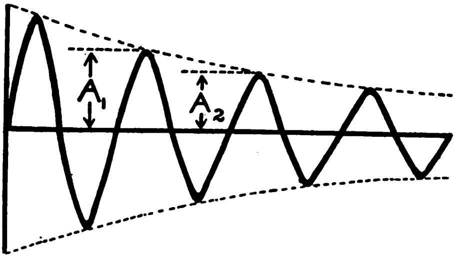


FIG. 69.

$\frac{A_1}{A_2} = \frac{A_2}{A_3} =$ etc. $= \epsilon^{\delta}$, and $\delta = \log_{\epsilon}\frac{A_1}{A_2} = \log_{\epsilon}\frac{A_2}{A_3} =$ etc. The value of the current at any time t in an oscillation is given by $C = A\epsilon^{-f\delta t}\sin(2\pi ft + \phi)$.

Damping is due to loss of energy in resistance, radiation, and transfer; it is evident that when two circuits are coupled the damping of oscillations will be different in the two circuits. In the closed circuit the resistance damping will be comparatively large and will depend on the design of the spark gap; the transfer damping will also be large and will depend on the degree of coupling. In the open, or aerial, circuit the resistance damping can be kept small by proper design of aerial cable and of the earth capacity connections, the transfer damping can be kept small by the use of a suitable degree of coupling and an automatic spark gap; the radiation damping is then the most important and will vary with the shape and design of the aerial.

The question at once naturally arises :—if the primary has a certain damping decrement, and the aerial circuit a different damping decrement, how is the decrement of transmission related to these two? Now, in the general case of two coupled circuits, the energy radiated has two maxima at two different wave lengths; with tight coupling one of these is very nearly zero, with close coupling the two wave lengths are very distinct and can easily be found with a wavemeter, with very loose coupling they practically merge into one principal wave length. The damping decrements of transmission for the two wave lengths are given by the formulæ—

$$\delta_1 = \frac{\delta_p + \delta_a}{2} \times \frac{\lambda}{\lambda_1}$$

$$\delta_2 = \frac{\delta_p + \delta_a}{2} \times \frac{\lambda}{\lambda_2}$$

In these formulæ δ_p and δ_a are the decrements of the primary and aerial taken separately, λ_1 and λ_2 the two wave lengths at which maxima of radiation takes place—λ_2 being the longest, λ is the wave length to which both the primary and secondary are tuned, and δ_1 and δ_2 are the two decrements for the two principal radiation wave lengths λ_1 and λ_2. With *proper loose coupling*, when λ_1 and λ_2 are approximately equal (and equal to λ) it is easily seen that δ_1 and δ_2 are equal, so that—

$$\delta = \frac{\delta_p + \delta_a}{2}$$

The measurement of decrement is dealt with in Chapter XXII.

To sum up, it may be said that the *damping of the energy* *radiated to the ether mainly depends upon the coefficient of coupling, on the form of spark gap used, and on the design of the aerial.* The Telefunken Company claim that the decrement of radiation with their system is only about 0·08 to 0·1, with slow radiating umbrella and T aerials if they are working at their natural wave length, and is only 0·03 to 0·055 if the wave length is increased to three or four times the natural wave length of the aerial by the use of loading inductance.

The disadvantages of damped waves are :—(1) the first wave sent out is not followed by much energy in the waves behind it, so that it must itself carry a large amount of energy which can spread over a good range before it is dissipated. This means that the transmitting apparatus, to give a large initial impulse, must be larger than if the same energy was conveyed by a number of smaller but more equal impulses ; in other words, with slightly damped waves a given range can be covered with much smaller apparatus. (2) Damped waves imply that instead of most of the energy being radiated at one wave length it is spread more or less over a wide range of wave lengths. A receiver station, tuned to one wave length, loses the energy which is conveyed by waves not in tune with it, and all the receiving stations of different wave lengths within the shortened range of the transmitter are affected by it, causing the nuisance of interference. (3) If the damping is mainly due to a tight coupling the energy is radiated at two principal wave lengths, and as a receiver can only be tuned to one of them it misses all the energy conveyed by the other ; this also decreases the range of transmission.

Tuning.—Now let us consider the question of tuning, and the effects produced on the tuning of circuits according as the coupling is fast or loose. To say that a spark transmitter radiates energy at a certain wave length means that the greatest amount of energy will be carried by ether waves of that length, calculated from the electrical constants of the oscillating circuit; it does not mean that all the energy is radiated on that one wave length. The oscillating discharge will set up ether waves of many different lengths, but the principal wave length will be that which carries most energy. In a similar way the disturbances at the sun set up many different lengths of ether waves, the one carrying most energy being a heat wave ; a note struck on the piano sets up different lengths of air waves, the one of most energy corresponds to the fundamental note, the others are called harmonics. The same note sounded on a flute will give less energy to air waves corresponding to harmonics. If the aerial and earth wires in a radio-transmitter are directly connected to the closed circuit in which oscillating discharges are taking place, and a curve is plotted showing the energy transmitted to the ether in any one direction at different wave lengths, it would be of a shape such as shown in Fig. 70. Most energy in the particular case shown is transmitted at 300 metres wave length, but at the same time a considerable amount of energy is transmitted at 200 metres and 400 metres wave length. A receiving station closely tuned to 300 metres wave length would only be acted upon by a small portion of the energy, such as that shown shaded; all the remainder of the radiated energy would not affect it. At the same time a receiving station tuned to any wave length between 100 and 500 metres would probably receive signals from such a transmitting station in its neighbourhood, for the curve shows that there may be sufficient energy at any of these wave lengths to affect the corresponding receivers. Such a transmitting station is not really a tuned one, and will interfere with all the stations near it.

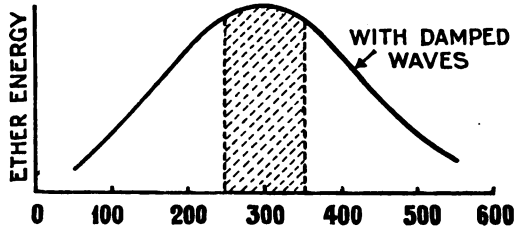


Fig. 70.

The object to be aimed at is to get as much of the energy as possible radiated at, or near, one definite ether wave length, so that if a receiving station is tuned to that wave length most of the radiated energy will act upon it. At the same time eceiving stations not in tune will not receive the signals. Thus Fig. 71 would show an ideal case. Most of the energy radiated into the ether is carried at 600 metres ether wave length, and nearly all the energy radiated in any one direction would act upon a receiving station, in that direction, tuned to 600 metres, but stations tuned to 500 or 700 metres would not be acted on by sufficient energy to affect their receiving apparatus. Of course it is only the shape of the curve of energy that need be considered, for the actual amount of energy at any point depends on the distance from the transmitter, and it gradually dies away with increasing distance; also the energy is spread in all directions round the transmitter. Thus the curves simply show the *comparative* distribution of energy on different ether waves.

Now if the aerial, or radiating, circuit of the transmitter is magnetically coupled to its closed, or primary, circuit by either of the methods described, and if *the coupling is loose,* then it is found that most of the energy is radiated on one principal wave length. This wave length is that of the aerial circuit to which the closed circuit has also been tuned. If, however, the circuits are close coupled then the curve connecting radiated energy and wave length will be as shown in Fig. 72. It will be seen that there are two points of maximum value on the energy curve, showing that the circuit is radiating energy at two principal wave lengths, neither of which is the natural wave length of the oscillating circuits. These wave lengths can be easily discovered by the use of a wavemeter, as shall be described in a later chapter. Referring to Fig. 72, a receiving station tuned to a wave length of 630 metres would in this case be unaffected by all the energy carried at 570 metres wave length; that is to say, efficient use is not being made of all the radiated energy. The closer the open and closed transmitter circuits are coupled the greater will be the difference of the two wave lengths of

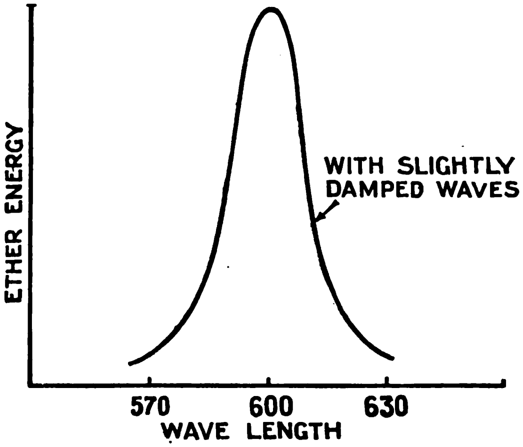


Fig. 71.

maximum radiation, until with tight coupling one is practically reduced to zero, and radiation occurs on all wave lengths as shown in Fig. 70.

Coupling.—If M is the mutual inductance between the circuits, and L_1 and L_2 the respective self-induction coefficients, what is called the " Coefficient of Magnetic Coupling " is given by the formula $\frac{M}{\sqrt{L_1 \times L_2}}$, but it is more usual to speak about the " Degree of Coupling " which depends not only on the coefficient of coupling, but also on the decrements of damping in the two circuits. If, as is usual, we denote " degree of coupling " by k then—

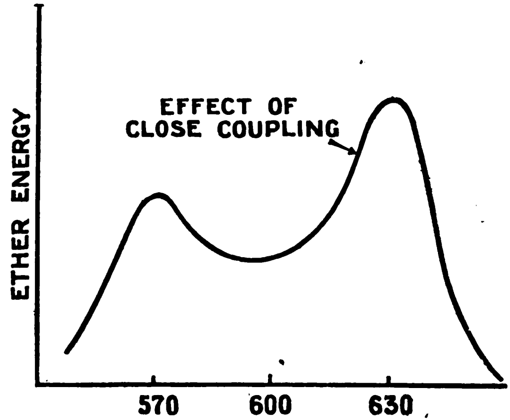


Fig. 72.

$$k^2 = \left(\frac{M}{\sqrt{L_1 L_2}}\right) \sim \left(\frac{\delta_p - \delta_a}{2\pi}\right)^2$$

where ~ represents difference between.

With tight coupling $\frac{M}{\sqrt{L_1 L_2}}$ will be greater than $\left(\frac{\delta_p - \delta_a}{2\pi}\right)$. With loose coupling the reverse will be the case.

Now, in general, when two circuits are coupled, energy is radiated at two lengths ; these are—

$$\lambda_1 = \lambda\sqrt{1-k} \text{ and } \lambda_2 = \lambda\sqrt{1+k}$$

λ being the wave length to which the circuits are tuned, and λ_2 being longer than λ_1. In order that λ_1 should nearly be equal to λ_2, *i.e.* that we should have single waveness, it is easily seen that

$$\sqrt{1-k} \text{ should be equal to } \sqrt{1+k} \text{ approx.}$$

and this can only happen if k is very small.

For k to be very small the coupling must be loose so that the coefficient of magnetic coupling, $\frac{M}{\sqrt{L_1 L_2}}$, is very much smaller than $\frac{\delta_p - \delta_a}{2\pi}$ and approaches zero in value, in which case—

$$k = \frac{d_p - \delta_a}{2\pi}$$

and is very small. This is the condition for single wave radiation when $\lambda_1 = \lambda_2 = \lambda$.

With a wavemeter it is easy to measure the two resultant wave lengths of coupled circuits, and thus we have a means of measuring the degree of coupling; thus—

$$\lambda_1 = \lambda\sqrt{1-k} \text{ and } \lambda_2 = \lambda\sqrt{1+k}$$

$$\therefore \lambda_1{}^2 = \lambda^2 - \lambda^2 k, \qquad \lambda_2{}^2 = \lambda^2 + \lambda^2 k$$

$$\therefore \frac{\lambda_2{}^2 - \lambda_1{}^2}{2\lambda^2} = k$$

This can be written $\frac{(\lambda_2 - \lambda_1)(\lambda_2 + \lambda_1)}{2\lambda^2} = k$ and $(\lambda_1 + \lambda_2)$ is very nearly equal to 2λ for a transmitter fairly loosely coupled, therefore, cancelling these, we have—

$$\frac{\lambda_2 - \lambda_1}{\lambda} = k \text{ approximately.}$$

Direct coupling is a particular case of very tight coupling where the aerial and earth are directly connected to the closed circuit as in Marconi's First Transmitter, Fig. 61. It is sometimes spoken of as "plain aerial," in which radiation of energy is spread over a considerable range of wave lengths, so that jamming is bound to ensue with consequent interference of commercial traffic. The International Radio-Telegraphic Convention of 1912 laid down that the waves emitted must be as pure and as little damped as possible, and that plain aerial should not be allowed except in cases of distress.

With ordinary unquenched spark gaps the degree of coupling (*k*) cannot be more than 10 per cent. if the condition of single waveness is to be approached, and in most transmitters it would be found that the value used in practice is not often above 7 per cent. With quenched spark gaps it is possible to employ a degree of coupling up to 20 per cent. without undue damping of the aerial circuit. The Telefunken Co. use a degree of coupling up to 20 per cent. and slightly mistune the closed circuit from the aerial circuit so that the longer of the two resulting wave lengths is strengthened.

If the circuits are coupled too loosely the energy will be radiated from the aerial sharply to one wave length, but its amount will be small, because few of the magnetic lines of the primary coupler will interlink with the aerial circuit coil, and thus very little energy will be transferred to the latter circuit. Much of the energy oscillating in the primary circuit would then be wasted, and the transmitter is again inefficient. Fig. 73 shows the resonance curves of a properly coupled circuit (*a*); one too tightly coupled (*b*) and one too loosely coupled (*c*).

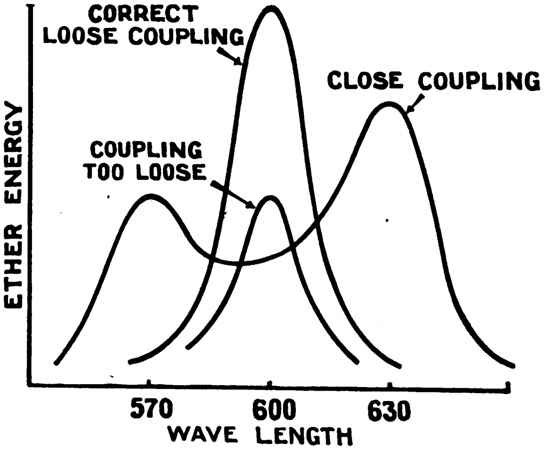


Fig. 73.

In explaining the tuning of coupled circuits, and the coupling conditions necessary to obtain maximum radiation effects at a sharply defined wave length, it was assumed that two circuits, primary and aerial, were tuned to the same wave length. As a matter of fact with spark systems one cannot get zero damping effect in the aerial circuit, so that the maximum resonance is obtained when the frequencies of the two circuits are slightly different, and this difference will increase with the resistance of either circuit. Thus we find that in the Telefunken transmitter the circuits are slightly mistuned, the aerial circuit having a free wave length about 2 per cent. higher than that of the primary circuit, and this mistuning is increased with the closeness of coupling. It is claimed for this arrangement that it aids the quenching of the oscillations in the primary circuit, thus leaving the aerial circuit free to oscillate at its own frequency, and giving a well-defined maximum of radiated energy at that wave length.

Before leaving the question of tuning and coupling there are one or two particular cases which may be noted. It will be remembered that the complete Kelvin formula for frequency is—

$$n = \frac{1}{2\pi}\sqrt{\frac{1}{LK} - \frac{R^2}{4L^2}} \text{ or } = \frac{1}{2\pi}\sqrt{\frac{1}{LK} - \left(\frac{R}{2L}\right)^2}$$

If the primary circuit is such that $\frac{R^2}{4L^2} = \frac{1}{LK}$, then its discharge is a direct one and not oscillatory; if it is coupled to an aerial circuit the latter will oscillate at its own natural frequency, no matter what may be the values of K and L in the closed circuit.

If, on the other hand, the aerial circuit resistance is increased while the closed circuit has its usual low resistance, both circuits will oscillate, and the aerial circuit will never cease to oscillate before the closed circuit; its oscillations will, however, be forced oscillations of the frequency of those in the closed circuits.

These results were obtained by Dr. Fleming in a valuable series of oscillograph records on oscillatory circuits.

Whether the auto-transformer or Tesla-transformer method of coupling should be adopted largely depends on the design of other portions of the apparatus, such as the spark gap; the desired distance of transmission, and the closeness of tuning required.

The jigger, or two-coil coupler, gives the sharpest tuning, and thus best avoids interference with, or by, other stations, but the auto-transformer would for a given amount of energy transmit farther. Thus the Telefunken Co. use the auto-transformer coupling for long-distance transmission, and the two-coil coupling for shorter distances when interference with neighbouring stations is likely to occur.

From the foregoing it will be seen that damping effect, efficiency, tuning, and interference are all involved in each other, and in the degree of coupling. If the coupling is too close the damping effect becomes great, less energy is radiated, and there is no definite wave length. If the coupling is loose enough, and the spark gap of such a design that little energy is transferred back from the aerial to the primary circuit, then the radiation of energy occurs sharply at the fundamental wave length of the circuit, and tuning is good. Stations of other wave lengths are not interfered with; there will be more oscillations at each discharge, and the radiated energy is more persistent; also the transmitter will require a minimum of primary energy for the range of signalling accomplished.

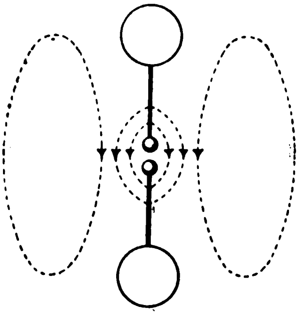
QUESTIONS AND EXERCISES.

1. Describe an oscillation transformer or jigger. Why has it not got an iron core?
2. The closed circuit of a transmitter has an inductance of 10 mhys. and a capacity of 0·0074 mfd. If the radiating, or aerial, circuit has an inductance of 63·4 mhys. what must be the capacity of the aerial so that the two circuits shall be in tune?
3. What is the wave length of the transmitter described in Question 2 if the circuits are loose coupled?
4. Why are two wave lengths of maximum resonance obtained when two tuned circuits are close coupled?
5. Explain how the degree of coupling influences the effects of interference on stations not in tune with the transmitting station.
6. Why does the International Radio-Telegraphic Convention specify that the degree of coupling of the two circuits of a transmitter shall not be greater than 15 per cent.?
7. A circuit has an inductance of 0·013 henry, a capacity of 0·75 mfd., and a resistance of 16·5 ohms. Calculate its natural frequency, its damping factor, and the decrement of damping.
8. When the two circuits of a transmitter are coupled and oscillatory discharges sent through them, each being tuned to 600 metres wave length, the radiated energy is found to have two maxima, at 630 metres wave length and 570 metres wave length respectively. Calculate the degree of coupling of the circuits.
9. What modification of the closed circuit spark gap of a transmitter would enable closer coupling to be adopted without increasing the damping of the radiated energy?
10. Explain why maximum resonance is obtained by slightly mistuning the closed and aerial circuits of a transmitter.
11. What is meant by sharp tuning?
12. A Transatlantic transmitter uses wave lengths of 6000 metres; what is the frequency of this radiation?
13. A station transmitter sharply tuned to one wave length of radiation has a radiation decrement of 0·1. If the decrement of its aerial circuit is 0·08 what is the approximate value of the decrement of its closed circuit?
14. Draw a diagram showing a series of damped oscillations, and refer to it to explain what is meant by (*a*) amplitude, (*b*) period, (*c*) wave length, (*d*) decrement.
15. When we say that the frequency of an oscillating circuit is 1 million oscillations per second do 1 million oscillations actually occur every second in the circuit?
16. The Radio-Telegraph Act of Canada stipulates that in no case shall the logarithmic decrement of a complete oscillation exceed two-tenths. For this decrement calculate the ratio of the amplitudes of two succeeding positive halves of oscillation.

CHAPTER XII

HOW ETHER WAVES ARE PROPAGATED

When a simple Hertz oscillator, such as in Fig. 74, is charged one side is at positive potential, the other at an equal negative potential, and lines of electric strain are set up in the ether around it. The ends of these lines represent units of positive and negative charge on the two sides of the oscillator. Let us briefly review what happens when an oscillatory discharge takes place across the spark gap. At a certain difference of potential the insulation of the spark gap breaks down and the discharge commences; the flow sets up magnetic lines in circles round the circuit, and the self-inductive effect of these magnetic lines keeps the discharge from rising to a maximum instantaneously. During this building up of the discharge and of the magnetic field the electric lines are collapsing; their feet rushing together as the positive and negative charges neutralise each other. When the discharge is a maximum it should be complete with no difference of potential between the two sides, but the magnetic



LOOPED STRAINS
AROUND HERTZ OSCILLATOR.

Fig. 74.

lines set up round the circuit collapse on it. Their inductive effect is to set up a difference of potential in the circuit which sends an extra current across the gap, until what was before negatively charged is now positively charged, and *vice versa*. As the magnetic strain dies away so also does the extra discharge, but on account of it the circuit is now charged in the opposite sense to what it was before; electric lines of strain are set up in the ether near it in the opposite direction to their former direction, and a fresh discharge takes place with similar results. Thus the discharge oscillates backwards and forwards, losing energy at each swing, in radiation and resistance, until it eventually dies out; the whole process, however, only taking a fraction of a second and constituting what is called a spark. That there is energy in the discharge is seen by the heat and light set up in the spark gap, and by the effects of the ether strains set up round the circuit.

Let us concentrate our attention on the electric strain in the ether round the oscillator. A discharge means the collapse of this strain, the positive and negative charges neutralising each other. The shorter electric strain lines collapse completely into the spark gap circuit as each positive unit of charge meets a negative unit. The unit charges which exist in the two sides of the oscillator at the ends of the longer strain lines also rush to meet each other in the discharge; these strain lines also tend to shorten into the gap and vanish. But, owing to the good conductivity of the metal oscillator, the feet of these lines have met before the loops of the lines have collapsed; thus a closed loop of electric strain is set up in the ether all round the oscillator, sections of this loop being diagrammatically shown in Fig. 74.

At the instant represented in Fig. 74 the discharge current has passed its maximum value, and in dying away is charging up the sides of the oscillator in the opposite sense to their former charges; hence new lines of electric strain in the ether are being set up round the spark gap as shown. As the discharge oscillates backwards and forwards successive loops of strain in the ether round the oscillator are thus set up; the strain force represented by any loop acting in the opposite direction to that of the loop just preceding it.

Now let us consider the magnetic strains set up in the ether. We know that when a discharge takes place across the oscillator the ether round it is strained magnetically, that is to say concentric circles of magnetic lines are set up owing to the discharging current. One would think that when the magnetic strain is a maximum the electric strain in the ether should have disappeared, and the discharge would be finished if it were not for the inductive effect of the magnetic strain lines when collapsing. But is it true that the electric strain is zero when the magnetic strain is a maximum ?—is the difference of potential of the two sides of the oscillator zero when the current in it is a maximum, and *vice versa?*

Such conditions would be as represented in the diagram of Fig. 75. As the current rises to a maximum value (from A to B) the potential difference falls to zero, but when the discharge current dies away to zero (from B to D) the potential is being built up again in the opposite direction, (shown by drawing the potential curve below the horizontal line at F (Fig. 75)). Similarly when the current in the opposite direction rises to a maximum and falls to zero (from D to E) the potential is reduced to zero again and then raised to a maximum in the opposite direction (at E). Thus the oscillator at E would be just in the same condition as it was at A; the changing conditions from A to E represents a complete cycle, and the distance AE is said to represent 360°. Thus AF represents 90°, or the maximum of current occurs 90° from the maximum of volts.

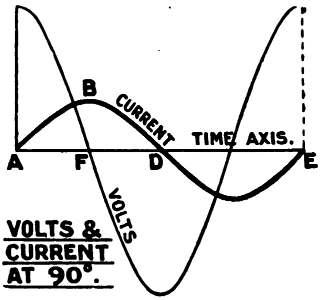


FIG. 75.

Now if the current and volts were at 90° to each other there would be no energy available from the discharge, for the energy represented by the current in rising, and discharging the oscillator, would be just equal to the energy of recharge of the circuit in the opposite direction, when the current is dying away to zero. Any student familiar with the elementary theory of alternating current knows that when current and potential in a circuit are at 90° to each other no energy is available, or expended, in that circuit.

Yet with our oscillatory discharge we know energy is available in the circuit, for some is turned to heat and light in the spark gap, some heats the wires or conductors, and some is given to the ether. Therefore the current and potential cannot be exactly at right angles to each other, and around the oscillator the electric strain is not zero when the magnetic strain is a maximum, or *vice versa.* The strains are *nearly* at right angles to each other, and the nearer they are to this condition the more oscillations there will be at each discharge, while less energy will be given out at each oscillation. The actual conditions of strain at each oscillation might be represented in a vector diagram, as shown in Fig. 76. Here OE represents the electric strain force and OM represents the magnetic strain not exactly at right angles to OE. Any force such as OM can be resolved into two components at right angles to each other, hence we can resolve OM into a component OM_1, acting with the electric strain, and OM_2 acting at right angles to the electric strain. The component of the magnetic force OM_2 at right angles to the electric strain acts with the latter to make the discharge oscillatory; the other component OM_1 in phase with the electric strain represents the energy produced by an oscillation.

The important conclusion to remember is that the magnetic and electric strains are not set up in the ether round the oscillator exactly at right angles to each other; if they were no energy would be radiated.

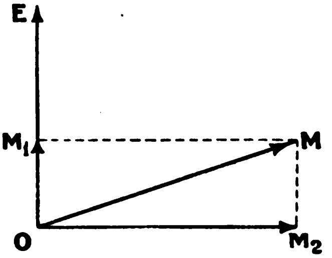


FIG. 76.

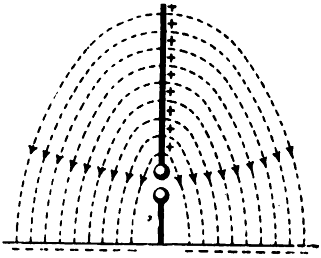


FIG. 77.

One of the first steps taken by Marconi in the development of radio-telegraphy was to join one side of the transmitter to earth, the other side being a wire (the aerial) raised high in the air. The action in such a circuit when the discharge takes place is very similar to that already described. When the oscillator is charged up the electric strain in the ether is as shown in Fig. 77, the lines of force stretching from the aerial to the earth.

When a conductor is statically charged electric lines enter or leave it at right angles to its surface; note that the ether all round the oscillator is strained, hence what is shown in the Figure is only a section of the strain. It will be seen later that elaborate arrangements are made to provide good conductivity on the earth's surface all round the aerial circuit.

When a discharge starts the upper ends of the strain lines rush down to meet the lower ends; the latter move comparatively slowly as they pass along the earth's surface, which offers a certain amount of electrical resistance effect to their progress. By the time the upper ends of the electric strain lines have reached the bottom of the aerial the discharge current has reached its maximum and, as it dies away to zero, is charging the aerial circuit up in the reverse direction, as shown in Fig. 78. Hence, loops of electric strain are formed round the oscillator with their feet on the earth; and new strain lines formed by the completion of the discharge in one direction.

If the direction of the strain as shown by the arrow heads is studied, (the direction of an electric line being from a positive charge to a negative charge), it will be seen that the ether near the oscillator is electrically strained in an upward direction; a little farther out it is strained vertically in the opposite direction: each loop of strain close to the oscillator being completed by a portion of the oscillator and earth, while each loop farther out is completed by the earth's surface. At the next discharge the direction of the vertical strains in the ether round the oscillator will be reversed, since the discharge current is reversed.

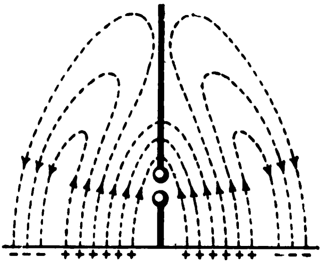


Fig. 78.

Now we must try to realise how the electric and magnetic strains set up in the ether round the aerial are propagated through it to great distances. In the first place we may note that harmonic wave motions are propagated through mediums owing to the fact that the mediums possess the properties of elasticity and inertia.

Elasticity is measured by the ratio of the strain set up in the medium to the stress force which sets it up; inertia is proportional to the mass or density of the medium. Thus if e represents the elasticity and ρ the density of the medium, both being measured in suitable units, the velocity of a sound wave in air, water, or any solid is given by the formula: $V = \sqrt{\frac{e}{\rho}}$. The velocity of sound in air at 0° C. is 330 metres per second, in hard steel it is 5600 metres per second; compare these with the velocity of light and radiant heat waves in ether, which is 300,000,000 metres per second, and with the strain effects set up in ether by electrical oscillations which travel at the same velocity. Since they are propagated through the ether at a definite velocity the ether medium must possess properties corresponding to elasticity and inertia; since the velocity is so great we must conclude that its property of elasticity must be very great or what corresponds to density must be relatively small. The ether in which the strains are set up is contained in air, which is a non-conductor or dielectric, and the effects corresponding to elasticity and density may be caused by the electric and magnetic properties of the dielectric. It is an interesting fact to note that if K represents the dielectric constant and μ the permeability of air, or a good vacuum, both measured in C.G.S. units, the value of $\frac{1}{\sqrt{K\mu}} = 3 \times 10^{10}$ which is the velocity of ether waves in metres; thus $\frac{1}{K}$ corresponds to elasticity and μ to density.

Clerk Maxwell showed that if an electric ether strain in a dielectric moved or changed in any way it had the same effect as a current; that if it was increasing or diminishing there would be closed circles of magnetic strain set up around it. For this reason a changing electric strain in a dielectric was called by him a *displacement current;* he explained that a diminishing electric strain in the ether is equivalent to a current in the opposite direction to the strain, and an increasing electric strain is equivalent to a current in the same direction as the strain.

A current of electricity flowing in a straight wire or path is surrounded by concentric circles of magnetic strain in the ether at right angles to the wire or path. An increasing or decreasing electric strain is equivalent to a displacement current, therefore magnetic strain is set up in the ether at right angles to it.

Now let us consider what is happening in the ether round the aerial in which oscillating charge and discharge is taking place. Referring to Fig. 78, the loops of electric strain in the ether round the aerial will tend to die out owing to the property corresponding to elasticity, but at a moment later, in the same body of ether, new strains acting in the opposite direction will be growing up owing to the next oscillation of current in the aerial. Thus the electric strains set up in the ether by an oscillating current have never a steady value; they are always rising or falling in magnitude. Their effects are therefore equivalent to an oscillating displacement current in the ether, and their rise and fall will set up rising and falling magnetic strains, acting at right angles to the electric strains as regards time and at right angles in space. That is to say the magnetic strains will be a maximum when the electric strains are passing through zero value, and *vice versa*; the electric strains are nearly vertical in the ether, the magnetic strains are set up nearly parallel to the earth's surface.

Consider a section of one of the loops of electric strain in the ether near the transmitter, its direction being as shown in Fig. 79; suppose it is decreasing, it is then equivalent to a displacement current in the opposite direction as shown by the curved arrow, and earth current will flow from B to A completing the circuit.

The displacement current or decreasing electric strain will set up magnetic strain as shown.

Now when a changing magnetic strain is interlinked with a conductor, such as a copper wire, we know that the ether in the conductor is strained and because of this strain, and because it is a conductor, electrons move along the wire so that one end is charged positively and the other negatively. This is the ordinary electro-magnet induction effect, as in a dynamo. Similarly when changing magnetic strain is interlinked with a dielectric, such as air, the ether in the dielectric is electrically strained, but there is little motion of electrons because the dielectric is an insulator.

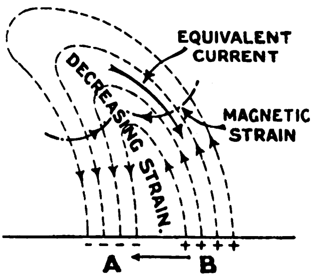


Fig. 79.

Thus when the magnetic strain set up in Fig. 79 collapses it induces loops of electric strain in the ether; the loops are linked with the magnetic strain and extend over into the ether beyond B. The direction of this new induced strain at B is in opposition to the previous strain, thus tending to reverse the strain at B, and this action is helped by the strain effects produced by the reversal of the oscillating current in the neighbouring aerial.

The new conditions will then be as represented in Fig. 80, where a new strain has been set up, looping over from B to the ether at C. A similar effect will occur at C, and so on; in this manner the strain effects will spread outwards through the ether. At each oscillation of current in the aerial new impulses of strain energy will be radiated or sent out into the ether, just as fresh impulses of energy are given to ring waves in water by continuing to plunge a stick up and down in it. Note that no electricity goes into the ether from the aerial, at least if it does it means a loss of efficiency. At large stations, with high voltages in the aerial, there is what is called a brush discharge, or leak of current, from the aerial into the air; this may make the aerial glow at night, so that it appears lit up on a photograph, but it represents loss of energy and efficiency. Note also that in this propagation of energy out into the ether the latter does not itself move; water does not move outwards when ring waves are set up in it, nor air when it conveys sound waves.

In Fig. 80 the distance from A to B, or B to C represents one half cycle or half wave disturbance, *i.e.* it equals $\frac{\lambda}{2}$.

At any given instance the strains in the ether might be represented in section as shown in Fig. 81; at the instant taken the electric strains are a maximum at A, C, and E, and zero at B and D; an instant later they will be a maximum at B and D and zero at the other points; an instant later still they will be a maximum again at A, C, and E, but reversed in direction so that the arrow heads would be shown reversed. The magnetic strains are represented in section by the dots. The strains will penetrate to some extent into the ether in the earth, and the earth is more or less a conductor; ether strains in a conductor induce currents in it. Hence the passage of the strains through the ether will set up oscillating currents in the earth's surface over which the feet of the strain lines travel.

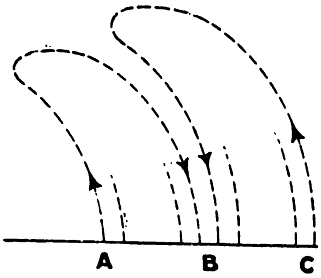


Fig. 80.

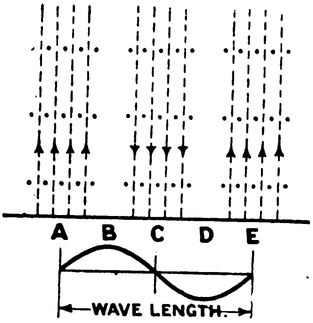


Fig. 81.

Imagine that we could see the strains in the ether as colours, that an electric strain acting downwards is represented by red, one acting upwards by blue, a magnetic strain in one direction by yellow and in the opposite direction by green. Then a person standing in the ether would see a red colour of electric strain which will grow in intensity and then die out, giving place to a yellowish colour of magnetic strain which grows in intensity as the red dies out. As the yellow fades away it will give place to a blue colour of electric strain; this deepens and then fades away giving place to a green magnetic one. As the green one fades away the red will come on again and the whole cycle will be repeated. The rapidity with which any colour, such as the red, repeats itself depends on the frequency of the oscillating current in the aerial.

Another person standing farther out in the ether will see the same thing, but he may not see the same colours at exactly the same time as the first observer. If he is exactly half a wave length away he will be getting the sensation of blue at the moment when the first observer is getting a red sensation, if he is a complete wave length away they will both get the same colour sensations at exactly the same moment.

At every oscillation of current in the aerial the strains will progress through the ether by one wave length; thus if the frequency is n oscillations per second the wave disturbance should travel through the ether to a distance of $n\lambda$ metres in one second. This distance is never attained because the wave energy becomes attenuated and dissipated as it spreads outwards. However, since it travels at the rate $n\lambda$ metres per second, this is the velocity, v, of propagation. Now v is always 300,000,000 metres per second for any length of ether wave, hence we have the important relation :—

$$\begin{aligned} n\lambda = v &= 3 \times 10^8 \text{ or } 300{,}000{,}000 \text{ metres} \\ &= 300{,}000 \text{ kilometres} \\ &= 186{,}000 \text{ miles approx.} \end{aligned}$$

Professor A. Blondel showed that the maximum of energy was radiated straight out from the aerial and no energy is radiated upwards in line with the aerial. Thus the direction of wave disturbance is at right angles to both the electric and magnetic strains. As the strain effects move outwards through the ether they will also probably penetrate upwards in it, but the maximum energy or strain will always be near the earth.

In practice we do not generally employ a plain vertical aerial, so that the electric strain lines are not vertical to the earth's surface through all their length ; indeed we shall presently consider the fact that if the electric strain started vertical near the aerial it does not remain so. Early in the course of his wireless developments Marconi discovered that an L type aerial gave strong directional effects to the radiated energy in the direction opposite to that to which the L pointed. Fig. 82 shows the form of the ether strain round such an aerial; it will be seen that the strain acts on a much larger body of the ether on one side of the aerial than on the other; the circuit is, as it were, more open on one side than on the other.

We shall see presently that at great distances the strains are probably bent forward in the direction of propagation, instead of being bent backwards as they are when they leave the transmitter.

If a stick is plunged up and down in a pond so as to set up ring waves in the water the energy in the waves gets less and less as their distance from the origin of disturbance increases, finally disappearing so that no waves are apparent far out in the pond. Similarly the energy of ether waves spreads out over larger and larger wave fronts, so that at any place the ether wave energy will be inversely proportional to the distance of the place from the transmitter.

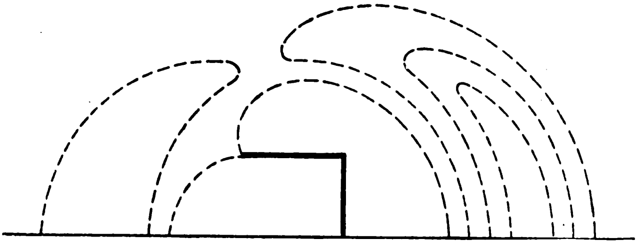


FIG. 82.

In addition to the attenuation of ether wave energy caused by spreading there are several other effects which cause energy dissipation; these we must now consider.

Screening Effects.—Remembering that the ether medium pervades everything, suppose that there is a plantation of trees, or a number of houses with iron pipes down their sides, near the transmitter or receiver and in a direct line with them. When oscillations of current occur in the transmitter aerial electric strains are propagated out through the ether; thus the ether in the trees or pipes experiences these strains. But trees and iron pipes are conductors connected to earth, so that if the ether in them experiences an oscillating strain currents of electrons will oscillate up and down them. Thus some of the ether strain is changed into energy of electron movement measurable in watts ($= C^2R$), and there is less energy to penetrate as strain or wave motion into the ether beyond. Each tree, each house in the path is, as it were, a receiver aerial to trap some of the energy in the ether and make it move electrons. Some years ago Colonel Squier of the United States Army received signals using a tall tree only as a receiver aerial; this showed that energy was absorbed from the ether waves by trees directly in their path. The student can picture an analogy of water waves meeting posts sticking up out of the water in their path.

Duddell, experimenting in Bushey Park near London, found that when the receiver was placed close up behind a plantation of trees the receiver currents were much weakened, but when he moved it to a greater distance they increased in strength to something less than what would have been their normal value if the plantation had not been there. From this we learn, first, the importance of having the transmitter and receiver in the open and well away from screening effects; second, that whereas raised conductors, or semi-conductors, in the range path will absorb some energy out of the ether yet the ether beyond will have strain effects induced in it; this induction is caused by the propagation of strain effects which have passed round the obstruction, or through the interstices of the screen.

It will be remembered that one of Marconi's earliest experiments was to signal from Cape Lizard to St. Katherines, a distance of 300 miles, with aerials only 200 feet high. Between these points the curvature of the earth raised its surface high up between the aerials and the experiment proved that this curvature was no barrier; the ether waves followed the curvature of the earth. We now know that it is possible to signal half-way round the world, also across mountain ranges with aerials of moderate height, though the latter is not quite the same problem as that of earth curvature.

Earth and Sea Effects.—One side of the open circuit coil is connected to the aerial, the other to earth, so that the earth forms one half of the open circuit oscillator. When the aerial is charged up positively the earth surface around is charged negatively, and *vice versa;* when loops of ether strain are formed round the transmitter aerial the feet of the strains are on the earth's surface, and different parts of the surface are at positive and negative potentials respectively, as shown in Fig. 78. The earth being a conductor oscillating currents will flow in it as the ether strain oscillates. Around a high-power transmitter in action there must be comparatively large oscillating currents in the earth surface; moreover it is evident that oscillating earth currents are set up wherever the ether waves extend. For example, it is easy to pick up signals from the Eiffel Tower transmitter at a distance of 100 miles by simply connecting a valve relay, or amplifier, to two points in the earth 100 yards apart; thus applying to it the oscillating potentials of the earth's surface induced by the penetration of the ether strains into it.

When the ether strains corresponding to a wave of light, *i.e.* a very short ether wave, meet a surface of water or glass the strains are not suddenly stopped; they continue into the ether in the water or glass, and the light wave passes into or through these substances, though it will be bent where it enters or leaves them. When a light wave meets a non-transparent substance the strain effects penetrate but little into the ether in the substance and are therefore quickly stopped.

Similarly electric and magnetic strains corresponding to the long ether waves of wireless telegraphy are set up not only in the atmospheric ether but also, to some extent, in the ether below the surface of the earth or sea. The depth to which they will penetrate depends on the resistance of the earth or sea at the place. If the resistance is low they will not penetrate far, but if it is high the penetration will be comparatively great. The greatest induction of earth currents will take place immediately around the transmitter where the ether strains are strongest; therefore we should have a low earth resistance at or round the transmitter.

We have seen that one of the effects of this ether strain in the earth's surface is to set up oscillating earth currents, and the deeper the strain penetrates the deeper will these oscillating currents be found, turning strain energy into energy of electron movement. If the earth or sea surface over which the strains travel were a perfect conductor, or if we connected the transmitter and receiver earth terminals by a thick band of copper, the strain effects in the ether would not penetrate perceptibly into the surface; oscillating currents would be induced only on a thin layer of the surface and the ether waves would skim over it without much loss of energy.

The magnetic strains set up in the ether in the earth or sea surface are probably more damped out than the electric strains, for they are parallel to the surface, and, as they change in value, cause most of the induction of oscillating currents ; *i.e.* waste of radiated energy.

The greater the resistance of surface over which the waves travel the greater will be the strain penetration, with consequent loss of strain energy in the air. Brylinski has calculated the resistance of damp earth to be 6600 ohms per cm. cube, and of sea water 373 ohms per cm. cube ; he also demonstrated that surface currents may penetrate to a depth of 15 metres in land but only to 2 or 3 metres in sea water. The penetration will depend on the frequency of the strain effects, that is to say the longer the waves the less the loss of energy due to earth or sea absorption.

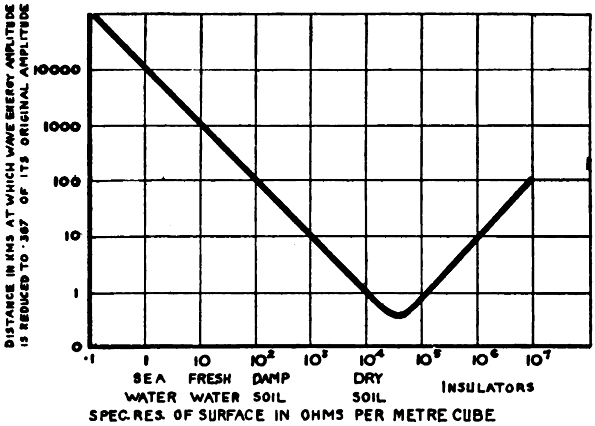


Fig. 83.

The resistance of the earth and its dissipation of energy will mainly depend on the nature of the surface ; sandy deserts are hard to signal over on account of their high surface resistance, limestone has a greater resistance than sandstone, and both have a much greater resistance than damp soil or sea water.

Zennech has drawn curves showing the distance that the waves will travel before their intensity is reduced, by surface penetration alone, to a certain fraction of their original intensity. One of these, as annotated by Dr. J. Fleming, is shown in Fig. 83.

From these considerations it will be apparent why greater ranges of signalling are possible over sea than over land, sea range being approximately double land range for the same heights of aerials and strengths of signals.

Day and Night Effects.—It is a well-known fact that the range of signalling is much greater at night than in the daytime; for example, the Telefunken type E. transmitter has a guaranteed range over sea of 470 miles by day and 950 miles by night, using the ordinary Telefunken crystal detectors in the receiver.

It is evident that the phenomenon is due to changing conditions in the atmosphere, and many different theories respecting it have been published from time to time. Up to the outbreak of the war measurements of comparative strengths of signals failed in accuracy, owing to the erratic and unreliable behaviour of crystal detectors which were the only ones then available; it is probably due to this fact that opposite conclusions have been arrived at by different scientists on certain points, and it is to be hoped that the perfection of valve detectors and amplifiers will soon give reliable data on such an important phenomenon.

Let us first review the known conditions of the atmosphere in which the ether is strained by the transmitter oscillations. The atmosphere consists essentially of a mixture of several forms of matter in a gaseous state—hydrogen, nitrogen, oxygen, helium, argon, and geocoronium; it is most dense at sea level and gets rarer as the height gets greater; in fact its composition changes with the height. Up to a height of 100 kilometres we find that the percentage of the heavier gases in the mixture, such as argon, oxygen, and nitrogen, is greatest at sea level; in the strata above 100 kilometres the atmosphere almost wholly consists of the lighter gases hydrogen and geocoronium, with a trace of helium. In addition to what might be called its essential constituents the lower regions of the atmosphere near the earth's surface contain water vapour evaporated from the earth and sea, and dust particles with which, as nuclei, the water vapour forms clouds; these may attain a height in the atmosphere which varies from 7 to 13 kilometres. Now the earth's surface contains a permanent negative charge of electricity, the origin of which is at present unknown; the atmosphere also contains both positive and negative charges in the form of ions and electrons, the positive charges normally predominating in the lower layers of the atmosphere. The sources of this atmospheric electricity are many, but the principal ones are discharges from the sun and the earth. Owing to the violent electrical disturbances at the surface of the sun ions and electrons are shot from it into the ether in interplanetary space; in the daytime when the sun is above our horizon some of these ions and electrons will penetrate into the atmosphere in our regions. The electrons, being very small, will be stopped by the increasing resistance of the atmospheric density, and thus will remain in the higher layers of atmosphere where it consists almost wholly of hydrogen. The ions will probably penetrate deeper and arrive closer to the earth. At sea level the atmospheric pressure is 760 mms.; at 100 kilometres high it is only 0·0128 mm. Thus, as a whole, the layers of the atmosphere near the earth contain positive charges, and the difference of potential between the earth and the atmosphere at various heights has been measured by Kelvin, Makower, and others. Makower proved that at 3000 feet high the potential of the atmosphere was 40,000 volts above that of the earth. But discharge of negative electricity, or electrons, is continually taking place from the earth's surface into the lower regions of the atmosphere, partly from radioactive constituents in the earth's crust, partly as direct discharge from vegetation and other conducting points, partly carried upwards by dust and water vapour. During the war in France, when the hot, dry months of August and September brought consistent daily lightning storms, and continuous trouble from atmospheric discharges in the receiver circuits, the author was often led to consider the disadvantages of ripened wheatfields and dusty roads from a wireless point of view.

Again, ultra-violet rays of light, of wave lengths shorter than $\frac{135}{10^9}$ metres, have the power of separating electrons out of gaseous molecules, thus forming positive and negative ions; these ultraviolet rays always accompany sunlight and in the daytime are a source of positive and negative ions in all layers of the atmosphere.

Thus at times the lower regions of the atmosphere may contain an abnormal mixture of positive and negative ions; in the middle regions of the atmosphere positive ions probably predominate, and electrons collect in the high regions of very rarified atmosphere.

In 1901 Heaviside pointed out that somewhere in the atmosphere there must be a well-defined layer of ionised strata which would act as an upper conducting surface, just as the earth acts as a lower conducting one. The ether strains in the air dielectric would be confined between these two conducting layers, and this would account for the comparatively great ranges to which they spread, and for the fact that the ether strains follow the earth's curvature. In connection with the conducting *Heaviside layer* Sir J. J. Thomson has shown that, whilst the atmosphere is nearly a perfect dielectric, or non-conductor, near the earth's surface, it becomes conductive to alternating currents at a height of 35 miles, and immediately above that it is a better conductor for these currents than sea water.

If the strains extend to the ether at this layer the ions in it will move backwards and forwards as the strains oscillate; this ionic movement corresponds to an oscillating current, so that strain energy will be dissipated by these conduction currents in the Heaviside layer. Since, however, its resistance is very low the energy thus lost will be very small compared to that lost at the feet of the ether waves in the surface of the earth or sea.

Even in the lower regions of the atmosphere, where we set up and use ether strains, they will encounter ions and electrons, the movement of which will represent a diminution or absorption of strain energy; during the daytime when the sun is overhead and the ground warm there is likely to be a great number of the electrons and ions; during the night-time when the sun it not pouring them down, when also ultra-violet rays are absent and the earth is cool, the supply will be less and there will be a re-combination of positive ions and electrons taking place. Yet this difference does not nearly account for the observed difference of day and night signal strength. Professors Pierce and Zenneck have shown that the *absorption of energy due to the ionisation of the lower atmosphere is small*, and Dr. Austin has pointed out that increases of ground absorption effect, much greater than those possibly set up by an ionised atmosphere in daylight, give a very slight variation to the strength of the signals.

Therefore we must look for some other source of variation of strain energy, and we get a clue to it in the fact that energy at one wave length may be seriously diminished in daylight, compared to the effects at night, while that on another wave length may not be appreciably changed. This result was noted by Marconi in his early transatlantic work and it suggests a refraction effect. We know that light waves are refracted when they pass from one medium to another of different density; we get the sunlight after the sun has gone down below the horizon because the rays are bent as they pass through the layers of atmosphere of different density, curving over the horizon towards us in the form of twilight. We also know that light waves of different lengths are refracted, or bent, by different amounts in passing from a denser to a rarer medium; short light waves such as violet rays will be more refracted than long ones such as red rays. This accounts for the formation of the rainbow, and for the fact that we can separate white light into its seven constituent colours by means of a glass prism.

Since long wireless waves travel better, and arrive with more of their initial energy, than shorter ones we may conclude that the electric ether strains are bent forward in passing from the denser to the rarer layers of atmosphere; thus though started vertically from the transmitter their tops bend more and more forward in the ether as the distance gets greater. This refraction will localise the strain effects to the ether near the earth surface and prevent dissipation of energy in the charged upper atmosphere.

If M is the refractive index of a gas and d its density, $\frac{M-1}{d}$ is a constant; if k is its dielectric constant then M is proportional to $\sqrt{k}$, hence $d = a\sqrt{k}$ where a is a constant. Ether wave velocity in it is proportional to $\frac{1}{\sqrt{k\mu}}$; thus it is inversely proportional to the density. Hence the velocity of a wave strain effect is greater in the higher atmosphere than in the lower; this means that the tops of the waves will move forward faster than the feet and so bend the waves forward. *This normal refraction effect is small and would not account for the observed difference in day and night effects;* there is, however, another refraction effect due to the ions in the atmosphere, which was first pointed out by Dr. W. H. Eccles in 1912. He showed that where an ether wave passed through a region of the atmosphere containing ions, which were moved to and fro by the ether strains, the velocity of the wave front at this point was increased, because the convection currents represented by the movement of the ions had the same effect as if the dielectric constant k were reduced. The velocity is proportional to $\frac{1}{\sqrt{k}}$ therefore a reduction of k means an increase of velocity. The tops of the waves travel faster than the feet and the wave front is tilted forward, so that the strain energy follows the curvature of the earth. Therefore we can see that if the waves start out from the transmitter aerial as shown in Fig. 82, further on in space they will be inclined forward as shown in Fig. 84, *and this effect is produced mainly by ionic refraction.*

The change of velocity due to ionic refraction is proportional to the square of the wave length, so that short waves are less bent than long ones. The energy carried on comparatively short waves will penetrate upwards into the atmosphere, and for small wireless stations this non-refraction of the energy, coupled with ionic absorption loss, may fully account for the difference in strength of day and night signals.

The suitability of long wave lengths for long ranges must not be confused with the fact that there is a best wave length for a given range and given heights of aerials; this will be dealt with in the Chapter on Aerials.

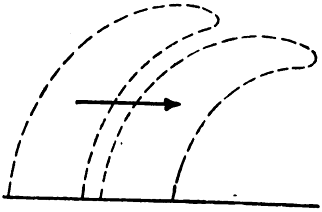


Fig. 84.

In 1913 experiments were carried out between the station at Arlington and the cruiser *Salem;* curves were plotted showing the strengths of day and night signals at different ranges. From these curves Dr. Eccles has pointed out that night transmission does not follow the same law of energy absorption as that in daylight. But it has already been pointed out that ionic absorption of energy has only a small effect on signal strength, therefore the difference between day and night signal strength must be looked for in some change of the conditions of ionic refraction.

In the daytime, with the sun well above the meridian and the earth surface warm, the lower regions of the atmosphere are highly ionised with no well-defined ionised layer; ionic absorption is comparatively great and refraction of energy so irregular that it may amount to dispersion and interference. When the sun sets a great amount of recombination of ions takes place in the lower atmosphere, decreasing the absorption; at the same time the ionised layer that remains is higher and more sharply defined, so that refraction effects are better.

Fig. 85 shows the strength of received current measured by H. J. Round at Chelmsford with signals from Clifden and Glace Bay. At Brant Rock signals received from Clifden gave currents in the receiver which rose from 35 microamps. in the daytime to over 100 microamps. at night; in the summer the daytime currents were only about 7 to 10 microamps. The longer the wave the less the difference in the strength of day and night signals. Hoyt Taylor and Blatterman, in 1915, carried out experiments which seemed to show that a wave length of 500 metres at night was better than one of 1500 metres, but this result will require confirmation by further experiments.

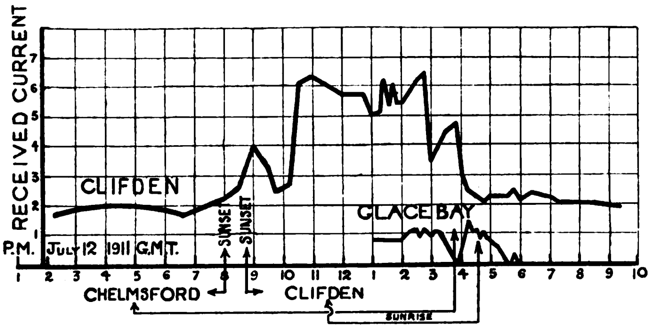


Fig. 85.

Twilight Effects.—In a lecture given at the Royal Institution in 1911, Signor Marconi stated that the strength of the signals received at Clifden from Glace Bay was a minimum about an hour and a half after sunset at Clifden, it being then daylight at Glace Bay. The strength was a maximum four hours later at Clifden, it being then sunset at Glace Bay. Just after sunrise at Clifden signals were again a maximum; an hour and a half later a minimum, and then before sunrise at Glace Bay they returned to their usual strength. A simple explanation of these facts was first given by Dr. Eccles in 1912. An hour and a half after sunset at Clifden the lower strata of atmosphere there has been largely de-ionised. and the active ionised layer for refraction is high; it is still daylight at Glace Bay, so that here refraction is taking place at lower altitudes. The weakness of signals at this time at Clifden will be due partly to the irregularity of heights of the refracting layers of atmosphere, partly to the electrical disturbances of de-ionisation of the atmosphere over Clifden at twilight. Four hours later the atmosphere was in a stable condition at Clifden, the sun had set at Glace Bay, and the ionised layer there was higher and more in uniformity with that at Clifden; the signals were then a maximum. Similar reasoning applies to the other changes mentioned.

As Dr. Eccles points out the twilight band is inclined to the meridian and moves with the sun; when it comes between the stations it may act as an obstruction to signals due to the irregularity of refraction height, when it comes near or over a sending or receiving station it may act as a reflector to strengthen or weaken signals according to its position.

Weather Effects.—Hoyt Taylor found that a cloudy day was followed by good signals at night. On a cloudy day the lower regions of the atmosphere are not likely to be highly ionised; there is probably more moisture in the earth, decreasing its resistance and absorption, so that the signals of the day should be more uniform with those of the succeeding night and both should be improved.

Wet weather is liable to lower the efficiency of the aerial insulators and increase the decrement at the transmitter aerial; at the same time it decreases earth resistance and therefore decreases ground absorption.

Signals may be weakened some time before the approach of a thunderstorm, when the air is in a highly ionised condition, and the formation of thunder clouds is causing irregularities of both normal and ionic refraction.

In dry hot weather the lower atmosphere is likely to be highly ionised in the daytime, and the earth resistance higher than usual, with a corresponding weakening of signals. The same remark applies to hot climates.

Freak Ranges.—It has often been noted that exceptionally long ranges can be covered by small transmitters at certain times and places; these long range effects are particularly prevalent in the Pacific Ocean. Again, in 1911 Signor Marconi stated that signals were better in a north-south direction than in an east-west one. Both these effects are probably due to some transient ideal condition of ionic refraction not yet sufficiently understood.

The permanent condition of the magnetic strain in the ether, called the earth's magnetic field, will not affect the strains of ether waves; these are simply superimposed on it, and pass through it just as sound waves can pass through compressed air.

Atmospherics, Strays, or Xs.—Besides the effects produced by the cyclical ionisation of the atmosphere, as already described, it is natural to expect that abnormal electrical conditions in the atmosphere would give rise to disturbances; unfortunately this is only too true, and constitutes one of the most serious handicaps to wireless signalling, especially in the Tropics. Irregular noises are produced in the receiver telephones which seriously interfere with the reception of the regular signals; they are due to "Atmospherics," or "Strays," or "Xs." Much investigation on their nature and origin has been carried out by Dr. W. Eccles, and valuable observations of their practical effects have been made by C. I. de Groot, the Engineer in charge of the wireless stations of the Dutch East Indian Department of Telegraphs.

De Groot has observed that there are three kinds of strays: (1) those which give loud and sudden clicks in the telephones, due to lightning discharges in the range of the receiver aerial; (2) those which give a constant hissing noise, due to the passage of low electrically charged clouds over the neighbourhood of the receiver; (3) those which give a constant rattling sort of noise like something tumbling down; these are the most prevalent, especially in the tropics, and are due probably to ionisation or de-ionisation effects in the regions of the atmosphere above the cloud strata. Type (2) gives a unidirectional current in the receiver aerial which seems to show a discharge between the aerial and the clouds, something like a brush discharge; at the same time the strength of the received signals falls off, partly due to the alteration of the aerial constants, and partly to overload on the detector. Strays of Type (3) are the most prevalent and therefore the most troublesome, as regards their interference with commercial working; in our own latitudes they are most prevalent during the afternoons of hot summer days. They are aperiodic in character. M. Dieckmann first suggested that the receiver aerial could be shielded from these aperiodic strays by surrounding it with an aperiodic cage, consisting of hoops of wire all connected together and to the aerial by a high resistance wire; this is now known as a Dieckmann Cage. Since the wire hoops are at right angles to the aerial they do not screen it much from reception of the periodic ether strain effects, but they screen it fairly effectively from static, or aperiodic, ether strain effects.

Other methods of reducing the effects of strays in the receiver detector and telephones are provided by special circuits, known as X Stoppers, Eliminators, or Rejectors, which are connected or coupled to the receiver aerial circuit; these will be dealt with in a later chapter. An account of De Groot's investigations was published in the *Wireless World* of 1917, also in the *Proceedings of the Institute of Radio Engineers*. From a practical point of view the great disadvantage of strays is that they necessitate the use of transmitter energy greatly in excess of that required if strays were not present, especially as their jamming effects are generally accompanied by a decrease of signal strength. In the Tropics this may lead to the necessity of using six to eight times normal energy in the transmitter to keep up commercial signal working; even then bad atmospherics will make work impossible at times.

According to Dr. W. H. Eccles for latitudes north of the Equator the stray minimum occurs a little after noon each day and the maximum a little after midnight.

QUESTIONS AND EXERCISES.

1. Show that the magnetic and electric strains in the ether immediately around an oscillating discharge circuit are not exactly at 90° out of phase.
2. Explain why the feet of the ether waves travel on the surface of the earth or sea, and what effect the resistance of the surface has on the wave propagation.
3. Why is the range of transmission much less over land than over sea ?
4. Write a short account of the effect of daylight on the transmission of ether waves.
5. A receiver station is 3000 miles from a transmitter station ; find the time taken for an ether wave disturbance to traverse the distance between the stations.
6. Explain why the ether strain effects cannot penetrate higher into the atmosphere than about 35 to 40 miles.
7. What are the two great advantages which the long ether waves of radiotelegraphy have over light waves as a means of signalling ?
8. What is the probable effect of twilight on the ether waves passing through it ?
9. Why is it probable that the ether wave front is bent forward in the direction of propagation after it has travelled some distance ?
10. Discuss the probable sources of Xs or strays, and explain the construction and action of a Dieckmann Cage.

CHAPTER XIII

TRANSMITTER CIRCUITS FOR SPARK SYSTEMS

A TRANSMITTER consists of three circuits: (1) a generating circuit for giving high voltages, either intermittent or alternating; (2) a closed circuit to which the high voltages are applied, and in which oscillating discharges take place; (3) an open or radiating circuit linked, or coupled, to the closed circuit.

For small power stations, up to 300 watts, the generating circuit consists of an induction coil joined to a battery through a manipulating key of the Morse pattern. As already described the induction coil should be specially designed with a low resistance secondary, and wound to produce resonance effects, so that a relatively large current will flow at each rise of secondary voltage. The induction coil will be fitted with a specially rapid make and break, giving a maximum of about 100 pulsations per second.

It is preferable to join choke coils in the leads connecting the secondary of the induction coil to the oscillating circuit. These are coils having such inductance values that they prevent the high frequency oscillating discharge currents from flowing back into the secondary of the induction coil, where they might cause such great potential strains as would damage the insulation. The choke coils do not appreciably stop the currents which flow from the induction coil secondary to charge the oscillating circuit.

Choke coils for this purpose can be made by winding a single layer of copper wire (No. 20 to 40, according to the current to be carried) on flanged and glazed porcelain cylinders, three inches diameter and about four inches long.

If such a coil has an inductance of L henrys the reactance it offers to a current oscillating, or alternating, at a frequency of f cycles per second is $2\pi f L$ ohms. Since the oscillating discharges in the closed circuit have a frequency of $\frac{3 \times 10^8}{\lambda}$

($f = 1{,}000{,}000$ when $\lambda = 300$ metres) it is easily seen that the reactance of the choke coils ensures that the oscillating currents will stay in the closed circuit, and cannot stray into the secondary of the induction coil. The frequency of the current which flows from the induction coil to the closed circuit is only 100 to 200, depending on the rapidity of the make and break, hence to these pulsating currents the choke coils offer little reactance. For small equipments the reactance of the induction coil secondary is relied upon to choke back the oscillating currents, but the end turns of the secondary are then subjected to undue potential strains and the use of auxiliary choke coils is to be preferred.

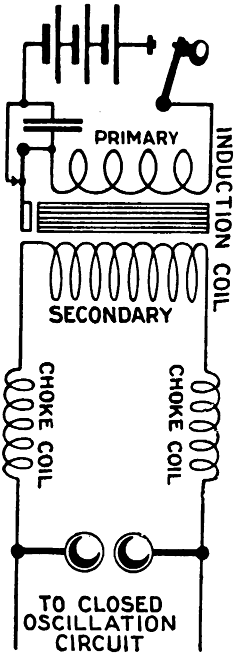


Fig. 86.

The complete generating circuit will be as shown diagrammatically in Fig. 86.

When a transmitter has to employ more than 300 watts of primary energy an alternating generator and step-up transformer take the place of the induction coil. The alternator generates 80–200 volts at a frequency of 100–500 cycles per second; the generated voltage is then transformed up to a suitable value for charging the condenser of the oscillating circuit. The Morse or other transmitting key will be joined in one of the leads from the alternator to the primary coil of the transformer. In this low voltage circuit it is usual to include an ordinary inductance, or choking coil, so that resonance effects may be obtained, the coil consisting of a number of turns of insulated copper wire wound on a laminated iron core. The wire must be of sufficient cross section to carry the current flowing through it from the alternator to the primary of the transformer. It has been already explained that an alternating current flowing in a capacity circuit leads the volts in phase, therefore the current flowing from the secondary coil of the transformer into the condenser of the oscillating circuit tends to be 90 degrees before the secondary volts. This current would be counterbalanced, as it were, by an equivalent current flowing into the transformer primary from the alternator, its phase leading that of the alternator's voltage. With given values of current and voltage the energy delivered from the alternator will be a maximum if the current and volts are in phase. In Chapter VIII: it has been shown that capacity reactance may be balanced by induction reactance. Therefore if a coil of suitable inductance is connected in the alternator, or primary, circuit and makes $2\pi f L = \frac{1}{2\pi f K}$, the current will be a maximum and in phase with the volts.

When resonance is set up the voltage across the condenser can build up to a much higher value than would otherwise be the case; in fact, it is now only limited by the spark gap length. *If we use resonance effects we may only get one discharge, or spark, for every* 3 *or* 4 *cycles of primary voltage,* as these may be required to build up the secondary voltage. This effect is not often used.

The inductance coil in the low voltage circuit has generally got several tappings so that the inductance can be chosen of a suitable value to give resonance. A state of resonance may finally be obtained by adjusting the speed of the alternator, and therefore the value of the frequency f. However, in practice, the value of f and the speed of the alternator are generally decided by other considerations, such as spark note. Choke coils are connected in the leads from the transformer secondary to the oscillatory circuit to guard the secondary from undue potential strains; their construction and action being similar to those already described in connection with the use of a spark, or induction, coil. As a further precaution against oscillatory effects in the alternator it is usual to shunt its terminals with a non-inductive shunt, such as a graphite resistance or a carbon filament lamp; oscillatory impulses of voltage will expend themselves in these resistances rather than through the inductive windings of the machine.

The alternator may be driven by a steam, gas, or oil engine, or by an electric motor. If it is a motor drive the speed of the alternator can be raised by putting resistance in the field circuit of the motor, and it may be decreased by lowering the resistance in the motor's field; the motor is therefore provided with a field rheostat. Thus the frequency of the alternator can be adjusted to the spark rate desired; if the sparking frequency is a synchronous one it will be twice the alternator frequency.

Now the voltage of the alternator also depends on the speed of rotation of the armature, and it may be desirable to change the speed or frequency without changing the voltage. If V = volts generated, M = magnetic lines per pole, Z = wires in series on the armature, f = frequency, then $V = \frac{2 \cdot 22MZf}{10^8}$. We see that the voltage can be changed by varying the strength of the magnetic field (M), and this can be accomplished by changing the field current flowing in the coils on the poles. Thus a field rheostat is joined in series with the field coils of the alternator; by changing the resistance of this the generated volts can be adjusted to the desired value. Our complete high voltage generating circuit will then be as shown in the diagram in Fig. 87.

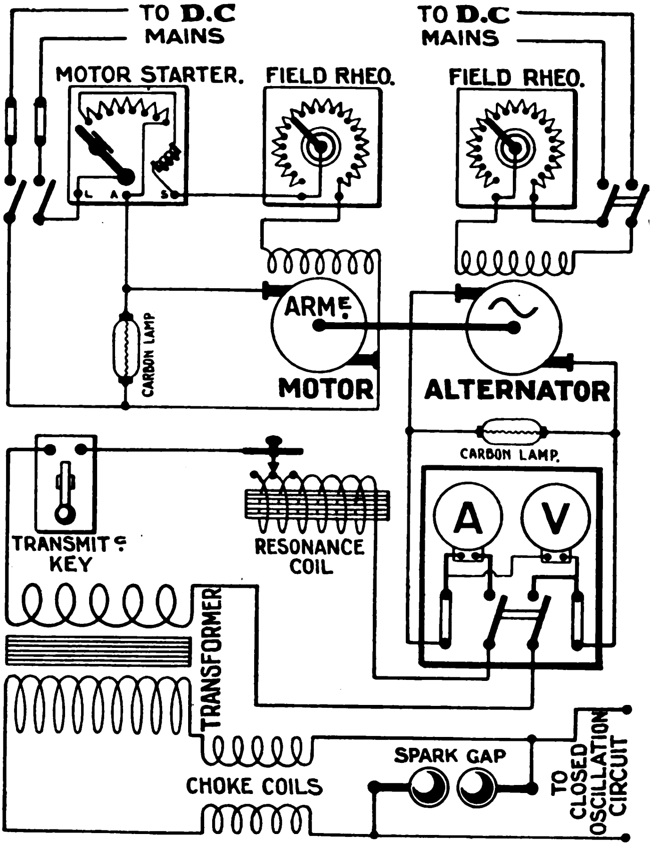


Fig. 87.

If a public alternating current supply is available, as in many parts of the United States and Canada, an alternator is not required; the high voltage step-up transformer is then directly connected to the supply mains, choke coils being joined in series with the leads to the primary coil. An adjustable iron core inductance coil should also be joined in series with the primary to bring the current into phase with the volts and thus give resonance. In this case the frequency, and hence the spark rate, cannot be adjusted. As the frequency of the public alternating supply in North America is never more than 125 the spark rate will not be high enough to give a good musical note.

The closed oscillatory circuit consists of a condenser, a few turns of inductance, and a spark gap or other form of discharger. The values of capacity and inductance in this circuit are chosen so that the oscillatory discharges will take place at a desired frequency—

$$f = \left(\frac{5 \times 10^6}{\sqrt{L_{\text{cms.}} K_{\text{mfds.}}}} \text{ approx.} \right)$$

corresponding to a radiation wave length

$$\lambda_{\text{metres}} = 60\sqrt{L_{\text{cms.}} K_{\text{mfds.}}} \text{ approx.}$$

This closed, or oscillatory, circuit is coupled to an aerial radiating circuit, the coupling being by direct connection when the energy applied to the transmitter is not more than about 30 watts: with larger energies the circuits will be coupled inductively by means of an auto-transformer or a jigger transformer. The coupling of these circuits has been dealt with in a preceding Chapter, and it was there shown that the two circuits should be arranged to have similar oscillation constants; *i.e.* $L_1K_1 = L_2K_2$.

The Aerial, open, or radiating, Circuit consists of an aerial of definite capacity, a coupling coil and generally a tuning coil which together provide inductance effect, a hot-wire ammeter to register the current oscillating in this circuit, and a balancing capacity which may be a system of wires not in contact with the earth, as in the Lodge system, or the earth surface itself. All these are connected in series with each other to form the circuit. The capacity (K_2) in the aerial circuit is generally much less than that in the closed circuit (K_1), hence the inductance (L_2) in the aerial circuit must be greater than that in the closed circuit. Up to a certain point this can be arranged by having more turns in the secondary than in the primary of the oscillation transformer, or "jigger." This ratio of secondary to primary turns qualifies the degree of coupling, hence with a certain number of primary turns, which is fixed for a given wave length, we are limited in the number of secondary turns it is desirable to employ. Therefore further increase of inductance in the aerial circuit must be made by a coil quite distinct from the oscillation transformer. This is called the aerial tuning coil; it is usually connected in series between the secondary of the oscillation transformer and the aerial. Its inductance may be varied, either by having adjustable connections on its coils (Marconi), or by mounting its coils so that they can be displaced relatively to each other (Telefunken). The aerial itself will consist of one or more wires, and the capacity in this circuit will be that of the aerial relative to the earth or lower balancing system. The inductance L_2 consists of three parts: that of the aerial itself, that of the aerial tuning coil, and that of the secondary of the oscillation transformer.

The fundamental, or natural, wave length of the aerial is that given by its own capacity and inductance, and if the aerial could be so arranged that its *natural wave length is that at which radiation is desired it would then be most efficient as a radiator.* Of course we must couple it to the closed circuit, which means the addition of artificial inductance, but the point to note is that the aerial will radiate most efficiently if it is of such a size that a loading inductance is not necessary.

In general it is not possible, owing to limitations of space, to make the aerial large enough to give the desired wave length: hence inductance coils must be added. By the use of inductance coils it is not practicable to increase the wave length to more than 4·5 times the natural aerial wave length without seriously decreasing the radiation efficiency.

The strength of the current which will oscillate in an aerial will depend upon its capacity, *i.e.* on its length, height, and number of wires; the energy radiated from it will depend on the square of its height and on the strength of the current oscillating in it. To load an aerial up with inductance is certainly increasing its wave length but not increasing its radiation factor, and we must note that the resistance increases with the number of turns in the loading coil; beyond a certain value this increase of resistance without increase of capacity or height means a loss of efficiency.

Thus it is important that the natural wave length of an aerial should be at least approximately known, and should not be too small compared with the wave length on which it is desired to transmit. The natural wave length of an aerial can be increased by increasing its length, so increasing both its capacity and inductance, or by using wires in parallel not too close to each other, thus increasing its capacity. This will be dealt with more fully in a later Chapter.

It may sometimes happen, especially with amateur stations, that the natural wave length of the aerial is longer than that on which it is desired to transmit. The aerial may be designed to receive on long wave lengths, but the Post Office licence may debar transmission on any but comparatively short wave lengths. For this case a condenser should be connected in series with the aerial for transmission; this will reduce the capacity and therefore the radiated wave length. It will be remembered that the capacity of two condensers in series (such as an aerial and a plate condenser) is less than that of the smaller. The condenser should be connected in the earth lead and should be provided with a short-circuiting switch so that it can be cut out of action when reception on long wave lengths is taking place. Thus passenger ships work on 600 metre wave lengths and smaller cargo vessels on 300 metres; the Marconi Company supply a condenser with their installations which can be switched into series with the aerial, so that a passenger ship can communicate with a cargo one on the shorter wave length by a simple and quick change of the ordinary tuning arrangements.

A point to remember is that a transmission condenser with strong dielectric between its plates, and connected in series with the aerial, effectively insulates the latter from the earth, so that the whole aerial circuit may become statically charged by atmospheric electricity. This is one disadvantage of the use of a series condenser, though it can be obviated by closing the short-circuiting switch across the condenser when transmission is not taking place, or when there is danger from storms. Another disadvantage is that the radiation is not efficient, because that part of the ether strain effect set up in the series condenser by the aerial oscillating currents does not contribute to radiation. The method adopted by the Marconi Company for shortening the radiation wave length is described and illustrated in Chapter XIV.

The aerial circuit should always include a hot wire ammeter by means of which the maximum value of the oscillating current can be measured. The current will be zero at the far end of the aerial and a maximum at the earthed end, hence the ammeter should be connected between the secondary of the coupling transformer and the earth connection. The readings on this ammeter provide a method of determining proper tuning, coupling, and spark gap adjustments.

The aerial circuit will also include a long-break highly insulated switch, by means of which the circuit can be connected either to the transmitter apparatus or to the receiver apparatus. In Marconi equipments this switch is often replaced by an earth arrester which consists of two heavy metal plates separated by a thin washer of mica. The oscillating currents in the aerial at transmission can easily spark across the small space between the plates, but the tiny currents set up in the aerial at reception cannot pass across the space and will go through the receiver circuits which are connected across the plates. The receiver may be connected to the plates of the arrester through a switch which can be opened when transmission is taking place. If it is kept closed it enables the operators at each end to break in, as in the case of a telephone conversation, but this is only possible with receivers which are fitted with robust detectors.

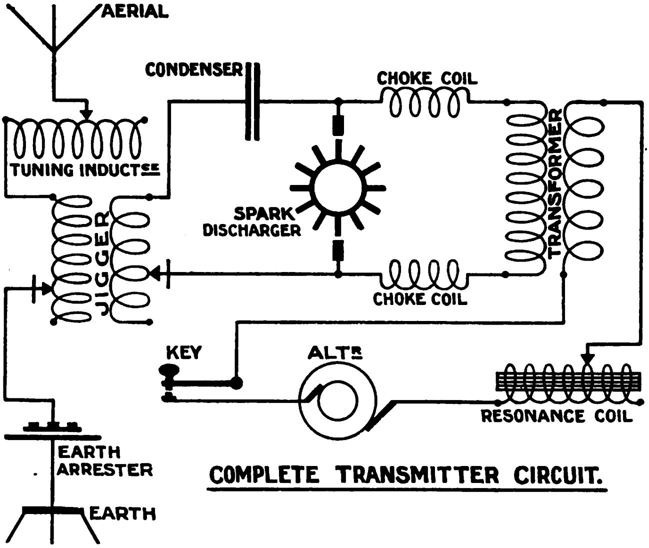


Fig. 88.

Fig. 88 shows a typical transmitter circuit, in which, however, the aerial ammeter has been omitted—it would be connected between the earth arrester and the jigger secondary, and may be provided with a short-circuiting switch.

Let us now consider the actual conditions of oscillating energy in the primary and aerial circuits. The simplest method is by means of an example; let us assume that the transmission wave length is 600 metres, then—

$$n = \frac{v}{\lambda} = \frac{300,000,000}{600} = 500,000$$

or the time of one oscillation is $\frac{1}{500000}$ second.

If there are 10 oscillations of energy in the primary circuit at each spark then the duration of a spark is $\frac{1}{50000}$ second.

The make and break of an induction coil will vibrate at, say, 100 times per second, and usually a spark does not take place at each break of the primary current; however, let us assume that there are 100 sparks per second, so that one spark is obtained in each $\frac{1}{100}$ second.

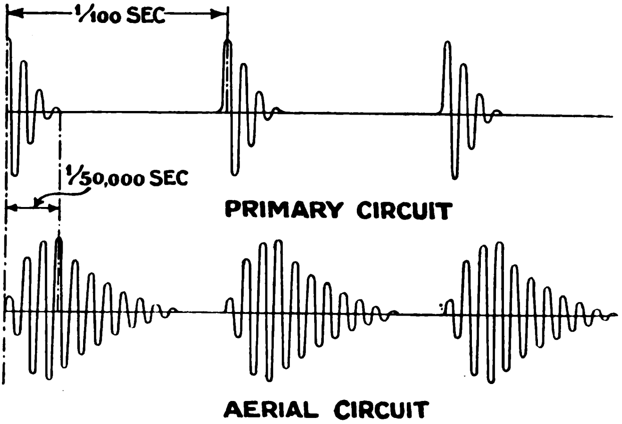


FIG. 89.

Under these circumstances the oscillating currents of the primary circuit are shown in Fig. 89. We see that, while a spark is obtained in each $\frac{1}{100}$ second, the spark itself only lasts $\frac{1}{50000}$ second; during a considerable portion of the complete time of transmission there is no oscillation of energy.

If an alternator and step-up transformer is used, the frequency will not be lower than 200 cycles per second, giving 400 sparks per second, or a spark in each $\frac{1}{400}$ second. In this case energy will be oscillated four times as often as is shown above; at the same time the difference between $\frac{1}{50000}$ second, which is the duration of a spark, and $\frac{1}{400}$ second, the interval between sparks, is still very great.

Now let the closed, or primary, circuit be coupled to an aerial circuit with not more than 7 per cent. degree of coupling; close enough to cause the transference of about 30 per cent. of the energy to the aerial circuit, but loose enough to avoid much damping effect in the latter owing to re-transfer of energy. Oscillations are then set up in the aerial circuit; these are slightly damped, chiefly on account of radiation of energy to the ether at each oscillation. If the radiation of energy is fairly slow, *i.e.* if it radiates only a comparatively small amount of energy at each oscillation, then, with proper coupling and a suitable spark gap, damping of the aerial oscillations will be small. Energy will continue to oscillate in the aerial, at each spark, after the corresponding oscillations have ceased in the closed circuit. This is shown in Fig. 68. In Chapter XVI. it will be shown that slow radiation, and a slightly damped aerial, can be obtained by using a suitable design—such as the umbrella type; but even with an L or T aerial the oscillations in the aerial circuit will continue after the spark is over, provided a suitable design of spark gap and suitable coupling conditions are employed.

Yet even in the aerial circuit, when transmission is taking place, there are comparatively long intervals between successive trains of oscillations. At first sight it might appear as if these intermittent trains of oscillations should cause irregularity in the sending of dot and dash signals; a little consideration will remove this idea.

If the rate of signalling is, say, 20 words of 5 letters each per minute, that is 100 letters in 60 seconds or $\frac{6}{10}$ second per letter. Let the letter consist of four dashes separated by four intervals of equal duration; this would give us $\frac{6}{80}$ second per dash. Then 100 sparks or oscillation trains per second will give nearly 8 trains of oscillations to each dash; thus each signal sets up a great many oscillations in the aerial circuit and sends out a great many ether waves to act on the distant receiver.

With an ordinary spark gap in the closed circuit it is probable that the degree of coupling, required to transfer a sufficient amount of energy to the aerial circuit, will not prevent some of this energy from being transferred back to the closed circuit, with consequent damping of the aerial oscillations. But when a Marconi rotary spark or a Telefunken quenched spark is used this re-transfer of energy does not take place, and the aerial currents are thus free to oscillate without much damping. Also in the Marconi and Telefunken Systems the spark frequency is very high, giving what is called a "musical note." The Telefunken System spark frequency is often 1000 (alternator generating frequency 500); also the oscillations in the closed circuit are rapidly damped out so that only about 5 oscillations of energy take place at each spark. Let us consider these conditions for a 600 metre wave length. The time of oscillation is $\frac{1}{500000}$ second, therefore each spark of 5 oscillations takes $\frac{1}{100000}$ second while the interval between sparks is only $\frac{1}{1000}$ second; thus we obtain 50 oscillations in $\frac{1}{100}$ second. In the example of Fig. 89 we had only 10 oscillations in each $\frac{1}{100}$ second. Thus with high sparking frequency we increase the oscillations of energy in the closed circuit at each signal, and when the aerial currents are oscillating freely without much damping the effect is still more magnified. Instead of what might be called spasmodic oscillations we have now persistent oscillations: these may have a smaller amplitude than before but since they are more numerous the total energy radiated to the ether is increased. This has been already shown in Fig. 68.

It follows that with less energy applied to the primary circuit, (less watts delivered from the battery or alternator), the use of a rotary or of a quenched spark may increase the radiation of energy —not only that, but owing to the small aerial damping the energy is radiated at a more closely defined wave length, therefore will have more effect on a receiver tuned to that wave length.

Transmitter Calculations.—*Primary Energy.*—For small sets where the source of primary energy is a battery the watts applied equal VC—the product of the voltage of the battery and the current that flows from it. Of this energy applied to the spark coil only about half is available for the closed circuit since the efficiency of a spark coil is never much over 50 per cent.

On larger transmitters fitted with alternators and transformers the primary energy from the alternator is VC cos ϕ watts, where V and C are the effective volts and effective current of the machine and cos ϕ is the power factor. Even with resonance effects this power factor will not be likely to exceed 0·9, and in ordinary practice it is doubtful if its value exceeds 0·8 unless the resonance adjustments have been carefully carried out.

To obtain the power of the motor or engine which drives the alternator it is necessary to allow for the generator and engine efficiencies, also for the fact that the speed must not change when the load is put on by the key.

The efficiency of a transformer is very high and can be taken as 90 per cent. for a 5 KW. unit to 95 per cent. for a 100 KW. unit.

Closed Circuit.—Let us fix the wave length (λ), and therefore the oscillation frequency (*f*); and suppose that the decrement of damping (δ) is known. With a spark coil the effective voltage (V_1) of the secondary charges up the condenser $K_{1\,\text{mfds.}}$ and the energy in each charge is $\frac{1}{2}\frac{K_1V_1^2}{10^6}$ joules.

This is the energy of each discharge and if there are *s* discharges or sparks per second the power in the closed circuit is $\frac{1}{2}\frac{K_1V_1^2 \times s}{10^6}$ watts. Thus if $K_1 = 0{\cdot}002$ mfd., $V_1 = 20{,}000$, and $s = 100$, the watts oscillating in the closed circuit—

$$= \frac{0{\cdot}002 \times 20{,}000 \times 20{,}000 \times 100}{2 \times 1{,}000{,}000} = 40 \text{ watts} = 0{\cdot}04 \text{ KW.}$$

V_1 is not the voltage at the spark coil secondary on open circuit; its value can be approximately determined by the length of the spark gap.

With an alternator and transformer the voltage from the secondary of the transformer is got by the relation: $\frac{V_s}{V_p} = \frac{T_s}{T_p}$. Assuming the power applied to the transformer to be $W_1 = 0{\cdot}8VC$, and that the transformer has an efficiency of 90 per cent., then the power from the transformer on full load is—

$$W_2 = \frac{90}{100} \times 0{\cdot}8VC$$

The effective current flowing from the secondary of the transformer to the closed circuit $C_s = \frac{W_2}{0{\cdot}8V_s}$ amps., where 0·8 is the power factor. If the transformer circuits are tuned to be practically in resonance at the supply frequency, and the spark is synchronous it can be proved that the voltage to which the condenser is charged $= \frac{\pi}{2}V_{s\,\text{max.}} = \frac{\pi}{2} \times \sqrt{2} \times V_s = 2{\cdot}2V_s$ approx. With rotary spark gaps the resistance effects will reduce this to about $1{\cdot}5V_s$.; with fixed spark gaps it may be still less if the gap is set too short.

Let us call this condenser voltage $V_{1\,\text{max.}}$, then the energy of each discharge is $\frac{1}{2}\frac{K_{1\,mfd.}\times V_1{}^2{}_{max.}}{10^6}$ joules, and the power in the closed circuit discharge is $\frac{1}{2}\frac{K_{1\,mfd.}\times V_1{}^2{}_{max.}}{10^6}\times s$ watts. In most cases the spark will be a synchronous one, since it is desirable to have a high or musical note, so that the sparking rate, *s*, is twice the frequency of the alternator. If the capacity of the closed circuit (K_1) and the wave length (λ) are fixed the inductance (L_1) of the closed circuit can be calculated; it is then easy to get approximately the maximum and effective values of the discharge current (C_1).

Let the voltage applied to the closed circuit condenser be $V_{1\,max.}$, then approximately—

$$\tfrac{1}{2}K_1V_1{}^2{}_{max.} = \tfrac{1}{2}L_1C_1{}^2{}_{max.}$$

$$\therefore C_1{}^2{}_{max.} = \frac{K_1}{L_1}V_1{}^2{}_{max.}$$

$K_1 = \frac{2\times 10^6 \times \text{watts}}{5V^2}$; its value is therefore determined by the permissible voltage in the closed circuit; *for a given amount of power to be handled the smaller the condenser the higher the voltage, and vice versa.* Suppose the sparking rate is 500 and that 5 KW.s of energy is being oscillated in the closed circuit. With a condenser of 0·02 mfd. we have—

$$5000 = \tfrac{1}{2}\times\frac{0{\cdot}02\times V_1{}^2{}_{max.}\times 500}{10^6}$$

from which $V_{1\ max.}$ is 31,600 approx. and the voltage of the secondary of the transformer is 31,000 ÷ 1·5 = 21,000 volts. If K is only 0·006 mfd. $V_{1\ max.}$ will be 57,700, and the secondary voltage of the transformer will be 38,400 approx. Thus the size of the closed circuit condenser will depend upon the permissible step-up ratio of the transformer and insulation effects; also it must be remembered that a large condenser means a large current, therefore increasing the size of spark gap electrodes, or sections, and the surface area of the closed circuit inductance.

In the Marconi ¼ KW. Set the transformer secondary effective volts is 5700; in other Marconi Sets it varies generally from 10,000 to 20,000 volts depending on the wave length (see Chap. XVI. for change of wave length adjustments). In portable stations it is usual to work with comparatively large capacity and low voltage. At the Arlington Station, U.S.A., the 100 KW. Fessenden transmitter has a closed circuit condenser capacity of 0·252 mfd., and a transformer secondary voltage of 25,000; at the Sayville Telefunken 40 KW. station the values are 0·044 mfd. and 60,000 volts; at the Eiffel Tower 60 KW. transmitter the closed circuit capacity is 0·7 mfd. In a 5 KW. Telefunken Set 12,500 volts at the secondary transformer terminals is standard practice.

Assuming that δ is very small compared to π the effective current in the closed circuit is obtained from the formula :—

$$C_{1\,\text{eff.}} = C_{1\,\text{max.}} \times \sqrt{\frac{s}{4f\delta}}$$

Note that $f\delta$ is the damping factor.

Thus suppose we are transmitting on 1200 metres wave length with $K_1 = 0{\cdot}02$ mfd., then $L_1 = 20{,}000$ cms. and $f = 250{,}000$. If the effective voltage from the transformer secondary is 12,000, the condenser voltage $= 1{\cdot}5 \times 12{,}000 = 18{,}000$.

Then $$C^2_{\text{max.}} = \frac{0{\cdot}02 \times 10^9}{10^6 \times 20{,}000} \times (18{,}200)^2$$

$$\therefore C_{\text{max.}} = 570 \text{ amps.}$$

Let $s = 500$ and $\delta = 0{\cdot}4$, then—

$$C_{\text{eff.}} = 570 \sqrt{\frac{500}{4 \times 250{,}000 \times 0{\cdot}4}} = 21 \text{ amps.}$$

It can be seen from the above that if the maximum and effective values of current in the closed oscillatory circuit are known or calculated it is possible to get a first approximation of the value of the decrement δ. A method of measuring the decrement will be given in a later Chapter.

From the decrement we can determine by Dr. Fleming's formula, given in Chapter IX., the number of oscillations in a train; thus if the decrement is 0·6 there will only be five or six oscillations per spark and the circuit is highly damped.

Aerial Circuit.—The aerial circuit will be coupled to the closed circuit with a degree of coupling of about 7 per cent., and certainly not more than 10 per cent. when an ordinary spark gap is employed. If a quenched spark gap is used the coupling may be over 20 per cent. without risk of retransfer of energy, but in practice it will be generally lower than this value.

The percentage of energy transferred from the closed to the aerial circuit will not be greater than about 75 per cent. with large transmitters using up to 100 KW.s of primary energy, and for small transmitters it will be very much less.

Now let the current at the base of the aerial as read on a hot-wire ammeter be C_2 amperes; this is the effective or root mean square current at the base, and the maximum value of the base current $C_{2\,\text{max.}} = \sqrt{2}C_2$.

Let V_2 be the maximum value of the voltage strain at the top or free end of the aerial; this will build up and will not be a maximum during the first oscillation. If K_2 is the capacity of the aerial and if the maximum voltage occurs in it when 50 per cent. of the closed circuit energy has passed to the aerial circuit we then have—

$$\tfrac{1}{2}K_2V_2^2 = \frac{50}{100} \times \tfrac{1}{2}K_1V_1^2 \text{ or } V_2^2 = \frac{K_1V_1^2}{2K_2}$$

Thus if the closed circuit condenser has a capacity of 0·02 mfd. and it is charged to 20,000 volts an aerial capacity of 0·000625 mfd. will experience a voltage strain of 80,000 volts; if the aerial capacity is 0·0025 mfd. the voltage strain will be only 40,000 volts, and the aerial energy ($\frac{1}{2}sK_2V_2^2$) is not changed. This means that *with the larger aerial capacity the primary energy can be reduced for the same radiation of energy and with less insulation strain on the aerial.*

Therefore the greater the aerial capacity the less the maximum voltage, and the less will be the power required for transmitting. We can increase the aerial capacity by increasing the number of wires in parallel in the aerial, or by increasing its length; these methods are, however, limited by considerations of cost of construction and space.

We might increase the aerial capacity, and obtain an increased aerial current, by lowering the aerial and bringing it nearer the ground plate but this would actually decrease the amount of energy radiated, notwithstanding the increased current in the aerial, for the radiation of energy is directly proportional to the square of the height of the aerial.

The radiation of energy from an aerial is given by the formula:—

$$\text{Watts radiated } W = x\frac{h^2}{\lambda^2}C_2^2$$

where h is the height of the aerial and λ the wave length measured in the same units, C_2 the effective current read on a hot wire ammeter inserted in the aerial close to the earth connection, and x is a constant depending on the design of the aerial. For a plain vertical aerial $x = 640$, for a L or T type aerial whose vertical part is of height h, such that most of the capacity is in the top limb and the current is approximately uniform in all parts of the vertical limb, $x = 1600$; for an umbrella aerial x is about 1590. The effective height h is not the actual height, but this will be further dealt with in Chapter XV.

The watts radiated are equal to the square of the effective aerial current multiplied by the *radiation resistance*, but $W = x\frac{h^2}{\lambda^2}C_2{}^2$; thus we see that the *radiation resistance* $= x\frac{h^2}{\lambda^2}$ ohms, where $x = 1600$ for the usual L or T type aerials.

A Telefunken transmitter of the 5 T.K. standard type, which has 5 KW.s of energy in the aerial, would have a 10 KW. alternator driven by a 25–28 H.P. engine; this gives us an idea of the efficiency and losses between the generator and the aerial. Another example of transmitter calculation is given in Chapter XV.

QUESTIONS AND EXERCISES.

1. Do low frequency ether waves travel at the same speed as high frequency ones ?
2. Does the spark frequency affect the wave length ? What is the difference between spark frequency and oscillation frequency ?
3. What are the advantages of a high spark frequency ?
4. A transmitter is supplied with alternating current at 200 cycles frequency through a transformer whose secondary terminal potential is 20,000 volts. If the condenser in the closed circuit has a capacity of 0·0074 mfd. what is the oscillating energy in the closed circuit when the transformer circuits are tuned to be nearly in resonance ?
5. What is the disadvantage of having a condenser in series with a transmitter aerial to shorten the wave length of radiation ?
6. A wireless operator is always required to transmit with minimum effective power in the aerial. What are the methods of reducing aerial energy ?
7. How does an open oscillating circuit differ from a closed one ? What advantages are gained by coupling an open circuit to a closed one to form a transmitter ?
8. What is meant by a "resonance state" in the alternator and transformer circuit of a transmitter ? What are its advantages and disadvantages ?
9. Why should the aerial hot wire ammeter be connected into the circuit near the earth connection ?
10. If the synchronous spark frequency of a transmitter is 500 and it is supplied with energy from a 16-pole alternator at what speed does the alternator run ?
11. How is a state of resonance effected in the low frequency circuit of a transmitter ?
12. Discuss the limitations of using a short aerial to radiate on a long wave length, and of using a long aerial to radiate on a short wave length ?
13. An L-type aerial is 60 ft. high and the aerial ammeter reads 5 amps. If the transmission wave length is 600 metres what is the approximate amount of energy radiated ?

CHAPTER XIV

TRANSMITTING APPARATUS

Having dealt with the theoretical considerations under which transmission is carried out, a description of some of the apparatus used in transmitting circuits will now be given.

For small stations, or as a stand by to larger outfits on ships, the source of high voltage for charging the primary circuit consists of an induction coil and battery—the design of such coil has already been described.

In places where alternating current supply is available, as in many American towns, an ordinary step-up transformer can be used; its secondary delivering current at say 10,000 to 20,000 volts, and at the frequency of supply, 50 to 125 cycles per second. Nothing more than this is needed to charge the primary circuit condensers and give the spark. The secondary coil must be well insulated owing to its high voltage, and should be specially well insulated from the primary winding. Such transformers, made by the Clapp Eastham Co. of Cambridge, Mass., cost £3 for ¼ KW. size, £4 10*s*. for ½ size, and £7 10*s*. for 1 KW. size (1914). Choke coils should be connected in the leads from the transformer secondary as described in the previous chapter.

In all ship stations of ½ KW. size and over, and in all large commercial stations, an alternating generator is connected to a step-up transformer to provide the primary high voltage energy.

The generator of a Marconi portable outfit is driven by a petrol engine, and the armature of the generator has a commutator at one end through which the machine supplies direct current; this is used in the exciting coils on the pole pieces, also for charging the small batteries required in connection with the receiving circuit. To the generator shaft is also connected the rotary disc discharger used by the Marconi Co. as a sparking arrangement. Such a Marconi generating unit is shown in Fig. 90. The Telefunken Co. also use alternators and transformers to supply energy to their larger transmitting outfits; the alternators having a frequency of 500 cycles per second, which gives high rate of sparking, and therefore a musical note with the quenched spark gap employed by them. The frequency of the generator can be changed by varying its speed, and in this way the pitch of the spark note can be raised or lowered. Reactance may be employed so that the voltage builds up to give a spark only at every third or fourth cycle; this, however, is not usual as it is desirable to have a fairly high spark frequency giving a musical note; thus the reactance is only employed to improve the power factor and ensure that sparking takes place when the generator current is small.

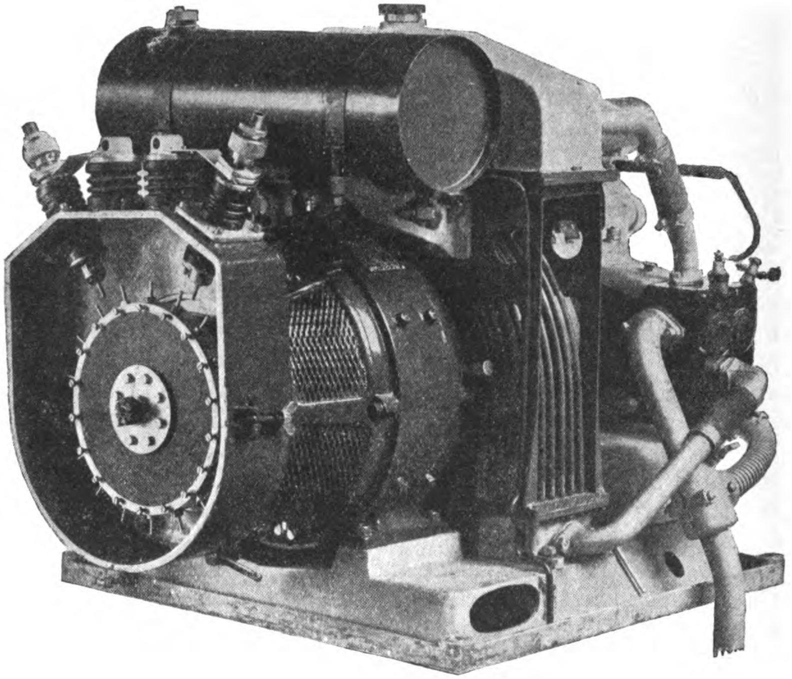


Fig. 90.

Where alternators are used it is important that the motor or engine which drives it should do so at absolutely constant speed in order that the frequency should not vary. For this reason the driving motor or engine should be rated to have an ample margin of power, so that the load put on it every time the transmitting key is depressed will not affect its speed.

A direct current motor requires to have a resistance in series with its armature at starting up because the armature has a low resistance, generally less than an ohm; thus if it were switched directly on to, say, 220 volts, the current which would flow into it would be so excessive as to either blow the fuses or damage the motor. The field coils of the motor are, however, switched directly on to the mains, as they have a high resistance and take only a small current. When the motor armature gets up speed there is induced in it an E.M.F., exactly as if it were a generator, but this E.M.F. opposes the entering current; *i.e.* acts in opposition to the applied E.M.F. Thus the current is cut down as the motor speed rises, and the resistance in series with the armature can now be cut out as it is no longer necessary. This resistance is therefore a variable one, known as the starting rheostat, or simply —the starter. Again if the current round the pole pieces of the motor is weakened, by inserting a resistance in series with the field coils, the number of magnetic lines crossing the armature will be decreased; that is to say the field is weakened, and this has the effect of making the motor run faster. Similarly if the field is strengthened by increasing the field current the speed of the motor is reduced. Thus a variable resistance called the field rheostat is always connected in series with the field coils, and by means of it the speed of the motor can be varied.

The equipment of a driving motor will therefore consist of a double pole switch and double pole fuse to connect it to the mains, a field rheostat in series with its field coils, and a starting rheostat in series with its armature. An ammeter may be joined in series with the mains and a voltmeter across them, in order that the current and voltage supplied to the motor may be known. To start up the motor the double pole switch is first closed, then the starter handle is pulled over on to the first or second contact and the motor starts. If it starts, not otherwise, the starting handle should be pulled quietly over, reducing the resistance until all is cut out and the handle is held over by the attraction of an electro-magnet through which the current going to the field coils is flowing. Then the speed can be adjusted by means of the field rheostat. A diagram of motor connections is shown in Fig. 87. Generally a tubular form of carbon filament lamp or a graphite resistance is joined across the motor terminals; any oscillations of potential which may be set up in the circuit, by the inductive action of the oscillating discharges in the transmitter circuits, are absorbed by this lamp or graphite resistance, and thus will not affect the motor.

Spark Gap.—The design of the spark gap, or gaps, is of supreme importance, and much of the rapid development of radio-telegraphy has been due to a proper appreciation of this fact by Signor Marconi, Prof. Wein, Dr. Fleming, and other pioneers.

Electricity always tends to discharge from or to points, a fact applied commercially in the pointed ends of lightning conductors; when, however, a circuit has to be charged up to a high potential before a discharge takes place points must be avoided, hence spark gaps were originally made with two spherical electrodes of polished conducting metal.

For small radio-transmitters the spark gap consists of two electrodes, generally of zinc which is better than brass or copper. These are mounted on ebonite insulating supports and have rounded edges to the sparking surface, sometimes broadening out into circular plates with rounded edges at the back—these plates are called radiation fins, because they serve to radiate away the heat caused by the spark discharge. The sparking surfaces of these electrodes become pitted and blackened by the discharge, and in the case of heavy discharges are worn away rapidly; they must be kept well polished and clean, otherwise the spark will not be a good one.

The distance between the spark electrodes must be very carefully adjusted; if the spark is too long it acts as a considerable resistance in the discharging circuit, and this causes great damping of the oscillations. If the spark gap is too short it either causes arcing to take place, which is simply a direct discharge without oscillations, or the condenser discharges across it before it has been charged up to the full voltage, with the full available amount of energy, so that the oscillations are unnecessarily weak.

The first oscillation of discharge ionises the air in the spark gap which makes it a better conductor; in other words the resistance of the air is broken down, hence there is a tendency for a direct, or arcing, discharge to take place continuously across the gap.

In the early days of radio-telegraphy this tendency was combated by putting the spark gap in compressed air or in vaseline oil, but these methods are now discarded. In 1912

Dr. W. H. Eccles, London, described experiments carried out by him, in which he had passed heavy discharges across spark gaps immersed in running liquids, such as oil, or even water, without any tendency to arcing. No commercial development on these lines has yet taken place.

If we put an open sparking device in the same room as the receiving apparatus the noise made by the spark will lessen the operator's acuteness of hearing for the faint signals he picks up in the receiver telephones; possibly also the signals transmitted by the sparks might be overheard. Therefore it is enclosed in a sound-proof box of heavy wood, well padded, though the front may have a glass window through which the operator may see that the sparks are passing properly.

The discharges combine some of the oxygen and nitrogen of the air into nitrous and nitric acids, which would deteriorate the insulating supports of the electrodes; thus these acid fumes must be got rid of, either by putting some quicklime in the box to absorb them, or by a fan arrangement which will carry off the vitiated air. At least one, if not both, the spark electrodes should be fitted with handles of insulating material by means of which the spark gap can be adjusted; when properly adjusted a good spark should give a sharp, crackling sound, and be of an intense bluish-white colour; an arcing spark will be more yellow in colour, and without what might be called viciousness.

Fig. 91 shows the spark gap used by the Marconi Co. on small outfits. The spark electrodes are of zinc, hemispherical in shape, mounted in a padded case through which the terminal rods pass in ebonite tubes, the distance between the electrodes being varied by rotating them. Below the main electrodes are seen two point electrodes, fixed at a constant distance apart which is somewhat greater than the usual working position of the main electrodes. This gap protects the condenser and other apparatus from injury due to excessive voltages, which would be set up if the operator, by inadvertence, left the main electrodes too far apart and started to work the circuit. The condensers might then be raised to such a high voltage that their dielectric would be pierced by a discharge, or the insulation of some other portion of the circuit broken down: the auxiliary point electrodes act as a safety valve to guard against these risks.

When it is desired to raise the closed circuit to a high potential before a discharge takes place it is better to use two or more short spark gaps in series rather than have one long spark gap.

As long distance transmission developed, with consequent increasing amounts of energy to be oscillated, as discharges, in the closed circuit, it became more and more difficult to operate these heavy discharges efficiently across the ordinary design of spark gap. Arcing took place or the insulation of the apparatus broke down; it became necessary to design some better form of discharger. Thus we find that an early development was to have one electrode in the form of a disc, rotated rapidly in front of the other electrode; by this arrangement a new surface was exposed to the discharge at each oscillation of current, preventing arcing and providing a fan effect to dissipate the vitiated air. Dr. Fleming designed an arrangement of this sort when the Marconi Co., transmitting across the Atlantic in 1901, found that ordinary spark dischargers would not handle the great energy (20 to 80 KW.s) required for signalling across this distance. Signor Marconi developed the rotary spark arrangement, and in 1907 patented his high speed disc discharger which has since been brought to great perfection. It not only gets over all difficulties of arcing but gives a high spark rate, the advantages of which for tuning and efficiency will become more apparent as we proceed, and it prevents retransfer of energy from the aerial.

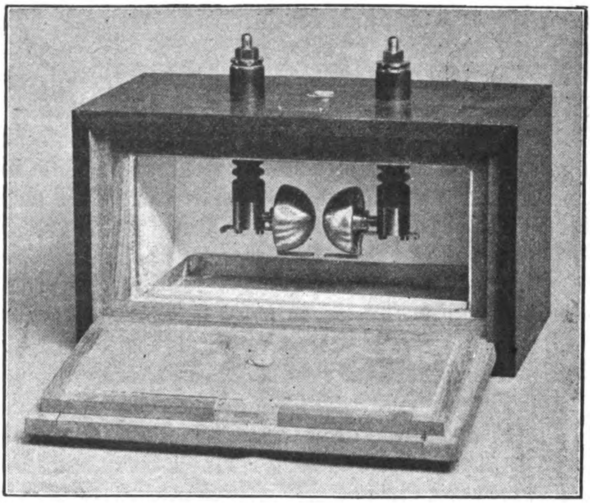


FIG. 91.

Disc Discharger.—The disc discharger fitted by the Marconi

Co. to their 25 KW. transmitter outfit is shown in Fig 92; its

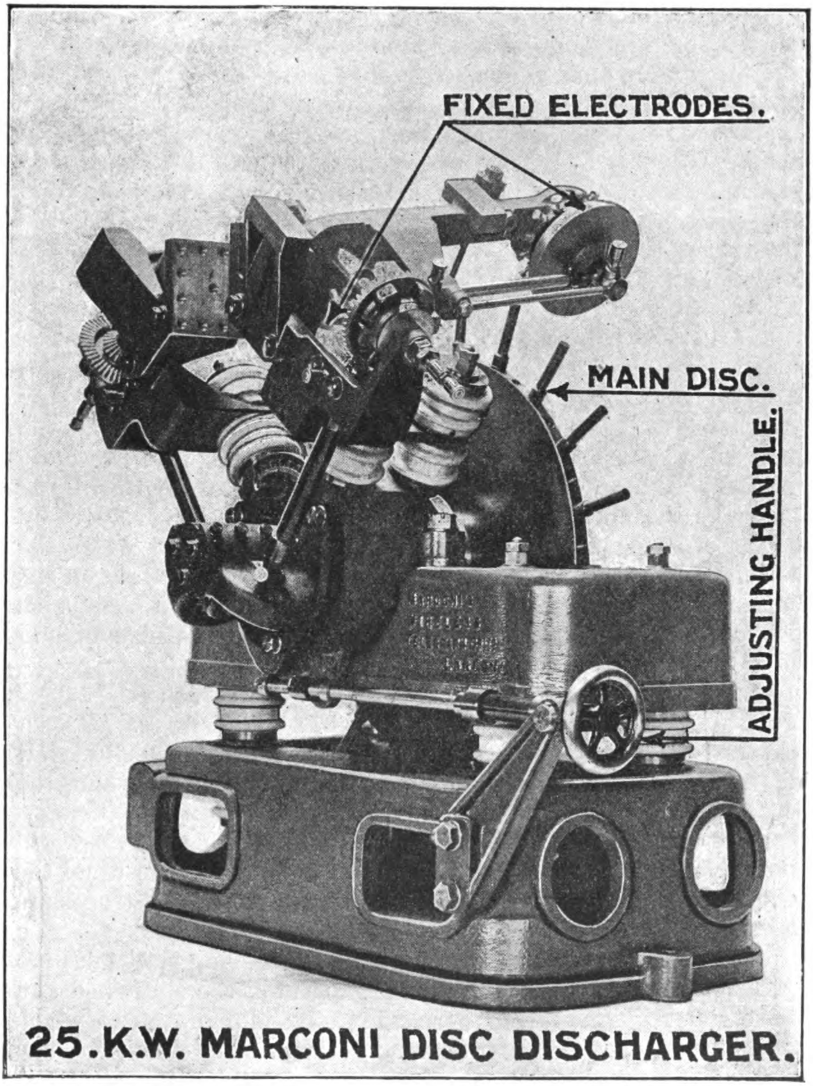


Fig. 92.

action is more or less similar to those used on the smaller outfits.

It consists of a large disc mounted on the end of the shaft of the alternator,* and insulated by a thick coupling disc of rubber. The disc has a number of metal projecting teeth, the number depending on the frequency of the alternator, on the number of poles on the alternator, and on the spark frequency desired. Two fixed electrodes are mounted on insulators, and the teeth pass in front of these as the disc revolves, thus providing two spark gaps in series. The fixed electrodes here consist of metal discs rotated slowly by a chain gear, which is itself driven by a worm gear from the shaft. This is clearly seen in the illustration. Also, the position of the fixed electrodes can be changed by means of a worm screw, operated by the handwheel at the right; thus the timing of the spark can be adjusted.

In smaller disc dischargers the rotating disc is of ebonite with a metal ring on which the teeth are fixed; the stationary electrodes are two copper teeth projecting from ebonite supports.

Owing to the capacity effect in the high potential circuit the maxima of voltage in it occur when the voltage wave of the generator is nearly at its zero value; the effect of capacity being to make the voltage in its circuit lead the primary voltage by nearly 90°, hence the spark discharges take place when the alternator's voltage is very small, and so throws no strain on the machine. The current from the alternator is nearly in phase with its volts since the reactance coil included in its circuit balances in it the capacity effect.

The advantages of a disc discharger are as follows:—

I. The discharge will commence when the distances between the revolving and fixed electrodes will be short enough to allow it, a distance which depends on the potential used and the capacity of the condensers; it will commence *before the two gaps are short enough to allow of arcing*, and at the same time there will be *no missing of sparks*, for if the voltage is lower than usual the discharge simply commences a little later, when the electrodes are a little nearer to each other.

II. After the discharge commences the moving electrodes are passing the fixed ones; the spark gaps are then shortened and have less resistance, thus decreasing any damping effect which would be due to spark gap resistance in the primary circuit. There will be no arcing with the shortened gaps, for the voltage has now fallen from its maximum, and is not, therefore, of a sufficiently high value to cause arcing.

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* It may be independently driven at the same speed as the alternator.

III. By the time the maximum oscillation has been established in the aerial circuit the rotating electrodes are moving away from the fixed electrodes; the spark gaps are thus automatically increased in length and resistance, so that no energy can return to the primary circuit from the aerial circuit; the latter is, therefore, left free to oscillate at its own natural frequency, without its oscillations being damped by giving back energy. The only damping then in the aerial circuit is that due to its own resistance and to radiation.

Thus we get regular sparking without any misses, therefore a pure musical note; no danger of arcing if the volts are too high; automatic prevention of return energy from the aerial circuit, allowing of closer coupling than with an ordinary spark; this means more energy delivered to the aerial, or a better efficiency obtained.

In disc dischargers of smaller size an iron casing encloses the electrodes and the revolving disc, and thus acts as a silencer to the spark; it is fitted with an inspection door and provided with a fan arrangement which circulates the air inside the casing, driving off the nitrous gases through outlets in the casing fitted with sound proof material.

Small rotary dischargers on the above principle, driven by electric motors, can be used on small sets with an induction coil if it has electrolytic or a motor-driven make and break; with the ordinary hammer break a rotary discharger will not give a musical note as the interruptions of primary current are too slow. As a matter of fact a rotary discharger is not a suitable one to use with an induction coil; the voltage induced in the secondary of the coil rises to its maximum and falls from it very suddenly, so that it is most difficult to synchronise this voltage with a suitable spark length of a rotary discharger.

A motor-driven rotary discharger will give a good note if the source of voltage is an ordinary step-up transformer on an alternating current supply, of say 100 cycle frequency, such as is obtainable in many towns in the United States; however, for satisfactory working, the frequency should not be less than about 200 cycles per second.

Fig. 90 shows a Marconi portable outfit, the alternator being driven by a petrol engine seen on the right; the disc discharger, enclosed in a case on an extension of the alternator shaft, is seen on the left of the Figure.

The ring which carries the fixed electrodes of a Marconi disc discharger can be moved round by hand, so that the actual time at which sparking will take place can be adjusted to give the best effect, according to the individual conditions of the apparatus of each transmitting equipment when assembled. For this purpose graduations are marked on the ring or case; the best adjustment is generally made and marked at the Marconi factory when the apparatus is being tested before delivery.

Telefunken Quenched Spark.—The quenched spark, or "singing spark" as it is sometimes called, invented by Prof. Max Wien in 1906, has been adopted by the Telefunken Co. as a characteristic part of their system. As made by them it consists of a number of metal discs, with grooves cut in them as shown in Fig. 93, each disc slightly recessed at the centre. The discs are separated by very thin insulating washers of mica, which extend only a little way across the grooves. The thinner these washers are the purer the wave at which the energy is radiated, so that the mica is only from $\frac{1}{10}$ to $\frac{3}{10}$ mm. thick. The metal discs are ground dead true, and it is seen that instead of the energy being discharged in one large spark, it is distributed over several in series with each other. The spark will start at any part of the inner portions of the discs, and, owing to the electromagnetic action of the magnetic fields which are set up round the discharging current, it is rapidly driven outwards towards the grooves where it becomes lengthened and extinguished. This constitutes the quenching action, which is similar to that which takes place in a horn type lightning arrester. Fig. 94 shows a complete quenched spark gap consisting of seven units; some of the units, if necessary, may be cut out of action by short circuiting them with metal spring clips, seen in the illustration. The number of units employed depends upon the amount of energy to be handled; for instance, if half the spark gaps only are employed then the condenser will discharge when only one quarter of the original

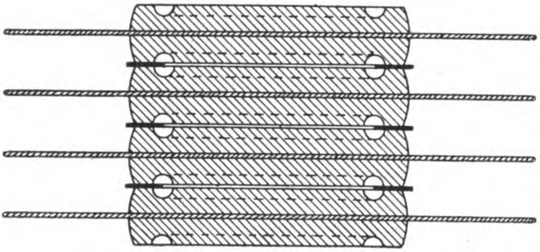


Fig. 93.

energy has been stored in them, for energy stored in $\frac{1}{2}KV^2$ and V depends on the total spark length. The Telefunken discs are of copper, the centres being faced with silver plates which form the spark gap proper.

For a 5 T.K. transmitter, (5 KW.s in the aerial), there are 14 gaps in series; this set has a transformer secondary voltage of 12,500 and a spark frequency of 1000. The quenched spark discs are mounted on heavy porcelain insulating supports, clamped between metal end plates by means of a screw handle, or bolt, which can be easily released to permit of cleaning and generally overhauling the spark units.

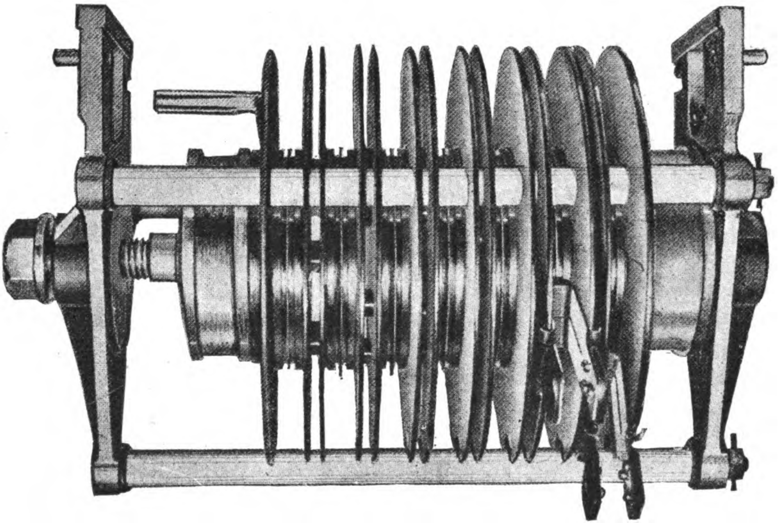


Fig. 94.

The larger discs seen in the illustration are of thin copper, placed between each spark unit to radiate away the heat caused by the sparks. The spark gaps should be inspected frequently, as the sparks are likely to wear away the inner edges of the mica insulating washers and the silver faces will require cleaning.

Quenched spark gaps, made on the above lines, can be used with induction coil and battery excitation, but will only give a musical note if the coil is fitted with a rapid make and break; otherwise the spark will be of a hoarse sound which is not heard well in the receivers. The Telefunkun Co. have designed a rapid make and break for the induction coils used in their smaller stand-by transmitting outfits. The quenched spark will not work well on alternating current supply of ordinary low frequencies, where the transmitter is excited by a high voltage transformer. For use in commercial stations the Telefunken alternator is generally designed for a frequency of 500 cycles per second; this will give a sparking rate of 1000 sparks per second in the quenched gap, so that a musical spark results.

Now let us consider and analyse the advantages claimed for the "quenched spark discharger."

I. A pure wave is radiated, in other words, most of the energy radiated is at one wave length. This is due to the fact that the spark is rapidly quenched so that it is extinguished by the time the oscillations in the aerial circuit have reached their maximum, hence no back transfer of energy can take place from the aerial circuit to the closed circuit through the coupling coils, whether the latter are of the auto-transformer or tesla transformer pattern. Therefore no damping of the aerial oscillations is caused by the coupling, and the aerial energy oscillates at its own natural frequency, thus emitting a pure wave. The degree of coupling may be as much as 20 per cent. but in practice a smaller value is usually employed; it can, however, always be greater than that used with an ordinary spark gap. The best effects are obtained when the aerial circuit is tuned to a little longer wave length than the primary circuit; the difference increasing as the coupling is made tighter; this mistuning causes a slight reaction of the aerial circuit on the primary circuit which assists the quenching of the spark. The aerial energy thus oscillates with a very small decrement of damping after the primary circuit discharge is quenched as shown in Fig. 68.

The Telefunken Co. claim that the damping decrement per semi-oscillation is only about 0·08 to 0·1 with slow radiating or T antennæ working at their natural wave length, and it is only 0·05 to 0·03 if the wave length is increased to three or four times the natural wave length by the use of inductance coils.

II. The range of existing stations using ordinary spark gaps can be doubled if a quenched spark gap system is employed.

This immediately follows from the above argument, for if a quenched spark gap decreases damping, and the aerial oscillations are free and persistent, the energy radiated, which would be spread over a fairly broad range of wave lengths with an ordinary spark gap, is now mainly radiated on one distinct wave length.

Thus, at this wave length, it may be almost doubled in value and a receiver tuned sharply to the wave length will pick up the signals at a much greater range.

But efficient working range depends as much on the strength of jamming signals and atmospherics as on the strength of those which it is desired to read; also, part of the advantage of the Telefunkun system, as regards range, is due to the high musical note or spark frequency employed, since it can be read through jamming much easier than a lower note.

III. High efficiency of transmission, or less transmitter power required for a given range.

This, in the first place, is due to the small damping effect on the aerial whereby a large number of oscillations of energy take place in it at each spark. Energy is therefore radiated from the aerial in persistent pulses rather than in one large impulse followed by a few smaller and rapidly decreasing ones; thus, instead of having to provide power for setting up a large impulse of energy, a small power unit capable of giving the persistent impulses will suffice; also there will be more total energy in persistent oscillations of a given value than in larger oscillations which are damped. In the second place the receiver telephones are much more sensitive to high frequencies than low ones, and will give the same effective sounds with a very much smaller amplitude of receiver current at a higher frequency, provided it is within the range of audibility. This effect will be referred to again when dealing with receiver telephones.

IV. Small transmitter apparatus and aerials.

V. Large ranges compared with ordinary spark system. These advantages are involved in those already explained.

VI. High speed of signalling.

This is owing to the high rate of sparking, thus it can be calculated that the usual rate of 1000 sparks per second would enable signalling to be done at the rate of 240 words per minute, allowing 5 sparks to a dot and 15 to a dash.

VII. Less interference at the receiving station due to atmospherics or to other transmitters.

This is partly because of the musical pitch of the spark, which can easily be distinguished from other sparks even if the latter cannot be entirely tuned out, and partly owing to the sharp wave length radiation, which prevents stations not exactly in tune from causing interference at the sharply tuned receiving station.

Now if the student will study each of the considerations set out above and apply them to a Marconi disc discharger he will find that it also can claim these advantages; in fact the quenched spark and the rotary spark are simply two different means of attaining the same object. The object is to allow the aerial circuit to oscillate freely without the damping effect of transferring energy back to the primary circuit; also to have a high spark frequency giving a muscial note, which will be easily distinguished amongst interfering disturbances, and will make high speed signalling possible.

It does not follow that these dischargers are equally good in all cases; the Marconi disc discharger would seem to be the best for dealing with the large energy values required for trans-oceanic work; for instance it is a better design for radiating away the heat losses, and would not require the frequent renewals and overhauling which are necessary to a quenched spark gap.

The Telefunkun quenched spark gives sharp tuning with coupling which is closer than that used with the Marconi apparatus; in this respect it may give more efficient transmission.

Rarefied Air Dischargers.—A transmitter equipment used commercially in Japan, and called the T.Y.K. method after the initial letters of the names of its Japanese inventors, employs a form of discharger in which the electrodes are enclosed in a space of rarefied air or gas. The electrodes are a copper anode and an aluminium cathode, the latter having a pinhole bored through the centre to steady the discharge; these are spaced about ½ millimetre apart in a vessel from which the air is evacuated to a pressure of from 10 mms. to 2 mms. of mercury.

The electrodes are of comparatively heavy cross section or are made with fins, as it is found that the discharge becomes unsteady if the electrodes are hot; the steadiness of the discharge also depends greatly on the pressure of the rarefied air within the vessel, and best results are obtained with the pressures quoted above.

It has been found in practice that this form of discharger has good quenching properties; with a coupling as close as 60 per cent. between the discharge and aerial circuits the oscillations in the latter are so little damped that the system can be used for radio-telephony transmission. The discharger is connected across an oscillating circuit of the usual type, consisting of a condenser and an inductance coil, but the primary source of energy is simply a D.C. generator at 500 volts, connected through resistance and choke coils to the oscillator. The aerial circuit is coupled magnetically to the closed circuit in the usual manner.

Transmitter Condensers.—The simplest form of condenser is the Leyden jar which is made up in various sizes; the capacity of a pint Leyden jar being about 0·001 microfarad. Condensers in the transmitting circuits have to stand very high potentials, and if the Leyden jar type is employed it is usually of a design specially adapted for this purpose. Thus the Telefunken system use the form of a Leyden jar shown in Fig. 95. The inside and outside coatings are of specially prepared tinfoil, and the glass dielectric extends considerably above the coatings to prevent any risk of brush discharge loss, which depends on the length of the metallic edge of the coating in each jar. This type of condenser has the advantage of taking up very little floor space for the amount of capacity in each jar; it is light and can stand hot climates.

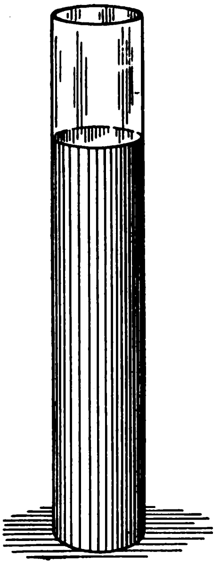


FIG. 95.

In ordinary ship and land outfits the Marconi Co. use a plate condenser. For those of ½ KW. size the plates are made of zinc 14 cms. × 34 cms., separated by glass dielectric, the glass being 0·3 cm. thick and extending about 6 cms. beyond the zinc in each dimension. The zinc plates are made with lugs so that they can be easily attached to the connecting-rods joining alternate plates together, and plates can be quickly added to or subtracted from the condenser. The whole is contained in a stout teak box filled with transformer oil which eliminates any danger of direct arcing, while the terminals of the condenser are heavily bushed with ebonite. The capacity of the condenser here described, with 32 zinc plates, is 0·0074 microfarad; the addition of an extra zinc plate increases the capacity by 0·00092 microfarad.

The whole system of zinc and glass plates can be easily lifted out of the tank for the purpose of renewing a glass plate, if one should break down under undue strain. The condenser can be protected by a pair of spark points from any heavy strain of potential put across it, and the discharge of these spark points will notify to the operator the necessity of making better adjustments in his circuit.

For large transmitters a battery of similar or larger condensers of the same pattern is employed. When a single condenser is used the capacity is changed by putting in or taking out one or more of the zinc plates and glass dielectrics; on stations of about 5 KW. size, where a battery of these condensers is installed, a commutating switch can be used to vary the number of condensers in the circuit, according to the length of the wave it is desired to transmit. When it is desired to transmit short waves by connecting a condenser in the aerial circuit the condenser may be of the same design as that described above.

In the 1½ KW. military (lorry) station of the Marconi Co., the transmitting condenser consists of 22 tube Leyden jars 24 ins. high, the coatings being of electrolytically deposited copper. Similar condensers, though smaller and, of course, less in number, are used in the Marconi cavalry type station and in the special portable station of ½ KW. size for landing from warships.

It might be noted here that in ship outfits the size and height of the aerial are necessarily limited, therefore the potential to which it can be charged is also limited. In them it is usual to employ larger condensers than would be necessary in a land station of the same range having a higher and larger aerial. By this means the same amount of oscillating energy can be generated at the lower potential, as shown by the calculations given in the previous chapter.

For small transmitting outfits a suitable condenser can be made with zinc plates, using crown glass sheets as dielectric; ordinary soda glass should not be used as the dielectric hysteresis loss in it would heat up the condenser. The zinc plates should be cut with rounded corners, and the glass should extend two or three inches beyond the zinc on every edge; the whole can then be tied together with tape and placed in a box which should be filled with melted paraffin wax. The thickness of the glass will depend directly on the voltage to which the condenser will be charged taking into account resonance effects; this voltage would be from 1·5 to 2·2 times the transformer secondary volts.

"**Dielectric Hysteresis.**"—When a condenser is charged we know that positive charges are accumulated on one set of plates and negative charges on the other set, while electric strain lines are set up in the ether between the positive and negative charges, that is to say in the dielectric between the plates. When a discharge takes place these lines should disappear, but it is found that, to a different degree with different dielectrics, all the electric strain does not disappear when the discharge should be complete. This means that all the electrostatic energy of charge is not turned into electromagnetic energy of discharging current, and hence a loss of energy occurs ; before the condenser can be charged up again in the opposite direction, as it is by the oscillating currents, the remaining electric strain lines must first be wiped out and some energy of charge is wasted in doing this. The effect is called " dielectric hysteresis " : it is negligible with air dielectric, and is very small with oil dielectrics or flint glass ; it may be very considerable with ordinary glass or mica.

The effect of dielectric hysteresis is to heat up the condenser, just as all wasted energy is turned into heat ; also since the dielectric hysteresis loss increases with the temperature it is easily seen that the effect becomes cumulative, and *the condenser may become very hot.*

When the Marconi Co. first set up their transatlantic stations the condensers in the primary discharging circuit consisted of large metal plates separated by glass sheets. The loss of energy due to dielectric hysteresis in the glass was found to be appreciable, therefore the condensers now consist of large metal sheets suspended from insulators side by side, so that air is used as a dielectric and there is no hysteresis loss of energy.

Tesla Type Coupling Transformer.—In the Marconi system the coupling transformers are termed "jiggers," and much experimental work, which it is unnecessary to describe here, was carried out by Signor Marconi and his scientific staff before the present form of jigger was evolved. In the Marconi ½ KW. Set the primary consists of a thick copper ribbon wound on edge as a square shaped spiral, mounted on an ebonite support which is held in a wooden frame with metal supporting legs. Over the primary there is an insulating sheet of ebonite, and on top of this is placed the secondary, which consists of insulated copper stranded cable, wound in one layer on a square wooden box with ebonite top. Tappings are taken from several points on the secondary winding to brass sockets mounted on the ebonite top. One end of the secondary is connected to the aerial by means of a plug inserted into a socket, and the connection to the earth plate is made by plugging into one of the other sockets, so that the number of turns of the secondary in use can be varied. If separate aerial inductance is also used the aerial plug is inserted in its terminal socket, and a flexible cable, with a plug at each end, connects one of the other tappings of the tuning inductance to one of the tappings of the transformer secondary. The connections to the transformer primary are made by spring clips so that the inductance effect in use on it can also be chosen to suit the wave length desired. This Marconi jigger is shown in Fig. 96.

The secondary frame is made to slide in graduated grooves on the primary frame, so that it can be placed in the best position to give efficient coupling; the degree of coupling used being from 10 to 15 per cent. In the ½ KW. station the primary spiral has 7 turns of copper ribbon $\frac{3}{4}'' \times \frac{1}{10}''$, and the secondary has 21 turns of insulated stranded cable, the whole being mounted on a frame about 20″ square.

The Marconi 1·5 KW. military station has a tuning inductance square spiral in the closed circuit: the jigger primary consists of one turn, made of a number of wires insulated from each other in order to provide a large surface for the oscillations; the secondary has 15 turns of stranded cable, with 3 tappings to a 3-way switch by which it is connected to the aerial tuning inductance; as before the coupling is varied by sliding the secondary over the primary.

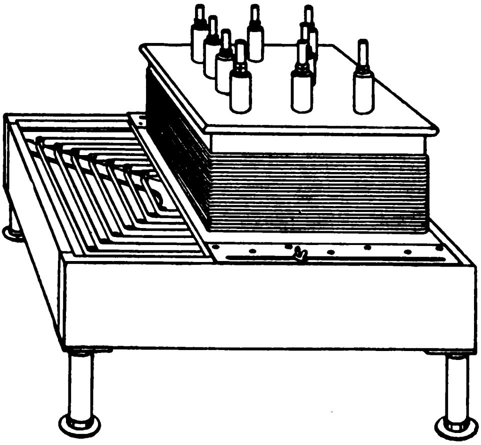


FIG. 96.

In a smaller Marconi outfit, where again an adjustable tuning inductance is used in the closed oscillating circuit, the jigger primary is a square spiral of 3½ turns; the secondary is a similar coil of 6 turns with 3 tappings.

The Telefunken Co. have also developed various forms of Tesla transformer for electromagnetically coupling the closed primary oscillating circuit to the aerial circuit, but this inductive coupling is used by them, as a general rule, only for stations of 15 KW. or over. It consists, in both primary and secondary, of spirally wound circular coils of copper ribbon, wound on edge and mounted on the back of a switchboard; the degree of coupling being adjusted by moving the secondary nearer to or farther from the primary.

Auto-Transformers for Direct Coupling.—These transformers or couplers consist of one coil, of which only two or three turns are included in the primary or closed circuit and several turns

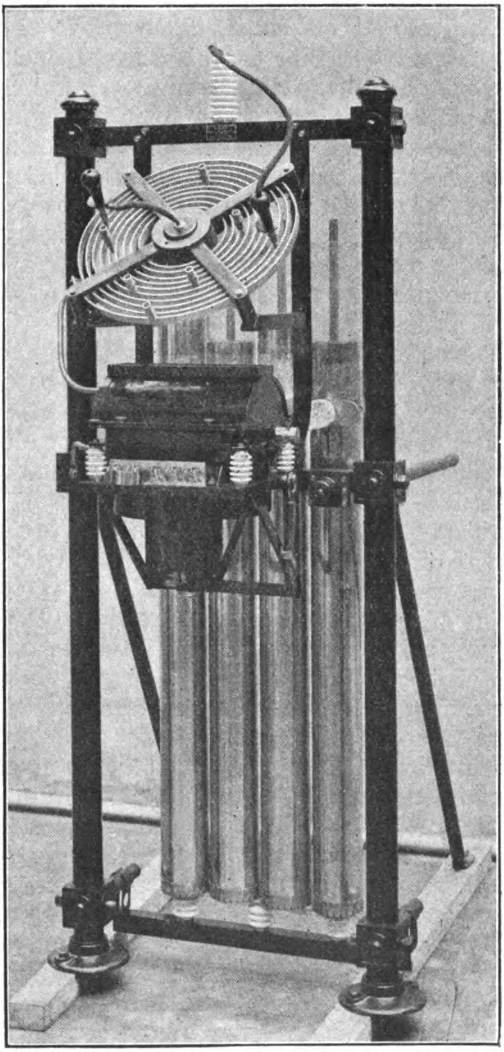


FIG. 97.

in the aerial circuit; the number of turns in each circuit being chosen so as to tune the circuits to each other.

For small outfits they can be made by winding 8 to 10 turns of copper ribbon, or copper tube, on a rectangular frame, with four ebonite supports screwed to end plates of mahogany, teak, oak, or other hard wood; the coil can be about one foot square, or one foot in diameter, and the tube or ribbon may be held in place on the ebonite by insulated cleats or screws.

The Marconi Co. do not use this method of coupling on any of their outfits, but it is used by the Telefunken Co. on stations up to 15 KW. size. The Telefunken stations are rated according to the power in the aerial circuit, not by the primary power, so that a 15 KW. station means one in which 15 KWs. are oscillating in the aerial.

The Telefunken coupling coil is a spiral of copper strip, wound on edge, and mounted in a wooden or ebonite frame of radial arms. On the spiral is fixed a number of sockets, into which can be fitted plug connectors from the other apparatus in the circuit, so that three or more definite wave lengths can be chosen. Fig. 97 shows the coupling coil, together with the condensers and spark gap of the Telefunken E type station. The wave length can be adjusted to 300, 450, 600 and 900 metres, with an aerial 300 feet long on masts 100–120 feet high.

Aerial Tuning, or Loading, Coils.—These coils are for adjusting the wave length of the aerial circuit independently of the tappings on the coupling coil or coils, which are used only to give the proper degree of coupling. In the ship outfits made by the Marconi Co. the aerial tuning inductance is made of stranded cable, well insulated and braided, wound in one layer on a square box former: its design being similar to the secondary of the coupling transformer. Tappings are taken from the coil to brass sockets on the front of the frame, into which brass plug connectors can be inserted, one from the aerial, the other to the coupling transformer secondary. Fig. 98 shows the aerial inductance coil for a ½ KW. station, having 13 turns of cable on a box frame.

In the Telefunken equipments the aerial tuning inductance consists of two or more spirals of copper strip, with plug sockets; the design being similar to that of their coupling coils. One of the spiral coils is on a hinged frame; by altering the position of this coil with respect to the others their combined inductance effect can be changed, so that the tuning can be done by this method as well as by using the plugs. The advantage of this is that the aerial resistance can be kept constant and thus damping decrement is not changed by adjustment of wave length. These tuning coils are seen in the illustrations of Telefunken apparatus given later, the movable coil being the one which is shown fitted with a handle.

The Telefunken Co. have also developed an arrangement of tuning coils known as a "Variometer," or variable inductance. It consists of two circular flat plates of ebonite placed coaxially, one being fixed the other capable of rotation about its axis. Each plate has two flat coils on it wound as shown in Fig. 99, and, by means of a switch, the four windings can be joined in series or in parallel. If the plates are so placed that the magnetic fields, set up in the coils by the oscillating currents, are all at any moment acting in the same direction, *i.e.* are added, then the inductance effect is a maximum; if the movable plate is now turned through an angle of 180° the magnetic fields in its coils oppose those in the fixed coils, and the inductance effect is a minimum.

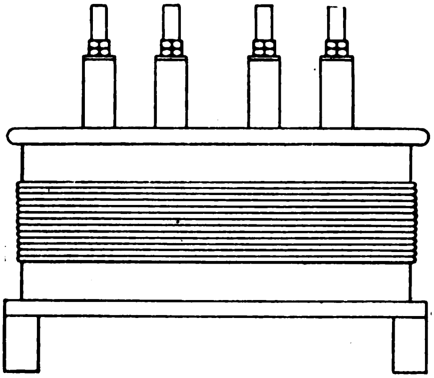


Fig. 98.

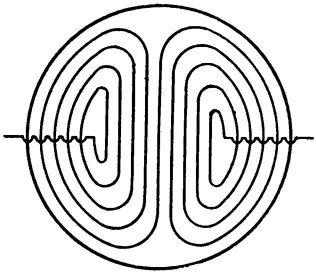


Fig. 99.

By connecting the coils in series or in parallel, and by rotating the movable plate, a large range of wave lengths can be obtained; the movable coil is graduated to show the wave length corresponding to each position of it, so that the transmitting apparatus can be quickly set to any desired wave length. This is an advantage which is of importance in naval and military outfits, as by changing the wave length at pre-arranged intervals it becomes more difficult for unauthorised stations to pick up the messages by tuning in. The message would be in secret code and the variation of wave length is only an extra precaution. In the Marconi military outfits the same object is attained by having three tappings, or switches, on the tuning coils, so that three different wave lengths may be used.

Transmitter Key.—This is always connected in the low potential side of the induction coil or transformer, and, if the outfit is a small one, it may be a simple key of the Morse pattern with good platinum contacts.

When an aerial switch is used to change over from receiving to sending it should have auxiliary contacts which open the circuit across the detectors and telephones when in the sending position, thus avoiding any heavy inductive effects in these from the transmitter oscillations. In the Marconi system there is no aerial switch, an earth arrester taking its place as already described, hence, when sending, the receiver telephones have to be protected from the effects of the sending circuit. The receiver apparatus as a whole is protected by a micrometer spark gap connected in shunt across it, but this would not prevent the telephones from responding loudly to each sending spark, thus dulling the aural sensitiveness of the operator for the received signals.

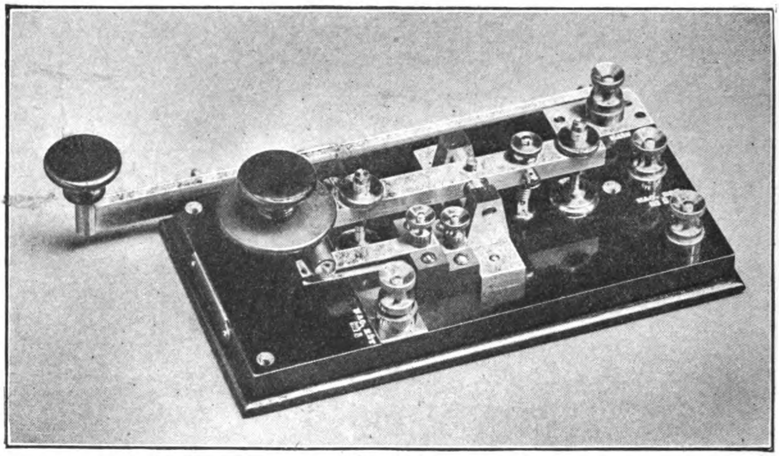


Fig. 100.

Therefore the Marconi Morse transmitting key has small auxiliary spring contacts at the side, and each time the key is depressed an ebonite bar, projecting from its side, presses the auxiliary contacts together. These are connected across the receiver telephones which are thus short circuited each time the key is closed. (The contacts may also be used to open the receiver circuit at each side of the detector.) The Marconi key is shown in Fig. 100; the switch at the left-hand side breaks the circuit completely, thus cutting the transmitter key out of action. Even when such arrangements are adopted it is best to have a switch which will disconnect the receiver from the aerial while transmission is taking place. When large amounts of energy have to be dealt with in the transmitter the sending key is more elaborate and its make and break contacts may be enclosed in oil, or acted upon by an air blast, to extinguish or avoid heavy arcing which would rapidly burn away the contacts. In larger outfits the sending key may not be in the main generator circuit but may be used to close and open an auxiliary low voltage circuit. The current in this circuit flows through the coils of electro-magnetically operated switches which open and close the main circuit.

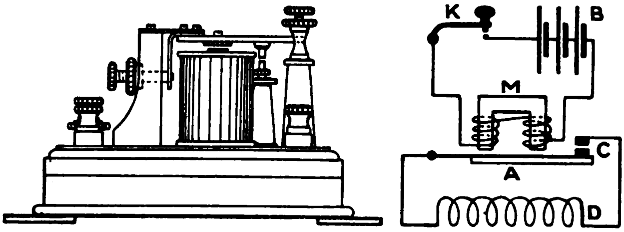


Fig. 101.

A simple arrangement of this type is shown in Fig. 101, the sending key K, when closed, energises the electro-magnet M by the current from the 6-volt battery B. The magnet attracts its soft iron armature A, thus closing the contacts C, it in turn closing the circuit of the coil D, which may be the primary of an induction coil, or of a step-up transformer. The Marconi Co. use a double magnetic key working on this principle, a diagram of which is shown in Fig. 102. When the key is depressed the low voltage electro-magnet attracts its armature, A_1, which closes a circuit from the alternator through the second electro-magnet.

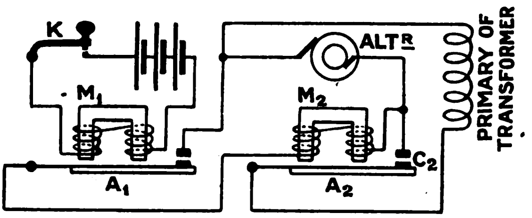


Fig. 102.

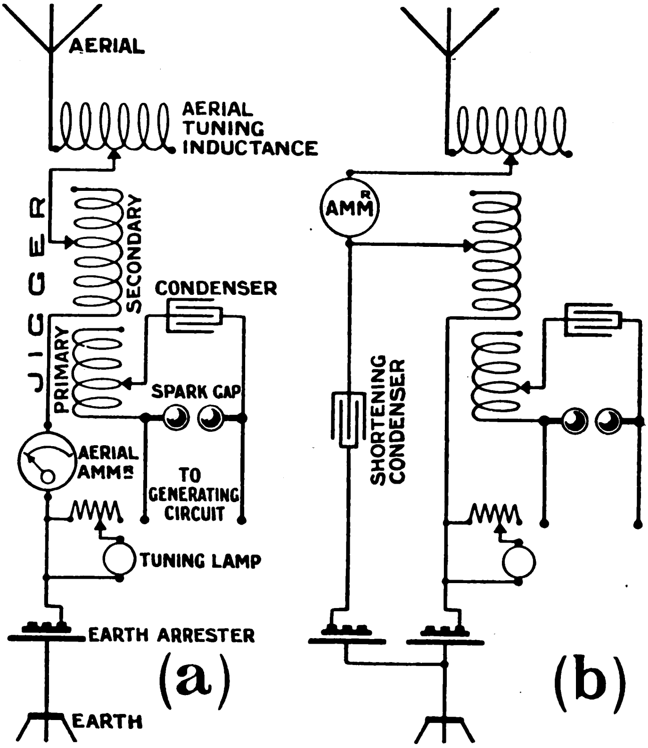
This attracts its armature A_2, closing the circuit from the alternator through the primary of the step-up transformer. When the key is opened A_2 will not fall away from M_2 until the alternator's voltage is going through its zero value, and when, therefore, its current is also very small, so that there will be little current and little arcing at the contacts C_2 when they break away from each other. The frequency being comparatively high the difference in time between the opening of the key and the opening of C_2 is inappreciable and does not affect the signals.

Change of Wave Length.—In ship work it is necessary that the operator on a vessel, normally working on 600 metres wave length, should be able to change over quickly to 300 metres wave length, in order to communicate with smaller cargo vessels. This means that the aerial and the closed circuit must be tuned down to 300 metres, and it is desirable to keep the oscillating energy to the same value as that available on the 600 metre adjustments.

In the previous Chapter the disadvantage of putting a condenser in series with the aerial to reduce its wave length has been discussed; the Marconi Company get over the difficulty by switching out some of the aerial tuning inductance and connecting a condenser from the top of the aerial inductance (or the top of the jigger secondary) to an independent earth arrester. The operator can quickly change the A.T.I. to a new adjustment, ascertained beforehand, and connect up the condenser so that this change of the aerial tuning can be expeditiously made. The connections for long and short wave length working would be as shown in Fig. 103.

In the Marconi 1½ KW. transmitter the transformer has two primaries connected in parallel and two secondaries which are connected in parallel for 600 metres wave length and in series for 300 metres wave length; thus the voltage at the transformer secondary terminals is doubled when working on 300 metres wave length. The closed circuit contains two box condensers which are in parallel for tuning to 600 metres wave length, but the capacity is reduced for 300 metres tuning by connecting them in series. Thus when it is desired to change the tuning quickly from 600 metres wave length to 300 metres a condenser is switched into series with the aerial, the closed circuit condensers are changed from parallel to series by means of a switch supplied for the purpose, and the secondary windings of the transformer changed from parallel to series by changing the connections at their terminals.

The energy in the closed circuit is $\frac{1}{2}KV^2$; when the condensers are changed from parallel to series the capacity is changed from K to $\frac{K}{4}$, and when the transformer secondaries are changed



(*a*) Transmitting on long waves. (*b*) Transmitting on short waves.

FIG. 103.

from parallel to series the voltage is changed from V to 2V. Thus the energy in the circuit is now $\frac{1}{2}\frac{K}{4}(2V)^2 = \frac{1}{2}KV^2$, *i.e.* it is the same for the 300 metre connections as for the 600 metre ones.

Tuning Lamp.—In the Marconi Transmitters a small low-voltage lamp is sometimes connected across a portion of the aerial circuit, for instance it may be connected between the bottom or earth terminal of the jigger secondary and the top plate of the earth arrester. The voltage tapped off this portion of the aerial circuit will be sufficient to light the lamp when the aerial is in tune with the closed circuit and the current in it is of sufficient amplitude; in fact the correct tuning of the aerial circuit can be gauged by the brightness of the lamp. The lamp may be connected in series with a few turns of copper wire wound on a porcelain cylinder; the number of turns in use is adjusted by means of a sliding contact to have the lamp full bright when the two circuits are in tune; the adjustment would then be kept fixed at this value. The coil with its sliding contact is shown mounted on a small base in the bottom right hand corner of Fig. 104, which is the diagram of a Marconi ½ KW. set; the coil and tuning lamp are also shown in the diagrams of Fig. 103.

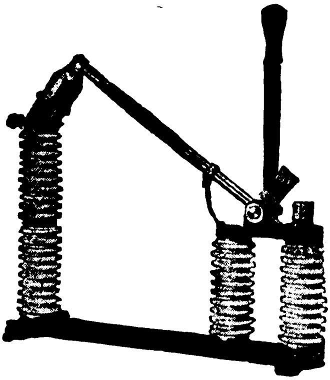


Fig. 105.

Fig. 105 shows a Telefunkun aerial switch: it is of the change-over pattern, and when in the sending position it breaks the receiver circuit at each side of the detector.

Telefunken Stations.—In January, 1914, the official list of radio-telegraphy stations gave a total number of 3865 then licensed. Of these about one-half are equipped on the Telefunken system, including 86 British vessels, 1204 other vessels, 381 land stations, and a great number of naval and military stations of which there are no particulars. Messrs. Siemens Bros. & Co., of London and Woolwich, control the British rights of the Telefunken or Quenched Spark system, the outstanding peculiarities of which are the quenched spark discharger, the high note signals which it gives, the use of umbrella, or slow radiating, antennæ for their land stations; also the fact that their stations are rated by the energy in the aerial, and not by the output of the generator. An efficiency in the aerial of from 50 to 75 per cent., according to the size of the station, is claimed for this system.

Much of the Telefunken transmitting apparatus has already been described; it remains only to give a short description of some of the complete equipments as used on ships.

The smallest set made up for ship work takes 300 watts of energy, using battery and induction coil; its range being 18–30

miles to a simple crystal receiver. The other equipments for ships are made up in four sizes, known as Types A, B, C, and D respectively.

Type A takes 400 watts; uses an induction coil to obtain the charging voltage, and has a guaranteed range of 45 miles by day and 60 miles by night with 50 ft. masts, and 90 miles by day, 125 miles by night with 100 ft. masts, using ordinary crystal reception.

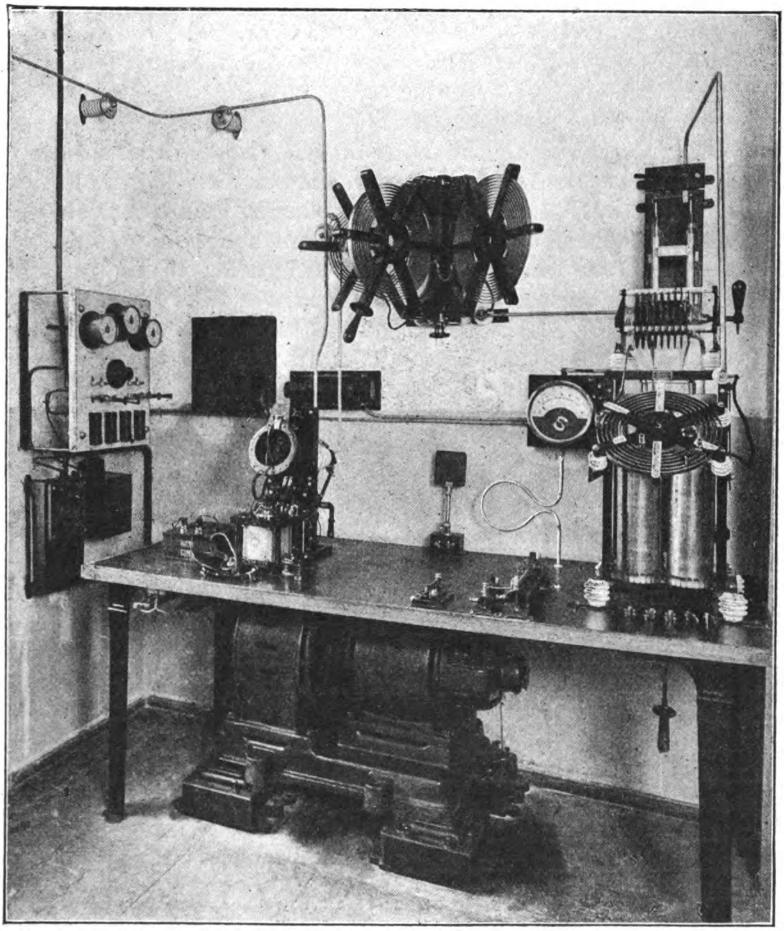


FIG. 106.

Type B has a motor-driven alternator giving 0·4 KW. at

220 volts and 500 frequency. The range is about double that of Type A.

Type C has a 1 KW. alternator; Type D a 1·5 KW. alternator, and Type E, suitable for land or ship stations, a 5 KW. alternator.

Type D is the size suitable for passenger vessels, and is shown in Fig. 106. The alternator's voltage (220 volts) is transformed up to 8000 volts, and the current led to the primary circuit, consisting of tubular jar condensers, as already described, primary inductance flat spiral coil, seen on the right of the picture, and an 8-gap quenched spark, seen just above the inductance. To the left of the primary inductance is a hot-wire aerial ammeter; on the wall, in the centre, is seen the three-coil aerial inductance, of which the centre coil, fitted with a handle, is hinged and movable. The normal wave length range of this station is 200–600 metres. In the centre of the table is the transmitter key which operates an electro-magnetic relay in the armature circuit of the alternator. At the extreme left of the table is the receiver apparatus.

Fig. 107 shows condensers and inductances for the aerial circuit of Type E station. The tuning of the aerial transmitting circuit is accomplished by moving two coils, which are mounted between three other fixed ones. The condensers are connected in series with the aerial if it is desired to shorten the wave length.

With umbrella aerial, 220 feet high, this equipment has a range of 470 miles by day and 950 miles by night over sea, if installed in a land station with good earthing facilities over a space of 800 feet in diameter. The ranges quoted are for crystal reception.

Fig. 108 shows the diagram of connections of a Telefunken transmitter; the aerial switch S_1 and the exciter switch S_2 are operated by the main send and receive switch. It will be seen that the aerial circuit is coupled to the closed circuit by auto-transformer coupling, and the A.T.I. may consist of two or more helical coils which can be moved relatively to each other. The closed circuit is charged by an alternator and transformer, the transformer primary circuit containing a choke coil for low frequency tuning and a magnetic key M. When the manipulating key K is closed some of the direct current generated in the exciter flows through the key and the coil of the magnetic key so that the latter closes the primary circuit of the transformer. The exciter has the constant resistance R across its armature so that the load on it is fairly steady, the only addition when the key is pressed being the current through the coil on the magnetic key.

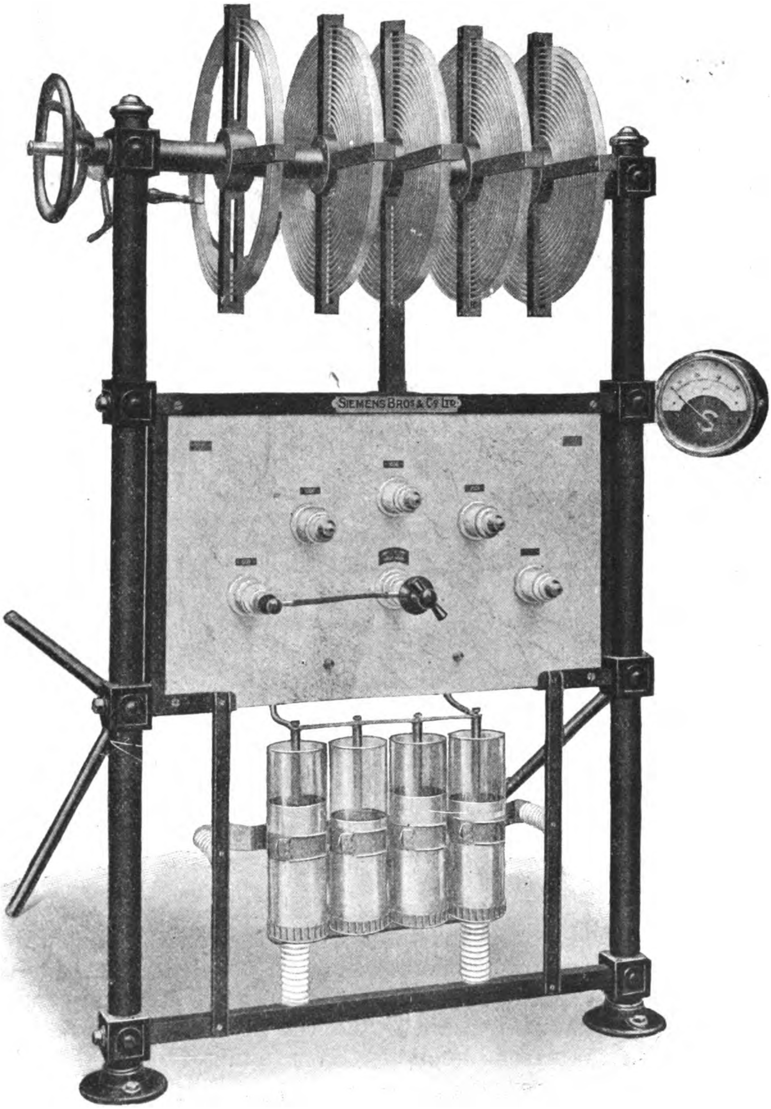


Fig. 107.

The alternator field coils are connected in parallel with a portion of the resistance R, which portion can be adjusted by sliding contacts to give the proper amount of energising current in the coils. It will be noted that the alternator armature, the exciter, and through R the alternator field coils, are each protected from oscillating surges by earthing through split condensers. There are the usual arrangements of ammeters, voltmeters, and double pole switches and fuses in the alternator and exciter circuits.

At the Eiffel Tower station in Paris the main spark transmitter takes energy from the public alternating current supply mains at a frequency of 42 cycles per second, and the plant can work up to 220–250 KW.s. The spark gap is a special form of water-cooled cone discharger, one electrode of which is rotated; the closed circuit capacity is provided by groups of Moscicki condensers arranged in series parallel, while the closed circuit inductance is one or more turns of a coil of copper tubing 4 ins. in diameter. The aerial is auto-coupled to the closed circuit by connecting into it several turns of the copper tubing coil, the ratio of coupling turns being about 4 : 1. There is no other loading inductance in the aerial circuit and on full power the aerial current can

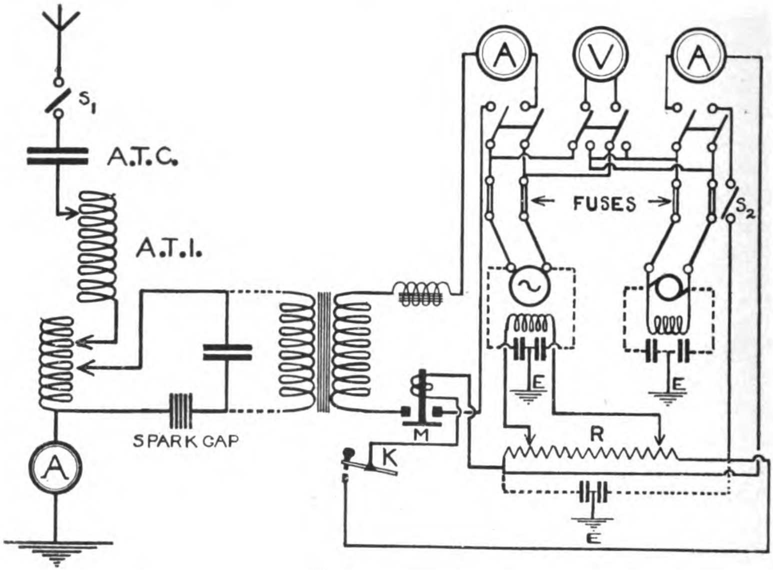


FIG. 108.

attain a value of 100 amperes. The usual equipment of oil-cooled transformers and primary circuit choke coils are provided. Transmission is effected by throwing the circuit into resonance when the transmitting key is depressed, as will be described in Chapter XV.

QUESTIONS AND EXERCISES.

1. Discuss the possibility of using (*a*) a rotary discharger; (*b*) a quenched spark discharger, when the oscillating circuit is charged from an induction coil.

2. What is the object of fitting the alternators used on Marconi portable outfits with commutators as well as slip rings ?

3. How can the pitch of the spark note be varied; how can you tell if the spark is a good one; and why should the spark chamber have a ventilating draught through it ?

4. What are the advantages claimed for a Marconi disc discharger ?

5. With a Marconi disc discharger the actual time of sparking is not the time of shortest distance between the fixed and moving electrodes. Explain why.

6. From the particulars given in this chapter of the condenser used in a Marconi ½ KW. outfit, calculate the specific inductive capacity of the dielectric used.

7. Describe the construction and advantages of a quenched spark discharger.

8. A Marconi disc discharger has got 8 rotating teeth; how many poles are on the alternator and what is the spark frequency if the speed of the alternator is 3000 revolutions per minute ? Neglect resonance effects.

9. What are the advantages of transmitting with a musical note ?

10. Explain why it is that if the closed circuit is quickly damped, and the aerial feebly damped, much less power is required at the transmitter for a given range.

11. What are the conditions necessary for high-speed signalling ?

12. Describe the condenser in the oscillating circuit of a Marconi ship outfit, and in that of a Telefunken ship outfit.

13. A condenser on a small transmitting outfit is found to get warm when in use. Explain the cause of the heating and how the fault can be remedied.

14. Describe the construction and action of a variometer.

15. What are the disadvanatges of using a condenser in series with the aerial to shorten the wave length ?

16. How would you make an oscillation transformer for radio-telegraphic purposes ?

17. Describe, with a diagram, an electro-magnetic transmitting key.

CHAPTER XV

SYNCHRONOUS, ASYNCHRONOUS, AND RESONANCE SPARKING—FAULTS IN TRANSMITTERS

Synchronous and Asynchronous Sparking.—If an alternating voltage is applied to a condenser circuit a charge current will flow into the condenser and its potential will rise all the time this charging current flows; let us suppose that the current is in phase with the applied volts, then the condition of affairs will be as shown in Fig. 109, where V is the applied volts, C the resulting current flow into the condenser, and V_K the potential to which the condenser builds up. It has already been shown that under the conditions existing in wireless transmitter circuits $V_K = \frac{\pi}{2}\sqrt{2}V = 2{\cdot}2V$ approx. in the ideal case, but in actual practice it is rarely more than 1·5V. If a rotary discharger is employed two of the rotating studs should be almost opposite the two fixed electrodes at the moment A, when the condenser is charged up to maximum voltage, so that a maximum of oscillating energy may discharge across the spark gap. This will give synchronous sparking and implies that there is one spark for each half cycle of generator voltage, so that the sparking rate equals twice the generator frequency. The rotary disc will have as many studs as there are poles on the generator and will be driven at the same speed as the armature, preferably mounted on the same shaft for small power transmitters. It will be found that the edges of both the movable and fixed electrodes will wear away on the sides of them which approach each other; this will slightly upset the proper tuning of the spark unless the fixed electrodes are

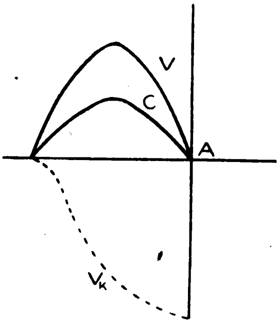


Fig. 109.

shifted a little forward or the faces of the electrodes filed down and the length of the gap readjusted to its proper value.

Now if there are more studs on the rotary disc than poles on the generator a discharge can be obtained before the half cycle is complete; the condenser will charge up again during the completion of the cycle and a second discharge may be obtained during the half cycle. In this case the condenser will never charge up to the maximum voltage, therefore the oscillating energy at each discharge will be less than before; also the spark gap will have to be shorter, and the condenser voltage may not necessarily be the same for the two discharges in the half cycle. We have now less energy at each discharge but more discharges per second, therefore the ultimate oscillating energy per second may be the same as with synchronous sparking and there is the advantage of a higher spark note. The sparking rate is now $\frac{\text{r.p.m.} \times \text{No. of studs}}{60}$ where r.p.m. is the speed of the rotary disc. As there is not necessarily the same amount of energy in each discharge some of the movable studs may regularly get the heavier sparks and wear away faster than the others. This is obviated in practice by putting the fixed electrodes at a distance apart on the supporting ring corresponding to 45°, instead of 90° as used for synchronous sparking, thus ensuring that every stud will get a heavy and a light discharge alternately and the wear on all the studs will be equal.

Resonance Coils and Transformers.—In the considerations dealt with above it was assumed that the current from the secondary of the transformer was in phase with its volts; the secondary transformer circuit is shown in Fig. 110, where it is seen that the current path is made up of the capacity of the condenser K, the inductance and resistance of the secondary winding T_s, and the inductance of the oscillatory circuit tuning and coupling coil (L_1). In Chapter VIII. it was shown that when an alternating current flows in a circuit containing inductance and capacity it will be in phase with the volts only when $2\pi f L = \frac{1}{2\pi f K}$, or when $L = \frac{1}{(2\pi f)^2 K}$, where L is the total inductance

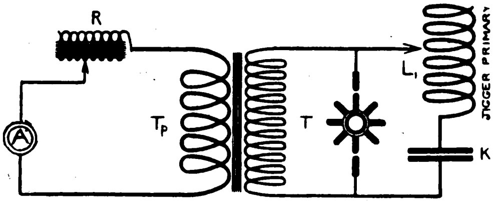


FIG. 110.

effect in the circuit and f is the alternator frequency. For the size of condensers and the machine frequencies employed in spark transmitters this means that L will require to have a value of several henrys; for example if $f = 400$ and $K = 0{\cdot}02$ mfd., $L = \frac{10^6}{(6 \times 400)^2 \times 0{\cdot}02}$ approx.; $= 8{\cdot}7$ henrys approx. Now the coil L_1 has only a value of a few microhenrys (5 microhys. for a 600 metre wave length tuning), therefore the transformer circuit will have to be designed to provide an inductance effect in this case of nearly 8·7 hys.

Instead of designing the secondary circuit to have an inductance of 8·7 henrys we may design the primary circuit to have an inductance of $8{\cdot}7\left(\frac{T_p}{T_s}\right)^2$ hys., where $\frac{T_s}{T_p} =$ ratio of transformation.

This inductance of primary transformer circuit is partly provided for by the inductance of the primary winding and that of the armature of the alternator (A), but as a general rule the two combined do not provide sufficient inductance effect. We cannot increase it by putting more turns on the transformer primary since the number of turns is fixed by the transformation ratio or step-up of voltage desired; thus the additional primary inductance to give resonance is provided by an additional coil R in the circuit, whose inductance can be adjusted, either by having tappings on its windings or an adjustable iron core.

This additional coil is known as the Resonance Coil, or Low Frequency Tuning Coil. From the formula for resonance $2\pi f L = \frac{1}{2\pi f K}$, we get $f = \frac{1}{2\pi\sqrt{LK}}$, thus for a circuit with a given L and K resonance can be obtained by adjusting the frequency to this value. In practice the frequency of the alternator and transformer is generally determined by the sparking frequency desired, so that an adjustment for resonance by altering the alternator speed is not desirable, except for small adjustments.

When the low frequency circuit is arranged for resonance the current from the generator is in phase with the volts and the power factor is unity; in practice these ideal conditions are not generally attained and the power factor may be considered to have a value of 0·8 to 0·9.

The best adjustment of the resonance coil can be obtained by noting the current as read on an ammeter in the primary circuit, since this current will be a maximum when resonance is attained;

the impedance of the circuit is then a minimum, being only that due to the resistance of the circuit. Since part of the inductance and resistance effects are in the generator armature the volts at its terminals will not have the same value or phase as the total generated volts. Fig. 111, (taken from " Wireless Telegraphy and Telephony," by Dr. W. Eccles), shows the phase relationships during the half cycle ; V_g is the generated volts, V_T the volts at the terminals and applied to the primary of the transformer, C_g the generator current, and V_K the voltage to which the condenser is charged. At the time X a discharge takes place when all the curves drop to zero values and build up again during the next half cycle in the reverse direction. It can be seen that the alternator current is zero when the spark takes place; as previously pointed out, this avoids burning of the key contacts. In order to get a clear spark note it is not possible in practice to work at the resonance point, which is critical and more or less unstable as it depends on the design of the transformer especially as regards magnetic leakage. In the larger Marconi stations the frequency constant of the primary transformer circuit is from 12 to 20 per cent. less than that of the generator.

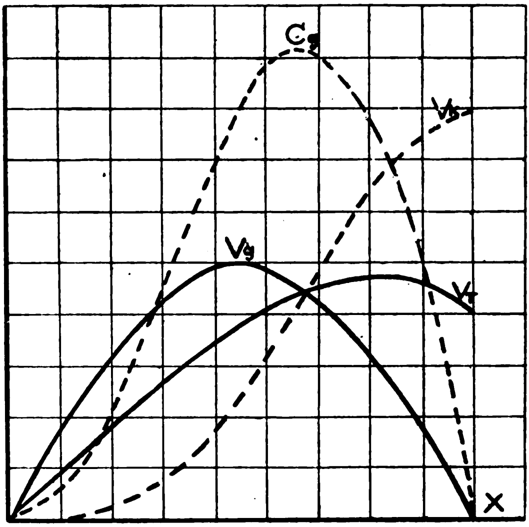


Fig. 111.

As an example of resonance calculation let us take the case of a transmitter in which 1 KW., or 1000 watts, is to be delivered to the primary transformer circuit from a 200 volt alternator whose frequency is 300 cycles per second. Assuming that the sparking is synchronous the sparking rate will be 600 per second, and let us suppose that the energy is to be delivered to a condenser in the transformer primary circuit. The size of the condenser will be given by the formula $W = sKV_K^2$, where W is the watts of energy, s the sparking rate, K the capacity in farads, and V_K the voltage to which the condenser is charged at each half cycle.

Now the maximum value of generator volts $= \sqrt{2} \times 200$, and if the circuit had a resistance much less than 1 ohm, the condenser voltage would be $\frac{\pi}{2}\sqrt{2} \times 200 = 2{\cdot}2 \times 200$, but assuming that the circuit had a resistance of about 1 ohm, the condenser voltage would not be more than $1{\cdot}5 \times 200 = 300$ volts.

Thus :—

$$W = sKV_K^2$$
$$1000 = 600K(300)^2$$
$$K = \frac{10^6}{54{,}000} = 18{\cdot}5 \text{ mfds.}$$

To tune the primary circuit to resonance frequency of 300 the necessary inductance is got from :—

$$L = \frac{1}{(2\pi f)^2 K} = \frac{1{,}000{,}000}{4 \times 10 \times 90{,}000 \times 18{\cdot}5} \text{ hys.} = 15 \text{ millihys.}$$

This inductance would be provided partly by the inductance effects in the generator armature and transformer winding, partly by a tuning inductance coil with iron core connected in series with them.

But the condenser is in the secondary circuit of the transformer, not in the primary, and to find the equivalent capacity in the secondary circuit we have the equation $K_s = \left(\frac{T_p}{T_s}\right)^2 K_p$, where T_p/T_s is the ratio of the transformer windings and therefore the ratio of the transformer voltages.

If T_p/T_s is small, in other words if the secondary voltage is high compared to the primary, the closed circuit condenser will be proportionately small, but the high secondary voltage means great insulation strain and longer spark gap or more gap sections if a quenched gap is used. On the other hand if the step-up of voltage is not great the condenser will have to be large, and the closed circuit discharge currents will be large, necessitating larger spark electrodes and possibly giving more heating trouble. The capacity in the closed circuit will to some extent be governed by the wave length at which it is desired to work, Suppose K_s is chosen to be 0·02 mfd., then $\left(\frac{T_p}{T_s}\right)^2 = \frac{0{\cdot}02}{18{\cdot}5}$ or $\frac{T_s}{T_p} = 30{\cdot}41$ so that the transformer secondary voltage is 6080 volts. If K_s is 0·005 mfd. T_s/T^p will be 61 and the secondary voltage will be 12,200. This question of condenser value has already been discussed in Chap. XIII.

In practice the maximum transformer primary volts may rise to be about 1·9 times the effective volts. The maximum secondary volts will be this multiplied by the transformation ratio, and the voltage at which the condenser will discharge is correspondingly increased.

Resonance Sparking.—When the low frequency circuits of a transmitter are tuned to resonance, as described above, and the spark gap is set so long that a discharge cannot take place at the first half cycle, the voltages and currents will build up in value, so that at the end of three or four pulses the voltage may be of sufficient value to cause a discharge. In the Eiffel Tower Station the primary circuit contains a resistance which just puts it out of resonance and the voltage of the charged condenser is not sufficient to cause a spark. When it is desired to send signals the manipulation of the key shorts this resistance; then the circuit is in resonance, and the voltage and current build up so that at the end of every three cycles the built up voltage breaks down the spark gap resistance. The station is supplied with A.C. energy at 42 cycles frequency, and the sparking rate is not 84 but $\frac{84}{3}$, *i.e.* it is about 28 sparks per second.

It can be seen that resonance effects provide a method of getting a high voltage of condenser discharge, and a high voltage strain in the aerial circuit, without having a correspondingly high transformer ratio. The spark gap length has to be increased, and there are less sparks per second, but the oscillating energy $(\frac{1}{2}KV^2)$ at each spark is increased on account of the resonance built-up value of V.

Faults in Spark Transmitters.—Let us first consider the case of a small transmitter in which the generating circuit consists of a battery, spark coil, and key. If on pressing the key no spark results it is not necessary to look beyond the generating and closed circuits for the fault. The interrupter screw may be screwed back too far and it is not making contact with the trembler so that the primary circuit is broken; the screw may be screwed up so tight that the trembler is held between it and the core of the coil so that interruptions are not possible. The key contacts may be dirty and thus no circuit completed when the key is pressed. There may be a break or disconnection in the battery leads or inter-cell connections. These are the most likely faults and first attention should be paid to them. If in these respects everything is satisfactory the next thing to look to is the closed circuit; the spark gap may be too long, or there may be a disconnection in the leads from the secondary of the spark coil to the closed circuit; if choke coils are used there may be a break in one of them. Try the effect of shortening the spark gap first; if no spark results then look for a disconnection; these are more likely faults than that the condenser or the inductance coil in the closed circuit is broken down.

The contacts of the key should be frequently cleaned with emery paper; in some keys the bar is hinged to the pillar by an iron roller which may get rusty and dirty and so cause a disconnection in the battery circuit; for this reason it is always well to connect the bar to the pillar by a short piece of bare stranded copper wire, attached to each by screws or soldering.

The contacts of the interrupter will get pitted, uneven, and dirty by sparking at bad adjustments; they should therefore be frequently examined, cleaned, and smoothed down by a carborundum file. A good adjustment of the interrupter contacts can be made by watching the aerial ammeter; if the interrupter is sparking badly the secondary volts of the coil will be reduced, decreasing the oscillating energy in the closed circuit, and therefore reducing the oscillating current in the aerial. See that the interrupter is not sparking and adjust it to get best aerial current and a good note.

The spark gap electrodes should be kept clean and polished, for the discharge voltage will be higher and the decrement less between polished electrodes than between dirty ones. The oscillating energy in the closed circuit depends on $\frac{1}{2}KV^2$, therefore on the square of the voltage of charge and discharge. Watch the aerial ammeter and adjust the spark gap to get maximum aerial current, the spark should then be a fat, white one, striking all round the electrodes. If during work the spark begins to fail it is probable that the battery is run down.

If on pressing the key a good spark is obtained but no aerial current is registered it shows that the generating and closed circuits are all right; the fault must then be looked for in the aerial circuit. The most likely one of all is a disconnection ; look to the aerial and earth connections and examine the hot-wire ammeter ; this instrument is very liable to be burnt out especially if worked near the maximum of its scale. It is best to use a hot-wire ammeter on which the normal working current is about half scale current, *i.e.* if the normal aerial current is 2 amperes use an ammeter which is calibrated up to 4 amperes.

If it is suspected that the ammeter is burnt out short the instrument terminals with a piece of cable, and see if sparking now occurs across the earth arrester on pressing the key. Where an earth arrester is not employed connect one end of a piece of insulated wire to earth and hold the other end close to the aerial, then sparking should occur between the aerial and the wire on pressing the key. Do not overlook the fact that the earth or balancing capacity and its connections form one half of the aerial circuit, and therefore these must be carefully maintained.

If there is no sign of any disconnection in the aerial circuit look to the coupling between it and the closed circuit; this may have become too loose and so account for the absence of aerial current.

The tuning of the closed and aerial circuits to a definite wave length will be done with a wavemeter, as shall be described in a later Chapter, but the fact that the aerial is in tune with the closed circuit can be checked by the aerial ammeter. With the coupling fixed the reading on the ammeter will be a maximum when the aerial circuit is tuned to the closed circuit.

When no wavemeter is available the aerial ammeter will help to adjust the coupling. If the coupling is tight a slight mistuning of the aerial will not greatly change the aerial current, but with proper coupling a slight mistuning of the aerial up or down will cause the aerial current to decrease appreciably.

Many of the considerations given above will apply to larger sets, and the student should learn to diagnose faults quickly so as to localise them to the particular circuit of the transmitter in which they are occurring. In the practical examination of students who wish to qualify as wireless operators faults are intentionally put on the transmitters, such as taking out a fuse, or putting a piece of paper between the contacts of the key ; the student should therefore practise himself in diagnosing faults and in thinking out how they will each affect the working; above all he should completely understand the diagram of the circuits.

In dealing with large transmitters the faults which may occur on steam or petrol engines are not within the scope of this book, but we will start with the assumption that the drive is from an electric motor or rotary converter.

To start up the motor the double pole switch connecting it to the mains is first closed and the starting handle pulled quietly over. If the motor does not start when the handle is on the second or third notch the handle must be released, and on no account pulled further over, otherwise the motor may be damaged by an excessive current.

The motor will not start if :—(1) one or both fuses are blown; (2) the brushes are not making contact on the commutator; (3) the field connection is broken, either on the machine, at the starter, or at the field rheostat; (4) the connections of the motor are loose in the starter or the motor terminals; (5) there are loose connections on the motor switchboard panel.

The fault should be looked for in the order given above.

It may be that the motor starts up but attains an excessive speed as the startling handle is pulled over; the starting handle should be at once released, as the field circuit is either broken or connected by mistake in series with the armature.

When the motor starts up all right and attains its proper speed the carbon filament lamp joined across the motor mains should be glowing bright; if it does not glow the lamp should be examined. Either (1) its filament is broken; (2) the glass is punctured so that there is no vacuum; (3) there are dirty or broken contacts in the lamp circuit or at its terminals.

The motor drives the alternator, which should therefore develop its proper voltage, and the carbon filament lamp joined across its armature should be glowing. If the lamp does not glow then :—(1) the lamp or its connections are defective; (2) the alternator's brushes are not bearing on the slip rings; (3) the alternator's field circuit is broken or faulty. Therefore, before proceeding further, look for the possible fault in the above order.

The lamp should first be examined, and, if doubtful, replaced by a new one. If the motor and generator lamps are rated at the same voltage they can be interchanged to see if the good lamp will light across the alternator. If the lamp circuit is not faulty examine the brushes and see that these are bearing well on the slip rings with clean contact surfaces. Then see that the field circuit is not faulty; the field switch, if there is one, may have been inadvertently left open, or connections may have become loose at the switch, at the field rheostat, or at the poles of the machine. If the unit is a rotary converter the field is common to both motor and alternator, hence if in good order for the motor there can be no fault in the field circuit.

If the motor and alternator, or the rotary converter as the case may be, are running properly and both lamps are glowing it is certain that there is no fault in this portion of the apparatus; care of course being taken that the bearings are properly lubricated, and that no oil or dirt is allowed to remain on any portion of the machines. Now if no sparks ensue when the transmitter key is closed the fault must be in the primary transformer circuit, or in the closed oscillatory circuit. First examine the transformer primary circuit: (1) see that the A.C. switch is closed and the fuses have not blown; (2) see that the leads are intact and the contacts good at the transformer primary terminals, at the terminals of the resonance coil, and at the terminals of the transmitter key; (3) see that the leads are joined to the proper terminals of the transmitter key; (4) see that the platinum contacts of the transmitter key are clean and not blackened with dirt or sparking.

When satisfied that the primary transformer circuit is in good order, if the fault still exists examine the closed oscillatory circuit as follows: (1) see that the secondary terminals of the transformer are connected to the choke coils; (2) see that there is no break in the fine wire winding of the choke coils, especially at the terminals; (3) see that the spring connections to the jigger primary have not been inadvertently left open; (4) examine the connections to the condensers and disc discharger; (5) see that the fixed electrodes of the disc discharger have not been moved too far away from the teeth on the rotating disc.

It will be seen from the above that the surge preventing lamps are most useful for locating faults to either the rotating or stationary parts of the transmitter apparatus, though of course there may be simultaneous faults in each part.

If the transmitter is giving poor sparks the most likely causes are: (1) dirty contacts on the transmitting key; (2) spark gaps too long; (3) fixed and disc electrodes burnt away on the leading side, or blackened; (4) fixed electrodes not properly set, so that the spark is not timed for the maximum value of voltage in each cycle.

When the fixed or disc electrodes have been burnt down to an angle at the sparking surface they should be filed to a true surface, and the spark length properly adjusted again by rotating the terminals of the fixed electrodes. If the sparking is still bad the timing of the spark should be *slightly* changed, forwards and backwards, by slightly rotating the ebonite disc on which the fixed electrodes are mounted until a satisfactory spark is obtained. The disc should then be clamped in this position by means of the locking screws, and the angle of position noted on the scale affixed to the discharger.

If the spark is advanced or occurs too soon an arc discharge will take place from the transformer secondary as the voltage passes over the maximum value. The ammeter in the alternator circuit will then show a high reading; this is due to the partial short circuit caused by the thick and arcing spark, while the oscillating energy is really less than it should be.

If the spark lags too much the voltage has passed its maximum value before the spark takes place, hence some of the energy which was stored in the condenser has been already discharged through the transformer secondary and the remainder gives only a weak and ragged spark.

It will thus be seen that timing of the spark is very important, and that a very thick spark is to be avoided as much as a thin one. The only instrument which really shows the conditions of oscillating energy is the aerial hot-wire ammeter.

A change of the timing of sparking should only be done as a last resort, since this is always properly set before the apparatus is delivered by the Marconi Co. Care must always be taken to see that the sparking gaps are not too long; this would expose the dielectric glass of the condensers to risk of puncture, owing to the high voltages which might be set up when no discharge takes place. On a 1½ KW. set the spark gap should be about 3 mms. for a 600 metre wave length.

As regards Telefunken transmitters an important point is that the faces of the quenched spark discs should be kept clean and will probably require polishing every day. It is a good plan to have a spare spark gap unit complete, so that the one in use can be taken out for cleaning and replaced quickly by a clean one.

Another point requiring attention in Telefunken transmitters is the plug and socket connections; the sockets are liable to accumulate dust and should be frequently cleaned.

QUESTIONS AND EXERCISES.

1. What is the difference between a synchronous and an asynchronous sparking rate ? Which is the most suitable for (*a*) low voltage high frequency, (*b*) high voltage low frequency supply to the closed oscillating circuit ?

2. What is meant by saying that the oscillations in the closed circuit of a transmitter build up by resonance ? When would such an effect be employed advantageously.

3. What determines the suitable capacity of the condensers in the closed circuit of a transmitter ?

4. In a motor driven transmitter what are the indications that (*a*) the main key contacts are dirty, (*b*) that something has upset the proper tuning of the aerial and closed circuits, (*c*) that the sparking is too much retarded ?

5. A spark transmitter delivers 2 KVA to the closed circuit at a secondary transformer voltage of 20,000. If the wave length is 600 calculate suitable values of condenser and inductance for the closed circuit ; also say what would be a suitable alternator to employ.

CHAPTER XVI

AERIALS, INSULATORS, AND EARTH CONNECTIONS

An aerial consisting of only one vertical wire is rarely used, except for experimental purposes or small stations. It was soon discovered that the aerial must have capacity to enable it to store oscillating energy before radiation commences, and incidentally serve for tuning purposes; thus, quite early in the development of wireless telegraphy we find Sir Oliver Lodge advocating the use of a horizontal network of wires at the top of the aerial, and in Marconi's early experiments, on the voyage of the *Carlo Alberto* to the Baltic, the aerial consisted of a number of vertical wires, suspended in the shape of a fan from a support stretched between two masts. When the Marconi Station at Poldhu was first opened the aerial consisted of 400 wires, supported in the shape of an inverted pyramid from four steel towers.

In 1905 Marconi patented his horizontal directional aerial, and, as he himself said before the Marconi Agreement Committee (1913), the real progress in long-distance transmission dated from this development. A simple vertical wire or symmetrical system of wires radiates energy equally in all horizontal directions, and, as regards reception of energy such a system would be equally effected by energy arriving from any direction. Marconi discovered that if from the top of the vertical aerial horizontal wires were stretched backwards the amount of energy radiated was greater in a forward direction than in any other. To a certain extent the signals by this means could be directed, or at least strengthened, in a selected direction, thus ensuring greater reliability and enabling greater distances to be covered in that direction. Similarly, at the receiving station, if horizontal wires are stretched *backwards* from the top of the vertical portion of the aerial ether waves coming from the forward direction will affect the receiving apparatus more than those coming from any other.

In 1906 Marconi described his experiments with a directional aerial; using a vertical receiver aerial with a Duddell ammeter to measure the received currents he proved that the distribution of radiated energy from a directional aerial can be depicted as in the polar diagram of Fig. 112. It was clearly a maximum in the direction opposite to that in which the free end of the aerial pointed.

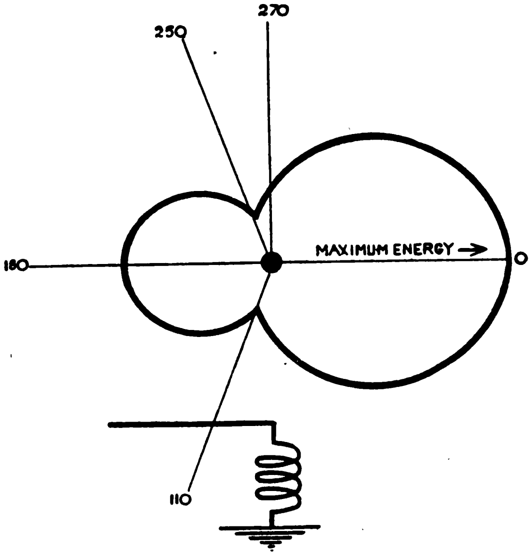


Fig. 112.

Professor Zennick has shown that, since the electric strain lines in the ether travel along the earth or sea which are of comparatively high resistance, the lower ends are retarded by this resistance, so that the upper parts of the waves become inclined forward, and when they reach the receiving aerial the wave front

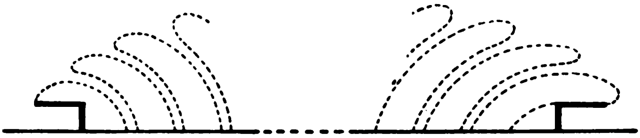


Fig. 113.

has a large horizontal component; therefore an aerial which has a horizontal portion coincides best with the received wave front.

According to this explanation Fig. 113 illustrates the effect of directional aerials at the transmitter and receiver ends.

It is seen that a directional aerial is a good radiator of energy in one direction and a good absorber of ether strain energy arriving from the opposite direction, so that the same aerial can be employed for both transmission and reception.

Design of Aerial.—Besides directional effect, and the question of having an aerial natural wave length which is efficient, the following main considerations enter into the design of an aerial:—

(1) The range of transmission, or the energy radiated, depends on the $(\text{height})^2$ for a given aerial current, and the energy received by it, or absorbed, depends also directly on the height. Increasing the height of a transmitting aerial may reduce its capacity and therefore the aerial current for a given induced voltage, but the increase of radiation effect will preponderate.

(2) An aerial designed to radiate slowly, *i.e.* to radiate small amounts of energy at each oscillation of current in it, will have a small damping decrement, with more oscillations per spark, and give sharp tuning effects at the receiver. A vertical wire is a quick radiator with comparatively large damping decrement; an umbrella aerial is a slow radiator.

(3) The greater the capacity of the aerial the less will be the maximum voltage strain on its insulation for a given aerial current, spark frequency, and wave length. The capacity is increased by having two or more aerial wires in parallel.

(4) High frequency or oscillating currents are not uniformly distributed over the cross-section of a wire but are most dense on the surface; therefore to keep the high frequency resistance low the wires should be stranded and the surface ample. The Marconi Company use bronze wires woven over a flexible core of non-conducting material. This increase of surface area also decreases loss caused by brush discharge.

(5) The greater the capacity of the aerial the more energy it will take from the closed circuit for a given voltage strain on the aerial insulation. In other words, if the aerial capacity is increased the primary energy may be decreased and yet the same amount of energy will be oscillated in the aerial for a given voltage strain (see Chap. XIII.). This consideration is important in the design of large transmitters, since it means that the size of the aerial and the size of the power plant should be chosen to give the most economical conditions.

(6) If wires connected in parallel are placed too close together the mutual inductive effect between the wires will keep the capacity value lower than it otherwise would be.

There are three general types of modern aerials, respectively known as the L, T, and Umbrella types; they are shown diagrammatically in Fig. 114.

The L type may consist of one wire arranged as a Marconi directional aerial, or it may consist of two or more such wires in parallel to give increased capacity effects for transmission. The length of an L type aerial is the length of one of its wires from the free end to the aerial terminal. Fig. 115 shows a four-wire L type aerial on a ship, arranged so that only half the capacity of the aerial may be used if found desirable. If one end of the aerial is higher than the other the leading down wire should be taken from the higher end.

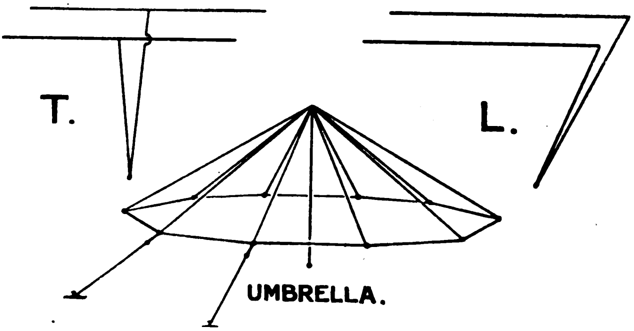


FIG. 114.

The outer ends of the wires comprising an L type aerial are generally insulated from each other.

A T type aerial is not much employed on land stations but is frequently fitted to large ships where the distance between the masts is comparatively great. The leads down should be taken from the electrical centre of the aerial, that is to say if the wires are exactly horizontal the leads down should be taken from the centre of each wire, but if the wires are higher at one end than the other the leads should be taken from points nearer the lower ends. This ensures that the capacities of the two halves of the aerial will be exactly equal, otherwise the natural wave lengths of the two halves will be different. Usually the T aerial is horizontal; its electrical length is the length from one end to the centre added to that of the down lead to the apparatus; the natural wave length is then about 4·5 times this aerial length.

If a ship has to transmit on a 600 metre wave length its aerial should have a natural wave length of at least 150 metres and more than this if possible; when the distance between its masts is not very great an L type must be adopted to get the necessary aerial length, but if the distance between its masts is great a better value of aerial natural wave length may be obtained by using the T type. Thus on torpedo-boat destroyers L type aerials with as many as 8 or 10 wires in parallel are seen, but on trans-atlantic liners the T type is most usual. Fig. 116 shows a good example of a T aerial.

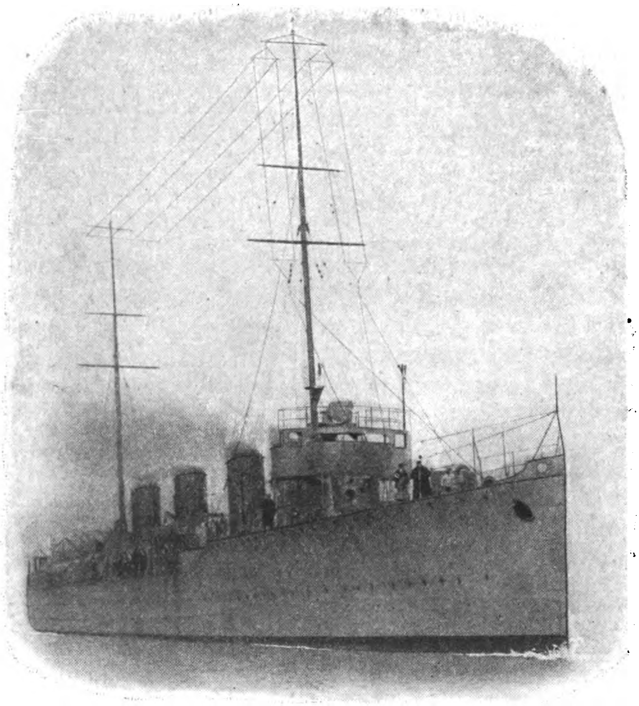


FIG. 115.—Torpedo-boat Destroyer *Almirante Lynch*. Telefunken L Aerial.

The Umbrella aerial has the advantage over L and T types of only requiring one main supporting mast or tower, to which the aerial wires act as top guys. It consists of four or more wires arranged symmetrically like the spokes of an umbrella, all connected in parallel to a conducting ring which is insulated on the top of the mast and from which a down lead is taken to the instruments. The outer ends of these wires are tied through insulators to strain ropes or wires anchored to the ground.

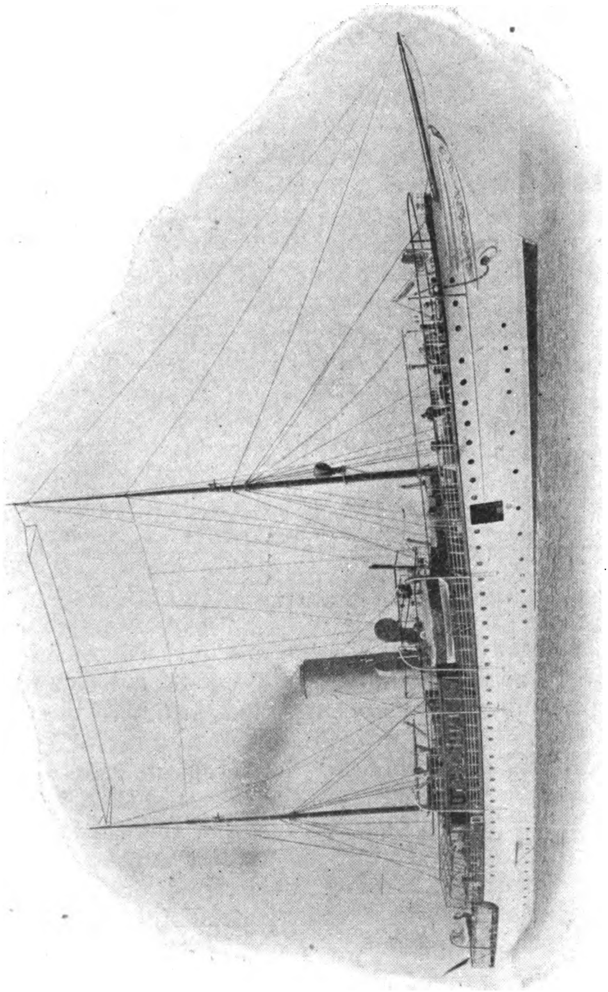
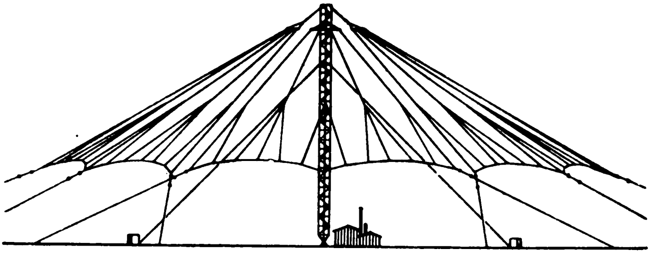


FIG. 116.—S.Y. *Mekong*. Telefunken T Aerial.

The effective length of an umbrella aerial is the distance measured from the centre of one rib wire to the top and then down the lead-in wire to the aerial terminal. Owing to the fact that the wires approach the earth the capacity effect is greater than if they were stretched horizontally at the height of their top ends: for this reason the natural wave length of an umbrella aerial may be as much as 8 times its effective length.

A good example of umbrella aerial was that erected originally at the large station at Nauen near Berlin, and of which a diagrammatic illustration is given in Fig. 117. It was supported on a girder steel mast, 900 feet high, which was insulated from its concrete base and could be raised or lowered on a ball and socket bearing. This original mast collapsed and in the new equipment of the station there are at least two large aerials each 891 feet high.

The range of this station when transmitting was said to be 4000–5000 miles before valve detectors and amplifiers came into general use. Many Telefunken stations in South America, with a range over land of 200 kilometres to crystal detector receivers, used similar umbrella aerials supported on lattice masts about 45 metres high.



AERIAL AT NAUEN STATION NEAR BERLIN.

FIG. 117.

Experiment has shown that the reception efficiency of an umbrella aerial is increased by raising the ribs, that is to say by increasing the angle between the ribs and the central support; such increase will also increase the radiation of energy at each oscillation. For this reason large modern stations which employ umbrella aerials have the outer ends of the ribs raised on supporting masts; thus the new Japanese station at Funabashi has a central lattice-work steel mast, over 650 feet high, and a ring of smaller masts of the same design, each 260 feet high, for supporting the outer ends of the ribs of the umbrella aerial. All the masts rest on ball and socket joints supported on concrete foundations, from which they are insulated by heavy porcelain insulators.

Comparing the different forms of aerials, the umbrella type is most convenient for portable stations while its radiation coefficient is less than that of any other form, especially if its ribs approach the ground. In other words it is a slow radiator, therefore aids close tuning. As Sir O. Lodge explained it the charge has to rise up the vertical wires before it falls down the ribs, so that it fails to exert its full magnetic force at a distance and conserves some energy which it might radiate; thus its radiation coefficient is comparatively small. At the same time the fact that the oscillations are not too quickly damped out by radiation means that it will oscillate at a pure wave length more persistently, and hence it will require sharper tuning at the receiving station, a condition which is favoured by the Telefunken Company. With the damped oscillations which are obtained from an ordinary spark discharge such an aerial would perhaps be best if very sharp tuning is desirable, but with undamped oscillations or feebly damped oscillations, such as are obtained from a quenched spark or rotating disc discharge, the natural oscillations will be persistent enough for sharp tuning purposes without curtailing the amount of radiated energy. Also the sharp tuning given by an umbrella aerial may be more than counterbalanced, as far as range is concerned, by the directional effect which an L type aerial would give.

The umbrella aerial requires more height than others for a given range, and requires also a larger area of flat land accessible around it for earthing purposes. If the tower is 100 feet high then earthing ground embraced in a circle of 800 feet should be accessible all round it. It is a cheap aerial to construct, the rib wires themselves acting as stays to the mast.

The fan aerial has good radiating properties; the L and T have not, perhaps, as high a radiation coefficient, but they have a certain amount of selective direction property which increases their efficiency as radiators. The T type is particularly suitable for ship work, though if the distance between the masts is not great enough the L type has to be used in order to get a sufficiently long natural wave length.

It can be shown that in a transmitter aerial the damping of oscillations due to radiated energy and ohmic resistance loss is least when the aerial is tuned to radiate a wave length twice the natural wave length of the aerial alone, and *when the radiated wave length is 1½ times the natural wave length of the aerial the ratio of the energy radiated to that wasted in ohmic resistance loss is a maximum.* Thus for best radiation efficiency and fairly low damping the aerial should be of such a size that its natural wave length is about two-thirds of the wave length of radiation.

Aerial Height and Ground Aerials.—It will be remembered that one of the earliest discoveries of Marconi was that the range of signalling increased with the heights of the aerials used; the range is proportional to the square of the height when this is the same at both transmitter and receiver, otherwise it is proportional to the product of the heights of the two aerials as shown elsewhere in this Chapter. It is a mistake to increase the height too much for two reasons: first, the necessary towers or masts will be very expensive both in initial cost and subsequent upkeep; second, the higher a receiver aerial the more interference is likely to be encountered from Xs or strays. The atmosphere is always more or less electrically charged, and the potential in the air with respect to the earth rises rapidly with the height, so that an aerial 400 feet high may easily be in a region of 10,000 or 12,000 volts potential and thus liable to frequent static discharges to earth. For this latter reason receiver aerials should only be moderately high, and in any case the perfection of valve reception apparatus makes high aerials unnecessary for long-range work. An indoor coil may even replace the aerial for reception over fairly long ranges.

The fact that signals can be received on an aerial of insulated wire laid directly on the ground led Somerfield to conclude that the signals were carried chiefly by surface waves, propagated along the boundary between the earth and the air. We have noted that oscillating currents and potentials are induced in the surface of the earth over which the feet of the waves travel, that indeed signals can be picked up over fairly long ranges on delicate valve apparatus by connecting it to two points on the earth surface, say 100 feet apart, which are likely to have different potential values at any moment when waves are sent out. Yet surface waves cannot be the only factor which makes reception possible, as demonstrated by the fact that commercial signalling is now possible between England and Australia.

Much experimental work has been carried on with ground aerials consisting of two lengths of wire connected to the transmitter or receiver terminals and pointing, one backwards—the other forwards, in the direction of desired propagation or reception; the lengths of the wire being chosen to give a maximum of current at the centre. The results on the whole have been disappointing, and in reception the interference from strays was not reduced, because atmospheric discharges are accompanied by earth potential changes which cause induction in the ground aerials. The development of valve apparatus has made it possible to receive signals on a simple coil of wire over long ranges from high-power stations, and even to transmit from a loop of moderate height, so that the application of ground aerial working has largely disappeared and it does not appear necessary to devote further space in discussing it.

Aerial Capacity.—On the capacity value of an aerial will depend its natural wave length, also the aerial maximum voltage and the power required to signal over a given range.

The formula for the capacity of a vertical wire far removed from earth conductors is :—

$$K = \frac{l}{\left(4{\cdot}6052 \log \frac{2l}{d}\right)900{,}000} \text{ mfds.}$$

where $l =$ length in cms.
and $d =$ diameter in cms.

But a vertical aerial wire does not come under the condition stated for one end of it is close to the earth. If it is positively charged there will be a negative charge on the surface of the earth around it, which will have the same effect as if the earth were replaced by another wire of the same size negatively charged. The vertical aerial wire corresponds to one side of a Hertz oscillator, and the earth surface to the other side. The opposite charge on the earth's surface constitutes what is called the electrical image of the wire ; the potential of the wire will depend partly on its own charge, partly on the effect of the charge of opposite sign on the electrical image near it which has the effect of reducing its potential (V) for a given charge (Q). Since capacity (K) $= \frac{Q}{V}$ we see that if any part of a charged wire is brought near the earth its potential is decreased and its capacity increased.

Taking this into account the capacity of a vertical wire with one end near the earth can be shown to be equal to :—

$$K = \frac{l}{\left(4{\cdot}6052 \log_{10} \frac{2l}{d} - 1{\cdot}72\right)900{,}000} \text{ mfds.}$$

Roughly the proximity of the earth increases the capacity by from 8 to 10 per cent. in practical cases with aerials.

The capacity of a single horizontal wire, l cms. long and d cms.

diameter, parallel to the earth surface at a height h cms. above it, is :—

$$K = \frac{l}{4{\cdot}6052 \log \frac{4h}{d} \times 900{,}000} \text{ mfds. approx.}$$

If two wires are placed parallel to each other and connected in parallel they should be at such a distance apart that there is no mutual inductance effect between them when oscillating currents are flowing in them; otherwise their combined capacity effect will be reduced.

If L_ϵ is the effective inductance in cms. per cm. of a wire, and K = its capacity in cms. per cm., then $L_\epsilon K = \frac{1}{v^2}$, where v = velocity of a high frequency wave propagation along the wire and is a constant; thus the smaller the inductance effect can be made the greater the capacity, and *vice versa.*

Now when two equal and current carrying wires are placed near each other the effective inductance of the system is $\frac{L+M}{2}$ where L = the inductance of one wire and M is the mutual inductance of the other wire on it. But $L = 4{\cdot}6052 \log\left(\frac{2h}{r} - 1\right)$ cms. per cm., and $M = 2{\cdot}303 \log \frac{4h^2}{d^2}$ cms. per cm.; h being the height of the wires above earth, d their distance apart, and r the radius of the wire, all measured in the same units. It is seen that by increasing d we decrease M, decreasing therefore the total inductive effect with a consequent increase of capacity effect.

The necessary distance between the wires in an L or T aerial will depend on the strength of the aerial current and the number of wires used; the more the aerial current is divided up among a number of wires the less there will be in each one, consequently they may be placed closer together without giving serious inductive effect.

Where two wires are used the standard distance apart for ship installations is 12 feet; if the aerial consists of six or eight wires they may be placed parallel to each other in the same horizontal plane, or spaced round the periphery of wooden hoops fixed at intervals along their lengths.

As many as ten wires are often used, in which case they are generally stretched parallel to each other in a horizontal plane and spaced about 2 feet apart. If such an aerial has 100 feet of horizontal length on top and 80 feet of vertical length in the lead down its capacity would be about 0·001 mfd.; this would be increased by about 15 to 20 per cent. if the spacing between the wires were increased to 6 feet.

In ship stations there are comparatively large inductance effects which can be avoided in land aerials; thus the capacity of a ship's aerial will generally be less than that of a similar one at a land station. However this is more than compensated for, as far as required energy is concerned, by the good transmission effects over sea water.

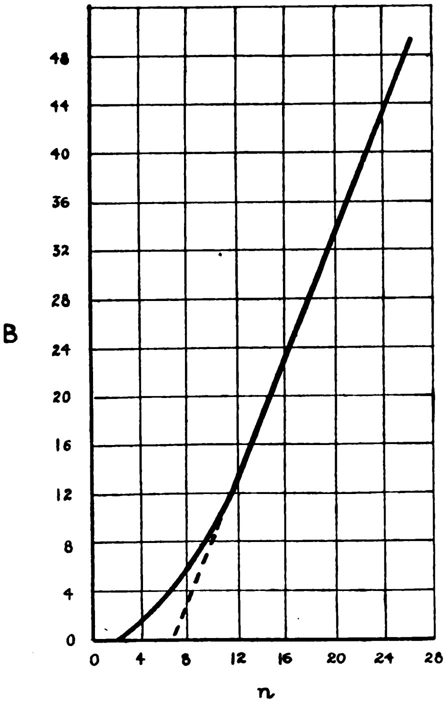


Fig. 118.

Prof. G. W. O. Howe has given a very accurate method of calculating the capacity of multiple-wire aerials, in articles published in the *Electrician*, 1914, and in the *Wireless World* of October and November, 1916. He assumes that the charge is uniformly distributed over the whole aerial, and taking this to be unit charge per cm. length, he calculates the average potential under these conditions. This average potential differs very little from the actual potential of the aerial at every point when the total charge has its own natural distribution in it. Howe obtains for the average potential the formula :—

$$V_{av} = 2n\left(\log_\epsilon \frac{l}{d} - 0{\cdot}31\right) + 2\log_\epsilon \frac{d}{r} - 2B$$

where l is the length of each wire, d their distance apart, r the radius of each wire, all in the same units, and B is a constant, given by the curve in Fig. 118, whose value depends on the number of wires, n, in the aerial.

He then calculates the effect on the potential of the charges of opposite sign induced on the surface of the earth, in the mast, and in neighbouring conductors such as walls and houses. Suppose an aerial consists of a horizontal portion AB and a vertical portion BC; the positive potential of the horizontal portion of the wire AB is mainly due to its own positive charge, but this potential is increased by the proximity of the positively charged wire BC and decreased by the induced negative potential of the earth partly due to its own charge, *i.e.* its own image, and partly to the positive charge on the vertical wire, *i.e.* the image of the vertical wire. The potential is also reduced by the induced negative potential on the mast and other neighbouring conductors.

Taking into account all these effects the potential of the portion AB is calculated, as is the potential of CB in a similar manner; the average potential of the whole wire:—

$$V = \frac{V_{AB} \times Q_{AB} + V_{BC} \times Q_{BC}}{Q_{(AB + BC)}}$$

$$= \frac{V_{AB} \times \text{length of AB} + V_{BC} \times \text{length of BC}}{\text{Total length}}$$

The total charge Q on the wire, with one unit per cm. length, is given by the total length of the wire in cms.; then

$$K = \frac{Q}{V \times 900{,}000} \text{ mfds.}$$

The image of the horizontal portion of the aerial reduces its potential by an amount which can be calculated from the formula:—

$$V = 2(\sinh^{-1}\frac{l}{2h} + \frac{2h}{l} - \sqrt{1 + \frac{4h^2}{l^2}},$$ where h is its height and l its length, both measured in the same units.

This method is rather complicated and for a first approximation of the capacity of a multiple-wire aerial the following formula due to Howe may be employed:—

$$K = \frac{16{\cdot}94n}{n\left(\log_\epsilon \frac{l}{d} - 0{\cdot}31\right) + \log_\epsilon \frac{d}{r} - B} \text{ mfds. per foot}$$

increasing this by about 10 per cent. to allow for earth and mast effects with ordinary L or T aerials. To enable calculations to be made quickly Prof. Howe has published (in the above-mentioned articles in the *Electrician* and *Wireless World*) tables and curves from which the capacity per ft. span of aerial can be obtained.

In practice wireless engineers are generally guided in designing aerials to have a given capacity by their knowledge of the known capacity of similar existing aerials, determined by actual measurements under transmitting conditions. Methods of measuring the effective capacity of an aerial will be given in a later Chapter; for the present a few examples will be given of the capacities of existing aerials.

The Eiffel Tower aerial consists of six wires each 7 mms. in diameter and 330 metres long, stretched from the top of the Tower fan-shaped to guys anchored to the ground, the average distance between the wires being about 22 metres. The capacity of this aerial is about 0·0073 mfd. Howe calculates that the capacity of the aerial considered alone is 0·00562 mfd., that this is increased 22·7 per cent. by the proximity of the earth, and increased again 9 per cent. by the proximity of the Tower.

The capacity of an L type aerial consisting of two Marconi stranded cables 10 feet apart, 70 feet high, and 450 feet horizontal length, is about 0·00175 mfd. The capacity of a single wire receiver aerial 284 feet long, supported at one end on a chimney 150 feet high, and at the other end on an entering insulator 8 feet high, was found to be about 0·00517 mfd. The lower end of this aerial stretched over some low buildings.

The capacity of a receiver aerial 380 feet long and 142 feet average height, consisting of two single wires 12 feet apart, was found to be about 0·001375 mfd. The capacity of an aerial 70 feet high and consisting of two wires 10 feet apart is about 3·3 micro-mfds. per foot, and its inductance about 16·4 cms. per foot.

If an aerial consists of twelve wires, each No. 10 S.W.G. and 1440 feet horizontal length, the wires being spaced 4 feet 6 inches apart, its capacity will be about 0·0045 mfd., as calculated by Howe's method, without taking account of earth and mast effects and of the capacity of the leading in wires. These will depend on the height of the aerial and will probably bring the capacity to over 0·005 mfd.

If the aerial capacity is made too great the inductance turns necessary to tune it to the correct wave length will have a low value; this may lead to an inefficient loose coupling between it and the closed oscillatory circuit.

Brush Discharge from an Aerial.—If the maximum voltage induced in an aerial wire is too great a direct discharge will take place from the aerial into the atmosphere; this will represent a loss of, or waste of, the oscillating energy, and has the same effect as if the ohmic resistance of the aerial had been increased. The limiting voltage depends on the surface area of the aerial wire or wires, therefore brush discharge can be minimised and high voltages used if the aerial consists of copper wires plaited over hemp or other insulating material as made by the Marconi Company. At large stations it may occur, under certain conditions of the atmosphere, that the aerial wires show up on a dark night with a phosphorescent glow when transmission is taking place: this is caused by brush discharge radiation or loss.

Natural Wave Length of an Aerial.—The natural wave length of an aerial is difficult to calculate because its oscillating potential distribution is complicated by the effect of induced potentials in the earth, masts, and other conductors near it; as already explained in the previous section these induced potentials increase the aerial capacity and therefore increase its wave length.

Suppose we have a very thin wire arranged as a plain aerial with a spark gap near the earth connection, and let us assume that its capacity and inductance are each uniformly distributed along it. When charged by a difference of potential V volts acting across the spark gap the earthed end will be at zero potential and the potential will rise through the full difference of potential along the wire so that the other end is at a potential of V volts. There will thus be a rise of potential all along the wire, the top having a maximum potential strain to earth. This condition is shown in Fig. 119 (*a*) by the dotted line at the right hand side; there is a node of potential at the earth connection and an antinode at the free end. Suppose the wire to be charged negatively, when the discharge takes place the charge flows down the wire and across the gap; the current flow starting with zero at the top of the wire gathers more units of charge as it descends until there is a maximum of current at the bottom flowing to the earth. Thus there is a node of current at the top of the wire and an antinode at the earthed end; just the opposite to the potential effect. The length of the wire represents therefore a quarter of a cycle of potential of current change, and during the time the current or potential goes through a complete cycle the disturbance in the ether traverses through it one wave length. Thus the length of the wire (l) represents one quarter of the wave length radiated, or $\lambda = 4l$. If K is the distributed capacity of the wire and L its distributed inductance, measured respectively in mfds. and cms., then the time taken for the current to make a complete oscillation is $\frac{\sqrt{LK}}{5\cdot033 \times 10^6}$ second, and the wave length of radiation is $59\cdot6\sqrt{LK}$ metres. Thus $\lambda = 4l = 59\cdot6\sqrt{LK}$.

In practice the wire is not very thin and the induced charges

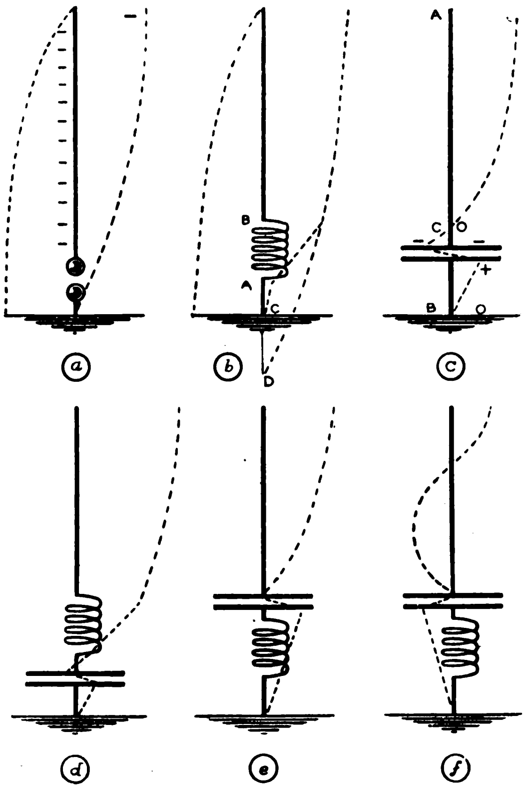


Fig. 119.

on the earth and other conductors near it lower its average potential and increase the value of K, so that the wave length is more than four times the length of the wire. For a plain vertical wire it will be from $4\cdot2l$ to $4\cdot5l$, and for a fan of vertical wires it will be about $5l$.

In practice also the aerial will not have a spark gap near the earth connection but a coupling coil, and possibly a tuning coil, in which the inductance effect is artificially increased, as it were, by changing a portion of the aerial from a straight wire to turns of wire. It may also have a condenser connected in series with it. With artificial inductance effect added to the aerial the distribution of potential along the wire will be as shown in Fig. 119 (*b*); there will be a concentrated difference of potential across the coil AB owing to its concentrated inductance effect; starting from zero potential at the earth connection there is a small change of potential to the bottom of the coil then a great change across the coil, and then the potential rises to a maximum value (which may be positive or negative varying with the oscillations), at the top of the aerial.

The length of the aerial from the earth to the top does not represent the full quarter wave of potential change, to complete which the length CD in Fig. **119** (*b*) has to be added; thus the wave length is no longer $4l$, (or rather $4{\cdot}2l$–$4{\cdot}5l$), but has been increased by the increased inductance effect. It is also clear that an increase of L in the formula $59{\cdot}6\sqrt{LK}$ increases the wave length.

Now if L_A is the distributed inductance of an aerial and K_A its distributed capacity, and if we add in series with it a coil of inductance L_x, it is not correct to assume that the wave length has been changed from $59{\cdot}6\sqrt{L_A K_A}$ to $59{\cdot}6\sqrt{(L_A + L_x)K_A}$. L. Cohen, in the *Electrical World*, January, 1915, has shown that the correct wave length in this case is obtained from the formula:—

$$\lambda = k \times 59{\cdot}6\sqrt{L_A K_A}$$

where k is a constant whose value depends on the ratio of L_x to L_A. The value of this constant can be obtained experimentally by measuring the wave length of the unloaded aerial and its wave length when the coil of inductance L_x is connected in series with it. Dr. W. H. Eccles has given approximate values of the constant; these are quoted in a succeeding paragraph.

If a condenser is connected in series with the aerial the effect will be as shown in Fig. 119 (*c*); suppose for example that the potential at any moment is positive at the top of the aerial; it is zero at the earth connection and rises a little to the bottom plate of the condenser which is therefore slightly positive. The plates of a charged condenser are of opposite sign, therefore the top plate must have a negative potential, and from that the potential rises along the wire to a positive maximum at the top. The effect is seen to shorten the quarter of the natural wave length from AB to AC.

If a condenser is connected in series with the aerial and a coupling coil, which may also include a tuning coil, the condenser will usually be below the coil in transmitter work, and the potential gradient for this case is shown in Fig. 119 (*d*); again the effect of the condenser is to shorten the fundamental wave-length.

Dr. W. H. Eccles has given the following approximate formulæ for the fundamental wave length (λ) of a simple vertical wire aerial:—

(*a*) Thin vertical wire alone $\lambda = 4{\cdot}2 \times$ length.

(*b*) Wire with coil of inductance L in series, the distributed inductance of the aerial being L_0:—

1. When L is greater than L_0 the new wave length

$$\lambda_1 = \lambda \times \frac{\pi}{2}\sqrt{\frac{L}{L_0}} \times \left(1 + \frac{L_0}{6L}\right)$$

2. When L is less than L_0:—

$$\lambda_1 = \lambda\left(1 + \frac{L}{L_0}\right)$$

This case rarely occurs.

(*c*) Wire with a distributed capacity K_0 and a condenser K in series:—

1. When K is greater than K_0,

$$\lambda_1 = \lambda\left(1 - \frac{4K_0}{10K}\right)$$

2. When K is less than K_0,

$$\lambda_1 = \frac{\lambda}{2}\left\{1 + \frac{K}{K_0} - \left(\frac{K}{K_0}\right)^2\right\}$$

If a condenser and inductance coil are formed into a closed circuit and this circuit is found to have a wave length equal to that of an aerial system, when the condenser, coil, and aerial are all connected in series the fundamental wave length of the combination is the same as that of the aerial alone. This case is shown in Fig. 119 (*e*).

Harmonic oscillations of higher frequencies may be set up in an aerial at the same time as the fundamental one; thus it may radiate energy on wave lengths which are one-third, one-fifth, etc., of the fundamental wave length. In reception an aerial tuned to a short wave length may receive signals from a long wave station because it is responding to, or in tune with, a harmonic wave length of the transmitting station. Thus Fig. 119 (*f*) shows an aerial circuit which is the same as that at (*e*), but the potential strain depicted is that due to a harmonic which is one-third the wave length, or three times the frequency, of the fundamental shown at (*e*).

An interesting case occurs when it is desired to tune down an aerial of long wave length to pick up signals on a very short wave length. For example, suppose an aerial with its necessary coupling coil has a wave length of 3000 metres, and it is desired to pick up signals on 600 metres. A variable condenser is connected in series with the aerial, but when the value of the condenser is decreased to zero the fundamental wave length will still be greater than half the fundamental wave length of the aerial alone. However, the condenser may be so adjusted that the third harmonic (or first overtone) is 600 metres, in which case the aerial will radiate or receive energy on that wave length. This will occur when the values of the capacity and inductance are such that if they are formed into a closed circuit the wave length of this circuit is 600 metres; the third harmonic of the condenser, inductance, and aerial in series will then be 600 metres.

In practical wireless engineering the radiation wave length of an aerial circuit and the fundamental, or natural, wave length of an aerial are very seldom calculated but are measured by means of a wavemeter. The above considerations and formulæ are therefore only discussed in order that the results which occur in practice may be understood. Experimental methods of measuring the capacity, inductance, and natural wave length of an aerial are given in Chapter XXII. Before leaving the question of aerial wave length it is to be noted that if two aerials have the same natural wave length the addition of the same amount of inductance to each, in the form of a loading coil, does not necessarily increase the fundamental wave length of each by the same amount. One aerial may have a greater capacity than the other but they may have the same wave length if $L_1K_1 = L_2K_2$; *the aerial with the greatest capacity will have its fundamental wave length more increased than the other by the addition of an inductance* L.

Radiation Resistance and Total Resistance of an Aerial.— If a current of C amperes flows through a resistance of R ohms the energy turned into heat in the resistance is C^2R watts. In an aerial circuit if C is the effective value of the oscillating current and R is the ohmic resistance of the aerial circuit then C^2R watts represents energy wasted in heat in the circuit. When oscillations are set up in a transmitter some energy is radiated into the ether and Rüdenberg has shown that this energy can be represented by the formula :—

$$\text{Watts radiated} = C^2 \times A\frac{h^2}{\lambda^2}$$

where C is the effective value of the current, h the average height of the aerial and λ the wave length of radiation, both measured in the same units, and A a constant whose value depends on the design of the aerial. For a plain vertical aerial, earthed through a spark gap, A is 640; for a simple vertical aerial with tuning coil A is about 400; for an umbrella aerial it is approximately 1600;[1] for an L or T aerial it is usually taken as being about 1600, assuming that most of the capacity effect is in the horizontal portion of the aerial at the top.

The coefficient of C^2 in the above formula might be called the radiation coefficient, but it is more usual to speak of radiation resistance, which we might denote by R_r. Thus the watts radiated is the square of the effective current in amperes multiplied by the radiation resistance, *i.e.*

$$C^2R_r = C^2 \times A\frac{h^2}{\lambda^2}, \quad \text{or } R_r = A\frac{h^2}{\lambda^2} \text{ ohms};$$

that is to say for all the usual types of aerials radiation resistance is equal to $1600 \frac{h^2}{\lambda^2}$ ohms approximately; the more correct value of A being 1585. In the above formula C *is the current as read on a hot-wire ammeter at the base of the aerial;* the current at the base is always a maximum value of current and the hot-wire ammeter reads the effective value of this current.

It is to be noted that the energy radiated does not depend only on the strength of the current oscillating in an aerial; the current in one aerial may be greater than that in another but the second may radiate the most energy on the wave length chosen because it is higher. For a given current and wave length the energy radiated depends on the square of the aerial height; for

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[1] For an umbrella aerial the effective height is the distance from the ground to the mean centre of the ribs.

a given height of aerial and wave length the energy radiated depends on the square of the effective aerial current at the base.

Suppose an aerial is 100 feet high and radiating on a wave length of 600 metres, or 2000 feet approximately, then its radiation resistance is $1600 \frac{100^2}{2000^2} = 4$ ohms approximately. This will probably be greater than the ohmic resistance of the aerial; the radiated energy is greater than the ohmic loss and has a greater effect in damping the oscillations of the aerial current.

The *total resistance of an aerial* takes account not only of the radiation and ohmic losses but also losses of energy due to induced currents in the earth around, and in neighbouring masts, steel guys, or other conductors. The total aerial resistance will depend on the oscillation frequency, *i.e.* on the wave length, and Fig. 120 shows a curve given by Dr. L. W. Austin for the resistance of a ship's aerial at different wave lengths.

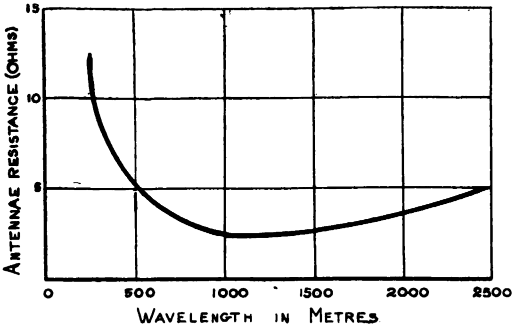


Fig. 120.

It is seen that in this case the total aerial resistance may be as low as 2½ ohms on a wave length of 1000 metres; of this total resistance the ohmic resistance can be kept very small owing to the good connection between the steel ship and the sea and the good conductivity of the sea water.

The resistance of a receiver aerial circuit will be much higher than that of a transmitter; for example the tuning and coupling coils are wound of finer wire, and the resistance value will be from 20 to 30 ohms in the case of a ship's aerial.

The following tables of radiation resistance for flat-topped or T aerials were published by Dr. L. W. Austin in the *Journal of the Washington Academy of Science,* November, 1911.

λ metres.	h = 40 ft.	h = 60 ft.	h = 80 ft.	h = 100 ft.	h = 120 ft.	h = 160 ft.
	ohm.	ohm.	ohm.	ohm.	ohm.	ohm.
200	6·0	13·4	24·0	37·0	54·0	95·0
300	2·7	6·0	10·6	16·5	23·8	42·4
400	1·5	3·4	6·0	9·3	13·4	23·8
600	0·66	1·5	2·7	4·1	6·0	10·6
800	0·37	0·84	1·5	2·3	3·4	6·0
1000	0·24	0·54	0·95	1·5	2·1	3·8
1500	0·106	0·24	0·42	0·66	0·95	1·7
2000		0·134	0·24	0·37	0·54	0·95
2500			0·15	0·24	0·34	0·61
3000			0·106	0·17	0·24	0·42
4000			0·06	0·093	0·134	0·24

λ metres.	h = 200 ft.	h = 250 ft	h = 300 ft.	h = 450 ft.	h = 600 ft.
	ohm.	ohm.	ohm.	ohm.	ohm.
600	16·4	25·8	37·4	84·0	149·0
800	9·2	14·5	21·0	47·0	84·0
1000	6·0	9·3	13·5	30·0	54·0
1500	2·6	4·1	6·0	13·4	24·0
2000	1·5	2·3	3·4	7·5	13·4
2500	0·95	1·49	2·2	4·8	8·6
3000	0·66	1·03	1·5	3·4	6·0
4000	0·37	0·58	0·84	1·9	3·4
5000	0·24	0·37	0·53	1·2	2·2
6000	0·16	0·26	0·37	0·84	1·49
7000	0·12	0·19	0·27	0·61	1·09

To calculate the watts of energy radiated on any wave length, multiply the radiation resistance as given in the Tables by the square of the reading of the hot-wire ammeter connected in the aerial circuit and near its base.

Aerial Efficiency or Radiation Efficiency *is measured by the ratio of radiation resistance to total aerial resistance expressed as a percentage.*

As an example of aerial values we may quote some calculations made on the aerial at the radio-station of Sayville, U.S.A. This is an umbrella aerial 490 ft. high at the centre and 100 ft. high at the rim, which spreads over a circle of 1570 ft. diameter, used with a counterpoise of radiating wires raised about 8 ft. above the ground. The following particulars of this aerial are taken from an abstract in *Science Abstracts* for 1917; the aerial capacity is 0·013 mfd., the aerial inductance is 462,000 cms., and its total resistance is 1·54 ohms on full power. The radiation decrement on full power in dry weather is 0·0258, and this increases about 29 per cent. in wet weather as might be expected. The radiation resistance is 0·317 ohm, and therefore the aerial efficiency is $\frac{0\cdot317}{1\cdot54} \times 100$, or 20·5 per cent. Taking a mean value of 1·70 ohms as the aerial resistance, with 120 amps. in the base of the aerial, the total aerial oscillating energy is $C^2R = 120^2 \times 1\cdot70 = 24\cdot6$ KW., and the radiated energy is $C^2R_r = 120^2 \times 0\cdot317 = 4\cdot6$ KW., which is 18·5 per cent. of the energy oscillated in the aerial.

Best Wave Length.—It has been found that for given heights of transmitter and receiver aerials, and given range, there is always an optimum wave length of radiation which will give maximum current in the receiver aerial. Dr. Kimura has calculated that if the transmitting aerial is 200 feet high and the receiving one 150 feet high, for a day range of 300 miles the best wave length would be 640 metres, and that the transmitter aerial current should be 2·9 amperes; for a range of 500 miles the wave length should be 800 metres with 9·7 amperes in the transmitter aerial. These figures apply to transmission from shore to ship; for work between ships the aerials may be of less height and the same ranges obtained with shorter wave lengths but stronger currents in the transmitter aerial. Dr. Kimura's calculations were made before the development of sensitive valve detectors and amplifiers; the advent of these has greatly revolutionised all wireless calculations.

Dr. L. W. Austin carried out important experiments in 1908 between the Brant Rock Station near Boston and two U.S. cruisers. Similar experiments were repeated later by J. L. Hogan, between the station at Arlington and the U.S. cruiser *Salem*, up to distances of 4000 kilometres.

For daylight working Austin first deduced the following formula :—

$$I_r = 4\cdot25 \frac{I_s h_1 h_2}{\lambda D} \epsilon^{-0\cdot0015 D \lambda^{-\frac{1}{2}}}$$

where I_r = receiver aerial current in amperes,
I_s = transmitter aerial current in amperes,
h_1 = height of sending aerial in kilometres,
h_2 = height of receiving aerial in kilometres,
D = range in kilometres,
λ = wave length in kilometres,
ϵ = Napierian logarithm base.

Austin found that 10 microamperes in the receiving aerial, corresponding to $\frac{1}{400}$ microwatt of received energy, gave a just audible signal, and that 40 microamperes, or $\frac{1}{25}$ microwatt, were necessary for good readable signals.

In Hogan's experiments more delicate receiving apparatus was employed, so that good results were obtained with half the above quoted value of received current or energy. Expressing received current in microamperes, transmitter aerial current in amperes, wave length in metres, range in kilometres and aerial height in feet, Hogan arrived at the formula—

$$I_r = 395\frac{I_s h_1 h_2}{\lambda D}\epsilon^{-0{\cdot}0474D\lambda^{-\frac{1}{2}}}$$

Austin introduced further modification of the formula by inserting a factor to correct for damping decrement in the two aerial systems.

The above expressions for received current are not, of course, reliable in all cases of radiation, owing to irregularities of earth absorption and other losses; yet, based as they are on careful experimental work, the formulæ are valuable because they demonstrate that there is a definite wave length which will give best results on any given range; this is important where long ranges are concerned.

The formulæ are also helpful in arriving at a first approximation of the design of a station; for example, if we decide on values for the minimum receiver current, also the wave length, range, and height of aerials, the formula enables us to determine what the transmitter aerial current should be approximately, and thus to determine the size of the transmitter plant.

In a later article, contributed by Austin to the *Electrician, January* 12th, 1917, he showed that the currents received at the U.S. Naval Laboratory from Nauen had, over six months, an average value of 1·44 microamperes. The range was 6650 kilometres, the wave length 12,500 metres, and the resistance of the receiving aerial circuit was 124 ohms.

The received currents varied in value from 0·1 microampere to 8 microamperes, but the results led to the conclusion that for long-distance work a first approximation could be fairly accurately based on the formula—

$$I_r = 377\frac{I_s h_1 h_2}{\lambda D R}\epsilon^{-0{\cdot}0015D\lambda^{-\frac{1}{2}}}$$

where R is the resistance of the receiving system in ohms, I_s is in amperes, h_1, h_2, and λ in metres, and D in kilometres.

Aerial Wire.—The wire used in the stranded aerial cable should have good conductivity and a tensile strength sufficient to stand the stresses to which it will be subjected. Suitable materials are hard drawn copper, phosphor bronze, silicon bronze, and aluminium. The tensile strengths of hard drawn copper, phosphor bronze, and silicon bronze are 14, 50, 40 tons per cube cm., while the conductivities are as 100 : 28 : 42 respectively. Silicon bronze is therefore much superior to hard drawn copper as regards tensile strength and has nearly twice the conductivity of phosphor bronze; for this reason aerials on commercial stations are generally made of hard drawn silicon bronze. The stretching tension put on an aerial should not be much greater than one-eighth of its breaking strain.

Dr. J. A. Fleming has advocated the use of aluminium because of its comparative lightness combined with fairly high conductivity. He points out that aluminium is less than one-third the weight of copper, and aluminium alloys are available whose tensile strengths are nearly equal to that of hard drawn copper. On the other hand, aluminium alloy for a given resistivity of aerial will cost more than copper, and in any case it will be much inferior to hard drawn silicon bronze as regards tensile strength.

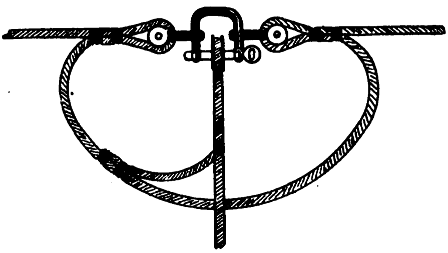


Fig. 121.

Where joints have to be made in aerials they should be soldered, but it must be remembered that the tensile strength of a hard drawn wire is mainly a property of the outer skin and is much weakened round a soldered joint; thus joints in the horizontal span of the aerial should be avoided, and if the leading down wires are soldered on to the horizontal ones the strain should be taken off the soldered joint. For T aerials a Marconi Co. method of doing this is shown in Fig. 121.

For a 1½ KW. spark station a good size of aerial wire is $\frac{7}{18}$ or $\frac{7}{19}$ silicon bronze, using two such cables 12 feet apart to form an L or T aerial. A 50 KW. spark transmitter would require a multiple wire directional aerial of about 0·005 mfd. capacity; this would mean an aerial of 10 or 12 stranded cables in parallel, each having a diameter of about 0·13 inch or equal to No. 10 S.W.G. The specification of the Imperial Wireless Stations of the British Government stated that the aerial of each should be directional, each wire consisting of $\frac{7}{19}$ S.W.G. silicon bronze and at least 3000 feet long. The aerial to be supported on ten tubular steel masts each 300 feet high, and 2 ft. 6 ins. section; from these the aerial to be suspended by threading the wires through porcelain reel insulators attached to the bottom of porcelain rod insulators. The wave length of transmission was to be 30,650 feet.

Aerial Spreaders.—These should be made of light, durable, and fairly strong wood; ash possesses the best combination of these qualities.

For an L or T type aerial consisting of two stranded wires of silicon bronze 12 feet apart the spreaders at each end should be about 12 feet 6 inches long and tapering slightly at the ends from 3 inches diameter at the centre. They should be spar varnished with the aerial wires attached to steel bands carrying lugs and fixed on the spreaders about 3 inches from each end. The bands should also carry lugs to which the bridle is fastened by means of a thimble and shackle in standard Marconi Co.'s practice. The bridle is attached to the halyard by a thimble and the halyard passes over a pulley fastened at the top of the mast.

If the aerial consists of four wires these are best arranged as the sides of a rectangle, using spreaders in the form of a cross.

Aerials of six or eight wires on ship installations are often arranged around the peripheries of wooden hoops; on land stations they may be placed parallel to each other on ash spreaders, provided they are kept a sufficient distance apart to minimise mutual induction effects as already described.

Guy Stays for Aerial Masts.—The guys should be tightened up so that the vertical stresses on all the sections of the mast are in line with each other; also if the mast is slightly out of the vertical due to wind pressure or other cause the sections of the mast should remain in line, otherwise it is liable to buckle. Therefore stretching of the guys, due to wind pressure on the mast, should be uniform and proportional to their length.

For comparatively short masts the guys are generally made of hemp rope, but for masts of 60 feet or over steel cable should be used. The steel cable should be of stranded galvanised strands with steel wire centre, its diameter and weight depending on the height and size of the mast and the consequent stresses to which it will be subjected. The top guys will experience more stress than the bottom ones and in the case of large steel masts the guy diameter will taper from 1 inch for the top guys to $\frac{5}{8}$ inch for the bottom ones, the guys consisting of seven-strand steel cable with 19 wires to a strand.

The guys should make an angle of 45° with the mast, which implies that the top guys should be anchored farther out from the mast than the bottom ones; for masts whose heights do not exceed 100 feet, and which have from three to four sets of guys, it is usual to anchor them all to four anchor pins whose distance from the mast gives an average angle of 45° for the guys.

The top back guy will have to withstand the horizontal pull of the aerial, which in the case of fairly large aerials may amount to 20,000 or 30,000 lbs. The stress on all the guys, as well as on the aerial and masts, will increase if they are covered with sleet or hoar frost; it will also increase on aerial masts and windward guys when a gale is blowing.

If the guys are of steel oscillating currents will be induced in them so that they will absorb some of the energy radiated from the transmitter, or screen some of the energy from the receiver. Also, if oscillating currents are induced in them during transmission they will radiate energy on wave lengths depending on their lengths. To avoid these effects steel guys are generally divided into sections by means of strain insulators so as to decrease their interfering wave length and their capacity for absorbing energy. A galvanised steel wire rope of 1 inch circumference will stand a breaking strain of 2 tons and will stretch about $\frac{1}{4}$ per cent. under a strain of $\frac{1}{2}$ ton.

For masts up to 70 feet high guy ropes of Italian hemp are often employed; a hemp rope of 1 inch circumference should stand a breaking strain of 1500 lbs., but the safe working load is not much over 100 lbs. Hemp rope guys must be examined frequently as they stretch considerably under undue wind strains, and require to be made uniformly taut at frequent intervals. They also deteriorate fairly rapidly under weather exposure. For this reason it is better to employ $\frac{1}{2}$ inch stranded steel rope for the guys of a 70 feet mast, terminating with a length of hemp rope at the lower end of each guy, the hemp rope being threaded through a cleat by means of which slack can be taken up round the head of the anchor peg.

Earthing.—It will be remembered that Marconi's first important development of Hertzian wave transmission was to connect one side of the spark gap to earth; by so doing he found that the range of transmission for a given height of aerial was much increased. Later, Sir O. Lodge used a balanced capacity network of wires or plates raised a foot or so above the earth and insulated from it, but when this was used it was found that the signals were improved by putting underneath it a similar network of wires in contact with the ground. It was evident, therefore, that range depended not only on the ether strains in the air, but also to some extent on the distribution of this strain effect in the space around the transmitter aerial, and on the earth currents resulting therefrom. Thus, except for portable military stations which may employ copper wire woven mats laid on the ground, modern wireless practice is to have a good earth connection at the bottom of the aerial circuit. It has already been pointed out that on any fundamental or harmonic wave length of the aerial circuit there is always a maximum value of current at the earth connection, therefore resistance at this point should be avoided just as much as in any portion of the aerial wire. All joints in the aerial should be soldered and the joint between the aerial and earth should similarly be made as good as possible. As a general rule it may be stated that the resistance of an earth contact will depend on the surface area of the contact; in an experiment made by the author the resistance between two steel pins stuck into the ground 100 yards apart was 492 ohms, but when four steel pins were used, two at each end about 2 feet apart, the resistance was only 152 ohms; this shows that much of the resistance measured was at the contacts between the steel pins and earths. It was also found in this case that the resistance was much reduced by packing wet charcoal round the pins.

Where possible, thick stranded copper wire should be well soldered to plates buried in the ground and a good connection made by these wires to the bottom of the aerial circuit. The earth lead should be as short as possible, and on no account should it run parallel and close to the lead-in from the aerial; if this happens the two would form a condenser and introduce a capacity effect where it is not wanted and where it does not contribute to free radiation strain effect.

At land commercial stations the earthing system consists of a wide circle of zinc rectangular plates sunk edgewise in the ground, and connected to the apparatus by numerous radial wires soldered to the ring; from the zinc plates other wires stretch out under the ground. The longer the wave length the longer should the earth wires extend out from the station; at some of the large Marconi stations the earth wires extend outwards for some hundreds of feet.

Another method adopted is to sink iron pipes vertically in the ground, in a circle round the station, each pipe connected by a thick copper wire to the earth terminal of the apparatus.

At Macrihanish station (working on the Fessenden system) the earth consisted of a large network of iron wire simply thrown on the rocks, and washed by the sea.

With the Marconi Co. 5 KW. Set an earthing arrangement sometimes adopted is to have a number of galvanised iron plates, No. 24 gauge, buried on edge in the earth in a large circle of 50 feet radius, and connected by wires to cables which are led to the earth terminal of the apparatus. These may be supplemented by long wires buried in the earth and radiating out from the iron plates.

For smaller amateur stations the water pipes may provide a good earth, especially if no part of them rises higher in the house than that joined to the apparatus—on no account should gas pipes be used as an earth, for leakage or explosion may ensue, owing to the danger of sparking at bad contacts.

The aerial should always be left connected to the earth wires when the apparatus is not in use, and amateur aerials should be fitted with a long-bladed knife switch which can be used to short circuit all the apparatus, so that if atmospheric or lightning discharges strike the aerial they can pass direct to earth.

The Marconi Co. use a device called an earth arrester, which consists of two heavy brass plates clamped together, but separated from each other by a very thin mica washer. This is connected in series in the aerial as shown in Fig. 122. A circular groove is cut in each brass disc, coinciding with the edge of the mica, to ensure that the sparking will not take place at the mica edge and burn it; the sparking then takes place across the outer edge of the upper plate. The gap is so short that it does not stop the transmitting aerial currents, which flow in sparks across it, but it acts as an insulator to the tiny received currents which must therefore flow through the receiving apparatus. Strong atmospheric or lightning discharges can flow across the gap, so that to such the aerial is constantly earthed. This arrangement does away with the necessity of having a change-over switch connecting the aerial to transmitter or receiver as required; at the same time the detector circuit of the receiver should be disconnected when transmission is taking place, therefore some switching arrangement is necessary where modern delicate detectors are employed, though it is not necessary for robust carborundum detectors.

The earthing arrangement at the Marconi transoceanic stations, on the shores of the Atlantic and Pacific, are very elaborate and costly. The sending and receiving units are in separate buildings from 20 to 30 miles apart; each of course with their own directional aerial system. In order that the interaction between the sending and receiving aerials should be as small as possible they are placed parallel to each other.

At the sending station a continuous circle, of 100 feet radius, is made by large zinc plates, all bolted together and buried in the ground on edge, the transmitting apparatus being at the centre of the circle. Soldered to the top edge of the plates are 224 stranded copper cables, all of same length and size, stretching out radially from the earthing side of the transmitter.

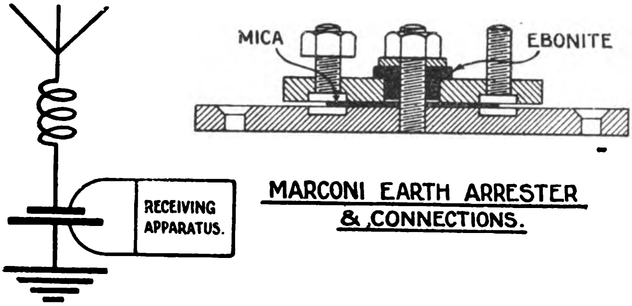


Fig. 122.

From the zinc ring 112 copper cables, 300 feet long, stretch out radially, each terminating in another zinc plate placed vertically in the ground. Some of these latter zinc plates will be under the aerial, and from these copper cables extend in the ground under the aerial to a point a little further than the span of the aerial itself. If the station is near a river or marsh this symmetrical system of earthing may be modified so that a good number of the plates may be in the bed of the river or in the marshy ground.

At the receiving station a continuous circle of 50 feet radius is made of zinc plates and, as before, joined by copper cables to the earthing side of the receiving apparatus. From this circle of buried zinc plates other cables extend out to marshy ground or a water way in the vicinity, each terminating in another zinc plate buried on edge.

At the new transatlantic Marconi station on Cefndu Mountain in Wales the earthing arrangements are as here described. The aerial consists of 32 silicon bronze cables supported on 10 tubular steel masts each 400 feet high.

Aerial Towers and Masts.—For larger stations the choice is between elaborate rigid steel towers, sectional steel masts supported by guys, or wooden lattice masts supported by guys. Rigid steel lattice towers have more to recommend them than sectional tubular steel masts supported by guys; the difference in initial expenditure is not so great as might at first sight appear, since the guyed mast necessitates the purchase of a large piece of ground round the aerial; guys have to be maintained and frequently overhauled by expert labour; and the necessary painting of the mast will require expert work, whereas a rigid tower can be scraped and painted every two or three years by ordinary labour. Unless the guying of tubular steel masts is very carefully attended to during erection and maintenance it is very liable to fail, as in the case of the 400 foot mast at Macrihanish, and the 492 foot mast at Ballybunion.

Wooden lattice masts up to 600 feet high have given great satisfaction; in initial cost and maintenance they are cheap compared to steel structures and are quickly erected. C. F. Elwell has described, in the *Proceedings of the Institute of Radio Engineers*, a method of building masts which have a triangular framework. Three columns of 8, 14, and 20 feet length respectively are erected in position and connected by brace pieces up to 6 feet high. A little hoisting derrick is now attached through a hole in the 20 foot column (which hole will eventually be used for a steel tie rod), and an 18 foot length is hoisted and fixed on top of the shortest, or 8 foot, column, after which steel tie rods and more brace frames are fixed. The shortest column has now become the longest, the derrick is removed to it and another 18 feet length is raised and fixed to the now shortest column. This procedure is repeated until the mast is completed, the men aloft working on a small wooden platform which is raised higher as each 6 feet of mast is completed. Guy cables are fixed as the erection proceeds and it is claimed that from 36 to 54 feet of mast can be completed per day. Fig. 123 shows this construction in the 440 foot masts erected at San Francisco; similar masts can be seen at Portsmouth in England and at Ballybunion in Ireland. Each section of the mast is a 6 foot square and it is estimated that of the 36 square feet of each section 30 square feet may be taken as wind-opposing surface, so that a load of 200 lbs. per foot of mast is used in calculating guy stresses. For masts up to 300 feet high Elwell recommends the use of only one size of timber, as an attempt to taper the columns and braces adds to the cost of milling, sorting, and fitting. For masts over 300 feet high two or three taperings may be employed. Wooden lattice masts are not suitable for erection in tropical countries owing to the climate and the ravages of insects; if erected in these countries they should be supported on concrete which rises well above the ground, and kept well coated with tar or other insect resisting compound.

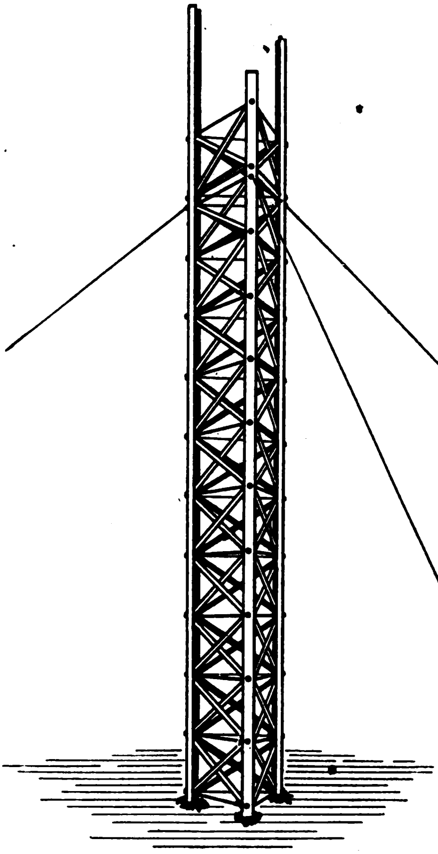


Fig. 123.

For smaller stations and ranges a tubular wooden, steel, or duralium mast can be built up, with sections which fit into each other, on the ground and hoisted by means of a derrick. One of the best examples of this type of mast is made by the Marconi

Company for a 1½ KW. station; it is shown in Fig. 124. The

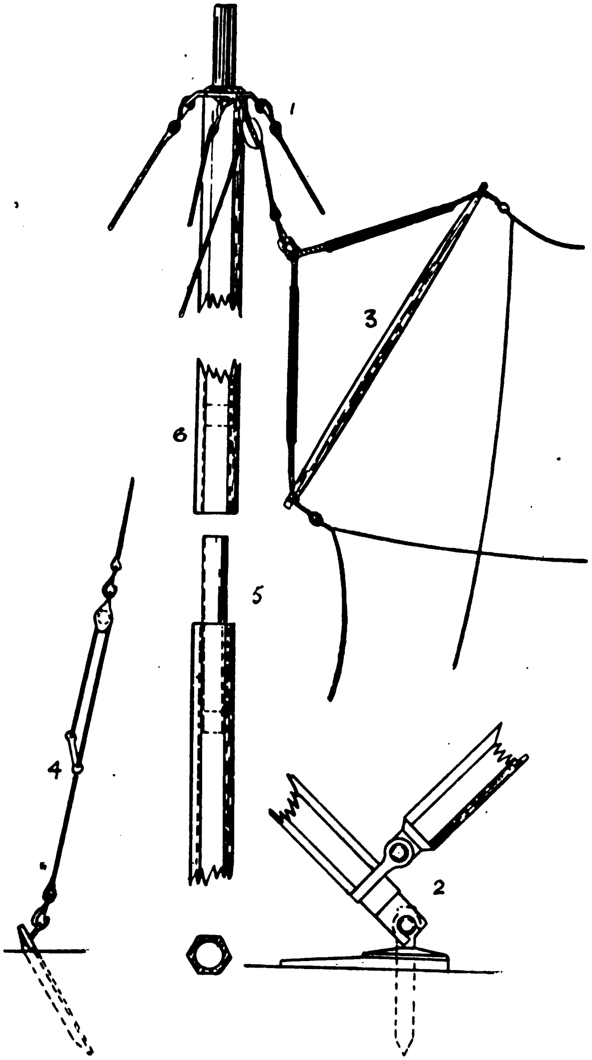
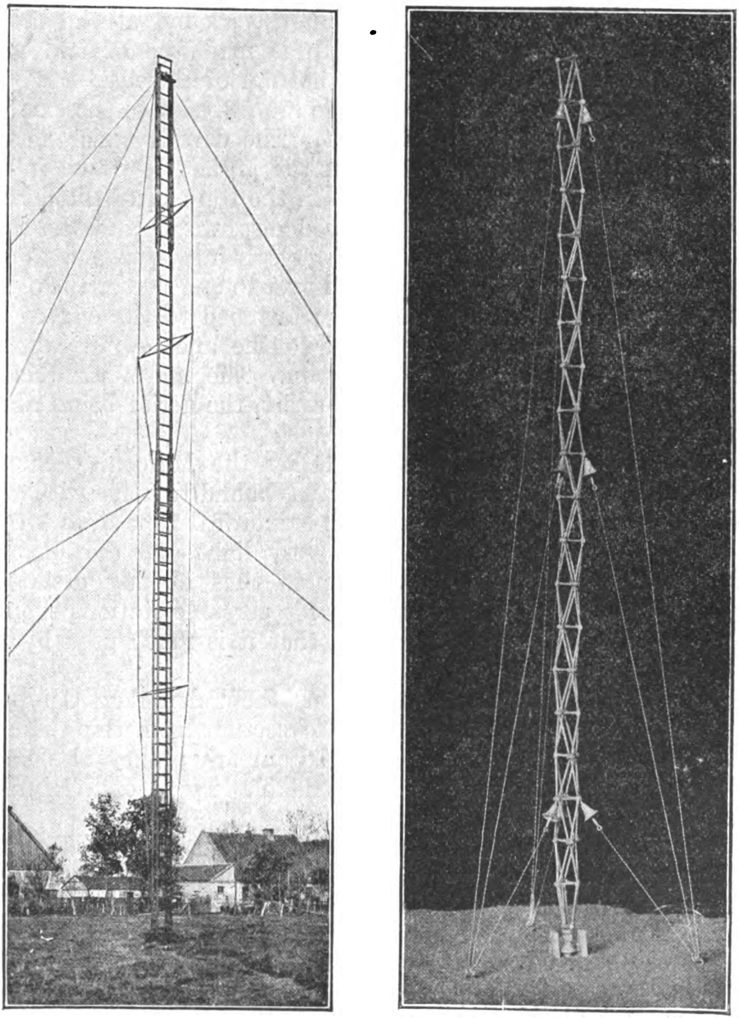


Fig. 124.—Marconi Military Mast.

1. Top guy plate with aerial attached through block. 2. Pin bearing for mast supported on ground plate, also showing derrick connection on swivelling ring. 3. Aerial spreader. 4. Bottom fastening of guy rope. 5. Steel plug fitting into socket 6.

aerial is of the two-wire L type, and the two supporting masts are each 70 feet high, made in six sections and guyed with three sets of guys. Each section is made of hollow hexagonal wood boxing with a socket at one end and a solid steel plug at the



(*a*) Telefunken Ladder Mast. (*b*) Telefunken Rendahl Mast.

FIG. 125.

other. The mast is assembled on the ground. with guy ring plates fitted over the plugs between sections at the proper intervals, guys clipped on the rings by means of spring hooks and fastened to the anchor pins in the ground at the proper positions. A derrick, whose length is made up of two mast sections, is fixed by a pin to the bottom of the mast, and the guys of the mast on the derrick side are fastened to the extreme end of the derrick and made tight. The derrick which was at right angles to the mast when on the ground is raised into a vertical position; then by pulling on the top end of the derrick with a block and tackle it is pulled downwards and the mast raised to a vertical position, the guys being tightened as the mast is raised so that it will not fall over to one side or the other. When erected the guys which were fastened to the end of the derrick are removed and fastened to the anchor pins already fixed in the ground to receive them. The masts for this 1½ KW. station are about 130 metres apart, the aerial being about 160 metres long.

Another very good mast made by the Marconi Company consists of eight sections of split bamboo bound together with steel binding wire at intervals to form a cylindrical tube over a light hollow steel core; this mast is very light and durable, the fitting and erection being similar to that already described. This style of mast is very suitable for portable stations such as those used in military services, so that it is much used by the armies of several countries.

For portable or military stations the Telefunken Company use wooden masts made of socketed sections something similar to those employed by the Marconi Company; they also use a type of steel mast designed by Rendahl. Types of Telefunken masts are shown in Fig. 125.

Owing to the rapid and great development of valve detectors and amplifiers for receiver circuits it is probable that less transmitter energy will be required than heretofore, even where spark systems are not superseded by C.W. systems. Aerials will therefore be smaller, lighter, and lower, and supported on less elaborate structures than was formerly necessary.

Insulators.—The strain insulators used in the aerial must be of such a design that they will not break under heavy mechanical strain, and their insulating properties must not deteriorate by exposure to the weather. The Marconi Co. use a special type of flexible insulator consisting of a core of special cord completely covered with vulcanised india-rubber. The surface of the rubber is treated with a special bitumen compound which, though flexible, has a smooth surface ; this causes moisture to separate into drops, so that in wet weather there will not be a continuous surface of moisture on the insulator. The insulator is made up in two different lengths, 3 feet for a working strain of 15 cwt. and 5 feet for a working strain of 30 cwt., while, of course, the longer insulator has the greatest dielectric strength.

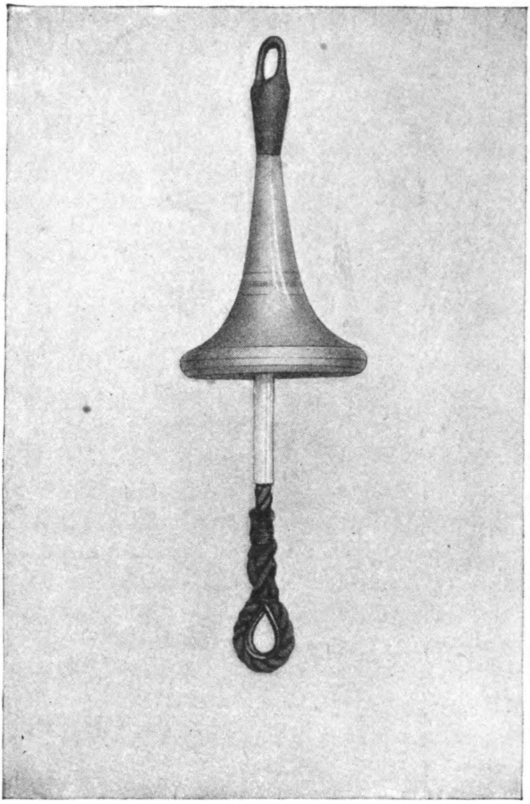


Fig. 126.

The Telefunken Co. use the Rendahl insulator shown in Fig. 126. The high pressure end is made of aluminium, funnel shaped, the effect of which is to spread the potential stress more uniformly along the stalk of insulating material than would otherwise be the case. The stalk is made of wood, impregnated with oil and protected by a porcelain tube.

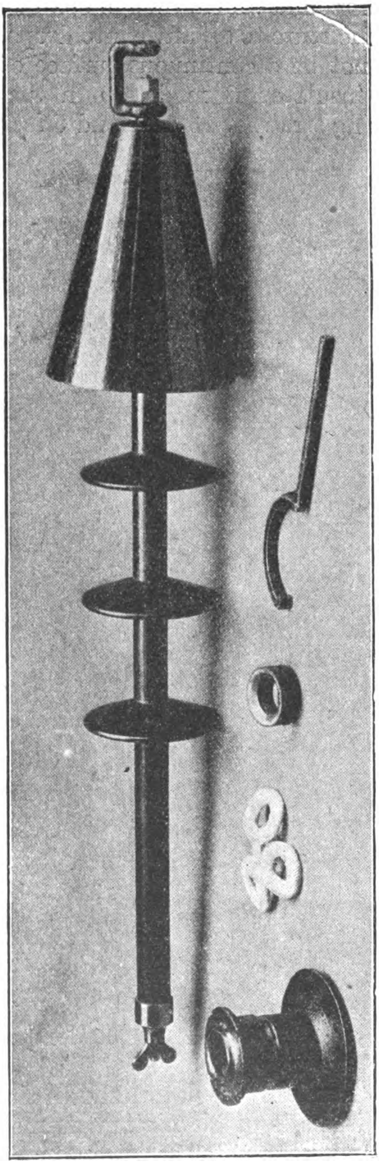


Fig. 127.

Strain insulators can be made by screwing metal eyes into the ends of ebonite rods from 9 inches to 12 inches long. The end of the rod and the metal eye should first be put in boiling water for some time, and it will then be found easy to screw the eye into the rod, after which the end should be plunged in cold water. Such insulators will stand a strain of 500 to 700 lbs. and, for a high voltage, two or more can be joined in series. They are suitable for use in the stay ropes which anchor each end of the spreaders to prevent the aerial swaying or turning round in the wind. Other strain insulators of porcelain or special composition, capable of withstanding large mechanical strain, can be seen in the lists of manufacturing Companies.

A good roof or wall insulator, for use where the aerial enters the operating room, can be made by threading an ebonite tube 36 inches long over a brass rod, the ebonite being $\frac{3}{8}$ inch thick. The brass rod is screwed at each end, and fitted with nuts by means of which the aerial wires, inside and outside, can be connected to it. For leading in purposes the Marconi Co. use the Bradfield Insulator shown in Fig. 127.

It consists of a stalk of ebonite with an iron rod running through it, the ebonite having three petticoat enlargements to give a longer insulating or leakage path. The whole is surmounted by a metal cone, which serves to keep off the rain and distribute the potential gradient. The insulator fits in a stuffing-box in the cabin roof, the box having an ebonite core and asbestos ring washers.

Fig. 128 shows a Chambers Lodge insulator, also a simple method of attaching aerial wires through insulators to the spreader and twisting halyard which is suitable for small stations.

For small stations a glazed porcelain tube, such as is stocked by most Electrical Supply Companies, might be used; the tube should be of such a length that it extends well beyond the inside and outside surfaces of the wall, and it should be filled with bitumen so that moisture is prevented from lodging in it.

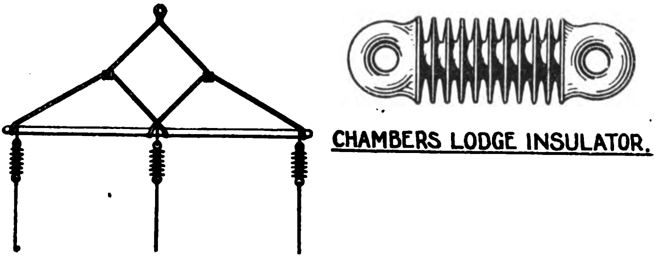


Fig. 128.

QUESTIONS AND EXERCISES.

1. What is a directional aerial and how is it used?
2. Why is it that the natural wave length of an aerial may be taken as about 4·9 times its actual length?
3. Explain why an aerial should not be loaded with inductance to produce a wave length greater than 4 times its natural wave length.
4. How would you produce a radiating wave length which is less than the natural wave length of the aerial?
5. An aerial has a capacity of 0·0005 mfd.; what inductance placed in series with it will produce a radiation wave length of 100 metres?
6. An aerial is 80 feet high and its horizontal portion consists of 10 wires 110 feet long, spaced 2 feet apart. Its capacity is 0·00095 mfd. and its inductance 0·0005 mhy. What is the natural wave length of this aerial?
7. Calculate the inductance of the coil which should be connected in the aerial in Question 6 to produce a radiation wave length of 800 metres.
8. What considerations determine the proper spacing of the wires of a horizontal aerial?
9. Why are aerials raised as high above the ground as possible?

10. What is meant by "radiation resistance"? How is it determined for any radio-telegraphic aerial?

11. Why is it necessary to have a large spread of earthing connections at a transmitter station?

12. What is the principal advantage of an umbrella type aerial?

13. If the effective current is 10 amperes at the base of a T aerial 120 feet high, and the wave length is 2000 ft., find the approximate amount of radiated energy.

14. Calculate the approximate wave length of the aerial used with the Marconi cavalry outfit described in this chapter.

15. What effect has (*a*) increase of aerial capacity, (*b*) increase of aerial inductance, on the amount of energy radiated from the aerial?

16. If an L aerial consists of a single stranded cable and has a natural wave length of 600 metres what is the approximate length of the wire; what is the most efficient wave length of radiation from it, and the maximum wave length for which it could be efficiently employed in transmission?

17. Why is it necessary to pay particular attention to the insulation at the far end of an aerial?

CHAPTER XVII

SPARK RECEIVER CIRCUITS

When electrical energy is oscillated in a Wireless Transmitter a certain percentage of it will be radiated into the ether in the form of strain effects. This energy is radiated in all directions and as the strains spread through the ether they will diminish in intensity, the decrease depending on the distance out from the transmitter, on the losses in the surface of the land or sea over which the strains travel, and on the losses in the ionised atmosphere through which the strains are propagated.

If a stick is plunged up and down in the middle of a pond it sets up strain effects of surface tension and inertia in the water which spread out in the form of rings of wave motion, gradually decreasing in size. Some of the energy put into the stick to move it up and down is carried or radiated outwards in the form of water wave motion. If a light cork is floating near the edge of the pond and the energy of wave motion has not died out before it reaches the cork the latter will bob up and down; since it has weight its movement implies that energy has been imparted to it by the wave motion in the water.

Exactly similar effects can be obtained if a vertical copper wire is raised high in the air at some distance from the transmitter, and at a point where the strain effects set up by the transmitter have not yet died out in the ether. Almost as soon as the key is pressed the ether in the distant copper wire experiences little electric and magnetic strains acting at right angles to each other. Now copper is a good conductor and when the ether in it is electrically strained electrons will move along it, also when the ether in it and round it is magnetically strained, at right angles to its length, an E.M.F. is induced in it which will tend to move electrons from one end of it to the other. Thus every oscillation of ether strain effect will cause a little oscillation of current in the wire, but the oscillating ether strains are due to the oscillations of current in the transmitter aerial, therefore oscillations of current in the transmitter aerial will give rise to tiny oscillations of current in the receiver wire. The oscillations in the receiver wire will be later by a small fraction of time than those in the transmitter, since the ether wave disturbance takes one second to travel 186,000 miles or $\frac{1}{1000}$ second to travel 186 miles. The amplitude of the oscillations in the receiver aerial will depend on the heights of the two aerials, the distance between the stations, the nature of the surface over which the feet of the ether waves have travelled, the ionised condition of the atmosphere through which they have travelled, and the presence or absence of screening effects such as trees, hills, or houses between the two stations. The little oscillating currents set up in the receiver wire represent energy; if R is the resistance of the wire and C the effective value of the current by Ohm's Law, the energy turned into heat in the wire is C^2R watts, and by methods to be presently described some of the energy given to the receiver wire, or aerial, can be made to cause vibration of telephone receiver diaphragms and thus record signals.

In 1913 Dr. L. W. Austin found that an effective current of 5 microamperes in an aerial of 25 ohms resistance, or an aerial energy of $\frac{0{\cdot}625}{10^9}$ watt, gave just readable signals; since that time the perfection of valve amplifiers has made it possible to obtain good readable signals with very much smaller values of current or energy in the receiver aerial.

It has been described in a previous Chapter that the wave front of ether strains bends over in the direction of propagation, especially with long ether waves sent over long ranges; thus to obtain the best results the receiver aerial should be bent so that it will coincide with the electric strain effect and be at right angles to the magnetic strain effect when these arrive at the receiver; this has already been illustrated in Fig. 113, and leads to the use of L or T type directional aerials at the receiver.

Again the amplitudes of the oscillating currents set up in the receiver aerial can be increased by making the electrical frequency of the circuit equal to that of the ether wave impulses acting on it; the self-induction and self-capacity of the aerial wire are comparatively small, therefore to tune the aerial circuit to the frequencies, or wave lengths, of commercial working it will be necessary to connect an adjustable inductance coil in series with it. Apart from the desirability of tuning the aerial circuit to the ether waves some of the inductance effect in it must be in the form of a coil, for reasons which will be apparent in what follows. The adjustment of the inductance in the circuit is generally made by means of tappings from the coil to a multiple switch ; unless there are many such tappings the adjustment for tuning can only be a comparatively rough one, and it is better to supplement the inductance by connecting a variable condenser in series with the aerial and coil. Very fine adjustments of the capacity effect can be made with the variable condenser, so that the tapped inductance coil can be used for rough tuning and the variable condenser for final fine tuning. A suitable maximum value for the variable condenser is 0·001 mfd. When the aerial circuit is in tune with the ether waves the amplitude of the currents oscillating in it will be a maximum, and the received signals will then be strongest. To tune the aerial circuit the variable condenser should be set at its maximum value, or short-circuited, (most condensers have their fixed and movable plates short-circuited when the index pointer is at 180°) ; the inductance coil switch is then put on the stud which gives a value of inductance just too great for strongest signals ; the aerial wave length is now a little too long and by decreasing the capacity of the variable condenser the wave length can be reduced until it is equal to that of the ether waves. Note that the condenser is in series with the aerial earth capacity, therefore the capacity of the whole is smaller than the smallest of these two and will be decreased by decreasing either. If the self-capacity of the aerial is 0·0002 mfd., and that of the variable condenser is set at 0·0005 mfd. the combined capacity, $\left(K = \frac{K_1 K_2}{K_1 + K_2}\right)$, is less than 0·0002 mfd., *and it will be decreased if the capacity of the variable condenser is decreased.* Because a condenser in series with an aerial shortens the wave length, some students have the erroneous idea that the larger this condenser is made the more it will decrease the wave length.

Now if it is desired to pick up signals carried on comparatively long ether waves it may be that with all the tuning coil switched in and the aerial series condenser at maximum value the aerial wave length is not yet as great as that of the ether waves ; in this case it would be best to replace the tuning coil by one having a larger value of inductance. If such a second coil is not available a variable condenser may then be connected in parallel with the inductance coil ; this will increase the capacity effect of that portion of the aerial circuit and therefore the capacity effect of the whole. Fine tuning can be obtained by adjusting the condenser. Fig. 129 shows the simplest arrangements of aerial receiver circuits for normal or short wave lengths, and for wave lengths which are very long compared with the size of the aerial and tuning coil; a simple switching arrangement can be fitted by means of which the variable condenser may be connected in series or in parallel with the tuning coil as desired.

If, as in the Marconi system, the receiver aerial is connected across the plates of an earth arrester, as shown in Fig. 130, the transmitter tuning inductance and jigger secondary will remain in the circuit and form part of the receiver inductance.

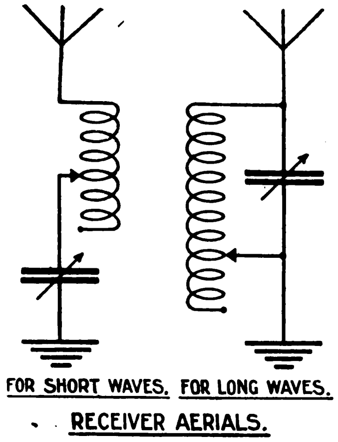


Fig. 129.

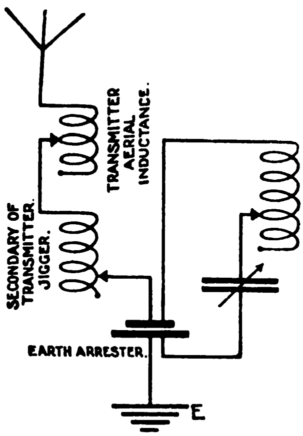


Fig. 130.

The effect of the ether strains on the aerial circuit will depend directly on the height and length of the aerial, for the greater these are the more it will entrap strain effects in the ether; whether it is better to have great height or great length in an L or T aerial will depend on the shape of the wave front arriving at it, but in any case it should be high enough to clear all screening conductors which are absorbing energy out of the lower portions of the ether strains. The design of the aerial will be considered more fully in a subsequent section.

With small oscillating currents thus induced in the receiver aerial by the ether waves we have now to consider the method of employing them to record signals. The receiver telephones cannot be connected directly in series in the aerial circuit for three reasons :

(1) the telephone receivers consist of coils wound on magnets, and have therefore a high value of inductance, L, so that their impedance, $\sqrt{R^2 + (2\pi fL)^2}$, is very high and would damp out the little current oscillations ; (2) even if the small current oscillations were not entirely damped out they are of very high frequency and the inertia of the telephone diaphragms would prevent them from vibrating at such a frequency ; (3) if the diaphragms could vibrate at the high frequency no sound would be heard, as the human ear cannot hear vibrations at a higher rate than about 25,000 per second, and vibrations of 5,000 per second are about the limit of comfortable audibility.

Now the oscillating currents in the aerial circuit will set up an oscillating magnetic field in the ether along the axis of the tuning coil ; this oscillating magnetic field, interlinking with the turns of wire in the tuning coil, will induce an oscillating difference of potential at its terminals. We can therefore apply a recording circuit to these terminals in order that it will be acted upon by the oscillating potentials set up. A pair of telephone receivers connected across the terminals of the coil would not lead to any results for reasons similar to those just given, but if a detector is connected in series with the telephones the combination will provide a delicate recording or detecting circuit. A detector is an apparatus which has a much higher resistance in one direction through it than in the other direction for small electrical currents ; thus, if small oscillations of potential are applied to a circuit which includes a detector in series, the detector allows current to flow when the potential is acting in one direction, but when the potential acts in the opposite direction the detector resistance in that direction is so high that practically no current gets through it and the circuit. Such a property is possessed by contacts between certain crystals and metals, or between different kinds of crystals, or by vacuum tubes in which one electrode is kept hot ; these are called crystal or valve detectors and will be described in subsequent chapters.

Now let us consider what happens when a pair of telephone receivers in series with a detector is connected across the tuning coil of a receiver aerial circuit, as shown in Fig. 131 (*a*). When a spark occurs at the transmitter there are four or five oscillations of current in the transmitter closed circuit, and this starts a train of oscillations of current in the transmitter aerial circuit as shown in Fig. 132. This radiates energy out through the ether in the form of a train of strain effects, or waves. A fraction of time later,

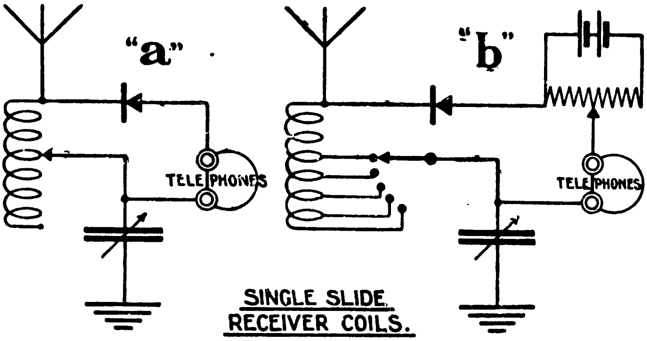


Fig. 131.

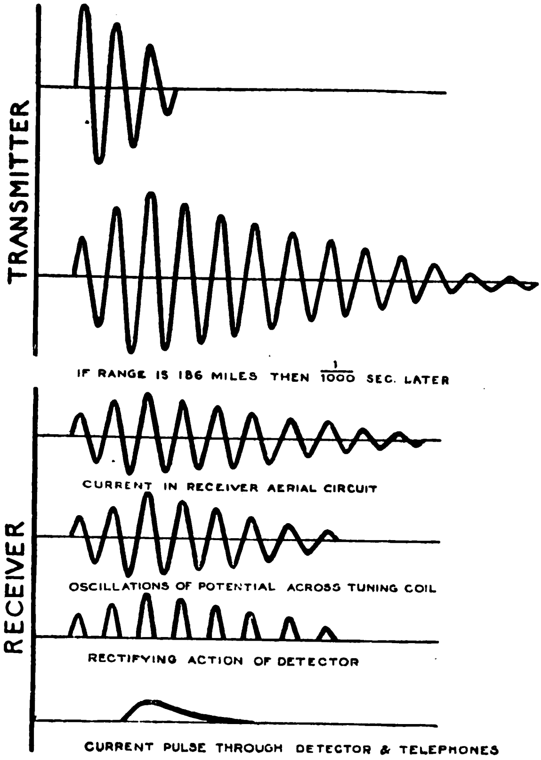


Fig 132.

($\frac{1}{1000}$ second if the range is 186 miles), the ether round and in the receiver aerial experiences these strains, weak now owing to dissipation losses; they induce little oscillations of current in the receiver aerial circuit and thus oscillating potentials across the receiver tuning coil. One set of halves of these oscillating potentials are rendered inoperative by the action of the detector, the other halves of the oscillations tend to send high frequency pulses of current through the detector and telephones. Since these pulses of potential and current always act in the same direction the detector is said to rectify the oscillations, and is sometimes called a "*Rectifier*." Owing to the high impedance of the detector and telephones no current flows in them until the potential across the coil is sufficiently built up by the oscillations in it; when built up a pulse of current will flow through the detector and telephones as shown in Fig. 132, and this pulse actuates the telephone diaphragms. The current discharge due to a train of rectified potential oscillations is smoothed out into one pulse owing to the high impedance of the detector-telephone circuit.

It is thus seen that one vibration of the telephone diaphragm is given for each spark at the transmitter, therefore the *diaphragm vibration frequency is the same as the transmitter spark frequency*, and the note heard in the telephones is the same as the note heard in the spark:—a high sparking rate means a high note in the receiver telephones. The ether waves are sent out in trains, as many waves in a train as there are oscillations in the transmitter aerial; each train of waves sets up a train of oscillations in the receiver aerial and gives one pulse of current through the telephone receivers. The number of oscillations induced in the receiver is not necessarily the same as that in the transmitter aerial, indeed it will generally be less, for the smaller oscillations in the transmitter will set up strain effects in the ether which will probably have died out before the range is covered, and the damping effects in the receiver circuit will not allow the oscillations in it to persist long after the ether strains have ceased. Also the discharge through the detector and telephones damps out the energy oscillating in the receiver circuit and cuts short the train.

As will be described in the Chapter on Detectors some of the latter work best when a small steady current is flowing round the circuit consisting of the detector, telephone receivers, and receiver tuning coil; the necessary direction and value of this current will vary for different detectors, therefore it should be supplied by a variable source of potential such as a potentiometer wire with

3 or 4 volts drop of potential along it. This gives us the arrangement of simple receiver circuit shown diagrammatically in Fig. 131 (*b*).

The simple receiver circuit as shown in Fig. 131 will work very well on long waves, when the inductance coil will necessarily have a large value and the series condenser may be short-circuited or omitted ; the longer the waves the less delicate may be the tuning adjustments to give the same percentage accuracy of tuning. We may note that the energy oscillating in the circuit at one moment is stored up in the aerial capacity and an instant later is setting up inductance effects ; if the coil is relatively large most of the inductance effect of the circuit is located in the coil, and therefore most of the oscillating energy is applied to the detector circuit at the moment when the energy is setting up inductive effects ; *i.e.* when the energy is represented by $\frac{1}{2}Li^2$, where L is the inductance of the coil, and i is the effective receiver aerial current. *Thus with crystal detectors the strength of received signals is proportional to the square of the aerial current.*

But the arrangement is not suitable for receiving short wave signals on the same aerial ; to tune the circuit down to short waves the inductance would have to be reduced by switching out some of the turns in the coil. As shown in Fig. 131 (*a*) or (*b*) the circuit is tuned to short waves and the potential difference induced across the coil by the current oscillating in it will be weak, because it now consists of only a few turns in series with each other ; consequently the effect in the detector and telephones will be weak.

Two-Slide Coil.—This defect can be overcome by having a second set of tappings on the inductance coil so that the number of turns across which the detector circuit is applied may be greater than that included in the aerial circuit.

Referring to Fig. 131 (*a*), when the aerial circuit currents oscillate in the turns of the coil included in the circuit, the oscillating magnetic field set up by them will not only interlink with those turns but also with the neighbouring turns which have been switched off, inducing oscillating potential in all these turns. Therefore if we could include all these turns in the portion of the coil applied to the detector circuit we should have larger potential effects to act on that circuit. This can be realised by having two sliding contacts or two sets of tappings on the coil, using one for tuning the aerial circuit and the other for adjusting the inductive effect applied to the detector circuit. Such an arrangement is shown in Fig. 133; it gives, as it were, a transforming up effect, since the oscillating voltage applied to the detector circuit is greater than that induced in the portion of the coil included in the aerial circuit; it is in fact an auto-transformer. At the same time we have now two oscillating circuits coupled together; one is the aerial circuit with its definite values of inductance and capacity, the other is that portion of the coil connected to the detector circuit—it has a different value of inductance which with its small self-capacity determines its oscillation constant. The best effects will be obtained if the secondary circuit is accurately tuned to the aerial circuit. Rough tuning can be done with the inductance by a proper adjustment of the second slider, or multiple switch, but for fine tuning a small variable condenser, shown at A in Fig. 133, is connected in parallel with the secondary portion of the coil, forming with the coil a closed oscillatory circuit coupled to the aerial circuit. The variable condenser A, across the closed circuit, must be of very small capacity and used only to give accurate tuning between the studs on the inductance coil; this condenser has to be charged up before a discharge takes place through the detector and telephones. If it is of too large a value the small oscillating currents flowing into it from the coil will not raise its potential to any appreciable value; it will thus damp out the potential effects on which we are relying to send currents through the high resistance and inductance effects of the detector and telephones. A suitable maximum value of the capacity of this condenser is from 0·0002 to 0·0005 mfd.; to tune the circuit the condenser should first be set at zero value and the inductance increased until best effects are obtained on it; the condenser should then be gradually increased from zero until the signals are loudest—when it is evident that the closed circuit is in tune with the aerial circuit.

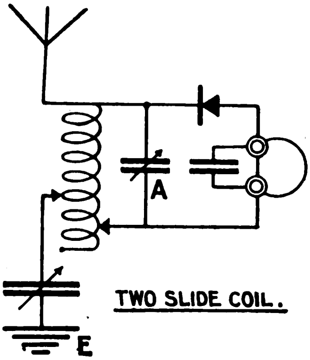


Fig. 133.

As a matter of fact, with high resistance detectors which function on potential effects, the receiver would be most efficient if designed so that no capacity effect were required in the secondary circuit beyond the self-capacity of the coil, and this should be kept as small as possible by properly designing the coil.

In passing it may be remarked that when low resistance detectors and telephones are employed, as in the case of the Marconi Magnetic Detector, the secondary circuit condenser may have a larger value than that used with high resistance detector circuits.

Blocking Condenser.—In Fig. 133 a condenser is shown connected across the telephone receivers—this is known as a *blocking condenser*, and its function is to clear and improve the note heard in the telephones. The telephone receivers have a high value of inductance, since they consist of many turns of wire wound on magnetised iron; with the condenser they form a closed circuit whose natural frequency is very low, approaching that of the spark frequency or of the pulses of current in the telephones. Thus by suitably choosing the capacity value of the condenser it can tune the telephones to the frequency of the current impulses in them and suppress harmonic pulses. Sound waves, or air waves, of any length are generally accompanied by waves whose length or frequency bears a definite relation to the fundamental wave; thus when a note is struck on a piano one can distinguish in it the sound of a note which is an octave higher—this is called a harmonic—accompanying the fundamental note. The peculiar difference, called timbre, between the same note as sounded on the piano, or violin, or flute is due to the presence of different harmonics with the fundamental, according to the instrument played; a note on the flute is very pure compared to the same note on the other instruments because it is nearly free from harmonics.

In the same way ether waves of any fundamental length, set up by spark transmitters, are generally accompanied by harmonics owing to irregularities of tuning or contacts in the transmitter and receiver circuits; the pulses of current in the detector circuit are accompanied by little irregular pulses which confuse, as it were, the vibration frequency of the telephone diaphragms. The function of the condenser is that all these little irregular pulses shall join with the main pulse to flow into the condenser and charge it; they are thus all integrated and made into one whole before the condenser discharges through the telephone receivers. In much the same way a reservoir may be employed to gather up all the water contributed by small mountain streams, and perhaps one larger rivulet, before it sends a steady flow of water through a delivery pipe.

The size of the condenser should be chosen so that the natural frequency of the circuit made by it and the telephone receivers is equal to the main pulse frequency, *i.e.* the transmitter spark frequency; with the circuit thus tuned the strength of the main pulse will be accentuated. This means that the condenser value should depend on the inductance of the telephones and on the spark frequency, and should be variable to suit changes of either; generally, however, to save extra adjustments the condenser is made of a fixed value which is found to give the best effect with the telephones and spark frequencies usually employed. This value will be from 0·002 to 0·004 mfd.; if the condenser is too small it will have practically no effect, if too large it will reduce the potential drop across the telephones and thus reduce the strength of signals.

Now we have seen that the arrangements shown in Fig. 133 provide us with two tuned circuits coupled together, the oscillations in the aerial circuit inducing oscillations in the closed circuit in such a way that the potential effects are transformed up through the auto-transformer coupling. We must therefore consider the effects of loose or tight coupling. If the aerial circuit is tuned down to short waves few turns of the coil may be included in it and the coupling will then be loose; possibly so loose that signals are very weak. It may even be that best signals are now obtained by disregarding the tuning of the secondary circuit, leaving the variable condenser, A, at zero value and including a good portion of the coil in the detector circuit, not because this portion of the coil is in tune with the aerial circuit but because it gives a good step-up of potential. Again when tuning to long waves practically all of the coil is included in the aerial circuit, *i.e.* nearly the same amount of it as is in the closed circuit; this is tight coupling and the energy will tend to swing to and fro between the circuits on two wave lengths, neither of which is the main wave length in the ether, which results in a loss of efficiency. Therefore this arrangement is likely to be inefficient either because the coupling is too tight or too loose except on one definite wave length. Another disadvantage of single-slide or two-slide receivers is that they are very susceptible to jamming by atmospherics, or by signals on wave lengths to which they are not tuned.

The amplitude of the oscillations of a pendulum will be a maximum if it is tuned to the pulses acting on it, but this does not mean that it will not oscillate at all if impulses act on it which are not in tune, or do not synchronise with its swing. In the same way the amplitudes or maximum values of the current oscillations in an electrical circuit will be greatest if the circuit is in tune with the oscillating pulses of energy, such as ether strains, acting on it, but oscillating pulses of energy not in tune with it will still cause some oscillating effect. If the detector circuit is connected closely to the aerial circuit non-tuned pulses may cause sufficient electrical disturbance to vibrate the telephone diaphragms. Tuning the circuit or circuits with close coupling, such as is given by a single-slide or two-slide coil, may strengthen the effects for one wave length but will not reduce to zero the effects of other wave lengths. Thus with such coils tuning is mixed up with coupling; when tuned to give best strength of signals the coupling is likely to be so close that jamming is probable by signals on other wave lengths. It is better, therefore, to adopt an arrangement in which coupling is distinct from tuning and can be adjusted independent of the tuning; such an arrangement is provided by having two independent coils, one in the aerial circuit, the other in the closed circuit.

Loose-Coupled Circuits.—The closed circuit coil will generally have more turns than the aerial coil, and may be wound of finer wire because the closed circuit should be tuned with large inductance and small capacity effects; in the aerial circuit the capacity effects will be larger and the inductive effects correspondingly smaller when the two circuits are tuned to each other. The coupling between the circuits may be varied by making one coil slide along the axis of the other or by turning the axis of one coil relatively to that of the other. In the Telefunken receiver the secondary coil is hinged on a board and for tight coupling it embraces the aerial coil; when pulled upwards and outwards the axis of the secondary is no longer in line with that of the aerial and the coupling is loosened, and when the secondary coil is pulled right up it can be turned through an angle of 90°, thus putting the axes of the two coils at right angles to each other and well apart so that the coupling is very loose. Fig. 134 shows diagrammatically two arrangements of coupled receiver circuits; in the left-hand one the two tuning coils are coupled together which means that if the number of turns in either the primary or secondary coils is changed, for the purposes of tuning, it changes the degree of coupling, or necessitates a movement of one coil relatively to the other if the degree of coupling is to be kept constant. If the two coils are fairly large, wound in single layers and one slides into the other, they will form a condenser effect, and the tuning of both circuits will vary considerably as the coupling is varied. This disadvantage does not arise with the arrangements shown in the right-hand diagram; here the aerial circuit has a coupling coil quite distinct from the tuning coil, and the secondary circuit has no tappings on its coil so that it can be tuned only to the range of wave lengths given by the small variable condenser. In this case the coupling can be set to any desired value and will remain constant whatever the tuning adjustments may be. This is the best practice and is much used by the Marconi Company; the absence of tappings on the secondary coil reduces the range of wave lengths to which it is possible to tune the receiver, but in commercial practice a receiver is generally required to work on a definite wave length, and it is better to have an efficient receiver at that wave length than one which can be tuned to long or short wave length ranges which are not important. In any case a small variable condenser across the secondary coil gives a good range of tuning; for example, neglecting the small self capacity of the coil, suppose the variable condenser has a minimum value of 0·00004 mfd. and a maximum value of 0·0002 mfd., the minimum and maximum wave lengths to which the closed circuit can be tuned are:—

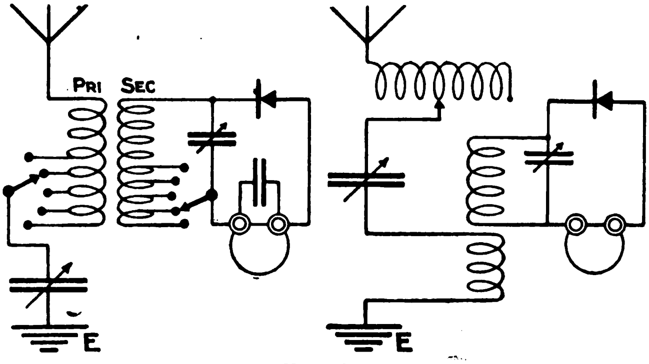


FIG. 134.

$$\frac{\lambda_1^2}{\lambda_2^2} = \frac{60^2L \times 0{\cdot}00004}{60^2L \times 0{\cdot}0002} = \frac{4}{20} = \frac{1}{5} \quad \therefore \frac{\lambda_1}{\lambda_2} = \frac{1}{2{\cdot}2};$$

in other words the condenser can be used to tune to a wave length more than double the minimum wave length. If the receiver is required to function on much longer wave lengths it is also possible to have a switching arrangement, by means of which an extra tuning coil can be connected in series with the existing coil in the closed circuit; the switch may even be so arranged as to throw extra inductance into the aerial circuit at the same time. For the present, however, we are only concerned with the principle that coupling should be kept distinct from tuning.

Fig. 135 shows the connections in a Marconi crystal receiver used for waves up to 1200 metres long. The turns of wire in both the primary and secondary of the coupling coil are fixed, *i.e.* there are no variable contacts. The aerial circuit is tuned by having in series with the primary a variable inductance coil with tappings taken to a multiple-way switch; a variable condenser is also joined in series, and is used to obtain finer adjustments of tuning. Since the secondary coil is of fixed value tuning of the secondary circuit is carried out by means of a small adjustable Billi condenser connected across the coil. Since the primary and secondary coils have a fixed number of turns the maximum coupling is fixed, but the "degree of coupling" can be varied by turning the axis of the primary coil out of line with that of the secondary, as shall be further described in Chapter XIX.

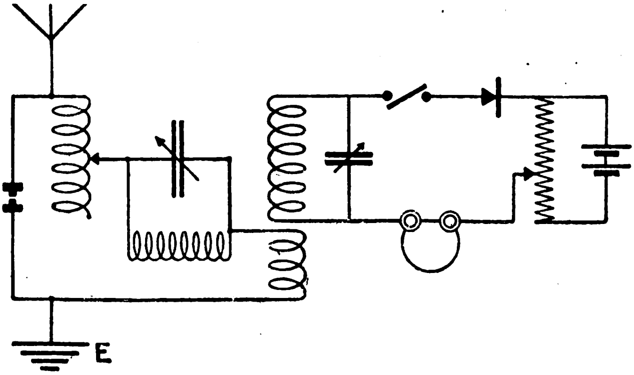


FIG. 135.

The Billi condenser is so named because its capacity is of the order of a billifarad.

A small spark gap $\frac{1}{100}$ inch long is connected across the whole aerial circuit from aerial to earth; through this abnormal discharges can pass, such as those induced by the station transmitter; it thus acts as a safety valve. Across the aerial condenser is shunted a coil whose inductance value is so high (up to 80 mhys.) that the ordinary oscillating currents in the receiver aerial circuit do not pass across it, but through it the aerial is permanently earthed so that it cannot become statically charged from atmospheric electricity. If such static charges were allowed to accumulate they would, on discharging through the apparatus, injure the detector or telephones. The variable Billi condenser across the secondary circuit is also fitted with a small safety spark gap not shown in the diagram.

The detector used is a carborundum crystal with a potentiometer and 4 to 6 volt battery. The construction of this Marconi crystal receiver will be further described in Chapter XIX.

It will be remembered that if the two tuned circuits of a transmitter are tightly coupled it results in radiation of energy on two wave lengths; similarly if the two tuned circuits of a receiver are tightly coupled the currents will oscillate in them at two frequencies, neither of which is that to which they are each tuned. This can be proved by buzzing the receiver circuits and finding the resulting wave length with a wavemeter, as shall be described in the chapter on Measurements. Therefore it is not sufficient for accurate tuning to the transmitted ether waves to tune each circuit accurately; the coupling between them must also be adjusted to give the condition of single waveness. Loose coupling also lessens the effects of jamming by other transmitters working on a different wave length; the ether strains due to these other transmitters will cause some oscillation of current in the receiver aerial circuit, but the resulting magnetic strains in the aerial coil will not be very strong and will not give strong effects in the secondary circuit, since the latter is not in tune with them besides being loosely coupled. Thus if jamming effects are troublesome the coupling should be made so loose that the jamming signals are very much cut down in strength and the signals it is desired to pick up are still readable. Making the coupling very loose will weaken the signals it is desired to read but will weaken much more the signals with which the receiver is not in tune.

Receiver with Intermediate Circuit.—Jamming and the disturbances due to atmospherics, or Xs, are more troublesome in wireless reception on a commercial scale than any faults of construction or adjustment of the apparatus. Sometimes the receiver has got a third tuned circuit, known as the intermediate circuit, whose function is to still further reduce these troubles, and ensure that only signals carried on ether waves with which the receiver circuits are accurately in tune can reach the telephones,

Fig. 136 shows the connections of such a Multiple Tuner, as used by the Marconi Company with a magnetic detector. The aerial circuit contains, as usual, tuning inductance, tuning condenser, and a coupling coil. An intermediate circuit AB is coupled to the aerial circuit as shown, and is tuned to it by means of the variable condenser C. Oscillating currents induced in A will flow through B. These currents in B will induce currents in the detector circuit, the latter being coupled to coil B in the usual manner.

A similar arrangement can be used with valve or crystal detectors, and further particulars of its construction will be given in Chapter XIX.

In the receiver here described we have three circuits, each of which must be tuned to the others and to the transmitted wave length ; it will be seen, therefore, that energy arriving at a different wave length will act on the aerial circuit, but its effect will be diminished in the intermediate circuit, and be scarcely apparent in the detector circuit since all three circuits are out of tune with it. Similarly the effect of strong atmospherics will be weakened, the impulses from them charging the condenser C, which is then discharged partly through A and partly through B. The whole arrangement forms a very weak coupling with a condenser filter in the middle of it, so that the receiver only responds strongly to waves with which it is in accurate tune. It may be noted that A, B, and C form two coupled oscillatory circuits, therefore A should be equal to B, and the wave length of either side is that due to the inductance of A or B and half the capacity of the condenser C.

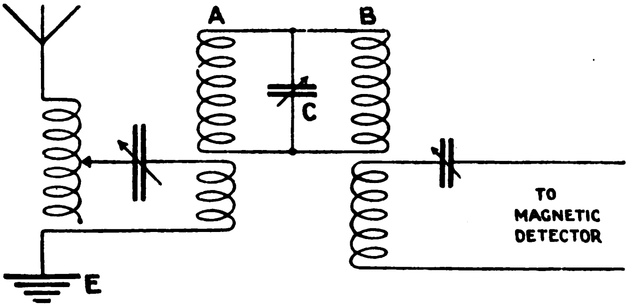
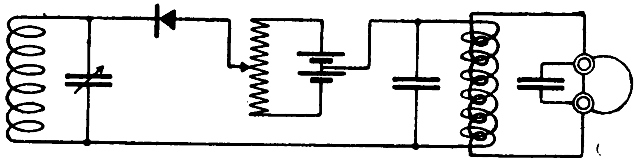


FIG. 136.

Telephone Transformer.—In some cases it is desirable to use low resistance telephone receivers, connected to the detector circuit through a small step-down transformer; the connections will then be as shown in Fig. 137.

Since the primary of the transformer replaces the telephones it should have approximately the same resistance as that of the telephone receivers which it has replaced, and would be shunted by a blocking condenser as shown.

Advantage can be taken of the fact that a transformer is used to have a step-down transformation, so that the secondary can be wound to a low resistance and low resistance telephone receivers connected to it. A crystal detector has a resistance of 6000 to 10,000 ohms, therefore it is usual to have in series with it telephone receivers of about 8000 ohms resistance, (each ear-piece coil having a resistance of 4000 ohms), for in all electrical circuits the best results are obtained when the measuring or recording instrument has a resistance of the same order as that of the circuit to which it is connected. If the telephone receivers are replaced by a transformer the primary of the transformer should have a resistance of 8000 ohms; the secondary may then be conveniently wound to only 120 ohms and telephone receivers of 120 ohms resistance used, *i.e.* 60 ohms per ear-piece. This use of a telephone transformer has several advantages; firstly, low resistance receivers are less delicate and less costly than high resistance ones; secondly, where a steady potentiometer current is employed in the detector circuit it may be flowing round the telephone coils in the direction which make it demagnetise the little magnets on which the coils are wound if they are in the circuit; thirdly, the use of a transformer removes out of the detector circuit any earth connection or leakage between the operator and the receivers he is wearing; such leakage or earth may upset the potential effects in the detector circuit which are relied on to produce signals, especially if valves are employed.



SECONDARY CIRCUIT WITH STEP-DOWN TELEPHONE TRANSFORMER AND LOW RESISTANCE RECEIVERS.

FIG. 137.

The blocking condenser shown across the telephone receivers in Fig. 137 may be omitted; it is not often employed as one across the telephone transformer primary will suffice.

Telefunken Receiver.—Some new considerations are introduced in Fig. 138, which shows the connections of a Telefunken Receiver Circuit. In the first place it will be noted that the aerial tuning condenser is connected through a switch S_1 by means of which it may be put in series or in parallel with the aerial tuning inductance, thus giving a short wave range and a long wave range of aerial tuning. All the switches marked S are opened by the change-over switch when the latter is put over to the "Send" position; the receiver is also fitted with a small safety spark gap X across the detector circuit. The receiver consists of an aerial circuit, a closed circuit coupled to it, and a detector-telephone circuit which is not necessarily connected across the whole of the closed circuit. The inductance tappings on both

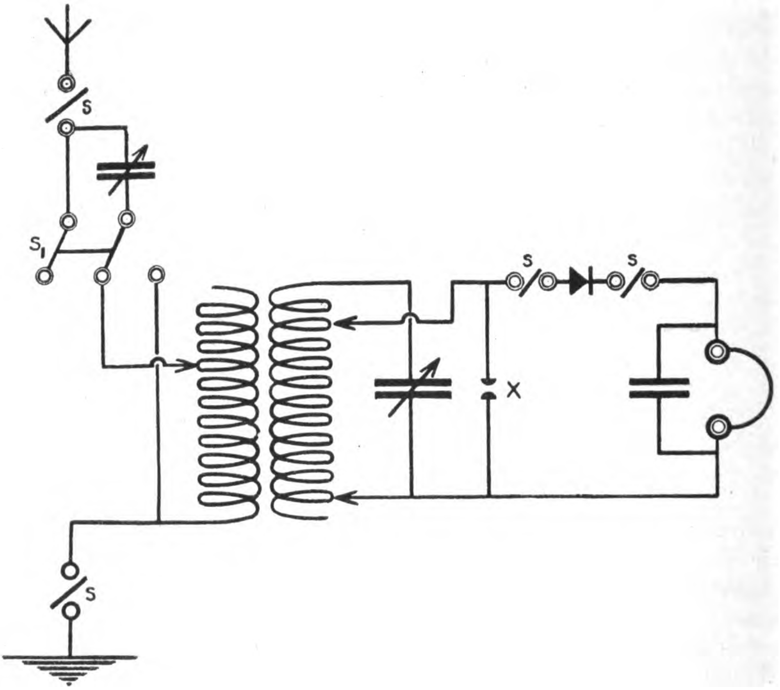


Fig. 138.

coils are made by plug and socket instead of tappings to a multiple switch; for long waves the two coils can be quickly replaced by others of higher inductance values. The detector circuit is connected to the inductance coil of the closed circuit by plug and socket tappings, and may be across only a portion of the coil; in other words the detector circuit can be loosely coupled to the closed circuit, which now acts like a tuned intermediate circuit. With a quenched spark transmitter a long train of ether waves is set up by each spark; the ether waves induce a similar train of oscillating currents in the receiver circuits, the amplitudes of the current rising to a maximum and then falling away slowly if the damping decrements of the circuits are small. Also, when a detector-telephone circuit is connected across the tuned secondary circuit a discharge passes through the detector and telephones each time the potential across the secondary condenser has been built up by the oscillations of current in the secondary circuit. This discharge through the detector and telephones represents energy taken from the secondary oscillations,—oscillating energy transformed into a slow pulse of energy, and this abstraction of energy damps out the oscillations in the secondary circuit. With the detector circuit connected across the whole secondary inductance this discharge may take place at the fourth or fifth oscillation, when only four or five of the ether waves in the train have acted on the circuits; thus the energy of the remainder of the ether waves in the train does not contribute to the effect in the detector circuit, and as their energy is decreasing they do not build up sufficient potential in the secondary coil to give a further discharge thrugh the detector circuit. In other words much of the ether wave energy is wasted, because we have taken the oscillating energy out of the closed circuit before it has time to build up to the maximum value it might have attained; we therefore lose the advantage of having low damping decrement at the transmitter, and we decrease the advantages of tuning and loose coupling.

Now suppose the detector circuit is connected across only a portion of the secondary circuit inductance; the ether waves induce oscillating currents in the aerial circuit and through it in the secondary circuit, and with the secondary circuit sharply in tune the amplitude of the oscillations in it will build up as they swing to and fro. Since the detector circuit is only connected across a few turns of the secondary coil a discharge will not take place in it until the oscillation amplitude is well built up, *i.e.*

until most of the ether waves in the train have acted on the circuit, and carried out a building up process because the circuit is in tune and in spite of the fact that the wave energy in the train gradually decreases.

Thus good use is now made of the fact that there are a lot of ether waves in each train, also that only trains accurately in tune with the circuit will give rise to a good building up of the oscillation effect so that jamming by signals on other wave lengths is very much diminished. In fact, by reducing the damping effect of the detector circuit in this way, it is possible to work with looser coupling between the aerial and closed circuits and thus reduce interference by jamming signals. Even when the discharge does take place through the detector circuit it is only a portion of the energy oscillating in the closed circuit; *the most efficient conditions are that the detector circuit should be so coupled to the closed circuit, or tapped off such a portion of the closed circuit inductance, that* 50 *per cent. of the energy oscillated in the closed circuit is changed into pulse energy in the detector circuit.* To have more means too high a damping decrement of the closed circuit, cutting down its selectivity; to have less means that not sufficient oscillating energy is transformed into pulse energy in the telephones to give signals, and the latter will be unnecessarily weak while the coupling adjustment will be critical.

It may be noted here that with hard valve detectors the grid filament circuit does not draw much current from the oscillating circuit, therefore the damping effect of a valve detector properly adjusted is very small.

Notes on Receiver Aerial.—The function of a receiver aerial is to absorb energy from ether waves and not radiate it; when, however, oscillating charges and discharges are induced in the aerial, no matter how small, they set up oscillating strains in the ether around so that some of the energy obtained from the ether waves is re-radiated. The existence of this re-radiated energy means that all the energy received from the ether waves is not available for setting up current pulses in the telephones; it also implies that in the ether around the receiver aerial there may be interference between the arriving and radiated strains or waves. It will be remembered that the radiation of energy from an aerial depends on the square of its height. Unfortunately some re-radiation loss cannot be avoided as the higher the aerial the better it will absorb energy from the ether, but at the same time the better will be its radiation of energy. Some compromise must be effected and Rudenberg has shown that "*a receiver aerial is most efficient when the energy re-radiated from it is equal to that in the closed circuit.*" Generally the same aerial will be employed for both transmission and reception, so that its design will be governed by transmission requirements as regards height, number of wires, length of wires, and surface area. If, however, an aerial is to be employed for reception purposes only it should be of moderate height to save radiation loss; the wires may be fairly thin since the oscillating currents in it are small. It must not be forgotten that a portion of the oscillating energy is lost in its resistance; if C is the current and R the high frequency resistance, C^2R watts will thus be turned into heat in the aerial circuit. Therefore the resistance must not be too high though it may be higher than that of the transmitter aerial circuit. The receiver aerial inductance is wound with small gauge wire and the connecting leads are of smaller diameter than those used in the transmitter, but the aerial resistance should not be greater than about 20 ohms. It should be realised that a bad or dirty contact in the connections may have a resistance of 100 ohms or more. The aerial should be high enough to clear all screening effects of houses, trees, etc., in the neighbourhood, and it should be long enough to give it a natural wave length equal to about half the wave length it is desired to receive. It may be recalled that a transmitter aerial cannot be loaded with inductance to make the radiated wave length more than four times the natural wave length of the aerial without sacrificing efficiency.

A receiver aerial can be loaded with inductance without greatly impairing the efficiency, provided always that the aerial is long enough to entrap a sufficient amount of energy out of the ether waves, and that, therefore, the resulting currents oscillating in it are strong enough to give good signals. Further consideration of this point is given in the following section. The current induced in a receiver aerial circuit will generally be increased by increasing the number of wires which constitutes the aerial, provided this does not unduly increase the capacity and with it the natural wave length.

Aerial Tuning and Coupling Inductances.—When the ether waves act on the receiver aerial circuit they set up electrical oscillations in it, *i.e.* charge and discharge. At each charge the energy in the capacity of the aerial is $\frac{1}{2}KV^2$, at each discharge this energy of charge is turned into energy of electrical movement in the inductance which equals $\frac{1}{2}Li^2$, where i is the effective value of the discharge current. It is when the energy is in the form of current flowing through inductance that some of it is transferred to the detector circuit, or the secondary circuit as the case may be. Thus in the coil we want a maximum of inductance effect and a minimum of capacity effect. Unfortunately it is not possible to make a coil or wire which has not some capacity effect, but by suitably designing a coil its capacity effect can be kept down, and this is especially necessary in the case of large coils required for long wave work.

The capacity of a coil can be kept down by keeping the turns on it slightly separated instead of winding them close together; this may be accomplished by winding a thin cord on the Former side by side with the wire so that the turns are separated by the thickness of the cord. The coil should be in one layer or it may be lap wound by winding three or four turns one over the other, then three or four more in the same manner beside the first, and so on. The wire used should be finely stranded rather than a single wire, and the former on which it is wound should be a good insulator, such as ebonite. If wood is used it should be well boiled in paraffin wax previous to winding. With finely stranded wire lap wound coils have been made whose inductance was 12,000,000 cms. and capacity only 0·000005 mfd.

Dead End.—When a receiver circuit includes a large coil, to give a large range of wave lengths, a good portion of this coil will not be in use for inductive tuning when the circuit is tuned to short waves, but its capacity effect will still be acting in the circuit. The portion of the coil not in use for inductive tuning is called the "Dead end"; switching arrangements should be provided to disconnect the dead end entirely from the tuned circuit to get rid of its capacity effect, especially with large coils. In order to avoid the necessity of a complicated switch the coil can be made in distinct sections; one section only is used for a certain wave length range, and further sections added as necessary by simple switching arrangements when it is desired to increase the wave length. Another method is to have a set of coils, using one for short wave lengths, another for longer wave lengths, and so on; this is the method adopted by the Telefunken Company, whose receiver is so designed that coils can be quickly interchanged in both the aerial and closed circuits. If a separate coupling coil, distinct from the aerial tuning coil, is employed it will not be of large inductance value, therefore will have relatively few turns and may be made of simple design and single wire.

If a given amount of energy is entrapped from the ether waves by the aerial circuit its value when it is in the form of current flowing through the aerial coils is given by $\frac{1}{2}LC^2$ watts. If we increase the size of the coil to increase the circuit's wave length we increase L, therefore we decrease C since the energy remains the same; also by increasing the size of the coil we increase the resistance, thus still further decreasing C. The induced potential across the coil is proportional to $2\pi fLC$ and it may therefore happen that the reduction of current more than wipes out the increased value of L, so that the effect on the detector circuit is diminished.

Secondary Circuit Inductance.—The considerations given above for the design of the aerial tuning coil apply equally to the design of the secondary circuit coil; it should have small self-capacity. It need not have as many tappings on it as the aerial tuning coil, since the secondary circuit has generally a variable condenser across it, and a good range of wave length tuning is given by a very small capacity range on this condenser.

It must not be forgotten that the receiver wave length will change with the degree of coupling so that if the coupling is changed the tuning adjustments should be corrected. With large coils this change of wave length, as they are put closer or further apart, may amount to 200 or 300 metres when the coils are not well designed; thus large coils have a considerable capacity effect if placed close to each other and are not properly designed.

It is best to have the secondary circuit tuned so that the inductance value is as large as possible and the condenser value small; if the capacity of the condenser is increased to increase the wave length the receiver becomes less efficient; the wave length should not be raised by means of the condenser to more than 2·5 times that obtained with the coil alone. For example if the full secondary coil has a natural wave length of 1000 metres, (which should be due to large inductance and small capacity), a condenser across it should only have a maximum capacity value which will raise the wave length to 2500 metres.

Aerial Tuning Condenser.—This may be connected into the aerial circuit above or below the aerial tuning coil; one disadvantage of putting it below the tuning coil is that the tuning coil will act as a choking coil to a sudden surge in the aerial due to atmospheric conditions, so that the discharge is then forced through the detector-telephone circuit and may cause injury. If the condenser is put above the tuning coil the surge will have to spark across the plates of the condenser and this will use up a good amount of its energy. It must not be forgotten that the top of a high aerial is in a region of the atmosphere where the potential is normally high compared with that of the earth, so that an aerial insulated by a condenser is likely to become charged. As explained before, a high inductance leak coil shunting all the aerial circuit apparatus will prevent the aerial from accumulating a dangerous static charge, and a safety spark gap will protect the apparatus against a sudden discharge between a cloud and the earth through the aerial.

The tuning condenser may have air dielectric but the plates have to be frequently cleaned by flushing them with petrol and drying them out, otherwise specks of dust are likely to short them and so cause trouble. A better design is that made by the Marconi Company in which the fixed and movable plates are separated from each other by thin sheets of ebonite; this avoids shorting trouble and decreases the size for a given capacity; the bulk is also decreased by having two sets of semicircular fixed and movable plates connected in parallel.

Trouble with air condensers is also caused by the fact that the distance between the fixed and movable plates changes through wear of bearings and jolting. This can be obviated by making the movable plates one solid mass, either by soldering or by cutting the whole thing out of the solid, also by making the fixed plates solid with their supports in a similar manner.

This construction is favoured by German manufacturers and, though expensive, amply repays the outlay in the satisfactory constancy of the capacity. The plates of a variable condenser can be cut to such a shape that the capacity increases along a straight line curve as the adjustment is made from 0 to maximum.

Instead of a variable condenser across the inductance coil a variable inductance, or variometer, may be connected in series with it. A form of variometer suitable for this purpose is described in Chapter XXII.

Since, in general, a spark transmitter radiates energy on two main wave lengths attempts have been made to design receivers so that they would receive energy on the two wave lengths simultaneously. Kimura has described a method of doing this, but his experiments demonstrated that no advantage was gained and that, in fact, it was best to have a looser coupling on the transmitter, radiating less energy but giving single wave effect.

QUESTIONS AND EXERCISES.

1. Explain the arguments against the use of coupling coils as tuning coils for the aerial and detector circuits.

2. Give a detailed account of what happens to the energy set up in the receiver aerial by the transmitted waves, and state the reason why transoceanic stations have separate transmitting and receiving aerials.

3. Kieblitz was able to receive signals from long distances with wires stretched only a few feet above the ground. How is this explained ?

4. State Rudenberg's rule for maximum receiver efficiency.

5. Marconi receivers have an inductive shunt across the aerial series condenser. Why do not the aerial currents go through this coil rather than through the condenser ?

6. What is the frequency of the currents in the telephones of a radio-receiver if the primary alternating current supplied to the transmitter circuit has a frequency of 300 cycles per second ? Neglect transmitter resonance effects.

7. What is the function of the highly inductive coil joined across the aerial condenser in a Marconi receiver ? How does its action differ from that of the micrometer spark gap joined across from aerial to earth ?

8. The secondary circuit of a receiver has a coefficient of self-induction of 500 mhys. when adjusted to receive signals on 1200 metre wave length. What value of capacity should be shunted across it to make the tuning accurate ?

9. What is the object of an intermediate circuit in a multiple tuner receiver ? Point out the possible disadvantages of such an intermediate circuit.

10. Explain the object of connecting a condenser across the telephones in a receiving circuit.

11. If the inductances in a receiving circuit consist only of the variable primary and secondary windings of the coupler, and if these coils are of relatively large diameter, it is found impossible to tune to (*a*) short wave lengths, (*b*) very long wave lengths. Explain the reason of failure in each case.

12. If a receiver coupler consists of a cylindrical secondary coil sliding into a primary one it is bad practice to have the secondary of such a diameter that it fits closely into the primary. Explain the inefficiency of such a design ?

13. Draw a diagram of the connections of a loose-coupled receiver, with primary and secondary coupling coils, and a potentiometer voltage in series with the detector.

14. If the inductance in a receiver aerial circuit is 30 millihenrys when it is tuned to Clifden wave length of about 6000 metres what is the combined capacity of the aerial and aerial inductance coils ?

15. The inductances of a receiver consists of a secondary coil sliding into a primary coil. When the secondary is pushed into the primary the two provide a capacity effect. If the secondary is moved out of the primary how are the wave lengths of the receiver circuits modified ?

CHAPTER XVIII

DETECTORS AND TELEPHONE RECEIVERS

LIGHT is conveyed by very short ether waves which are detected by means of the eye and conveyed to the brain; this receives different sensations of what is called colour according to the ether wave lengths present. Telegraphy with these short ether waves is carried on by means of a heliostat or flash lamp; here again the eye is used to detect the waves working in direct conjunction with the brain receiver.

The eye, though so delicate and sensitive, can only detect a very small range of very short ether wave lengths, and does not respond to the long ether waves employed in long distance telegraphy; for these waves artificial detectors must be provided, and the sensations conveyed to the brain in a secondary manner through the medium of one of the senses, usually the sense of hearing or the sense of sight.

The first detector of long ether waves was in the form of a tiny spark gap as employed by Hertz in his experiments, and by Sir O. Lodge with his Syntonic Leyden Jars. This was not very sensitive and was soon replaced by Branly's coherer; Marconi improved the design of the latter, and new arrangements of cohering devices were quickly discovered, while other detecting devices were evolved by making use of thermal effects, chemical effects, and other physical phenomena.

Coherers.—The coherer consists of a small glass tube having two silver plugs cut as shown in Fig. 139. The plugs are separated about 1 millimetre, and in the space between them metallic granules are placed, 5 per cent. silver and 95 per cent. nickel. The silver plugs are attached by wires, one to the aerial, the other to the earthed side of the receiving circuit; preferably the glass tube is sealed and exhausted of air, the tube being about 5 mms. diameter. To the coherer is joined a circuit consisting of a single primary cell and a relay. Under ordinary circumstances the resistance of the loosely packed filings in the coherer is so great that it does not complete the circuit of the cell to the relay, and consequently the latter does not act; when ether waves act on the receiver aerial the oscillating electrical potentials set up in it act across the coherer. This has the effect of breaking down its resistance so that it now completes the cell and relay circuit, and the latter is actuated by the current of the cell. The coherer acts like an open switch which becomes closed by the effect of the ether waves; the filings stick together, or cohere, so as to form a bridge conducting the current across from one plug to the other; the name "coherer" was given to this device by Sir Oliver Lodge, and Dr. Erskine Murray proved that its sensibility depended upon the difference of potential acting across it.

When it has cohered it remains in that condition, therefore in order that it may detect a train of signals it must be decohered after each signal. This is accomplished by tapping it with a little hammer attached to the soft iron armature of an electro-magnet, and actuated by the current of a circuit closed through the relay. The relay also closes at each signal a local circuit, consisting of a battery and either a Sounder or a Morse Tape machine. The connections of the coherer, the tapping device, and the local circuit have been already shown in Fig. 60.

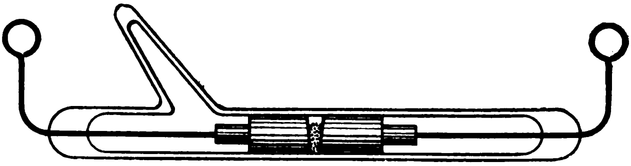


Fig. 139.

The disadvantages of the coherer are :—(1) it is erratic in its sensitiveness, which may be much decreased by local discharges, such as the spark discharges of the transmitter; (2) it responds to atmospheric disturbances or discharges, and consequently cannot be relied upon even as a calling-up apparatus. With strong impulses of energy in the receiver it enables one to print the received message, but for long-distance work it is not as sensitive as some other detectors which are of more modern development.

The **Italian Navy Coherer**, discovered by Lieutenant Solari, consists of a small glass tube with two iron or steel plugs between which is a small drop of mercury. This form of coherer has the advantage of being self-decohering, the mercury making good contact with the iron plugs only when the ether waves are acting on the aerial circuit.

The **Lodge Muirhead Coherer** is also self-restoring; it consists of a small steel wheel with a sharp edge, revolved by clockwork at a suitable speed, and just touching a little pool of mercury in a cup at the top of a brass terminal pillar. The mercury is covered with a thin film of oil so that in ordinary circumstances the oil insulates the wheel from the mercury; when oscillating potentials are set up in the receiving circuit the oscillations break down the insulation of the oil, and a local circuit of which the coherer forms a part is then completed. As the wheel revolves a new portion of it immediately comes into action and thus decoherence takes place. The resistance of this coherer when coherence takes place is very low, therefore it has the advantage *that no relay is required;* the battery and Morse tape or other recording apparatus can be connected directly in a series circuit with the coherer.

A coherer made on what is called the Stone system was employed in some of the portable wireless outfits of the United States Army. The **Stone Coherer** has two small steel plugs between which are placed loosely packed carbon granules. This is a self-decohering device; though not as sensitive as other forms of detectors it is well suited to the rough usage of portable outfits.

Before proceeding further with a description of various detectors it will be necessary here to digress into theory for a moment. It will be remembered that when electrical oscillations occur in an aerial circuit, and when these oscillations occur at the fundamental wave length of the circuit, maximum potential strains occur at the top, or outer end, of the aerial, and maximum current disturbances occur at the earthed end. (*See* Fig. 119, Chap. XVI.) Now the action of a coherer depends on potential strains acting across it, therefore we see that if it is connected into the aerial circuit near the earthed end it is not placed where the potential strains have their maximum effect. This was early realised by Marconi in the development of wireless telegraphy, and led to his connecting the coherer in a secondary circuit inductively coupled by the Braun method to the aerial circuit. The secondary circuit can be so arranged that the coherer is at a point of maximum potential strain in it, that is to say, at an antinode of potential. By this means not only is the high initial resistance of the coherer removed out of the aerial circuit, but it is also placed in a position where the action of the induced oscillations on it will be most effective. In passing we may note that the distribution of potential strains and current in a receiver aerial circuit can also be modified by series inductance coils or condensers, or both, near the earthed end. These change the wave length so that it is longer or shorter than the natural one, and hence produce new positions for the nodes and antinodes of potential and current. In the consideration of detectors it will be found that while most of them are actuated by potential strains, others, such as the magnetic detector, are current actuated devices. The latter are generally of comparatively low resistance, and will work well if connected directly into the aerial circuit near the bottom, where maximum current disturbances occur. Other considerations, however, such as tuning and avoidance of interference, make it advisable to use secondary circuits even with current actuated detectors.

Marconi Magnetic Detector.—The erratic behaviour of the coherer led Marconi to develop and perfect his Magnetic Detector,

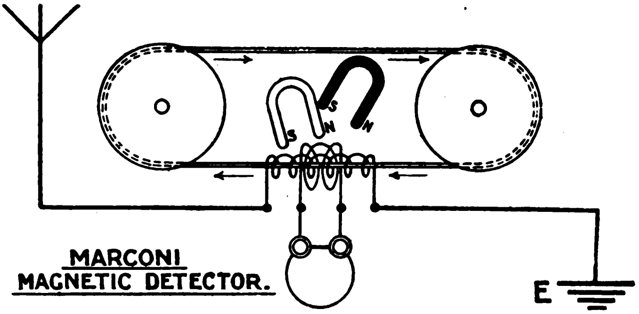


Fig. 140.

based on the results of experiments by Rutherford and other scientists. It consists of a band, made of fifteen or more slightly insulated soft iron wires, passing over two small wooden discs which are revolved by clockwork. In this manner the band continually passes in front of the poles of two small permanent magnets arranged as shown in Fig. 140. The band passes through a small glass tube in front of the magnets; on this is wound two coils, one being joined in the aerial circuit, or in the coupled secondary circuit as the case may be, the other joined to the telephone receivers as shown. The action of the detector is very simple. As the iron wires pass in front of the magnets they become magnetised, their magnetic condition depending upon the arrangement of the magnets. When iron or steel is magnetised it does not lose all its magnetism if the magnetising force is removed. This retention of magnetism depends in amount on the quality of the iron, and is due to what is called its "magnetic hysteresis." Thus the portion of the iron band passing away from the front of the magnets retains some magnetism or magnetic lines, but when the ether waves set up oscillating currents in the receiver circuit, (and therefore in the coil through which the band is passing), these oscillating currents have the effect of suddenly diminishing the number of magnetic lines in the band. Now consider the second coil which is connected to the telephone receivers; if the number of magnetic lines threaded through or interlinked with it is suddenly reduced an E.M.F. is induced in it; this sends an impulse of currents through the receivers. Thus at each train of oscillations set up in the receivers' circuit the band suddenly loses magnetic lines, and the resulting induced current causes a sound in the telephones. As the band is driven forward a new portion of it comes into action, so that the arrangement is self-restoring. Note also that it is a current actuated device. This detector is very reliable and was almost universally adopted for all Marconi ship stations; by means of it signalling across the Atlantic was first made possible. It is not as sensitive as some other detectors of more modern development, but probably no other form of detector is more stable, and, as Mr. Duddell remarked, it is almost fool proof. Its sensitiveness is not affected by "atmospherics" or strong transmitter discharges in its neighbourhood; when once adjusted by the Marconi Co. no further adjustment is necessary. It is specially suitable for long wave long distance reception, that is to say for comparatively low frequencies; being a low resistance detector and current actuated it may be joined directly into the receiver aerial circuit. In the Marconi equipments it is so joined when "standing by," *i.e.* when it is desired to pick up signals from any transmitter, irrespective of wave length. Fig. 141 shows the appearance of the magnetic detector; it does not require a potentiometer E.M.F. to be used in conjunction with it. A possible disadvantage is the necessity for clockwork mechanism; this may go out of order or run down in the middle of a message. Until quite recently ships were equipped with some sensitive form of detector but had in addition a magnetic detector to serve as a stand by, or for the use of comparatively inexperienced operators. It is quite possible that magnetic detectors could be further developed by more experimental research; for instance the action of nickel or Heusler alloys might be tried, or the detector in a new form might with advantage be used in conjunction with valve relays and amplifiers. It is usual to have a second set of magnets and coils to work on the other side of the band; one set will then serve to replace the other, and when receiving on long wave lengths the strength of signals is often increased by using the two sets of coils in series. For rapid sparking, or high-note signals, the band should be driven slightly faster than usual to obtain best effects.

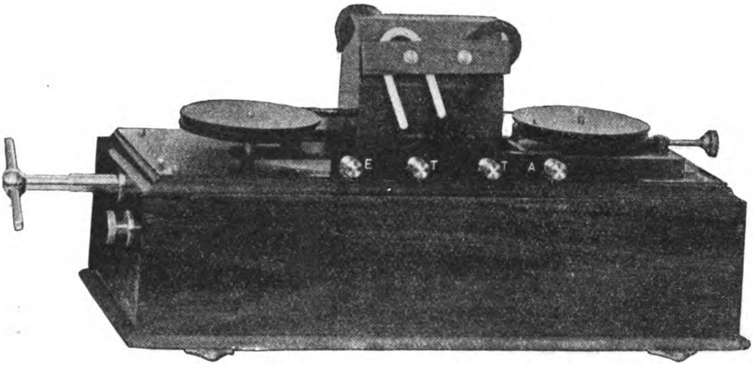


FIG. 141.

Use of Potentiometer.—Reference has been made to the fact that a potentiometer is not required with a magnetic detector, and before proceeding further it will be necessary to explain the use of a potentiometer in wireless telegraphy receivers.

If a 4-volt battery is connected across a long uniform wire there will be a uniform drop of potential along the wire. The wire should be of high resistance so that the current taken from the battery is a small one. If a voltmeter is connected across two points on the wire which are exactly half the length of the wire apart it will read 2 volts; if the points are exactly one quarter of the length of the wire apart the voltmeter will read 1 volt, and, similarly, we can tap any voltage from 0 to 4 volts off the wire. Such an arrangement of battery and wire is called a potentiometer; by means of it we can apply to a voltmeter or to any apparatus a voltage which can be adjusted from zero up to the full voltage of the battery.

For wireless telegraphy receiver circuits a potentiometer usually consists of a long fine German silver or platinoid wire having 200 to 400 ohms resistance, wound on a slate form, the turns being insulated from each other. It has a terminal at each end, and a third one joined to a sliding contact on the wire; by means of this sliding contact we can tap off whatever voltage we desire or find suitable, up to the full voltage across the whole wire. If the wire has 400 ohms resistance, and we apply 4 volts to it, the current taken from the battery is $\frac{4}{400} = \frac{1}{100}$ ampere; thus the battery can be used for a long time before it is discharged. Of course the battery may be switched off when the apparatus is not in use. Fig. 142 shows a potentiometer made by Messrs. Isenthal & Co., Neasden, London; if desired the potentiometer may be wound *non-inductively* by doubling the wire back on itself at each turn; this is, however, a refinement which is scarcely necessary.

Now it is found that some forms of detectors, such as valve or carborundum crystal detectors, are made more sensitive by having in series with them a small steady voltage such as can be tapped from a potentiometer wire. The reason of this may be explained as follows:—If a direct current flows in a circuit which is kept at a steady temperature Ohm's Law shows us that $C = \frac{V}{R}$, or the current is directly proportional to the impressed volts. Thus if we plot a curve connecting current and volts we shall get a straight sloping line, as shown at A in Fig. 143. If we take *any* point on the curve, such as X, and divide the current at X into the corresponding applied volts we obtain the resistance R of the circuit—$\left(C = \frac{V}{R} \quad \therefore \frac{V}{C} = R\right)$.

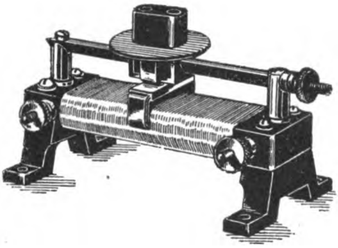


FIG. 142.

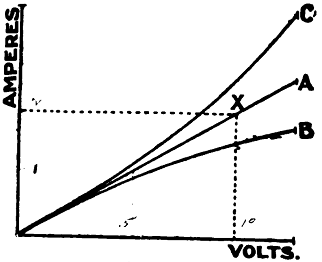


FIG. 143.

But when a current flows in a circuit it heats the circuit; if the circuit is of metal its resistance increases with the temperature, so that as the volts are raised and the current increases the temperature rises and the resistance increases. On account of this increase of resistance the current at any voltage will be less than usual. Hence, for a metal, the current voltage curve will not be a straight line but will curve downwards as shown at B, Fig. 143. On the other hand if the circuit is a carbon, mineral, or liquid one its resistance will decrease with rise of temperature ; therefore the current voltage curve will rise above the straight line as shown at C. The student should obtain the current voltage curves of carbon and metal filament lamps and verify the above remarks.

To sum up we may say that, in general, temperature variations change the resistance of a circuit and thus modify the amount of current flowing in it when a certain voltage is applied.

Again, if a circuit contains a contact between two dissimilar materials, such as a junction of two different metals or a contact of a metal and a crystal, a current flowing across this contact or junction will set up at it either a small evolution or small absorption of heat. Whether it is an evolution or an absorption depends on the material used and the direction of the current across the contact. This effect was discovered by Peltier and is called "*The Peltier Effect.*" Since a crystal detector always contains a contact between a crystal and a metal, or another crystal, it is easily seen that if a voltage is applied across it the resulting current will depend, partly upon the decrease of resistance of the crystal or crystals due to rise of temperature, and partly upon the amount of Peltier effect set up at the detector contacts. If, therefore, we apply small increasing voltages across a crystal suitable for detector purposes, and measure the resulting currents by means of a microammeter or galvanometer joined in series with the crystal, we shall find that the current voltage curve of the crystal has departed very considerably from a straight sloping line and that it bends upwards. Fig. 144 shows curves obtained by the author with a Carborundum and a Perikon detector respectively.

By means of these curves we see at once how a potentiometer voltage may increase the sensitiveness of a detector in some cases. Thus the curve for the carborundum crystal shows that a small increase of voltage above 0·8 volt will increase the current through the crystal very greatly. Studying the curve we see that if 0·6 volt acts across the crystal the resulting current through it is 1 microampere, but if we had already across the crystal 0·8 volt and add another 0·6 volt the resulting current through it at 1·4 volts is 25 microamperes ; an increase of current out of all proportion to the increased voltage.

Thus to make such a detector sensitive we should apply to its circuit by means of a potentiometer a voltage that will bring the current through it just to the bend of the curve; when ether waves act on the receiver aerial, setting up a small additional potential across the detector, the resulting current increase through its circuit will have a much higher value than if no voltage acted on the detector except the small one set up by the ether waves. In other words, instead of working the detector at the zero point on its current-voltage curve it functions at the bend, where it is most sensitive as regards current change, and where also it has good rectifying properties.

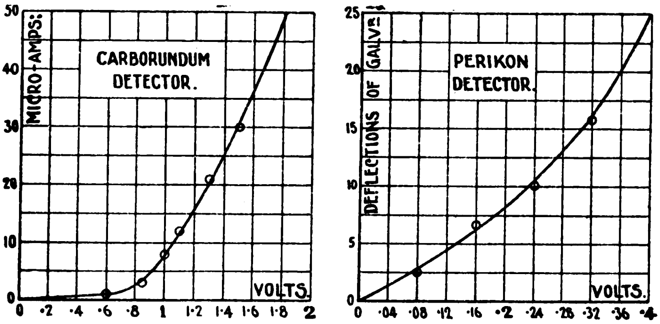


Fig. 144.

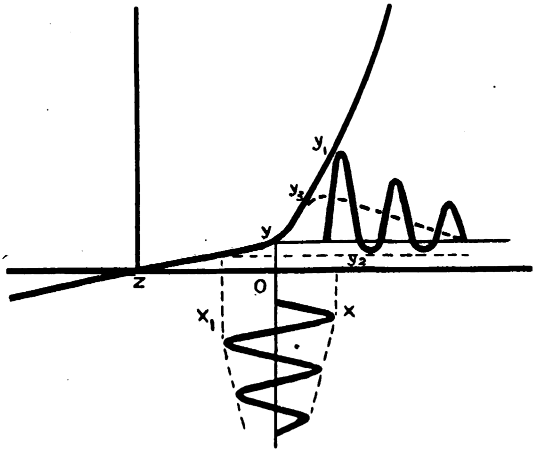


Fig. 145.

The rectifying action is illustrated in Fig. 145; here ZO represents a steady voltage applied to the detector circuit, which includes a pair of telephone receivers, and Oy is the resulting steady current through the circuit. This steady current will not cause the telephone receiver diaphragms to vibrate. If in addition to the steady voltage OZ an oscillating potential acts on the circuit its effect will be to make the resultant potential vary between the values Zx and Zx_1. When the potential is Zx the current rises to xy_1, but when the potential is Zx_1 the current only falls a little to a value xy_2. Thus during the action of an oscillating potential on the circuit the mean value of the current rises from y to some value y_3; the action sets up a pulse of increase of current in the circuit and this pulse will cause a vibration of the telephone diaphragms.

The high impedance of the detector and telephones will damp out ripples in the pulse of current, so that its form will be as shown by the dotted curve in Fig. 145 rather than the oscillating values shown by the full line oscillations.

It can be seen that the sensitiveness of any apparatus used in this way as a rectifier, or detector, will depend on the steepness of its current curve beyond the sensitive point. If the steady applied voltage is so great that the detector is functioning at some point on the uniform sloping part of its characteristic curve, such as y_1 in Fig. 145, the fall of current value during one half of an oscillation of potential will be equal to the rise during the other half, the mean value of current will not vary and the telephone diaphragms will not vibrate. At the same time the comparatively large current will probably damage the detector and may be deteriorating the telephones.

The train of damped oscillations of potential, shown below the horizontal line in Fig. 145, will cause one pulse of increase of current through the telephones, as has been explained above. One vibration of the diaphragms will thus be obtained at every train of oscillations, *i.e.* at every train of ether waves, corresponding to each spark at the transmitter. This has already been shown in Fig. 132. If the potentiometer voltage is applied to the detector in the opposite direction it will be found that the resulting current curve is similar to that shown in Fig. 145, but the values of current are very much smaller for small applied voltages. The detector has a higher resistance in one direction through it than in the other direction. The reverse current is shown in Fig. 145 by the portion of the curve drawn beyond the origin Z and below the horizontal line.

The proper adjustment of potentiometer voltage is obtained. by listening in the telephone receivers when small oscillations are being induced in the circuit and adjusting the potentiometer until the resulting signals are loudest.

The oscillations can be set up in the receiver by means of a small buzzer transmitter or wavemeter made for the purpose; such station testers and wavemeters are described in Chapter XXII.

The curve shown in Fig. 144 for a Perikon detector is fairly regular and with no decided bend; it thus demonstrates that no great advantage would be gained by using a potentiometer in series with this detector.

No two crystals of any kind will have exactly the same characteristic curve, and the correct polarity of the steady voltage to be applied to a crystal detector can only be ascertained by trial and error. Thus it is essential to have some quick method of reversing the current through the detector, such as reversing the connections of the detector or those of the potentiometer battery. Another method is shown in Fig. 146; suppose 4 volts are applied to the potentiometer wire, the potential drop along the wire from the positive to the negative terminals will be from + 2 to — 2 volts, the potential of the centre being zero, assuming the wire to be uniform. Suppose the potentiometer slider is at x; the potential of x is higher than the centre point, consequently a steady positive current will

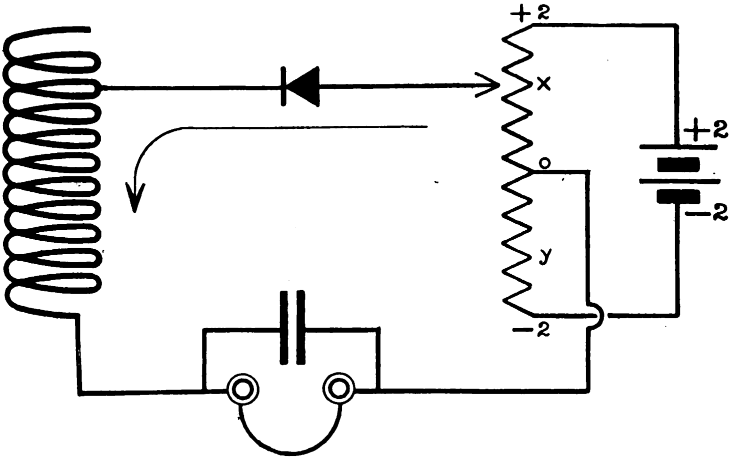


FIG. 146.

flow round the detector-telephone circuit in the direction shown by the arrow. If the slider is put at y the zero potential at the middle of the wire is higher than the negative potential at y, therefore the current will be reversed in the detector-telephone circuit. We have thus a method of applying a potential to the circuit which can be varied from 0 to $+ 2$ or from 0 to $- 2$ volts as found necessary. The connection from the telephone receivers can be taken to the middle of the battery instead of the middle of the potentiometer wire.

Fleming Valve Detector.—The Fleming Valve Detector was patented by Dr. J. A. Fleming in 1904; its action was reliable and sensitive and it was much used by the Marconi Co. The detector consists of a small electric lamp having a single loop filament of carbon or of tungsten. Inside the lamp and surrounding the filament is a cylinder of sheet or gauze copper, connected by a platinum wire passing through the glass to a third terminal on the lamp. The filament is lighted up, or raised to incandescence in the ordinary way, by means of a battery of 4 or 12 volts (according to the size of valve used) in series with a voltage regulating resistance. The *negative* terminal of the filament is connected in series with a potentiometer voltage and the telephone receivers to one side of the secondary circuit of the receiver, while the copper cylinder is connected to the other side. Various types of Fleming valves are shown in Fig. 147, while Fig. 148 shows the connections of a valve to the secondary circuit of a wireless receiver; it will be seen that the battery which lights the filament may be employed to give the necessary potential across the potentiometer wire. The cylinder is now usually known as the "Plate," or Anode.

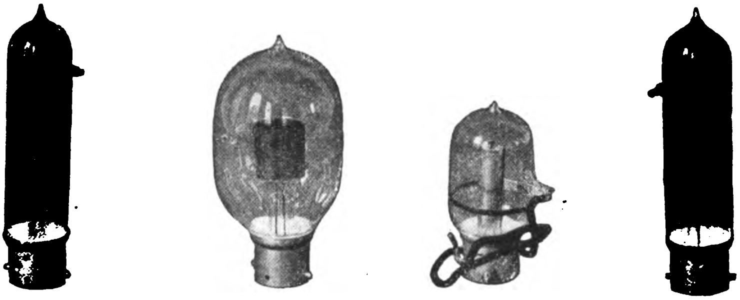
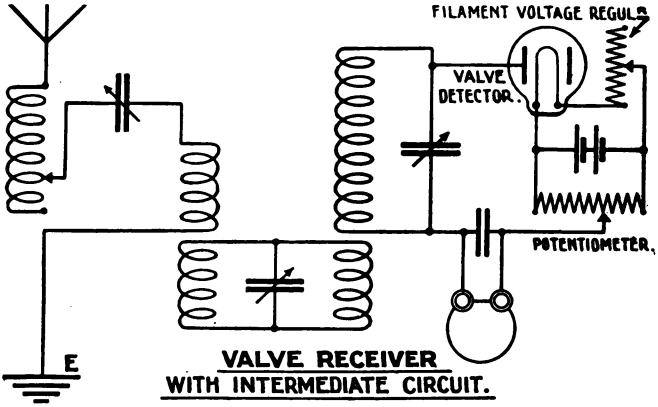


Fig. 147.—Fleming Valves.

When a filament is heated in a vacuum it gives off electrons which can move fairly freely through the vacuum; if the plate is at positive potential compared to the filament the electrons are attracted along the resulting ether strain between the filament and plate, and therefore flow to the plate and from it round the circuit to the filament again. On the other hand, if the plate is at negative potential compared to the filament the resulting ether strain between them is such that the electrons are repelled by the plate, and do not leave the vicinity of the filament, so that no flow takes place round the circuit.

Thus, when the ether waves induce oscillating potential in the receiver coil connected to the plate and filament, a current will flow through the valve telephone circuit only at the halves of oscillations which make the plate positive with respect to the filament. The valve is said to have "unilateral conductivity," *e.g.* it conducts current only in one direction; it can therefore be used as a rectifier in a circuit acted upon by alternating or oscillating potentials.



VALVE RECEIVER WITH INTERMEDIATE CIRCUIT.

Fig. 148.

The potentiometer adjusts the steady potential of the plate with respect to the filament to a point on the characteristic curve which gives most sensitive working; this may mean that there is a small steady flow of electrons through the valve and circuit all the time, and a train of induced oscillations of potential causes a pulse of increase of this steady flow with consequent vibration of the telephone diaphragms.

The flow of electrons from the filament depends on its temperature and can be regulated by the series rheostat. The strength of the current flowing to the plate depends on the potential of the latter with respect to the filament; the current flow can therefore be regulated by the potentiometer.

The action in the valve is complicated by reason of the fact that the residual gas in the vacuum contains positive and negative ions; the positive ions are attracted to the filament and repelled from the plate when the latter is at positive potential; this increases the current through the detector-telephone circuit.

The Fleming valve detector, though now more or less out of date, was very reliable and its sensitiveness was not impaired by strong atmospherics or strong signals. It was generally fitted with an earthed covering of copper gauze over the glass to prevent the valve from becoming statically charged.

The evolution of valve detectors and amplifiers is fully dealt with in Volume II., the Fleming valve being mentioned here because its invention marked a stage in the general development of wireless reception.

Crystal Detectors.—Certain crystals, when connected in series in an electric circuit, offer more resistance to the flow of the current in one direction than when the current flows in the opposite direction; in other words, they possess to a certain extent the property of "unilateral conductivity"; hence they will act as rectifiers of weak electrical oscillations in a similar manner to the Fleming valve. If an E.M.F. is applied in one direction across a carborundum crystal the current which flows may be 100 times stronger than if the E.M.F. is applied across the crystal in the opposite direction. The student can prove this for himself, using small E.M.F.s up to 4 volts, and having a delicate galvanometer in series with the crystal to measure the currents: the crystal itself being held between two metal contacts.

A similar property is possessed by many other crystals, such as silicon, galena, iron pyrites, zincite, molybdenite; or by a contact between two different crystals such as that between zincite and bornite. Several scientists, notably Eccles,[1] Pierce, and Austin, have investigated the action of oscillating currents on crystals; so far not much unanimity of opinion has been reached, but the results of their labours seem to show that the effects are mainly due to change of resistance at the contact point on the crystal. This is partly caused by the heating effect of the

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[1] Dr. W. H. Eccles read a paper on this subject before Section A, British Association, Birmingham, 1913, published in the *Electrician* of September 5, 1913; also one before the Physical Society published in the *Electrician* of October 3, 1913

current, and is also partly due to absorption or evolution of heat owing to the Peltier effect set up. The unilateral conductivity effect is best obtained when *small point contacts* are used between the crystal and the other portion of the detector, whether it is metal or another crystal; the small contact localises the physical changes set up by the current to a small area and thus intensifies the effects produced.

Carborundum Detector.—Probably the most satisfactory crystal detector, as regards reliability, and freedom from deterioration of action due to mechanical vibration or strong discharges across it, is the *Carborundum Detector,* much used by the Marconi Co. in their ship outfits, portable outfits, and wavemeters. One form of this detector as made by the Marconi Co. is shown in Fig. 149. The crystal is fixed by means of Wood's metal in a small metal cup supported at the end of an arm on a metal pillar. In front of this is a light spring support in which a hardened steel point is clamped, and by a screw action the steel point can be brought into contact with the crystal in front of it, with whatever pressure is necessary to give sensitive working. The base is of ebonite and terminals are connected to the crystal pillar and spring support. The ebonite base can be made like the cap of an incandescent lamp, so that it may be inserted into an ordinary type of bayonet holder like a lamp or a Fleming valve; in this way a crystal detector may be used to replace a Fleming valve or *vice versa.*

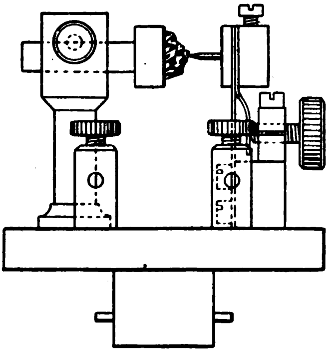


Fig. 149.

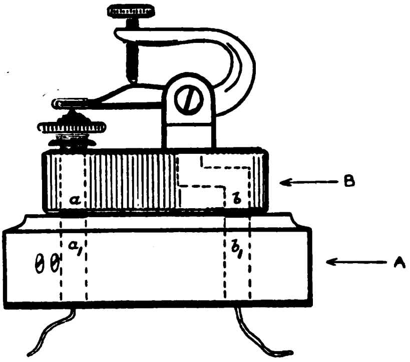


Fig. 150.

A more recent Marconi design of carborundum detector is shown in Fig. 150; the crystal is mounted in a cup which screws into a socket in the ebonite base, and a steel tongue makes contact with the crystal with a pressure which can be adjusted by means of the screw carried on a bracket arm above. Connections from the crystal and steel tongue are made by the rubbing contacts *a*, *b*, in the ebonite base B to similar contacts a_1, b_1, in another ebonite base A. The base B can be rotated on A through an angle of 180° to bring *a* in contact with b_1 and *b* in contact with a_1; thus the direction of the current through the crystal can be quickly reversed if found necessary.

While some carborundum detectors will be found to give quite good signals without the use of a potentiometer it will be generally found that some potentiometer voltage improves the working of the detector. The voltage required will depend on the crystal in use, as crystals vary greatly in resistance and in rectification properties. Out of a batch of a dozen pieces of crystal it may be that only one or two are suitable for use in detectors.

Carborundum is a fusion of silicon and carbon and generally there are metallic salts present; in practice three types of crystal are met with: a hard dark variety with great metallic lustre which has poor detector qualities; a soft crystal of a pale green colour, due to the presence of copper and iron salts, is very unstable in its action as a detector; and a dark grey crystal, which is the most satisfactory as regards sensitiveness and stability of action.

Attempts have recently been made to make good carborundum crystals by introducing a proper percentage of certain metallic salts into the fusion.

Carborundum detectors have a high resistance, of the order of 6000 to 8000 ohms, therefore high resistance telephone receivers should be used in series with them; generally the receivers are wound to a resistance to 4000 ohms in each ear-piece, giving 8000 ohms with the two ear-pieces in series. If a telephone transformer is used the primary of the transformer, connected into the detector circuit, should have a resistance of from 6000 to 8000 ohms.

The Marconi Company patented an arrangement, shown diagrammatically in Fig. 151. The two detectors and their potentiometers are arranged so that they are rectifying in opposite directions, but one is adjusted to the most sensitive position on its characteristic curve while the adjustment of the other is not made sensitive. When signals of ordinary strength are received the rectifying action will be the resultant of the rectifications of the two crystals in opposite directions; one being more sensitive than the other this resultant may be almost as good as with one accurately adjusted crystal alone. On the other hand when strong oscillations are set up, such as those due to local stations or atmospherics, the swings of potential will be so great that the rectification is roughly the same on both crystals, *i.e.* the current through the telephone receivers or telephone transformer is not much rectified; not much increase or decrease of the steady current is set up so that the effect on the telephone diaphragms is weak. Thus strong signals and atmospherics are more or less balanced out and this greatly increases the commercial efficiency of the receiving station.

For best results the two crystals should be about equally sensitive to start with, the receiving circuit is tuned up with each crystal in turn and then both crystals left on so that practically no signals are heard. One potentiometer is then adjusted until ordinary signals are heard about the same strength with the two crystals as when one only is used, and it will be found that strong local signals or atmospherics now produce only weak effects. If no jamming is being experienced work can be carried on in the usual way with one detector by cutting out the other. When the second detector is switched into use and a balance obtained by adjusting the potentiometers it will also be necessary to retune the circuit slightly as the resistance of the extra crystal has the same effect as a slight increase of capacity. It will be realised that the proper adjustment varies with the strength of signals it is desired to read.

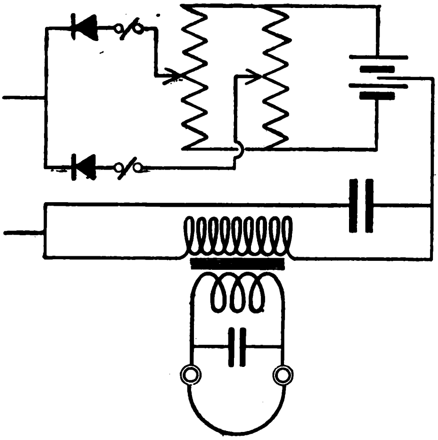


Fig. 151.

Galena Detector.—The Galena detector was much used by the Telefunken Co. and in the United States, but latterly it has become obsolete, because, though sensitive, it was not reliable and was very difficult to keep in adjustment.

It consists of a crystal of galena on which a light contact is made by the pointed end of a small rod of graphite such as is used in pencils. The pressure at the contact is adjusted by a spring and screw arrangement; unlike the carborundum detector the contact must be very light, hence the detector is easily thrown out of adjustment by mechanical vibrations such as would occur on board ship; also "atmospherics" or strong inductive discharges easily destroy the sensibility of a contact point, and necessitate frequent adjustment to find a new one.

Galena belongs to the cubic system of crystal; it therefore occurs in square shape, breaking up into pieces with rectangular sides and flat surfaces. Since the face of a crystal is flat it provides innumerable points on which sensitive contacts can be made. Galena is bluish black in colour, has a metallic lustre, and is fairly heavy. Instead of using graphite contact can be made by means of a tiny copper spring, its end lightly resting on the face of the crystal; a fine platinum wire can be used for the same purpose, or a pointed crystal of tellurium.

Fig. 152 shows a galena graphite detector made by the British Insulated Wire Co., Helsby; on it six galena crystals are mounted in cups fixed on a circular plate; this plate can be rotated so that a sensitive crystal can quickly be selected for use.

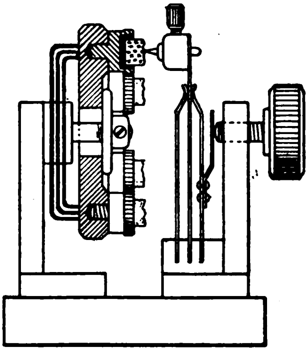


Fig. 152.

Galena graphite detectors are of comparatively low resistance and are not made more sensitive by a potentiometer voltage impressed across them; they are not suitable for short range work as strong signals destroy the sensitiveness of contact. In fact, though very sensitive to weak signals, they are very troublesome to keep in adjustment and not at all suited for commercial practice.

Perikon Detector.—This is a detector much favoured by amateurs because it is exceedingly sensitive and easy to adjust, though it requires continual adjustment. In its original form it consisted of a crystal of zincite (oxide of zinc) in contact with a crystal of copper pyrites (sulphide of copper), or of bornite (a compound of copper and iron sulphides—$Cu_2S.CuS.FeS$), or of chalcopyrite ($Cu_2SFe_2S_3$).

Zincite is of reddish brown colour, copper pyrites yellow grey, and bornite bluish grey. The crystals are mounted in little brass cups, either by means of clamping screws or soldered in with

Wood's metal, and they are brought into contact by spring and screw adjustments. The sensitiveness depends on the pressure of contact so that delicate adjustment is necessary; it will also be found that small pieces of crystals give better results than large pieces. Some crystals will be found to have apparently no sensitive point, others will make sensitive contact at almost any point chosen; if a crystal is found to give poor results a piece may be fractured off it to expose a new crystalline surface.

The detector can be made up in various designs as seen in the advertisements of wireless apparatus; some of these designs are very poor, especially in their arrangements for choosing and adjusting the pressure of contact. A design which has been found to give excellent results is shown in Fig. 153; it is very simple to construct and inexpensive for amateurs. On a round base of ebonite, $1\frac{1}{4}''$ in diameter, is mounted two brass plug contacts. One of these ends in a cup on the top of the ebonite and carries a small piece of tellurium. The other plug is extended to a pillar which carries a spring arm; on the extremity of the latter is mounted the zincite crystal in its cup. The adjustment of the crystals is made by means of a screw which carries a steel spring, and which screws into a brass receptacle on the ebonite base. The whole is covered by a brass cap held by bayonet joints on the ebonite case. It is seen that the detector plugs into a socket receptacle and can be easily disconnected or replaced.

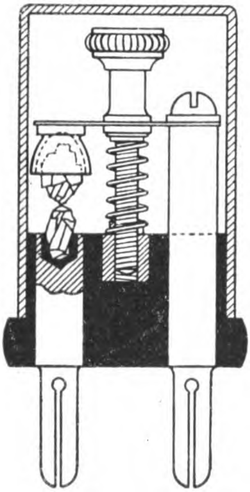


FIG. 153.

A contact between a crystal of zincite and one of tellurium has been found to give better results than the original form of Perikon detector. The Perikon or zincite detector is very sensitive and does not require a potentiometer voltage in series with it; unfortunately it is soon made insensitive by transmitter discharges close to it. It should always be short circuited or open circuited when transmission is going on, and should preferably be covered with an earthed metallic cap as an additional precaution. Though more sensitive than a carborundum detector it is not as reliable as the latter for commercial purposes. Zincite is not very hard and crumbles away at the point of contact.

Iron Pyrites Detector.—In this detector a gold point makes contact with a selected crystal of iron pyrites. Fig. 154 (*a*) shows this detector as made and used by the Telefunken Co. The base is of ebonite about 1¼″ diameter; on this is mounted a metal pillar into the top of which is screwed the crystal cup, the crystal being fixed in the cup by Wood's metal. In front of the pillar is a silver U-shaped spring carrying a little gold point. The spring is pressed forward by means of a screw until the gold point makes sensitive contact with the crystal. A light metallic cover is held on the base by a bayonet holder and sockets as on an ordinary incandescent lamp-holder. Instead of terminals the detector is fitted with plug contacts; thus it can be quickly plugged into socket terminals in the receiver apparatus. A pointed crystal of antimony may be used to make contact instead of the gold point, and indeed the sensitiveness is said to be increased by this means.

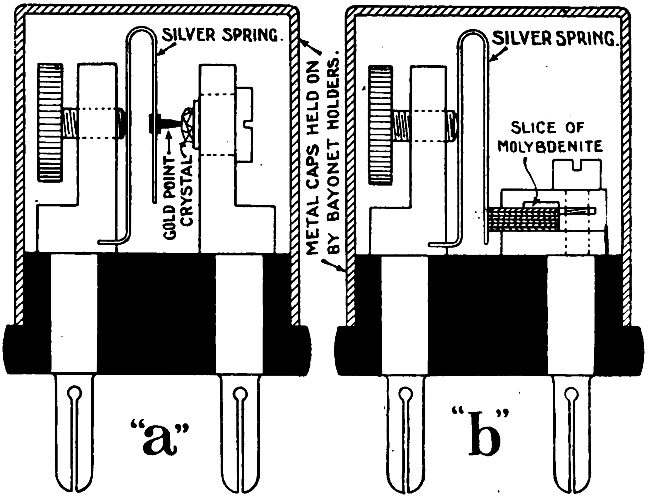


Fig. 154.

Molybdenite Detector.—This detector is also made and used by the Telefunken Co.; it is not as sensitive as the iron pyrites detector but is very reliable and robust. As shown in Fig. 154 (*b*) a flat piece of molybdenite is firmly held by screws between two brass plates, only its front edge projecting. Contact is made on this edge by a U-shaped silver spring, pressed towards it by means of an adjusting screw. If the detector becomes insensitive with use the molybdenite face is lightly cleaned with sandpaper, when a new sensitive surface will be exposed. The design of this detector, as regards shape and size, is uniform with the iron pyrites detector so that they can be readily interchanged on the receiving apparatus. This detector is suitable for short range work, for strong signals, and for use with portable outfits.

Silicon Detector—This consists of a gold point resting lightly on a crystal of silicon, though in cheap forms brass is used instead of gold. The sensitiveness depends on the contact point chosen on the crystal and the pressure of the contact; the general arrangement of the detector may be similar to some of those already described. On any given crystal of silicon there are not many points of sensitiveness to be found so that the silicon detector has become obsolete.

In comparing the different forms of crystal detectors one must bear in mind that reliability is of more importance than sensitiveness; for this reason it must be concluded that the carborundum detector is probably the best for all-round work though a good pair of crystals in a Perikon is the most sensitive. The iron pyrites detector is more reliable than the Perikon, and probably more sensitive than the carborundum detector, while, like the Perikon, it can be used without auxiliary potentiometer and battery.

A good soft metal for fastening the crystals in the cups can be made by melting down equal parts of ordinary lead fuse wire and tinfoil, and adding a little mercury—if too much mercury is added the metal will not have good holding properties. Wood's metal is a mixture of lead and tin with bismuth and cadmium in the proportions—2 lead, 1 tin, 4 bismuth, 1 cadmium; its melting point is about 60° C. In making it the lead should first be melted and then the other metals added.

Electrolytic Detectors.—If a current of electricity is passed, by means of two electrodes, through water diluted with sulphuric or nitric acid, hydrogen and oxygen gases are set free, the oxygen being deposited on the anode or plate joined to the positive terminal of the battery, and the hydrogen deposited on the kathode or plate joined to the negative terminal. Since oxygen is a very active gas the positive plate or anode should be of a material, such as platinum, which the oxygen cannot attack. This action of a current of electricity is called electrolytic action.

When the plates are coated with the gases they are said to be polarised; this polarisation not only increases the resistance of the circuit, since the gases are bad conductors, but also sets up a difference of potential between the plates which acts in the opposite direction to the applied E.M.F. and has a value of about 1·48 volts. Thus when polarisation takes place the current flowing in the circuit is reduced, and if the applied E.M.F. is adjusted to be nearly equal to the E.M.F. set up by the polarisation the current is reduced to almost zero value.

For detecting small electrical oscillations a very small electrolytic cell is made up, one plate of which consists of an extremely fine platinum or Wollaston wire of about 0·001 mm. diameter, sealed in a small glass tube drawn down to a capillary point at the end, and exposing just a tiny speck of the platinum or Wollaston to serve as a plate for the cell. The other plate may be of silver or mercury at the bottom of the cell, and the liquid a 1 : 5 solution of sulphuric or nitric acid in distilled water.

A battery of 3 or 4 volts is joined across a potentiometer resistance wire; a portion of the drop of volts across this potentiometer is tapped off and joined in series with the cell and a telephone receiver. A current will then flow in this circuit, but will immediately polarise the small platinum point, and if the E.M.F. tapped from the potentiometer wire is suitably adjusted no sound will be heard in the telephone receiver: if the E.M.F. is too great a bubbling sound will be heard.

When oscillations of potential are set up in a receiving circuit by the ether waves, and applied to the terminals of an electrolytic cell, one-half of each oscillation of E.M.F. will depolarise the platinum electrode so that a current impulse is allowed to pass through it. At each train of waves the oscillations build up in the receiver circuit until the potential across the cell is such that the electrodes are depolarised, and a pulse of current is allowed to flow through the cell and telephone receivers from the potentiometer.

The connections of such a detector to the receiving circuit are shown in Fig. 155 (*a*). Some difference of opinion exists as to whether the small point electrode should be the anode or kathode; Fessenden, who seems to have originated its use as a detector, made the point electrode the anode, joining it to the positive pole of the battery. Fessenden also explained its action by stating that it was due to change of resistance at the point electrode, while others considered that the polarisation E.M.F.s are responsible—it is possible that both resistance and back E.M.F. of polarisation are taking part in the effects which produce the change of current. Fig. 155 (*c*) shows an electrolytic detector made by the British Insulated Wire Co., Helsby. The glass-covered platinum wire is connected to a brass terminal, clamped by a screw to a brass arm and pillar. The base is of ebonite and supports a small glass-lined cup of ebonite, at the bottom of which is a small quantity of mercury connected to one of the terminals; the cup is filled with a 1 : 5 solution of sulphuric acid in water.

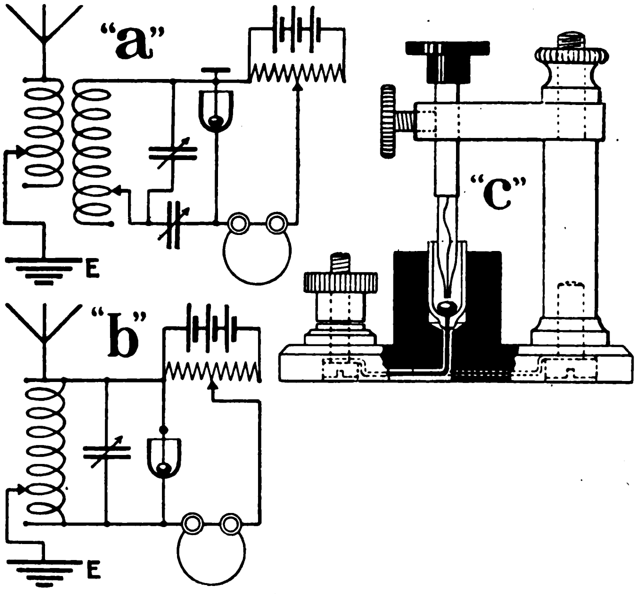


Fig. 155.

Sometimes the detector is connected as shown in Fig. 155 (*b*); this would apply to small amateur stations using a single slide tuning coil as shown in the figure.

The electrolytic detector ranks among what are called high-resistance detectors, and as such requires that the telephone receivers used with it should be very sensitive, with a great number of turns on the coils, therefore these should be of about 8000 ohms resistance. It was not much used in British wireless stations but had considerable vogue in the United States, where it was first introduced by De Forest and by Fessenden.

Soft Vacuum Valve Detectors.—Improvements in the original Fleming Valve came into prominence about the end of 1913, when the Lieben Reisz Valve Relay appeared in Germany and the Audion Valve of Dr. Lee De Forest was becoming well known in the United States. In both these a third electrode had been added; this third electrode was called the grid and was placed between the hot filament, or cathode, and the plate anode. Potential changes on this grid caused variations in the strength of the electron current flowing from the filament to the positive potential plate.

Although the whole subject of Valves will be fully dealt with in Volume II., a short description of the Audion and the Lieben Reisz Relay in their original forms will be given here to complete the record of detector development.

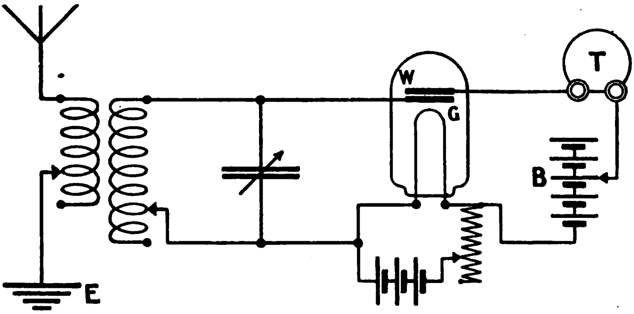


Fig. 156.

Audion Detector.—This modification of the Fleming valve had a tantalum filament in its original form, and had a perforated grid or cylinder between the filament and the positive plate. The distance between the filament and the grid G was about $\frac{1}{16}$ inch and a similar distance separated the grid from the positive electrode, or plate (W); in its original form the filament of the valve required 4 to 15 volts to heat it, according to the size of the valve.

A diagram of the valve and its connections is given in Fig. 156. G is the grid, W the plate, T the telephone receivers in series with the plate and an adjustable voltage from battery B by which the plate is kept at a positive potential with respect to the filament.

The electrons given off by the filament are attracted to the positive potential plate, *i.e.* through the grid G, and the rate of flow of electrons through G will be modified if G itself has a positive or negative potential. If G is positive it will help the plate to attract electrons so that the latter will move faster or there will be more electrons passing to the plate per second; if G is negative the electron flow will be diminished. It is seen that the grid and filament are connected across a tuned receiver circuit; oscillations induced in this circuit will oscillate the potential of the grid with respect to the filament, and thus produce changes in the electron flow from the filament to the plate.

Now when electrons go to the plate they would tend to charge it negatively, but it is connected to the positive terminal of the battery B therefore will remain positive; this is due to the fact that the chemical action in the battery causes a redistribution of electrons which pass round the circuit of plate, telephone receivers, battery, and filament in such a way that the plate is kept positive, or with a deficit, and the filament negative, or with an excess. The electrode potentials can be so adjusted that the negative halves of oscillations have not as great an effect as the positive ones; this causes an increase of current at each train of oscillations, and therefore one vibration of the telephone diaphragms per train as with crystal detectors.

The action of the valve was complicated by the fact that the vacuum was not hard and the gas molecules in it provided positive ions which were attracted in the opposite direction to the electrons and increased the resultant current effect. This made the adjustment of the valve very critical for most sensitive working, and indeed for some time the complete action of the valve was not clearly understood.

In Fig. 156 it will be seen that the valve acts not only as a rectifier, but also as a relay, for the potential effects on the grid are employed to cause pulses in the current flowing in the local circuit—plate, telephones, battery, and filament.

De Forest explained that the valve could be used as a relay pure and simple; thus the telephone receivers could be replaced by a step-up transformer, the secondary of which would be connected to the grid and filament of a second Audion; the pulses of current in the plate circuit of the first Audion would then produce pulses of potential in the grid circuit of the second with corresponding increased pulses of current in its plate circuit.

De Forest did employ Audions in cascade to produce this relaying up effect of current pulses, but for some considerable time no attempt was made to use the Audion as an amplifier of the high frequency oscillations before rectification.

Lieben and Reisz Valve Relay.—This relay was described by E. Reisz in the *Electrician* of February 6, 1914. It was a gas, or soft vacuum, valve relay somewhat similar in its action and design to De Forest's Audion, but was used by its inventors only as a pulse relay and not for rectification. A diagram of the relay and its connections is shown in Fig. 157.

The relay consisted of a glass cell exhausted of air, but filled with attenuated vapour of mercury at a pressure of 0·001 mm. at 20° C., the vapour being supplied from a small quantity of mercury amalgam placed at the bottom of the bulb.

The kathode (K) consisted of a comparatively long platinum strip 1 mm. wide and 0·5 mm. thick, wound zig-zag on a glass supporting stem, the strip being coated with a thin layer of barium and calcium oxides. Wehnelt had discovered that such oxide surfaces emit electrons better than pure metal surfaces.

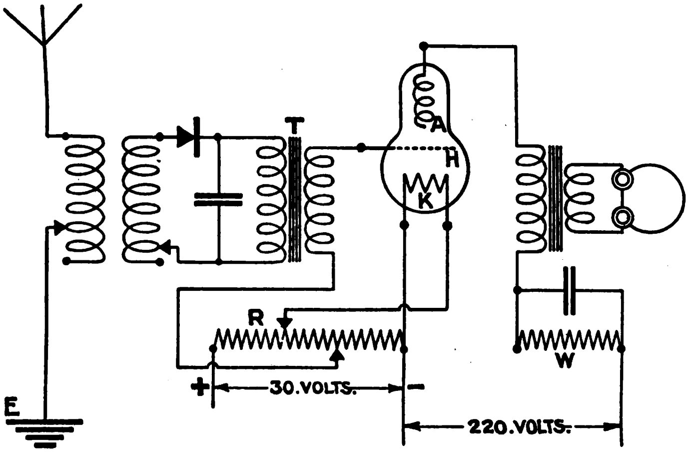


Fig. 157.

The anode (A) was a spiral of aluminium wire wound on the top portion of the glass central stem, while the auxiliary electrode or grid (H) was a thin plate of aluminium extending right across the bulb between the kathode and anode, with apertures or holes of 3½ mms. diameter distributed uniformly over it.

The kathode was raised to a bright red heat by an electric current, being connected by adjustable contacts to a resistance (R) which had 30 volts applied to it from a battery. Between the kathode and the anode 220 volts were applied from a dynamo or supply mains, the anode being positive.

The anode circuit includes a high resistance (W) shunted by a condenser, the function of which was to limit the current in the circuit when, for any cause, the vacuum got too soft and the gas part of the anode circuit became a good conductor; in other

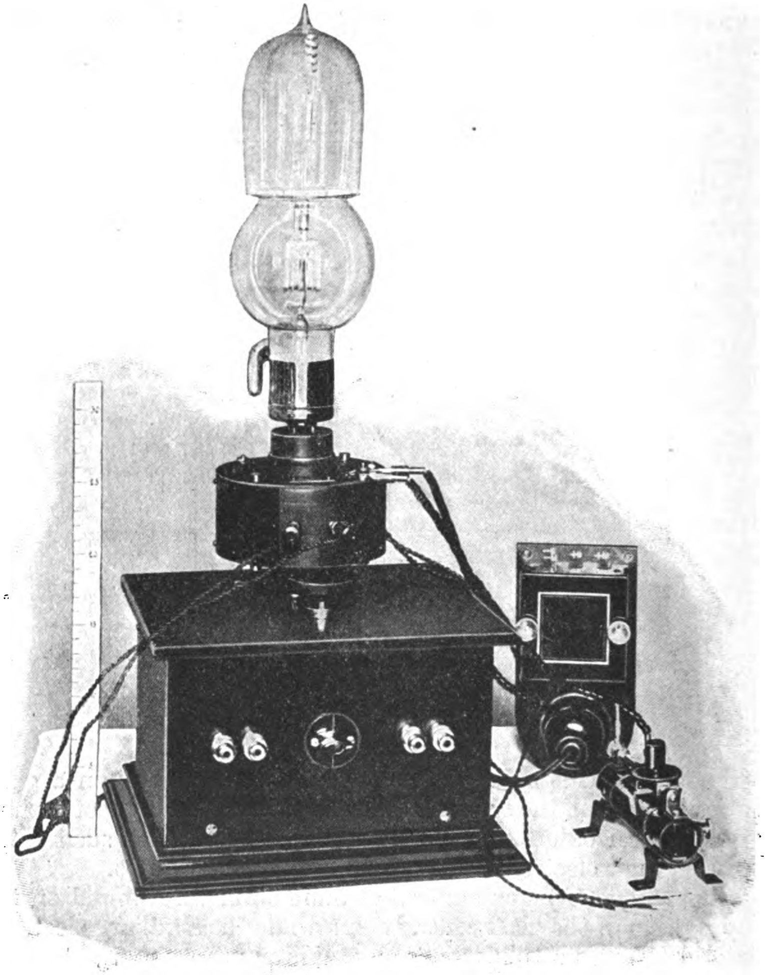


FIG. 158.

words when the supply of positive ions in the gas between the kathode and anode became abundant.

It will be seen from the diagram of Fig. 157 that this valve was used as a relay of the current pulses through the transformer (T), rectification being carried out by the crystal detector.

The appearance of the valve relay as made by the A.E.G. Co. is shown in Fig. 158, the auxiliary transformers, condensers, and connections being mounted in the case on which the valve holder is mounted.

Early Detectors for Undamped Wave Systems.—If the oscillations in the transmitter are undamped the radiation of energy will not be in trains of waves, and the discharges through the receiver telephones in series with an ordinary detector will not be in pulses of current. Thus the diaphragms will not vibrate and no signals will be heard unless something is done to break up the receiver induced currents into groups, so that the discharge through the telephones may occur at an audible frequency.

Tikker.—One of the simplest methods of breaking up undamped oscillations into groups is that originally adopted in the Poulsen-Pedersen system, *i.e.* to have a small "Tikker" in series with the telephones. A tikker is simply an intermittent contact between a small rotating wheel and a light metal brush bearing on it. In the Federal-Poulsen system the tikker consisted of a small revolving brass disc with a groove on its periphery and a fine steel wire about 1 inch long making light contact with the groove. The end of the wire was bent and the wheel was driven against the end as shown in Fig. 159, so that an intermittent contact was provided.

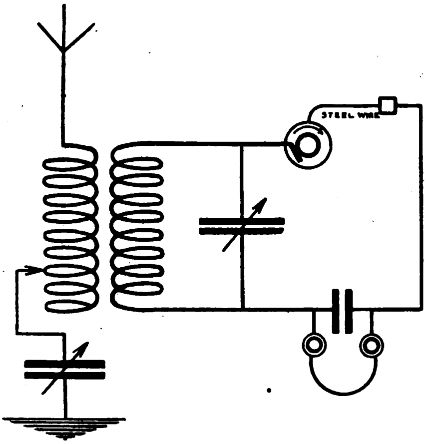


FIG. 159.

The tikker simply takes the place of a crystal detector; assuming that the receiver circuit is tuned to the oncoming waves, oscillations are built up in the secondary receiver circuit while the tikker contact is broken. When the contact closes a discharge takes place through the telephone receivers; the frequency of the telephone pulses and the pitch of the note are therefore dependent on the speed of rotation of the tikker disc. This forms a very sensitive detector arrangement, giving signals which are just readable with about $\frac{4}{10^{10}}$ watt in the receiver aerial; J. L. Hohan stated that unit audibility was given with about $3{\cdot}2 \times 10^{-10}$ watt in the aerial when a rotary tikker detecting arrangement was employed.

In later designs the tikker disc consists of a small toothed wheel, but tikker reception is now rarely employed as it has given place to the far more sensitive methods of valve heterodyning and valve amplification.

Fessenden's Heterodyne Detector System.—A method of forming beats in the receiver circuit, by compounding the oscillations induced in it by the ether waves with another set of oscillations induced in it by local means, was first put into practice by Prof. R. A. Fessenden, of Western University, Philadelphia.

The method can be most simply explained by considering a particular case; thus suppose ether waves of 600 metres length act on a receiver aerial the frequency of the oscillations induced in the latter will be 500,000, for $\lambda n = 3 \times 10^8$. Now if we have coupled to the receiver circuit a local generator of oscillations, such as a buzzing wavemeter, and the oscillations induced by it have a frequency of 499,000 or 501,000, then two sets of oscillations are induced in the receiver circuit simultaneously and differing in frequency by 1000; this will form a resultant oscillation whose amplitude will rise and fall at a frequency of 1000, such resultant oscillation being called a "beat." A similar effect occurs when two notes which have nearly the same frequency are sounded on an organ, the resultant beat of low frequency and great intensity is easily distinguishable and often very effective in organ music.

If such a beat occurs in the receiver circuit currents it means that the amplitude of the oscillations rises and falls in value, so that the effect is much the same as if the ether waves had arrived in damped trains following each other at low frequency.

It is seen that the method is peculiarly applicable to the reception of signals on undamped waves, though it is also very effective for damped wave or spark signals. As a matter of fact the beat method of reception is much more sensitive than a plain crystal detector for damped waves, or the tikker method for undamped waves. With it the audibility of the signals is proportional to the current induced in the receiver aerial, whereas with a crystal detector alone the audibility is proportional to the square of the receiver aerial current.

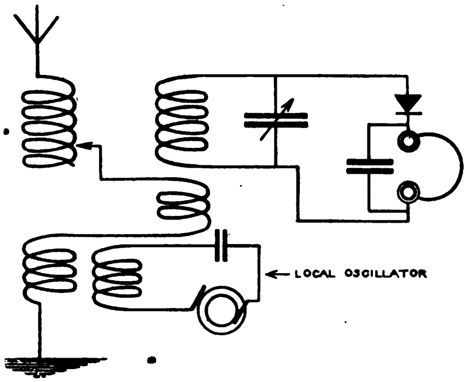


Fig. 160.

Fessenden named this the Heterodyne method of reception, and a simple diagram of it is given in Fig. 160; the local oscillator may be a buzzer wavemeter, a high frequency generator, or an arc generator. At present the hard valve has superseded all other methods of heterodyning, and the subject will be more fully dealt with in Volume II.

A method suggested by Fessenden for applying the heterodyning principle is shown in Fig. 161. A specially designed telephone receiver had a central core of fine iron wires on which was wound a coil connected to the local small generator of high frequency oscillating currents. The diaphragm was a small disc of mica attached to the centre of which was a small light coil connected to the secondary circuit of the receiver.

When signals arrive the diaphragm coil carries oscillating currents at one frequency, and the core coil oscillating currents at a slightly different frequency; the resulting beat caused magnetic effects in the core which made the diaphragm vibrate at the frequency of the beats. It can be seen that this method of reception reduces interference by jamming, since signals at other frequencies will form beats of too high or too low a frequency to give audible signals.

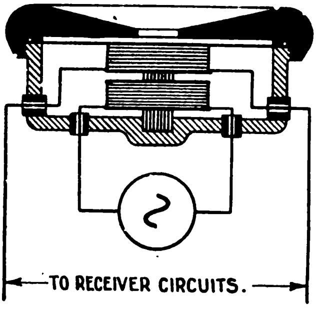


Fig. 161.

In the experiments carried out by J. L. Hogan, between the U.S. Station at Arlington and the U.S.S. *Salem* crossing the Atlantic to Gibraltar, the heterodyne method of reception was clearly demonstrated to be more sensitive than any other; even for spark signalling the heterodyne method gave 4·65 times as much telephone current as that obtained with an electrolytic detector, and it was proved that just audible signals could be obtained with $\frac{1 \cdot 5}{10^{10}}$ watt in the receiver aerial. Since that time the development of the valve for heterodyning and amplifying has revolutionised all wireless calculations.

Early Marconi-Round Method.—An early method of receiving on undamped waves, developed by H. J. Round and adopted by the Marconi Company, is illustrated in Fig. 162; two balanced carborundum detectors with potentiometers are arranged so as to oppose their effects and adjusted so that they can only receive signals which are comparatively strong—they will not give signals on ordinary weak oscillations. A local buzzer circuit is coupled to the detector circuit so that each train of oscillations set up by the buzzer makes the detector circuit conductive. During the intervals between the buzzer trains the undamped ether waves build up the oscillating amplitude in the tuned receiver circuit, and a discharge takes place through the detectors and telephones each time the detectors are made conducting, the intervals depending on the frequency of the buzzer interrupter.

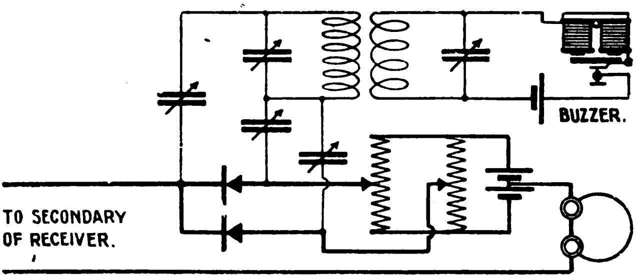


Fig. 162.

The Goldschmidt Tone Wheel.—The special form of tikker apparatus invented by Dr. Rudolf Goldschmidt was called by him a Tone Wheel, and has been successfully employed in the communication by undamped waves between the Eilvese Station in Germany and the German station at Tuckerton in the United States.

It consists of a toothed wheel disc rotating at a constant speed, the pitch of the teeth being about 1 mm. and the spaces between them being filled with insulating material. A copper gauze brush, covered with insulation material which wears uniformly with the gauze, bears on the periphery of the disc and is connected to one side of the receiver circuit, the disc itself being connected to the other side. Thus when the disc is rotated the circuit is complete when the brush is in contact with a tooth but is broken if the brush is in contact with the insulation between the teeth.

To understand its action suppose that undamped wave reception is taking place on a 6000 metre wave length, setting up oscillations in the receiver circuit at a frequency of 50,000; also let the breadths of the teeth and that of the insulation be equal, and let the wheel be driven at such a speed that it makes 50,000 contacts and 50,000 breaks per second. This would be accomplished if it had 800 teeth and was steadily rotated at a speed of 3750 revs. per minute. Under these conditions one half of each oscillation would be wiped out, and the other halves of oscillations at a frequency of 50,000 would be available in the circuit. The oscillations of current would then be as shown in Fig. 163 (*a*); these undamped half oscillations though rectified would not cause any sound in the telephone receivers. If,

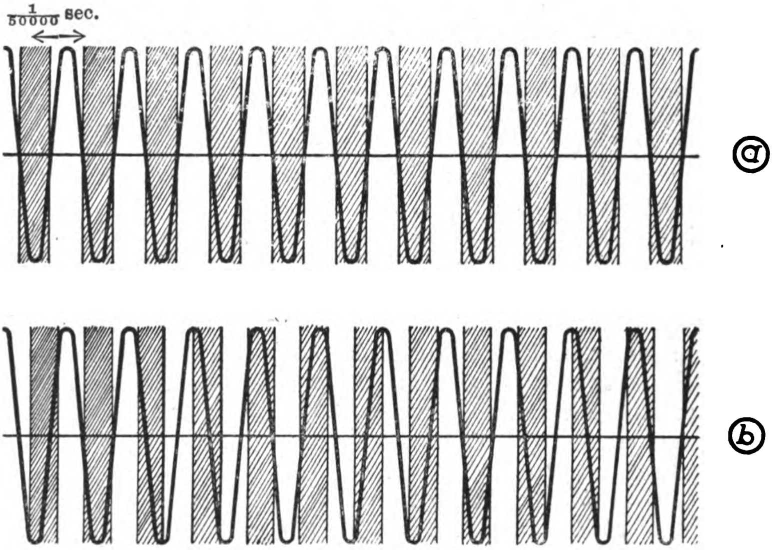


Fig. 163.

however, the disc is rotated slightly faster or slightly slower than synchronous speed, to give, say, 51,000 or 49,000 contacts per second, then the rectification will not be complete but a number of pulses in one direction will be followed by a similar number in the opposite direction—as shown at Fig. 163 (*b*), where they act alternately upwards and downwards—at a speed depending on the difference between the oscillation frequency and the contact frequency. These groups of potential pulses will send pulses of current through the telephone receivers at the beat frequency, therefore the note heard in the telephones will depend on the speed of the wheel.

The method is primarily applicable to long wave low frequency work, since for short waves at a high frequency the wheel would require to have a great number of teeth or be run at excessively high speeds.

For high frequency oscillations arrangements have been tried in which the wheel is run at the ordinary speed to produce first a high frequency beat current; this is then led back through the wheel to produce a lower frequency beat, and this may be done two or three times until a beat of audible frequency can be led through the telephone receivers. Another method for high frequency work would be to have two or more wheels in cascade but the simpler and more efficient methods of valve heterodyning are likely to make the Tone Wheel obsolete so that no further space will be devoted to its possibilities. It may be remarked that spark signals will only make a noise in the telephones, and that stations not on the same wave length will not cause interference as the beat resulting from them will be heard with very different notes if heard at all.

An advantage of all beat or heterodyne methods of reception is that the frequency of the beat can be chosen to be equal to or near the natural vibration frequency of the telephone diaphragms, so that a very marked increase of reception efficiency can be thus attained.

Telephone Receivers.—A telephone receiver consists of a small permanent steel magnet, which has soft iron extension pieces fixed to its poles, and on the poles or on the extensions are wound coils of fine insulated copper wire connected in series with each other. Held in equilibrium in front of the pole extensions is a thin disc, generally of special ferrotype iron, called the diaphragm, the centre of which is attracted by the poles of the magnet. The diaphragm is adjusted to be a very small distance from the poles so that it may vibrate; it forms an iron armature through which the magnetic flux travels from the N. pole to the S. pole of the magnet, crossing the very small air space between the diaphragm and magnet.

If a current flows through the small coils it either strengthens or weakens the magnetism, so that the disc is either more attracted or less attracted, and its centre moves slightly; if the current is in the form of pulses, such as those which flow in the detector-telephone circuit of a wireless receiver, the diaphragm will pulse or vibrate in unison with them, and the sounds caused by the vibration of the diaphragm will have a pitch corresponding to the frequency of the current pulses.

If an ordinary soft iron core were used in the coils instead of a permanent magnet the receiver would not be so sensitive. Let F be the pull on the diaphragm due to the steady magnetic flux M of the permanent magnet, then F is proportional to M^2. If now a small current in the coils changes the magnetic flux by an amount m, then the new flux is $M \pm m$, and the new pull on the diaphragm is proportional to $(M \pm m)^2$, or to $(M^2 \pm 2Mm + m^2)$; since m is very small compared to M we may neglect m^2 and say that the new pull is $M^2 \pm 2Mm$, *i.e.* it has been changed by an amount $2Mm$ which is therefore proportional to M, the permanent magnetism of the core. Thus the greater M is the greater will be the effect of a small increase or decrease due to a pulse of current in the coils on the magnet. This is true only up to a certain point as the advantage will cease if M is so strong that the diaphragm is saturated or nearly so; the thicker the diaphragm the less likely it is to be saturated. Diaphragms must be kept thin and small so that their natural frequency of mechanical vibration will be of the same order as the frequency of vibration imposed upon them by pulsing currents; under these conditions the telephone receiver is most efficient, therefore the strength of the permanent magnet in a telephone receiver is governed by the material and design of the diaphragm.

Resistance of Telephone Receivers.—It may be recalled that the magnetic effect of a current flowing in a number of turns of wire is proportional to the amperes × turns; thus 0·2 microampere flowing through a coil of 400 turns will produce the same magnetic effect as 0·8 microampere in a coil of 100 turns, for the value of the microampere-turns in each case is 80. Thus to get a certain magnetic effect with a small current in a coil it may be necessary to have a great many turns of wire in the coil, and since the current is small the wire may be of small gauge; this is convenient because the coil may have to go into a very small space as in the case of telephone receivers. The resistance of carborundum and perikon detectors is some thousands of ohms, therefore when they are connected in series with telephone receivers the current through the latter will be very small, hence the coils on the receivers should be wound with a great many turns; the wire used will be fine gauge because the currents are small, and because there is not much room in which to place the coils in the receiver ear-piece.

Unfortunately a great length of wire means that the coils will have a high resistance; this cannot be helped as we must obtain the necessary magnetic effect with the small current available to vibrate the diaphragm; the increase of magnetic effect due to increased number of turns in the coil greatly outweighs the decrease of current due to extra resistance, for it must be noted that this resistance is only a portion of the resistance of the whole circuit.

This may remove a misconception in the minds of some amateurs who seem to think that if telephones should have a high resistance when used with crystal detectors their coils might be wound with high resistance wire; the author once came across a wireless amateur who suffered from this delusion and was winding coils of fine German silver wire with which to make high resistance telephone receivers.

It must not be forgotten that telephone receivers, used in conjunction with the sense of hearing, form an electrical measuring instrument far more delicate than any ordinary galvanometer or other instrument that uses the sense of sight; for all electrical measurements the general rule is that a low resistance instrument must be used in a low resistance circuit, and a high resistance instrument in a high resistance circuit. An ammeter has a low resistance because the resistance of the mains in which it is connected is low and the current flowing through it will be large; a voltmeter has a coil of fine wire and is made of high resistance because the current which will flow through it should be kept as small as possible. In the use of galvanometers and other measuring instruments working on electro-magnetic effects, through the medium of current carrying coils, the coils should be wound to a resistance which is *approximately equal to the resistance of the circuit in which the instrument is connected* for most sensitive conditions.

The receiver usually employed consists of two ear-pieces, which are generally connected in series, but in some cases the wires from each ear-piece are brought out so that they may be connected in parallel if desired. Thus if a perikon or high resistance carborundum detector is used suitable ear-pieces would have a resistance of 4000 ohms each and be connected in series ; if a low resistance crystal detector is used the ear-pieces can be connected in parallel, thus giving a telephone resistance of 2000 ohms. A Marconi Magnetic Detector is of comparatively low resistance, and is a current operated device, hence receivers of 80–250 ohms would be connected to its secondary winding. High resistance telephone receiver coils are wound with No. 40 to No. 48 S.W.G. copper wire, lightly insulated with silk or enamel, and sometimes covered with a coating of paraffin wax after winding to keep out damp. It is becoming general practice now to replace the telephones in the detector circuit with a telephone transformer, the primary of which is wound to a resistance of 4000–8000 ohms for crystal or valve circuits, and the secondary wound to a low resistance so that the telephone receivers connected to it may have a low resistance. In England it is nearly standard practice to have the transformer secondary of about 120 ohms resistance, so that the receiver ear-pieces would each be wound to 60 ohms and connected in series. This is a great advantage because the low resistance telephones are cheaper to construct than high resistance ones; they are more robust and not so likely to develop faults since the coil wire may be thicker; also it removes any chance of leakage from the detector circuit through faulty insulation in the telephones to the body of the operator and thence to earth.

A point to be noted is that when the diaphragm is free to vibrate the effective resistance of the telephones increases with the frequency and the inductance effect decreases ; thus there will be a frequency at which the total impedance is a minimum and the telephones most sensitive. This was established by Dr. A. E. Kennelly in 1915, the best frequency being about 1000 for the receiver tested by him.

Sensibility of Telephone Receivers.—Wein and Austin have carried out experiments independently on the sensibility of telephone receivers at different frequencies, and each has shown that currents at a frequency of 800 to 1000 give the same effect as currents many hundreds of times greater at a frequency of 100. Duddell carried out experiments to find the maximum power required to produce audible signals in a telephone receiver, and found that 430 microwatts were required at 300 frequency, but only 7·7 microwatts at 900 frequency; at higher frequencies the necessary energy increased again. Since the time of his experiments more sensitive telephone receivers have been designed, such as the Baldwin in U.S.A., and the Brown in England; Dr. Austin writes of the sensitiveness of 2000 ohm Baldwin telephones as being 5×10^{-10} ampere at 1000 frequency to give just audible signals in a normal ear. Unfortunately a normal ear is most sensitive to a note whose vibration frequency is not generally the most sensitive one of the telephone receiver, and the latter is not generally synchronous with the natural vibration frequency of the diaphragm. On the whole, however, a high note of about 600 frequency is a good compromise, and such a note is most easily picked out by an operator amongst interfering sounds caused by leaks or strays, as was first pointed out by Fessenden. For this reason the adoption of a high sparking rate, by the uses of rotary or quenched gaps, increases the sensitiveness of wireless receivers very greatly and conduces to reliability of commercial working.

The necessary displacement of the diaphragm to give an audible sound is of the order of half a micromillimetre, its value depending on the frequency of the displacement.

Taking the combined sensitivity of a detector and telephones into account, Dr. Austin stated in 1910 that 10 microamperes in a receiver aerial circuit of 25 ohms resistance, or an aerial induced energy of $2{\cdot}5 \times 10^{-9}$ watt, gave a just audible signal, while 40×10^{-9} watt was necessary for good working. Later, in the tests on the U.S.S. *Salem*, J. L. Hogan used Fessenden's heterodyne receiver and found that the above values could be greatly reduced. This was before valve receiver apparatus had been developed. Austin has recently carried out experiments on the sensitivity of a valve and telephone combination, and found that unit audibility was given by an energy of 1×10^{-15} to 2×10^{-15} watt; it cannot be measured within narrower limits owing to the fact that the sensitiveness of the ear enters into the measurement.

Design of Telephone Receivers.—The diaphragm should be of such a diameter and thickness that its natural frequency of vibration is fairly high; it is perhaps necessary to explain what this means. When a wire string on a piano is struck the note given out by it due to its vibration depends on its length and thickness, and in the same way different gongs when struck by a drumstick give out different sounds depending on their size, thickness, and material. When struck the whole mass is set in vibration and continues vibrating at what is called its natural frequency of vibration; it sets up corresponding vibrations in the air to which it gives up some of its energy of vibration, and the note is carried to the ear by the resulting air waves. Owing to the energy given up to the air, or other medium around, the vibrations of the sounding body are soon damped out unless fresh energy is imparted, and the maximum vibration effect will be obtained if this fresh energy is imparted at a frequency equal to or in step with the natural frequency of the vibrating body.

This is analogous to the tuning of a wireless circuit so that the frequency of the impulses of energy imparted to it is equal to that at which currents tend to oscillate in it.

The diaphragm should be enamelled or oxidised so that it will not rust. The working parts of the telephone receivers should be enclosed in ebonite covers so designed that damp and dust cannot penetrate beyond the diaphragm. The ends of the coil windings should be brought to well insulated pillar terminals to which the leads can be attached, and the leads should be attached by screw terminals rather than by bolt and nut terminals as the latter will work loose even if locking nuts are provided.

The strain should be taken off the lead terminals by having an insulating cord in the flexible lead which can be attached to some portion of the body of the ear-piece, thus taking any accidental pull which may be applied to the leads.

Brown Telephone Receiver.—This receiver, patented by S. G. Brown, is one of the most sensitive in use at present. As shown in Fig. 164 instead of a diaphragm the receiver is fitted with a steel reed, one end of which is fixed and the other extends over the pole pieces of the magnet. The reed is cut away slightly at the sides and can be thus adjusted to have a natural frequency of from 800 to 1200. Attached to the reed by a small screw is a very light aluminium cone supported at the top by a ring of light parchment paper, the outer edge of which is supported by a light aluminium case which fits over the magnet. It is thus seen that when the aluminium case is fitted the receiver is totally enclosed. The magnet is fitted on a screw pillar with a thumb screw outside the back of the case, by means of which the distance between the magnet and the reed can be adjusted.

The sensitiveness of the receiver depends greatly on this distance, and can be set very efficiently by the screw adjustment.

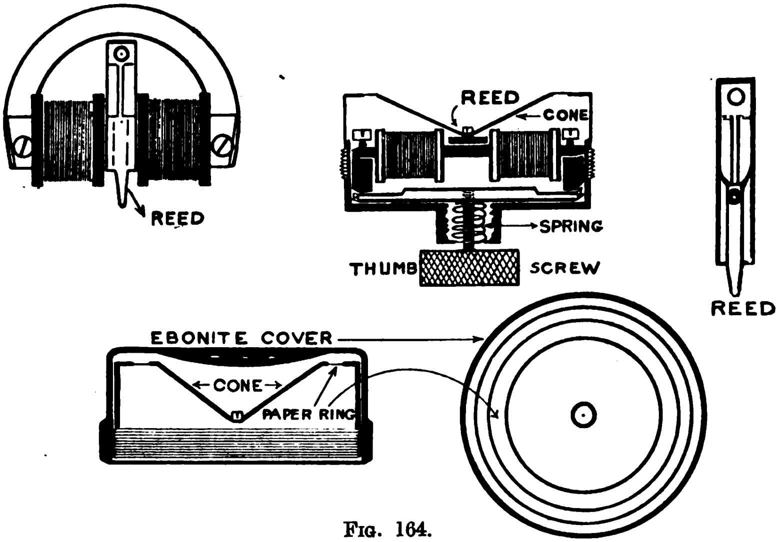
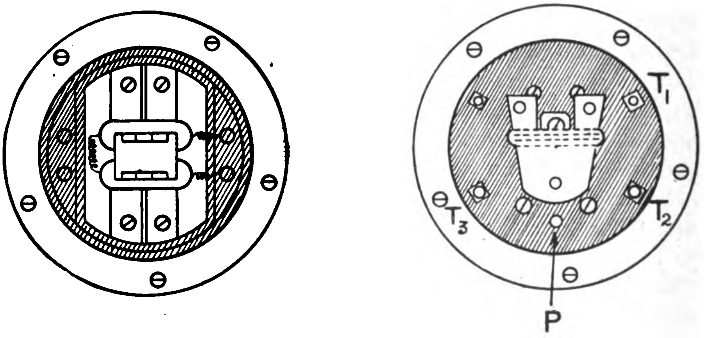


Fig. 164.

Fig. 165 shows the design of a receiver ear-piece of German manufacture which has several good features.

The base of the ear-piece is of ebonite on which is mounted two semicircular steel magnets with coincident and laminated pole pieces, bridged across by a thin sheet of ebonite dovetailed on. The coils on the pole pieces are connected in series and connected to two



Front View. Fig. 165. Back View.

nickel terminals on the ebonite base; a connection is also brought from the centre of the windings to a third terminal on the base.

The flexible leads are held on the terminal pillars by screw-down terminals with washers, and a cord in the flexible lead is tied to the pillar P to take the strain. The ear-piece is attached to the head band by a hinged plate seen at the centre of the back view; just showing under this hinged plate is a screw by means of which the magnet can be moved nearer to or farther away from the diaphragm. An ebonite cover is fitted over the back and held in place by a screw in the pillar P.

QUESTIONS AND EXERCISES.

1. Explain the action of a coherer when used as a detector.

2. Describe the use of a potentiometer wire with crystal detectors, and mention those detectors whose sensitiveness is increased by a steady voltage across them.

3. How would you experimentally determine the best voltage for lighting the filament of a Fleming valve, and how are small variations of voltage obtained in practice for this purpose?

4. How would you use two Audion detectors to increase the intensity of the received signals? Illustrate your answer with a sketch.

5. What is meant by "unilateral conductivity" and "rectified current"? Under what circumstances will the unilateral conductivity of a crystal be ineffective when used with a potentiometer?

6. What are the advantages and disadvantages of a galena graphite detector?

7. Draw a sketch showing the shape of the current voltage curve of a carborundum detector; explain its shape, and the effect of suitable potentiometer voltage joined in series with the detector and telephone.

8. What would happen if the potentiometer voltage in series with a carborundum detector were reversed? How are two carborundum detectors arranged in a circuit so that when strong oscillations of current flow in the circuit no sounds or extremely weak sounds are heard in the telephone receivers?

9. A carborundum detector is connected to a receiving circuit but no sounds are heard in the telephone. Explain why this does not necessarily mean that the crystal is a bad one.

10. Explain the action of Fessenden's heterodyne receiver.

11. A simple detector arrangement will not work in a circuit which is receiving energy from undamped waves. Why is this?

12. How would you adjust (*a*) a Fleming valve detector, (*b*) a carborundum detector?

13. Compare the advantages and disadvantages of a Marconi magnetic detector with those of a carborundum detector.

14. If a potentiometer has 200 ohms resistance and an E.M.F. of 4 volts is applied to it what current is drawn from the potentiometer battery?

15. If one-eighth of the potentiometer wire in Question 14 is tapped off and connected in series in the detector circuit what constant voltage is thus applied to the circuit?

16. What is the resistance of the carborundum crystal whose characteristic curve is shown in Fig. 144 when 1 volt is applied to it?

17. What are the advantages of the heterodyne method of reception?

18. Why are telephone receiver coils wound on the poles of a permanent magnet and not on ordinary soft iron cores?

19. What governs the choice of high or low resistance telephone receivers?

20. What are the considerations which determine the advantage of a fairly high note for radio signalling?

CHAPTER XIX

RECEIVERS FOR SPARK SYSTEMS

THE theoretical considerations involved in Receiver Circuits for Spark Systems have already been dealt with in Chapter XVII.; consequently the present Chapter will be mainly devoted to a brief description of a few typical receivers.

It is rather an unfortunate fact that remarkably good results are often obtained with receiver apparatus which is most inefficiently designed, and this is likely to be more than ever possible when valve detectors and amplifiers are universally employed. The tendency at the present moment is towards inefficiency in either of two ways: either to be careless in design, insulation, and wiring of apparatus because the great sensitivity of modern receiving apparatus will ensure signals in any case, or to waste battery current and valves in amplifiers and thus lower the commercial efficiency in producing signals which are unnecessarily loud.

Before dealing with the description of individual receivers it may be profitable to discuss briefly a few essential points in design. As already pointed out in Chapter XVII. receivers should be so designed that coupling and tuning effects are independent of each other or nearly so; in practice this suggests that there should be a coupling coil independent of the tuning coil in the aerial circuit. The coupling coil should be below the tuning coil and next the earth connection where the current effects are a maximum.

Since most modern receivers are fitted with high resistance detectors, which are potential operated devices, the aerial and closed circuit coils should be designed to have minimum self-capacity effects. In this respect coils made of finely stranded wire and lap wound to several layers, so as to have a short axial length, are very satisfactory. Examples of this class of coil are seen in the Telefunken receiver illustrated later in this Chapter.

Where large coils are necessary for long wave reception, and it is only possible to make long cylindrical coils of one layer winding, the turns should be kept slightly apart by winding on a separating thread at the same time as the wire. It is a mistake to use wire with heavy insulation, or to embed the turns in a preliminary coating of paraffin wax placed on the former; it is equally a mistake to coat the turns heavily with shellac after the coil has been wound with the idea of stiffening it, or strengthening its insulation; all this only increases the self-capacity of the coil.

Also it is a mistake to design a receiver for a large range of wave lengths by the employment of large coils, or tune to short wave lengths by using a variable condenser in series with a comparatively large coil; the inductance and resistance of the coil only reduce the value of the oscillating current induced in the circuit. It is better to have interchangeable coils for different wave length ranges, or to wind coils in sections with switching arrangements so that sections can be added or left out as desired.

A receiver should not be designed with complicated switching arrangements in order that it may be employed on many different ranges of wave lengths, or with fancy arrangements for cutting out dead-end effect or connecting condensers in series or in parallel. All this only introduces complications to go out of order and leads to vexatious unreliability. A receiver should be designed for one definite purpose, the wiring laid out symmetrically, and the parts assembled so that connecting wires are as short as possible, crossing each other as little as possible. The reliability of a receiver will greatly depend on the design and values of the tuning condensers and these should be carefully chosen.

According to Dr. W. H. Eccles, for a given length of wire, *i.e.* resistance, a single layer coil will have a maximum inductance if its diameter is about 2·5 times its length; the inductance (L) of such a coil is then nearly equal to $27{\cdot}6\, l^3n^2$ cms. where l is the axial length of the coil in cms., and n the number of turns per cm.

A suitable size of wire for receiver circuit coils is about the equivalent of No. 28 to No. 30 S.W.G., though with high resistance crystal and valve detectors the secondary coil may be of No. 34 S.W.G. Thick wire only increases the capacity effect of the coil and it is not necessary to have a very low resistance.

In assembling the apparatus care should be taken to avoid magnetic coupling effects between coils where it is not intended ; this is rather difficult to ensure when the apparatus is mounted on an ebonite panel and enclosed in a case, at the same time helpful precautions can be taken such as keeping tuning coils as far apart as possible, or assembling them with their axes at right angles to each other.

All connecting leads between the different parts of the receiver should be rigid as far as possible; loose connecting wires introduce capacity effect which varies as the wires change their positions, and this may make a very great difference in the efficiency of the receiver, especially when it is fitted with valve apparatus.

Good insulation is essential for all terminals and the use of ebonite for this purpose has become almost universal.

The Marconi Short Wave Multiple Tuner. — This receiver is designed for use with the Marconi Magnetic Detector, which is of low resistance and is a current operated device. For this reason the tuning condenser in the secondary circuit is in series with, and not across, the secondary coil. The receiver diagram is shown in Fig. 166, in which it will be seen that the aerial is connected in series with the aerial tuning inductance ATI, the aerial tuning condenser ATC, primary coil of coupler P, and earth. A micrometer spark gap S is connected from aerial to earth to save the apparatus from lightning effects or strong inductive effects produced by a neighbouring transmitter; also a coil X, of high inductance, is connected across the aerial condenser to provide a continuous wire circuit from aerial to earth. As there are no tappings on the secondary of the tuning coil all tuning of the secondary circuit is done with the condenser. Similarly the primary coupling coil is not variable, hence all tuning of the aerial circuit is done with the aerial inductance and condenser.

When Standing By a switch is thrown over so that the detector is joined directly in series with the aerial inductance and condenser to earth; the magnetic detector is of low resistance so that it will work well connected in series with the aerial to pick up any station within range. But it is not possible to cut out interfering stations with these connections, so that when a station is picked up the switch is thrown over to the connections shown in Fig. 166, the detector circuit tuned by means of its condenser, and interfering stations cut out by

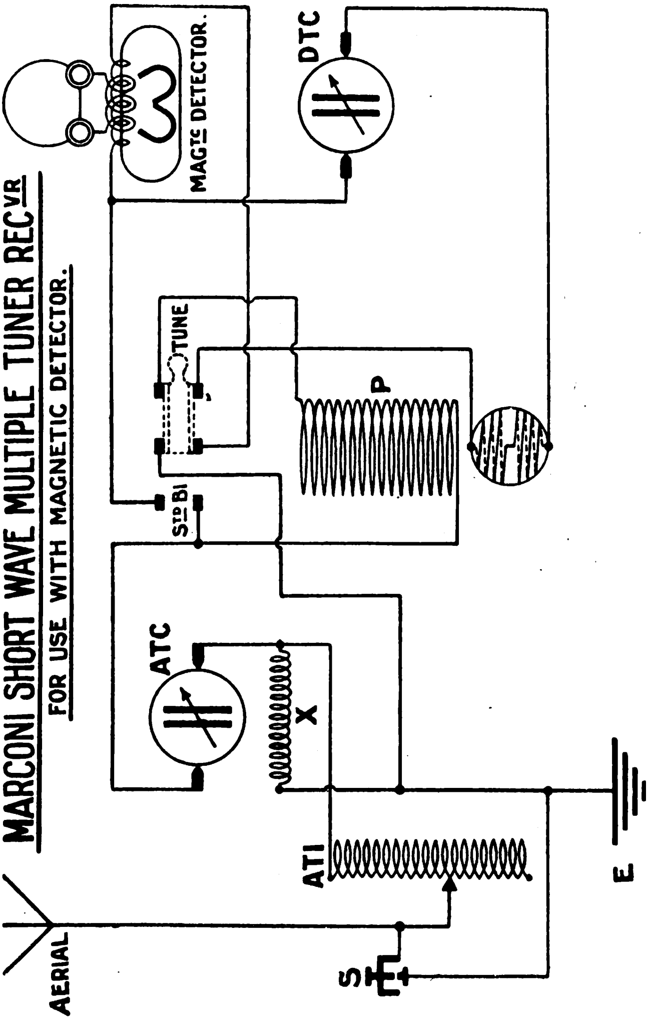


Fig. 166.

varying the degree of coupling, *i.e.* varying by means of an ebonite handle the position of the axis of the primary coil with respect to that of the secondary. The " stand by " connections are easily traced, while the receiver itself is shown in Fig. 167. It is suitable for wave lengths from 250 to 1750 metres.

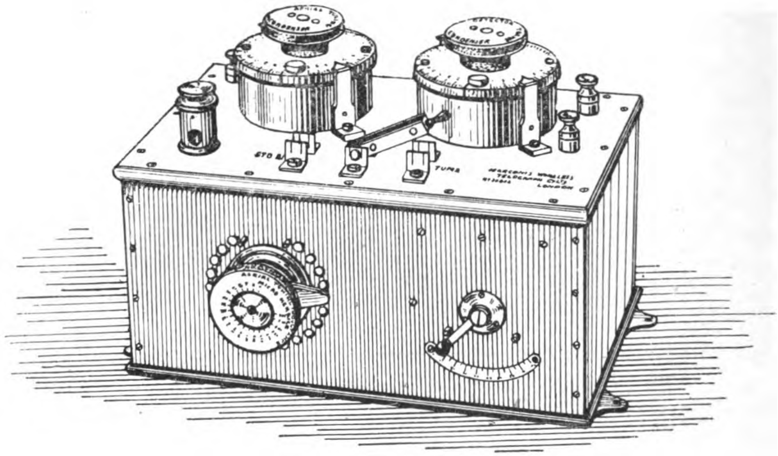


Fig. 167.—Marconi Short Wave Multiple Tuner.

Marconi Short Wave Crystal Receiving Set.—The connections of this set have been already described in Chapter XVII. Its normal range is 200–1200 metres of wave length, but it can be used for longer wave lengths if an additional loading, or tuning, coil is placed in the aerial circuit.

The aerial inductance is a coil of about 100 turns of No. 20 S.W.G. copper wire, 4 inches long and 3¾ inches diameter, with tappings taken to a multiple way switch on the top of the case. The aerial tuning condenser is of the moving vane type with ebonite dielectric: it has contacts which short circuit it when set to zero on the scale of graduations, and its maximum capacity value is about 10,000 cms. It is about 4 inches in diameter and 1¾ inches high.

The coupling coils consist of a primary of 24 turns, wound on a spherical former which is embraced by one end of the cylindrical secondary. The secondary coil is wound on a cylinder and is about 3 inches long by 3½ inches diameter, consisting of a small size copper wire—about No. 27 S.W.G. The primary can be rotated by means of an ebonite handle on the top of the case; this handle is called the Intensifier and simply loosens or tightens the coupling. When set to zero the coupling is zero, for the magnetic axis of the primary is then at right angles to that of the secondary, but when the intensifier handle is at 90, the coupling effect is a maximum, the axes of the coils being then in line, as shown in Fig. 168.

Interference by jamming stations can be minimised by loosening the coupling, and the tuning of the receiver is very sharp on account of its good design.

There are no tappings on the secondary circuit coil and tuning of this circuit is done by the Billi condenser shunted across it.

The secondary condenser is of the Billi pattern and consists of a double set of concentric metallic tubes, 2¼ inches long, separated by thin ebonite, the outer tubes being 0·8 inch in diameter. The whole condenser is only 4½ inches long, and the outer tubes can be made to embrace more or less of the inner tubes by sliding them along the ebonite, an ebonite handle being fixed to them for this purpose. A view of a Billi condenser is shown in the right hand front top of the receiver in Fig. 172. The maximum capacity of this condenser is about a billifarad, and by means of it the secondary circuit can be tuned to the range of wave lengths for which the receiver is designed. In fact the condenser is calibrated and indexed in wave lengths so that the secondary circuit can be quickly adjusted to any desired wave length within the range. Two carborundum detectors are mounted on the case and a German silver coil, of 400 ohms resistance, acts as a potentiometer to use with the one

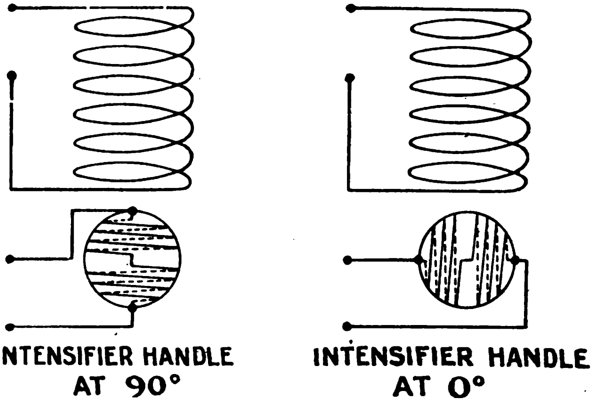


FIG. 168.

selected. In the centre of the top of the case are the telephone terminals, so arranged that one telephone set may be used alone or two telephone sets may be used in series. A two-way detector switch, micrometer spark gap, and high inductance aerial earthing coil completes the equipment of this receiver.

Suppose it is desired to adjust the receiver to pick up signals at 600 metres wave length. Having a 4–6 volt battery joined to the potentiometer send current through a buzzer near the receiver and set the potentiometer to give best sounds in the telephones. It may be necessary to reverse the direction of the current through the crystal in use, as carborundum conducts much better when the current is flowing in one direction through it than if it is reversed, and there is no means of knowing which is the best direction except by trial. To reverse the crystal in this receiver it is only necessary to give the whole detector a half turn on its base. Having got the detector into a sensitive condition set the Billi condenser to the adjustment corresponding to 600 metres—it is provided with graduations by means of which this can be done. Place the aerial condenser in its short-circuited position, the intensifier handle at 90, and tune in with the aerial inductance. When the signals are obtained, vary first the aerial condenser and then the secondary condenser until the strongest signals are obtained. If there is interference, loosen the coupling by means of the intensifier handle and tune again with the condensers. This receiver can also be used with valve detectors.

Marconi Universal Crystal Receiver.—This receiver has been designed to work with crystal detectors, such as zincite-bornite, zincite-tellurium, and others of similar resistance; it is intended for a range of wave lengths from 300 to 3000 metres.

The receiver differs from the one already described in that the primary of the loose coupler has three tappings, and the secondary of the loose coupler is made in three separate sections, fitted with a switch so that one section can be used alone, two in series, or three in series, according as the wave length increases. It will be remembered that in the first Marconi crystal receiver described the tuning of the secondary circuit was done by means of the small Billi condenser joined across it. This method of capacity tuning is suitable only if a comparatively small range of wave lengths is desired; but we have noted that a crystal receiver is most efficient when the capacity effects are small, therefore when tuning to long wave lengths it is better, indeed necessary, to increase the inductance effect in the secondary circuit rather than the capacity effect. Suppose that the secondary coil is made large enough to tune by inductance to very long wave lengths, when short ones are received it is not only necessary to decrease the turns used on the secondary but also very desirable to disconnect altogether the unused portion of the secondary coil; *i.e.*

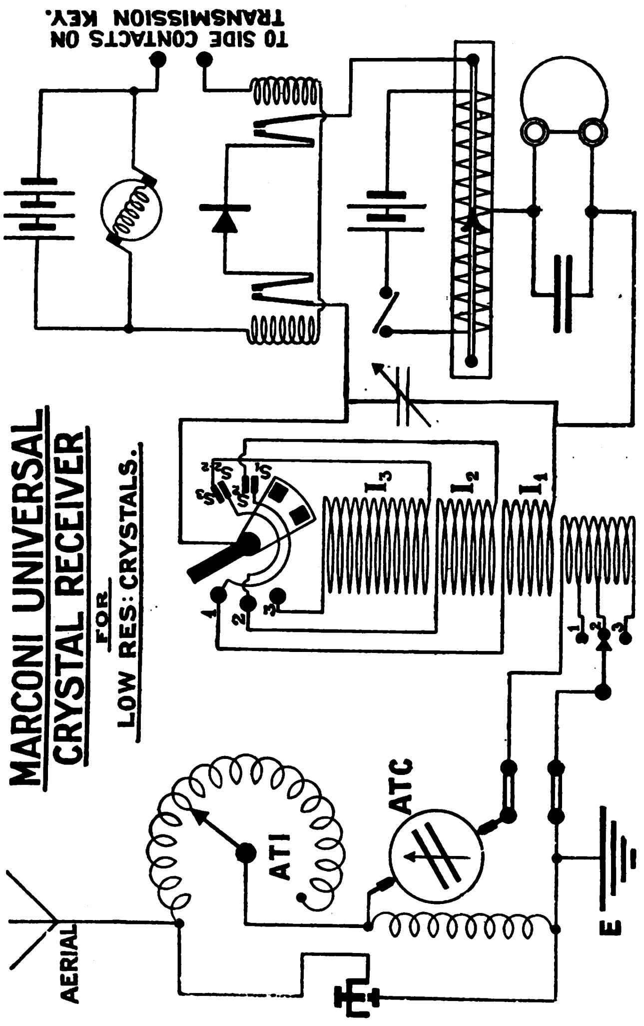


Fig. 169.

"the dead end." By this means we avoid a loss of energy in these turns called the "dead end loss." In other words, instead of simply taking tappings from the secondary to a multiple way switch it is better to wind it in separate sections, and have a switching arrangement which will join in series the sections which are required, leaving the others quite disconnected. Such an arrangement is fitted to the Marconi universal crystal receiver.

Another point of novelty about the universal receiver is that the detector is disconnected at both sides by means of relays when the transmitting key is depressed, thus preserving it from possible damage by the strong currents induced when transmission takes place. The side contacts on the transmitting key (see p. 212) close the circuits of the relay coils. The crystal detector is enclosed in a metal screening box to further protect it from induced currents.

The connections of the receiver are shown in Fig. 169. It will be noted that both primary and secondary coupling coils have three points of working, marked 1, 2, and 3, corresponding to wave lengths, (1) below 600, (2) 600 to 1600, (3) 1000 to 3000 metres respectively. If the primary is on stud 2 the secondary should be on the corresponding stud. The only points calling for remark are the secondary switch, the detector relays, and the telephone condenser.

When the switch is on contact 1 the detector is joined to the high potential end of the section I_1 of secondary inductance, the sections I_2 and I_3 being then completely disconnected. When the switch is on contact 2, the detector is joined to the high voltage end of I_2, the other end of this section being joined to the top of I_1 by a bridging piece carried on the switch—short-circuiting the springs S_1 S_2. Similarly when the switch is on contact 3, the springs S_1, S_2 are shorted, also S_2, S_3, and the whole of the secondary coils are then in series.

The relay connections of the detector are easily followed, the relays being worked by three or four primary cells through the side contacts of the transmitting key. A potentiometer is mounted on this receiver; if a carborundum detector is used three or four volts will be necessary for the potentiometer, but if a Perikon or any zincite combination is used a very small voltage, if any, is necessary.

Fig. 170 is a view of the receiver, the aerial tuning inductance being on the left front, above it on the top is the aerial condenser; in the centre is the potentiometer, behind it the detector box, and in front of it the three-way primary switch. On the top right front is the secondary circuit condenser of small disc form, and behind it the secondary three-way switch. In the front on the right is a handle sliding in a slot, by which the primary is moved to loosen or tighten the degree of coupling for the purpose of cutting out interfering stations. The telephone condenser is a fixed one, chosen to suit the receiver apparatus.

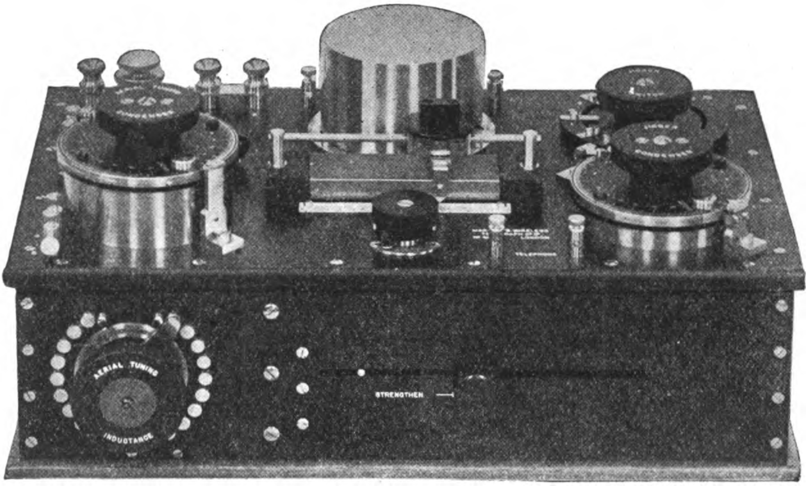


FIG. 170.

If a carborundum detector is used with this receiver the crystal should be one of low resistance.

The Marconi Valve Receiver.—The connections of a Fleming valve receiver have been given in Chapter XVIII., Fig. 148, and the one here described differs from it only in being a little more developed. A diagram of the connections is shown in Fig. 171, from which it will be seen that the aerial circuit is fitted with a throw-over switch, so that when "standing by" it is magnetically coupled direct to the valve circuit, but when switch is thrown over to "tune" the aerial and valve circuits are coupled through an intermediate circuit. The aerial and intermediate circuits are of the usual Marconi pattern; the valve circuit is slightly more complicated than a crystal detector circuit, owing to the necessity of having the valve filament incandescent with an adjustable voltage impressed on it. This voltage is adjusted by means of the battery and series resistance joined as shown.

It is most important that the + and — terminals of the battery should be connected to the corresponding terminals marked on

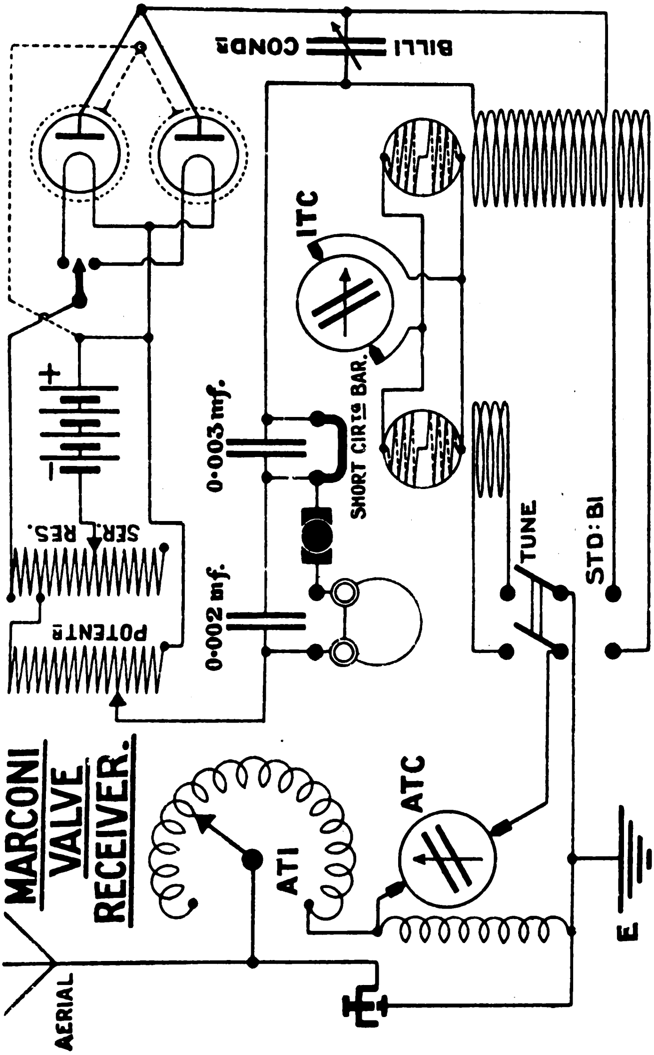


FIG. 171.

the case. The wire gauze shields, put over the two valves to protect them from static charges, are connnected to the positive terminals of the battery, these connections being shown dotted.

If no potentiometer and series resistance are used the short circuit bar across the 0·003 mfd. in the telephone circuit must be replaced by a special value of resistance coil.

The appearance of this receiver is shown in Fig. 172 and the student will easily recognise the usual apparatus. The potentiometer and series resistance are on the left side of the case, the Billi condenser is on the right front corner of the top panel, while the handle just seen on the right side of the case is connected to the intermediate circuit coupling coils. By rotating the handle from 90° the coupling can be loosened and interfering signals cut out; after adjustment of the coupling the tuning should be reset by slight variation of the condenser adjustments.

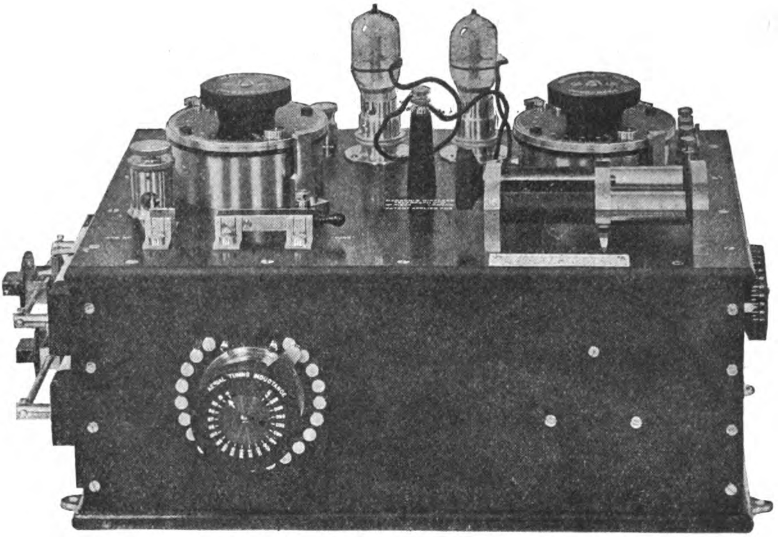


FIG. 172.

The strength of the signals at any time will greatly depend on the proper adjustment of the potentiometer and series resistance, and this will depend on the valve used. Fleming valves are now almost obsolete and receivers designed for modern valves are fully dealt with in Volume II.

The Marconi Multiple Tuner for use with Magnetic Detector.—This receiver was much employed on Marconi ship outfits, for the magnetic detector, though not so sensitive as valve or crystal detectors, is very reliable, requires no adjustments when once well set, does not jam with strong discharges, and is almost fool proof. As the name " multiple tuner " implies, the receiver has three circuits, aerial, intermediate, and secondary, each of which must be tuned, the tuning switches being connected together so that the three circuits can be tuned simultaneously.

The appearance of this Tuner is shown in Fig. 173; the switch handle on the right front of the case is linked to the three four-way switches which tune the three circuits simultaneously; finer adjustments of tuning are made by means of the variable condensers in the aerial, intermediate, and detector circuits, seen on the top of the case. The aerial loading inductance is adjusted by means of the multiple contact switch

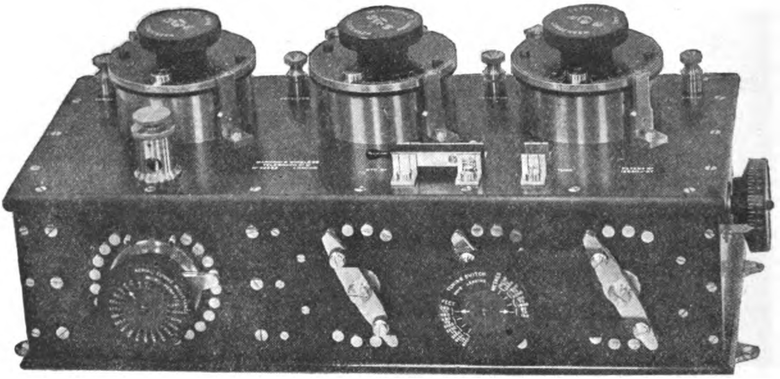


Fig. 173.

seen on the left front of the case. A two-way throw-over switch is mounted on the top of the case; in the " stand by " position it connects the magnetic detector directly into the aerial circuit; when signals are jammed it is thrown over to the " tune " position where the detector is in a tuned circuit coupled to the intermediate circuit.

A diagrammatic sketch of the connections of this receiver is shown in Fig. 174. Across the aerial condenser is the high inductive coil which prevents static charges accumulating in the aerial circuit; a small gap G is also provided. It is seen that when the detector switch is thrown over to " Std. Bi," the detector is connected in series in the aerial circuit. This method of use is possible with a magnetic detector since its primary coil has low resistance. When the switch is thrown over to " Tune " the detector is no longer in the aerial circuit, but the aerial current now goes through the switch S_1 and coupling coil AC in series with the aerial condenser, inductance, and earth. The coil AC is coupled to the primary coil PI of an intermediate circuit, of which the secondary coil SI is coupled to the coil in the detector circuit. The intermediate circuit is tuned by its variable

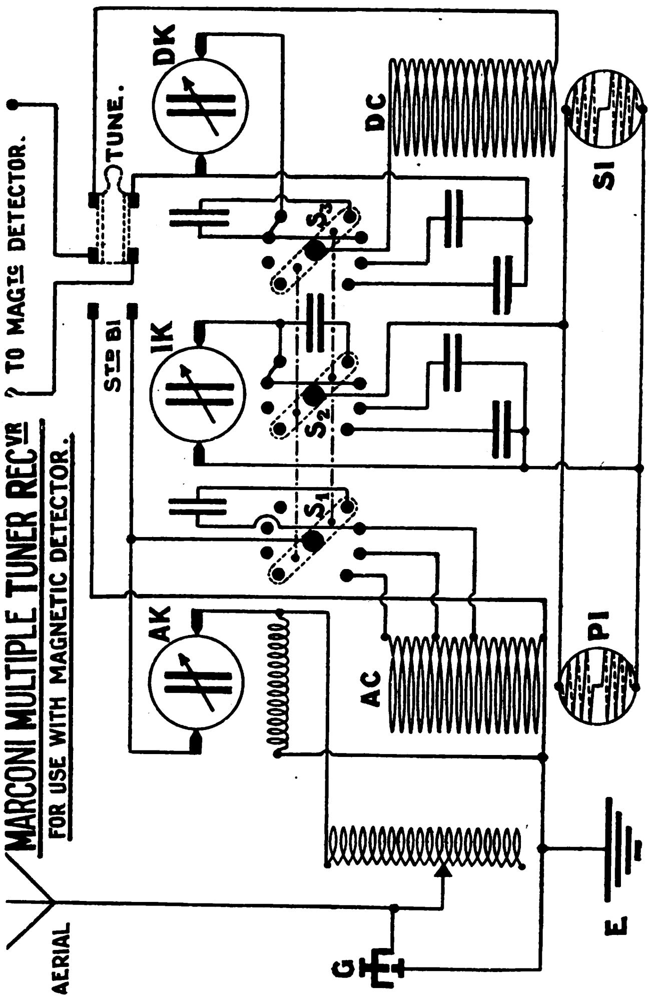


FIG. 174.

condenser IK and other condensers, the rough adjustment being made by the switch S_2. The detector circuit, which consists of the coil (coupled to the intermediate circuit), detector, detector condenser DK, and auxiliary condensers, is roughly tuned by means of the switch S_3. The switches S_1, S_2, and S_3 are all linked together so that the approximate tuning of all the three circuits to any wave length takes place simultaneously. Any finer tuning can be carried out by varying the condensers AK, IK, and DK, on the top of the case. The degree of coupling can be changed by moving the axis of the coils of the intermediate circuit relatively to the aerial and detector circuits coils; this is effected by rotating a handle at the side of the case. The four steps of the tuning switches S_1, S_2, and S_3 are marked in wave lengths, the instrument being proportioned to tune to all wave lengths from 300 to 8000 metres.

Telefunken Receiving Set.—The connection of this set has already been described in Chapter XVII., and its appearance is shown in Fig. 175. The aerial, or antenna, switch, whose handle is seen at the right extending from the back, can be switched to sending or receiving position. When switched over for sending it opens the circuit at each side of the detector, also at each side of the telephones, so that the strong inductive effects set up while sending will not act upon these delicate parts of the receiver. When the aerial switch closes to the receiving circuit the aerial is joined to the primary coil of the tuning inductance, which can be varied in three steps by means of a plug inserted into corresponding socket connections on the front of the primary coil frame. Two or three interchangeable primary coils of different inductance values are provided so that a long range of wave lengths can be obtained. One such primary coil is the small one seen at the side of the receiver.

The secondary of the tuning inductance is hinged over the primary, and can be moved outwards to loosen the degree of coupling; it can also be turned round on a horizontal axis when moved outwards so that it is possible to arrange a very loose coupling. The secondary can be varied in six steps by means of the plug and socket contacts seen on its flange, and for any given wave length a certain value of primary and secondary is always used. Thus fineness of tuning is effected simply by adjusting the condenser seen in the front of the set; this is of the usual movable plate design, and can be joined in series or in parallel with the primary tuning coil by means of a small two-way switch which is just below the primary. Two detectors are mounted behind the condenser; also terminals for the telephones or call apparatus. A wave range of 250 to 2500 metres can be got by varying the condenser and using one interchange of coils. Two secondary coils of different ranges are shown at the side.

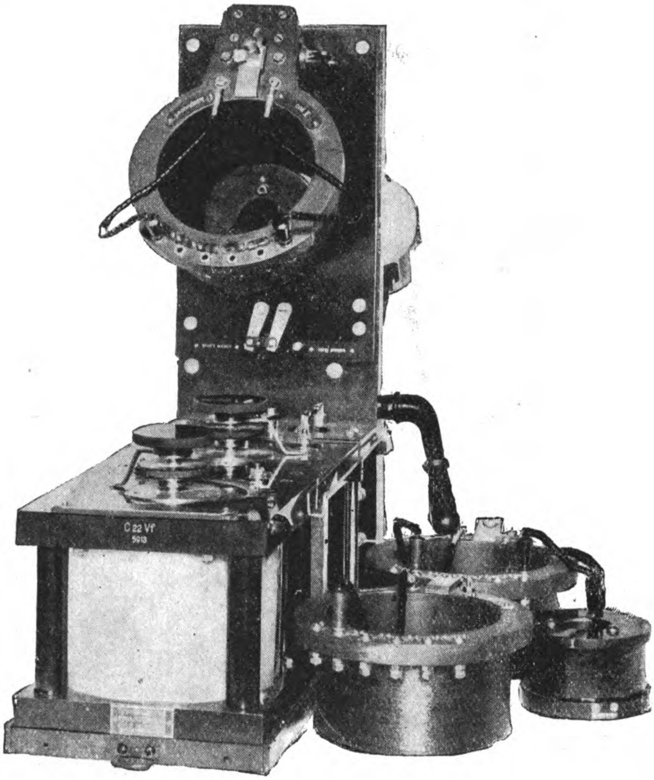


Fig. 175.

For this range of wave lengths the primary coils would be about $3\frac{3}{4}$ inches diameter (of flanges) and $1\frac{3}{4}$ inches broad, wound on $\frac{3}{8}$ inch ebonite with ebonite flanges $\frac{3}{8}$ inch thick. The short wave coil has an inductance of about 100,000 cms. with five tappings and the long wave coil an inductance of 650,000 cms. with four tappings, the latter coil being lap wound to four layers deep.

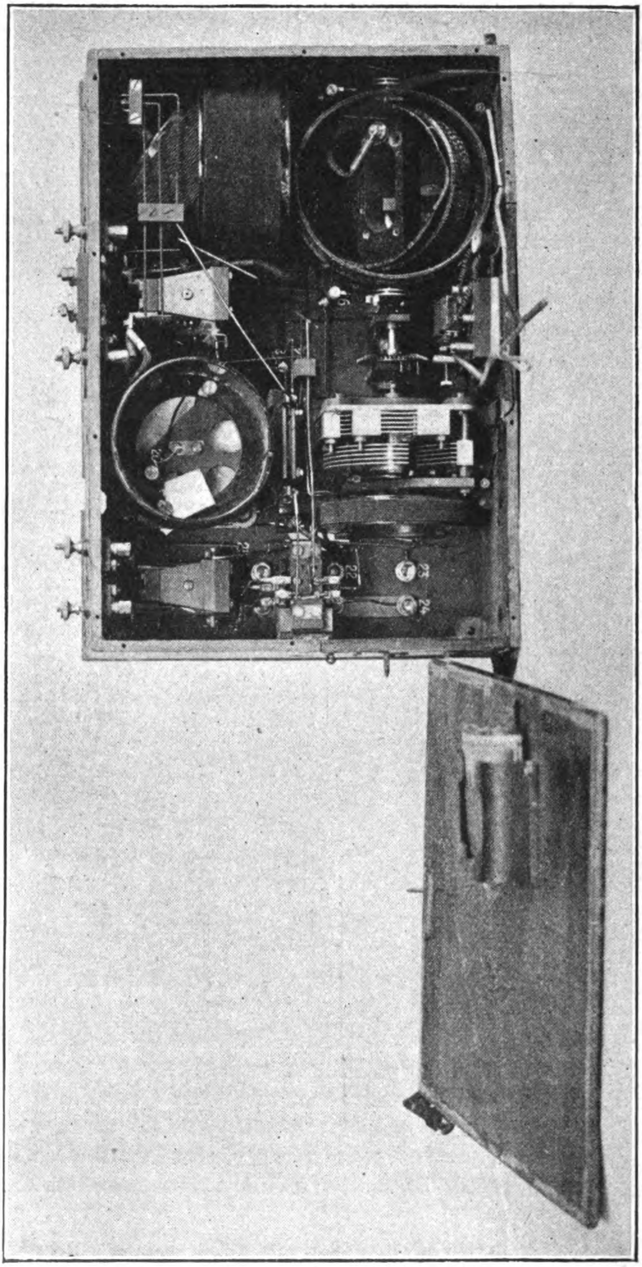


FIG. 176.

The secondary coil is $5\frac{1}{2}$ inches diameter over all and $2\frac{3}{8}$ inches broad, wound on an ebonite cylinder with ebonite flanges; it is lap wound to three layers and has an inductance of about 5,000,000 cms. with six tappings for different wave length ranges. The variable condenser has a maximum capacity of about 0·003 mfd.

Telefunken Receiver—Type E. 143*b*.—This receiver is typical of first-class design; the workmanship is good and every detail which leads to efficiency is well thought out. The apparatus is mounted on an ebonite panel and enclosed in a case; the internal connections are made with stiff wire supported where necessary on ebonite cleats or brackets, and the wires for each circuit are enamelled in distinctive colours so that the aerial, detector, or buzzer circuit can be traced out at a glance. A back view of the receiver is shown in Fig. 176; in the top right hand corner is seen the aerial tuning coil which has two tappings, and inside of which the secondary circuit coil can be rotated. Next to this is a barrel type switch, or controller, by means of which the aerial and closed circuits are adjusted for three different ranges of wave length, and the detector circuit adjusted for three degrees of coupling on each wave length range. In the middle is seen an extra coil for the secondary circuit on the longest wave length range, and inside it is mounted the secondary circuit variable condenser. At the top left is another barrel type switch by means of which any one of the three detectors may be brought into action. At the bottom from right to left are seen the aerial circuit variometer, aerial tuning condenser, and small aerial coil, coupled to a testing buzzer circuit, the buzzer being mounted in the bottom centre. The variometer and tuning condenser are geared together so that both are adjusted simultaneously by the movement of one handle. The solid construction of the variable condenser may be noticed. The back of the case carries the dry cells for working the testing buzzer; this is of the shunted type and has a small variable condenser across the interrupter consisting of two lengths of fine enamelled wire wound on a small reel. The aerial and closed circuit condensers are of 0·0005 mfd. maximum capacity, whilst the telephone terminals are shunted by a fixed condenser of zinc sheets and mica dielectric and of 10,000 cms. capacity. A small fixed condenser of 40 cms. capacity is added to the secondary circuit for the longest wave length range. A front view of the instrument is shown in Fig. 177, connected up to a two-valve amplifier which is shown on the left.

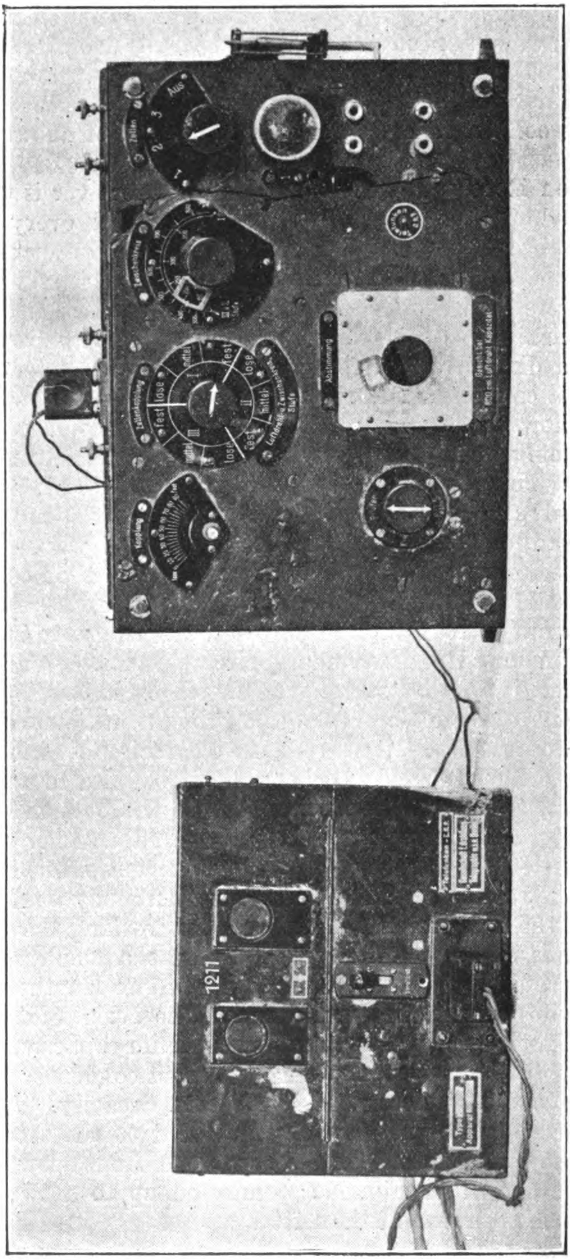


FIG. 177.

The combinations which can be made by the adjusting switch for different wave lengths and couplings are shown in Fig. 178.

On each wave length range the detector can be set to three different couplings—fast, medium, and loose—by adjusting the position of the switch.

It will be remembered that the oscillations in the secondary circuit send a discharge of energy through the detector and telephones; this discharge represents energy taken from the oscillations therefore it damps them out. The damping effect of the detector circuit will not be so great if it is connected across only a few turns of the secondary circuit instead of across the whole of it; this helps tuning and decreases interference. The best coupling of the two circuits is that which transfers half the oscillating energy to the detector circuit.

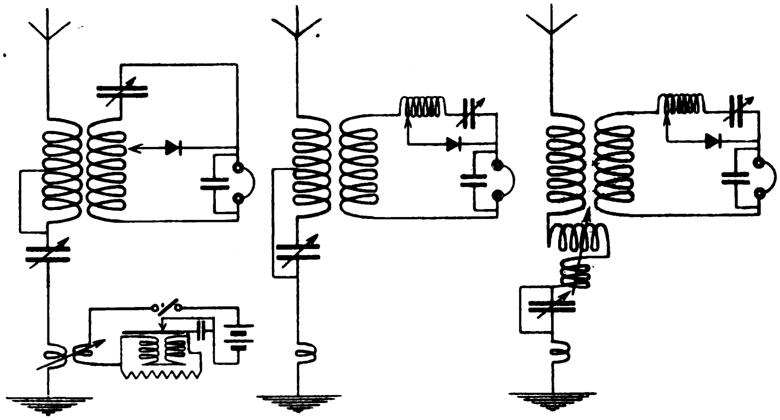

$\lambda = 150$—350 M. $\lambda = 250$—550 M. $\lambda = 400$—850 M.

FIG. 178.

On the shortest wave length range a part of the aerial coil is short-circuited, on the middle range part of the coil and the tuning condenser are shorted whilst an extra coil is added in the secondary circuit; on the longest range all the aerial coil plus a variometer coil is in action, but the condenser is short-circuited.

Receiver with Aperiodic Secondary Circuit.—To simplify tuning some receivers have been designed in which the secondary circuit is non-periodic, but because of jamming trouble it is always best to employ this only as a "stand-by" arrangement, and to have facilities for loosening the coupling and tuning the secondary. For standing by such a receiver will give good results, especially when fitted with a valve low frequency amplifier behind the detector.

Fig. 179 shows the diagram of a French design of receiver made on these principles; the aerial circuit is of the usual form except that the tuning capacity consists of a fixed condenser shunted by a variable one which can be of small capacity and thus give fineness of tuning.

On stand-by the switch S is left open and the secondary inductance tight coupled to the aerial circuit. Rough tuning can be made by tappings on the secondary coil; if jamming is present the switch S is closed, the secondary circuit is sharply tuned by means of its condenser, and the coupling between the circuits made loose. This receiver was designed for undamped wave reception, using a small oscillator near the receiver circuit with which to heterodyne the oscillations.

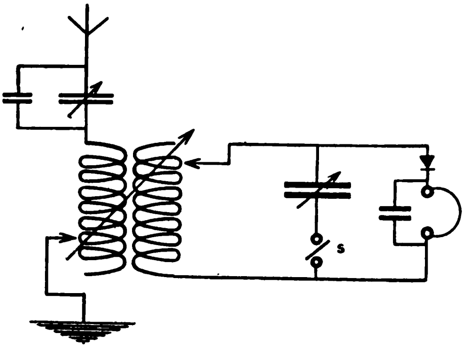


FIG. 179.

Electrostatic Coupling.—Fig. 180 shows a method of electrostatically coupling the aerial and closed circuits when the closed circuit may be periodic or aperiodic. The coils L_1 and L_2 are not magnetically coupled, but a static coupling between the aerial and closed circuits is provided by the variable condenser K_3 which should be of small maximum value, *i.e.* about 0·0005 mfd.

To use this receiver the switch S is first left open so as to make the secondary circuit aperiodic, and the coupling condenser adjusted to a fairly high value on its scale so that the coupling is close ; the aerial circuit is then tuned in the ordinary manner by means of L_3 and K_1. If the incoming signals are very sharply tuned or there is interference from other stations the switch S is closed and the secondary circuit tuned to the incoming wave length by means of K_2 ; coupling can then be loosened to reduce interference by decreasing K_3 ; after K_3 is changed the secondary tuning should be readjusted again at K_2.

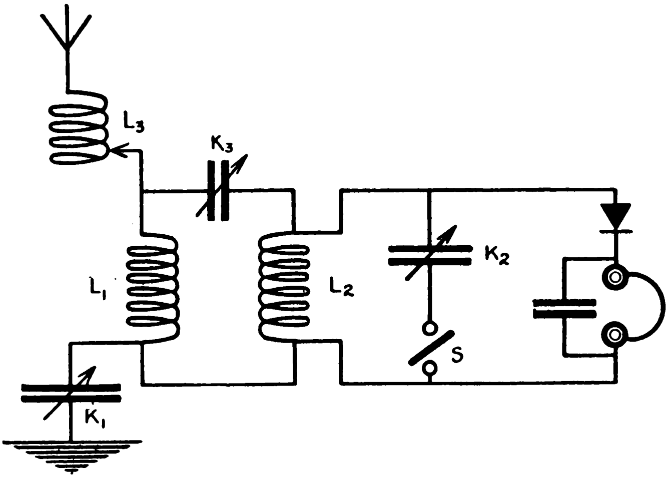


FIG. 180.

This method is often adopted with valve receiver circuits.

QUESTIONS AND EXERCISES.

1. Why should the coupling coil in a receiver aerial circuit be next the earth connection, and what is the advantage of putting the aerial tuning condenser above the aerial tuning inductance ?
2. Draw a diagram showing the switching arrangements required for connecting a condenser either in series or in parallel with a coil.
3. What is the advantage of having the detector circuit connected across only a portion of the secondary inductance rather than across the whole of it ?
4. What is meant by an aperiodic circuit ?
5. The closed circuit of a receiver can be calibrated in wave lengths, and thus indicate the wave length of a distant transmitting station. Explain why a receiver aerial circuit is not similarly calibrated.
6. A magnetic detector is joined in series in the receiver aerial circuit when listening for a call or for signals. Could this be done with any other form of detector—if not, why not ?
7. Calculate approximately the capacity of the Billi condenser described in connection with the Marconi short wave crystal receiver, if the ebonite

dielectric is 0·5 millimetre thick. The dielectric constant of ebonite may be taken as 2·5.

8. Describe how you would pick up and tune to a station with a Marconi multiple tuner, using a magnetic detector.

9. Why are high resistance telephone receivers used with most crystal detectors ?

10. How does the sensitiveness of a telephone receiver depend on the frequency of the currents flowing in it; and what is meant by saying that the receiver is most sensitive when the period of the currents is equal to the natural vibration period of the telephone diaphragm ?

11. A ship's aerial has a capacity of 0·002 mfd. and an inductance of 0·03 millihenry. Calculate the length of a coil, 6 inches diameter, wound with No. 20 enamelled copper wire giving 25 turns to the inch, which would tune this aerial to the 1200 metre wave length of the Eiffel Tower signals.

CHAPTER XX

SYSTEMS EMPLOYING UNDAMPED OR SLIGHTLY DAMPED WAVES

It will have become obvious to those who have read the preceding chapters that radio transmission becomes more efficient and selective the less the aerial oscillations are damped. During the time that the key on an ordinary spark transmitter is closed there are comparatively great periods of inactivity, or gaps between the trains of radiated wave energy sent out into the ether, even when quenched or rotary spark gaps are employed.

A system in which these gaps did not exist, and in which the radiation of energy would occur all the time the key is closed, would obviously be more efficient, from the points of view that it would radiate more energy in a given time, that therefore greater ranges would be covered for the same amount of primary energy, and that there would be a persistent, well-defined, fundamental wave length.

It follows that an ideal system would be one in which the waves are not damped at all; in this Chapter a short description will be given of some of the methods which have been developed to attain this result, leaving those which employ valves to be dealt with in Vol. II., which deals with Valves and Valve Apparatus.

Suppose it is desired to set up waves 6000 metres long; the frequency of the aerial oscillating currents would be—

$$\frac{V}{\lambda} = \frac{3 \times 10^8}{6000} = 50{,}000$$

thus if a uniform alternating voltage could be generated at 50,000 frequency and applied, either directly or through coupling coils, to the aerial, we should have oscillating currents flowing in the aerial of uniform values, the amplitudes would all be equal, and there would be no damping. We, therefore, see that this involves the design of apparatus which will generate alternating voltage at a frequency of 50,000 cycles per second, or at greater frequencies if the wave length is less than 6000 metres. It is easy enough to design an alternator, on similar lines to those used in ordinary electrical engineering practice, in which the frequency is 10,000 cycles per second, but the design of an ordinary alternator has to be discarded when we want 50,000 to 100,000 cycles per second.

It will be remembered that the frequency of an alternator is equal to the revolutions per second multiplied by the number of pairs of poles. Now suppose that we could drive the machine at a peripheral speed of 80 metres per second, and wish to have a frequency of 50,000, the distance between the poles would only be $\frac{80,000}{2 \times 50,000} = 0{\cdot}8$ mm., this distance would have to accommodate the iron of the core, the copper of the winding, and the insulation. Therefore it is easily seen that ordinary alternator designs are not feasible.

Some years ago Alexanderson designed an inductor type of alternator in which the currents were generated at frequencies up to 200,000 per second, but the development of this class of machine has been slow, and it is only within the last year or two that they have become a real commercial proposition. An inductor alternator is one in which the armature coils are stationary as well as the pole pieces, and alternating currents are induced in the former by rotating in front of them inductor coils or poles which cause interlinkage with the magnetic field of the stationary poles. The Alexanderson machine has an inductor of chrome nickel steel with from 300 to 800 slots on the edge filled up with phosphor bronze wire; the number of slots depends on the frequency required. This disc has a very small clearance from the stationary windings and iron core of the machine, and it is driven by an electric motor through a counter shaft and gearing at a speed of 20,000 r.p.m. This alternator is more fully described in Vol. II. together with methods of obtaining from it high frequencies without unduly increasing the speed of rotation. Within the last year much development of this design has taken place and there is no doubt it will provide a reliable method of obtaining undamped currents for high power stations. In these the use of high frequency alternators is likely to become standard practice.

Goldschmidt System.—The essential part of the Goldschmidt system is the high frequency alternator which Dr. Goldschmidt has developed and patented, a machine which has not a great number of poles, and which does not require to be run at dangerously excessive speeds to attain the necessary high frequency.

To understand the principles of the machine let us for a moment consider fundamental facts. In an ordinary alternator we get a complete cycle of induced voltage in any wire when it has passed through the magnetic field corresponding to a pair of poles, consequently the number of cycles per second depends on how quickly the wires cut through this magnetic field. Now it is easily seen that if the poles, or the magnetic field, could be rotated backwards as fast as the wires rotate forward, a cycle of voltage would be obtained in half the time, or the frequency would be doubled.

Instead of the usual design of pole pieces, if we make the stationary portion of the machine of laminated iron with slots on the inner periphery, with coils suitably joined up in these slots, and pass alternating current through the coils, we can obtain a magnetic field of invisible lines which rotates round the inner periphery of the stationary iron and coils at a speed equal to the frequency of the alternating current. An electrical engineering student will recognise that this is a description of the stator of an ordinary induction motor. Thus if we have wires suitably joined up on the armature, or rotor, of the machine, and drive this in the opposite direction to that in which the magnetic field is rotating and at the same speed, we induce in the rotating winding an alternating voltage which is at double the frequency of that applied to the stationary winding. The stationary part of such a machine is called the stator and the rotating part the rotor. The voltage of the rotor at the doubled frequency could be applied to the stator of a similar machine and from its rotor current at increased frequency obtained ; by connecting up several machines in this manner we could obtain a high frequency current, but the method would be inefficient as there would be serious iron and copper energy losses in each machine.

This is the principle on which the Goldschmidt high frequency machine is designed, but, as we shall see, there is only one stator and rotor ; not several joined in cascade to obtain the high frequency. The machine consists of a stator and a rotor, the stator being magnetised in the first place by direct current as in ordinary alternators, and the rotor being so designed that when driven at a speed which is within ordinary safe limits the frequency in it is about 15,000 cycles per second.

The rotor has connected to it an oscillating circuit consisting of condensers and inductance coils tuned to this frequency, hence currents at 15,000 frequency flow in this circuit. Now the rotor is magnetically coupled to its own stator so that in the stator currents at 30,000 frequency are set up, due to the inductive effect of the rotating magnetic field set up by the high frequency rotor currents. The rotation of the rotor in the magnetic field which is induced by currents at 30,000 frequency in the stator induces in it currents at a new frequency of 45,000; these currents have provided for them another tuned oscillating circuit, connected across the rotor terminals. Again the reaction of these rotor currents induces currents in the stator at a frequency of 60,000, and these swing in a closed circuit to which the aerial and earth are directly coupled. The diagram of connections is shown in Fig. 181. Currents at still higher frequencies might be generated by this method but the efficiency of generation would decrease with higher frequencies; magnetic, or hysteresis, losses of energy in the iron parts of the machine increase rapidly with the frequency, also the eddy current losses increase both in the copper and in the iron. Thus, at present, the Goldschmidt machine is only adapted for long-distance long-wave transmission, and it

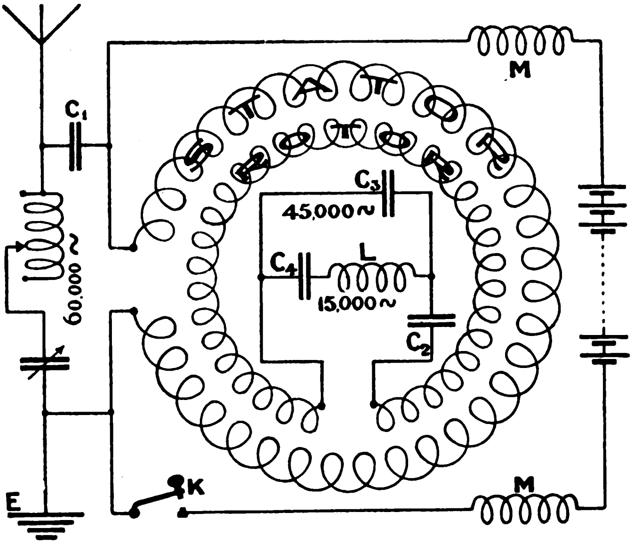


FIG. 181.

may be some time before an efficient machine is designed for 600 metre waves at 500,000 frequency.

In Fig. 181 it is seen that the stator is excited or magnetised in the first place by current from a battery or other D.C. supply; this current cannot pass to the oscillating circuit owing to the condenser C_1, while the choke coils, MM, prevent the oscillating currents from getting back through the supply mains. Oscillating circuits, made up of the condensers C_2, C_3, C_4, and the inductance coil L, are connected to the rotor, and in these flow the currents of the rotor at the different frequencies to which these circuits are tuned, *i.e.* 15,000 and 45,000.

A 150 KW. Goldschmidt generator has been employed in the Eilvese station near Hanover for transmitting to the station under German control at Tuckerton, U.S.A., the aerial being of the umbrella type on a high lattice steel tower. A point of importance in working with the high frequency generator is the necessity of keeping absolutely constant speed in order that the frequency, and therefore the wave length, should be constant. It will be noted that transmission is effected by manipulating the exciting current of the generator; every time the key is depressed load is thrown on, and when the key is released the load is taken off; the generator is driven by a steam engine or motor, and it is evident that some very accurate method of governing the speed must be used under these conditions. As a matter of fact the transmitting key not only changes the exciting current of the generator, but simultaneously changes the field current of the driving motor by such an amount that it does not lose speed when the load is thrown on it. The student will remember that the speed of a motor under increased load can be kept up by weakening its field, *i.e.* decreasing the current round its poles by putting more resistance in series with them.

Fig. 182 is a view of the 150 KW. Goldschmidt high-frequency transmitter outfit installed at Eilvese, while Fig. 183 is an exterior view of the Eilvese station. These views were kindly placed at the disposal of the author by the "Compagnie Universelle de Télégraphie et de Téléphonie sans Fil," who controlled the Goldschmidt patents. The author is also indebted to them for the following interesting details of construction and apparatus used at these stations:—

The high frequency machine has similar dimensions to ordinary electrical generators of the same output, the 150 KW. size running at 3100 r.p.m. while the 5 KW. size runs at 8000 r.p.m. They are specially ventilated and are lubricated by oil under pressure, the oil being itself cooled by water circulation.

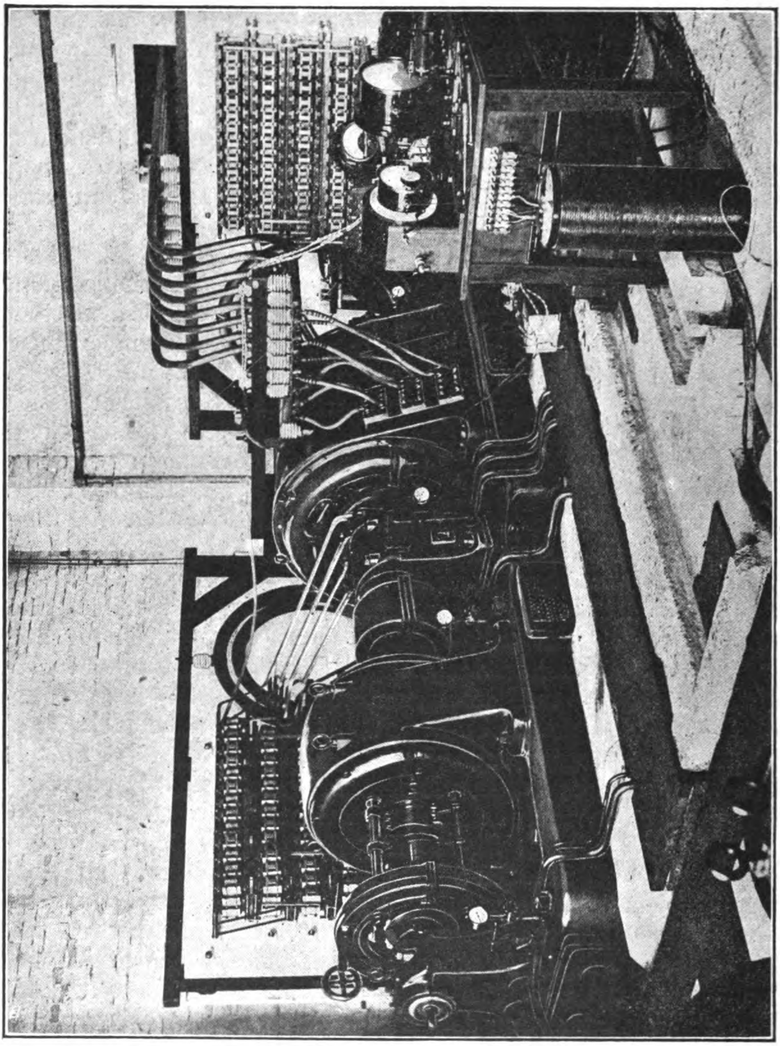


Fig. 182.

All iron cores of the machine are built of very thin laminations (0·05 mm. thick), with paper insulation between them, the iron being specially prepared. The winding consists of one conductor

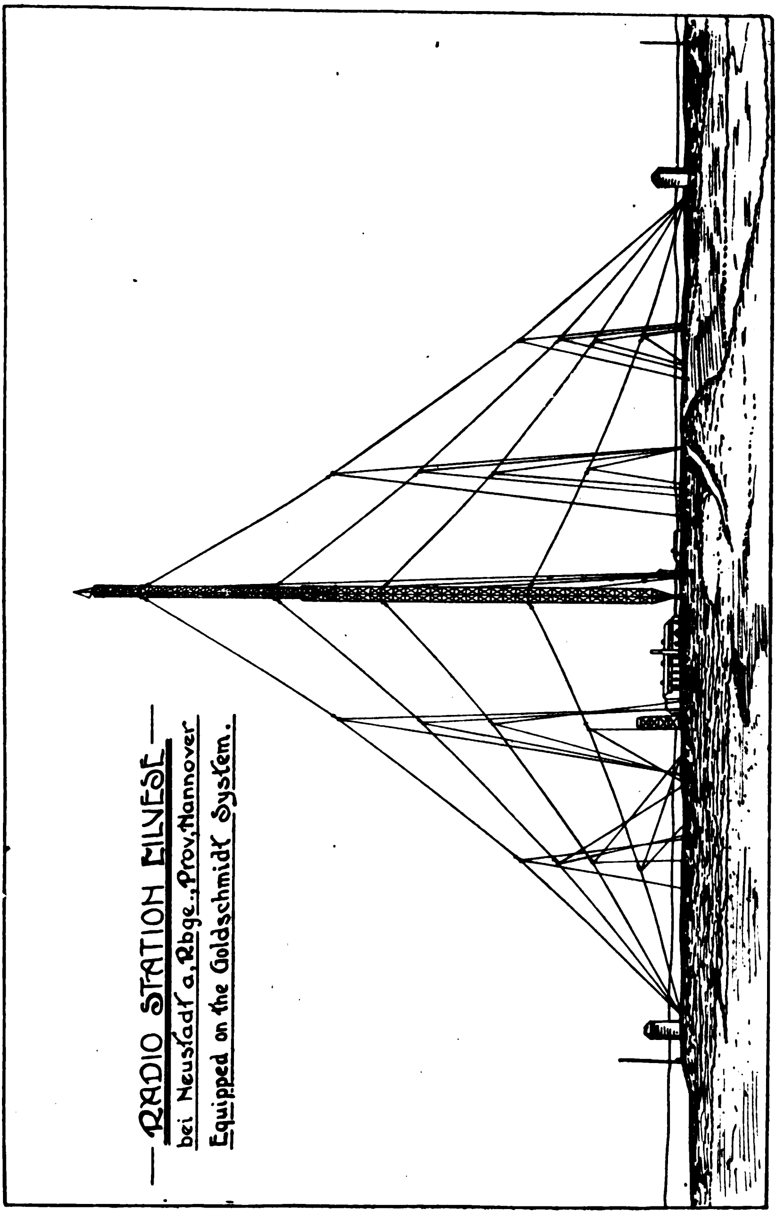

RADIO STATION EILVESE
bei Neustadt a. Rbge., Prov. Hannover
Equipped on the Goldschmidt System.

FIG. 183.

per slot, the conductor being made of many-stranded wire and wound backwards and forwards in the slots, in the simple manner shown in Fig. 184, so as to produce alternate N. and S. poles. The stator and rotor are electrically identical, with the same number of poles and the same winding; each winding is divided into several sections so that grouping may be made in series or in parallel, in order to vary the current and the voltage as desired. The 150 KW. machines are driven by steam turbines but small sizes can be driven by electric motors; as mentioned already the Wheatstone type transmitting key manipulates the excitation current of the machine, but for large sets it would be practicable to make the key manipulate the field circuit of the D.C. machine which supplies the exciting current to the high-frequency alternator.

As accessory apparatus for transmission it is only necessary to have inductance coils, condensers, aerial and earth connections.

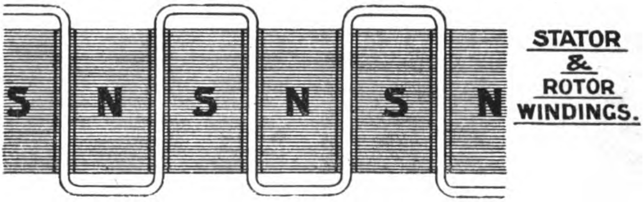


Fig. 184.

The inductance coils are of the usual type and do not require special description; the condensers are built up with tinfoil sheets and mica dielectric, and have, of necessity, large dimensions when dealing with 150 KW.s of power. Since there can be no damping the aerial and earth are connected directly to the stator oscillating circuit: the aerial is supported on a steel tower 250 metres high, and is a combination of double cone and umbrella, made up of 36 bronze cables of 8 mms. diameter, and extending over a radius of 500 metres. The tower is insulated at the base and halfway up, while steel cables, sectioned themselves by insulators, serve to support it. The construction of tower and aerial is well seen in Fig. 183, while it is shown diagrammatically in Fig. 185. Earthing is carried out by a network of wires, extending around the foot of the mast to a radius of 500 metres.

The complete connections of a transmitter with a Goldschmidt High Frequency Generator are given more fully in Fig. 186;

the stator of the machine is excited or magnetised in the first place by D.C. current from a small exciter; on rotation of the rotor this induces in the rotor a voltage at frequency f which sends a current into the circuit X tuned to this frequency. The currents flowing in the rotor circuit induce currents at a frequency of $2f$ in the stator, which has a circuit Y connected across it tuning it to a frequency of $2f$. The current alternating in the stator at frequency $2f$ reacts on the rotor inducing in it a current of frequency $3f$ which reacts back on the stator, producing in it induction at a frequency of $4f$, and this is employed to send alternating, or oscillating, currents into the capacity of the aerial-earth circuit.

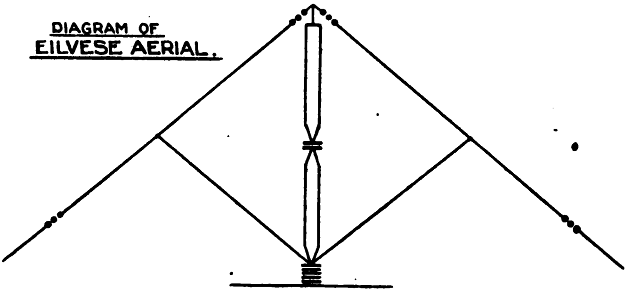


FIG. 185.

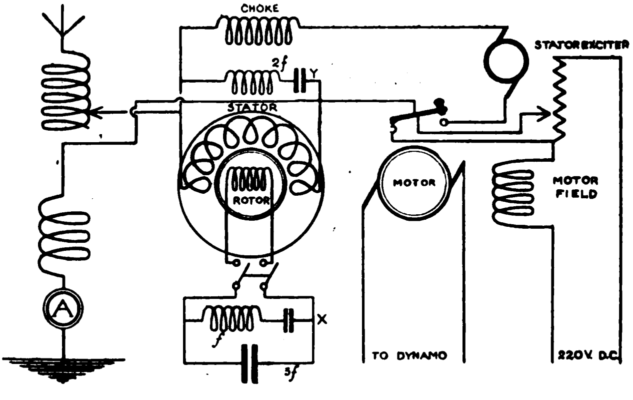


FIG. 186.

The motor field is separately excited and the speed of the motor must be maintained constant. The closing of the Morse key starts the excitation of the stator, it also weakens slightly the field of the driving motor by opening a short circuit on a portion of the field rheostat; this weakening of the motor field tends to increase its speed and counteracts the tendency to slow up when the load comes on.

Poulsen System.—Fourteen years ago Mr. Duddell discovered that if an oscillating circuit, *i.e.* one containing inductance and capacity with low resistance, is joined across the carbons of an arc lamp oscillating currents will flow through this circuit and across the arc when it is lighted. The suitable conditions under which such oscillations can take place are that the carbons should be solid, the arc short, the condenser of about 1 mfd. capacity, and that the arc should have a resistance in series with it to steady it.

According to the values of capacity, inductance, and resistance in the oscillatory circuit the arc column will give out a note of higher or lower pitch, and by changing the value of the inductance, or of the capacity, by means of plugs or contacts, the note can be changed so that the arrangement was called "Duddell's Musical Arc." It is shown diagrammatically in Fig. 187. The note given out depends on the frequency of the oscillating currents which flow across the arc from the oscillating circuit; this current, as it rapidly rises and falls in its oscillations, increases or decreases the thickness of the carbon vapour column which forms the arc; thus it sets up waves in the air around it and a note, or sound, is heard whose pitch depends on the frequency of these currents. When we have currents oscillating in a circuit they set up waves in the ether round it, and the frequency of these waves is given by the usual formula—

$$n = \frac{1}{2\pi}\sqrt{\frac{1}{KL} - \frac{R^2}{4L^2}}$$

where K, L, and R are measured in farads, henrys, and ohms, respectively.

The resistance of the oscillating circuit includes the resistance of the arc and this varies with the current which flows across it from the mains; if the arc is short and thick, so that R is small, the frequency is, as usual, approximately equal to—

$$\frac{1}{2\pi\sqrt{K_f L_h}} \quad \text{or} \quad \frac{5 \times 10^6}{\sqrt{L_{\text{cms.}}\, K_{\text{mfds.}}}}$$

In addition to the resistance joined in series with the arc a choking coil should also be joined in series in each main so that the oscillating currents will flow across the arc and are choked back from the direct current supply mains.

Why does an oscillatory current flow through the circuit and across the arc lamp under the conditions described? It is very simply explained if the relations between the voltage across the arc and the current in it are realised. Briefly the volts across the arc automatically rises if the current falls, and falls if the current rises in value, as shown in the curve Fig. 188; in other words an arc does not obey Ohm's Law but has what is called a negative resistance. The current oscillations are produced as follows:—

(*a*) When the condenser circuit is joined across the arc a current flows into it, therefore less current is left to flow across the arc and the volts rise until the condenser is charged.

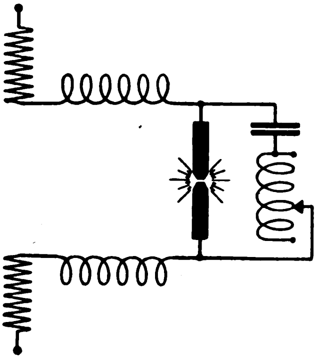


Fig. 187.

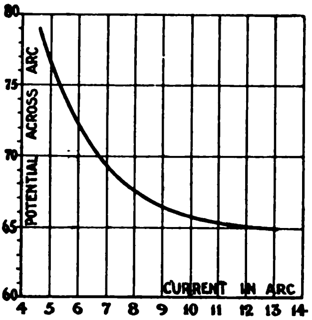


Fig. 188.

(*b*) When the condenser is charged the current across the arc now rises to its normal value, and the increased current means that the volts fall; but the condenser was charged to the higher voltage, therefore it discharges across the arc.

(*c*) Owing to the oscillatory nature of the circuit and the shortness of the arc the discharge is an oscillatory one.

(*d*) At each oscillation of current the volts rise and fall as described above, therefore the oscillations are indefinitely kept up as long as the current flows; in other words, there is a fresh impulse of energy at each oscillation, and the oscillations are consequently entirely undamped.

This provides us with a method of setting up undamped waves, and a system of radio-telegraphy based on arc generation of waves has been developed by Dr. Poulsen.

The student will readily realise that the length of the arc must be kept very constant for if its length varies its resistance would vary and this would change the wave length. Also, if the waves are to be propagated to long distances the arc will have to deal with large amounts of energy, the electrodes must be thick, and some method provided for dissipating the heat.

In the Poulsen system the arc is struck between a copper positive, (anode), and a carbon negative, (kathode), in a chamber which is kept cool by circulation of water. This chamber is filled with coal gas, or preferably with hydrogen, which enters at the bottom and passes out by a tube at the top ; the consumption of gas per hour depending on the size of the arc used. This gas cools the arc, and has the effect of modifying its current voltage curve in such a way that the oscillation effects are accentuated ; that is to say it makes the curve more steep than if the arc were an ordinary open one. At the same time the gas prevents access of air to the electrodes and decreases the rate of burning of the electrodes.

Extending into the arc chamber are the poles of a strong electro-magnet, the coils of which are in series with the arc so that their exciting current is the arc current ; indeed the electro-magnet coils act as choke coils in the supply leads and other choke coils are not required. The strong magnetic field which exists between the poles of the magnets acts on the arc and keeps it steady, while the length of the arc is kept constant by rotating the carbon kathode against a scraper to keep the end flat and uniform. The carbons have to be frequently renewed but the copper anode will last for two or three months.

The copper anode is kept cool by passing a circulation of water through it.

The connections are very simple, for since the oscillating currents are undamped the aerial circuit can be direct coupled to the oscillating circuit, as shown in Fig. 189 (*a*). In the Duddell musical arc, where the currents in the shunt or oscillating circuit are small and of high frequency, the arc is not extinguished, but in the Poulsen arc the condenser currents may be so large that the arc may be quenched out or extinguished when the charge current into the condenser is a maximum. The arc is then relit by the high voltage induced across it by the oscillatory discharge.

One interesting feature of this apparatus is the connections of the transmitting key. This cannot be put in the primary circuit, as is the case in spark systems, for if the primary circuit were broken by the key the arc would go out and would not light up again until the electrodes are brought into contact. Hence the arc must be kept lit all the time. The waves being undamped a very sharp tuning is necessary between the sending and receiving stations, and if the wave length at the sending station is changed by only 1 or 2 per cent. no signals are heard in the receivers. Thus the sending station is arranged to be slightly out of tune with the receiving station, and the transmitter key is connected across a few turns of the aerial tuning coil; when the key is depressed it short circuits these turns, and by changing the wave length of the transmitting aerial puts the latter in tune with the receiver so that the signals are heard. There are other methods of joining the transmitting key to obtain the same effect, but they are scarcely so reliable. Fig. 189 (*a*) shows the transmitting key connected as here described.

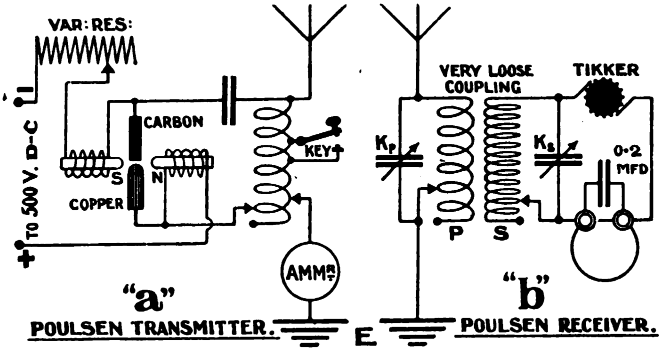


FIG. 189.

Several Poulsen arc transmitters of from 60 to 100 KW.s rating are now installed in England, France, and the United States, though it is probable that some of them will be replaced at an early date by C.W. valve transmitters.

The diagram of connections of a 100 KW. Poulsen arc transmitter, installed at Arlington, U.S.A., is given in Fig. 190; it will be seen that the sending key controls the current from a 110 volt circuit to a magnetic key which when closed shorts two or three turns of inductance in the aerial circuit. A starting resistance is employed to prevent an excessive rush of current from the machine when starting, or striking, the arc; it is cut out as soon as the arc is established and burning steadily.

The maximum efficiency of a Poulsen set as a converter of direct current into oscillating current is about 35 to 40 per cent., a good part of the direct current energy being used in the field coils and turned into heat in the arc. It has been proved that for a given wave length there is a certain value of shunt capacity across the arc which will give maximum efficiency and maximum oscillating energy. If the capacity is large for a given wave length, so that the inductance is small, the oscillations will be very unsteady unless resistance is introduced into the oscillating or shunt circuit. The oscillating energy can be maintained fairly constant over a fair range of wave lengths by suitably adjusting the strength of the magnetic blast, though the real function of the latter is to remove the ionised gases in the arc and promote steadiness of arcing.

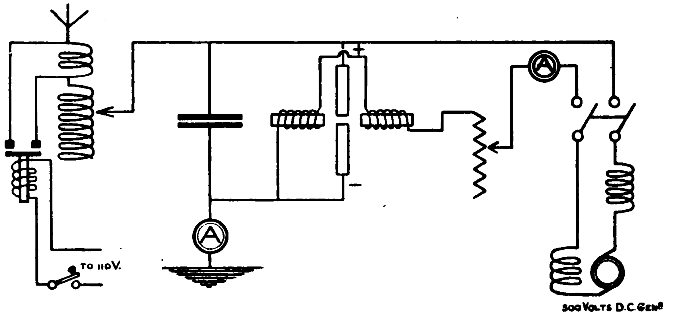


FIG. 190.

There is a fairly well pronounced second harmonic in the oscillations of a Poulsen arc which increases in strength with increase of fundamental oscillation frequency, *i.e.* decrease of fundamental wave length; it also depends on the capacity effects across the arc.

A typical Poulsen arc transmitter is shown in Fig. 190A.

A simple receiver circuit for the reception of signals from a Poulsen arc transmitter is shown diagrammatically in Fig. 189 (*b*); since the waves are almost undamped the oscillations induced in the receiver will be very persistent so that very loose coupling may be employed between the aerial and closed circuits. This is true for any undamped or continuous wave system and leads to the great advantage that interference may be reduced to a minimum. For long wave work, where the inductances of the tuning coils in the aerial and closed circuits are large, sufficient coupling is often obtained by having them on the same table and separated by a distance of from 2 to 5 feet.

If it is required that the Poulsen transmitter signals can be received on any spark receiver, *i.e.* one not fitted with "tikker" or heterodyne beat arrangement, this can be accomplished by connecting a rotating commutator, interrupter, or chopper in series with the key in the transmitter circuit. This interrupter will break up the radiated waves into groups or trains, as in a spark system, but unlike the spark system the waves in a train will be undamped. The interrupter introduces periods of non-

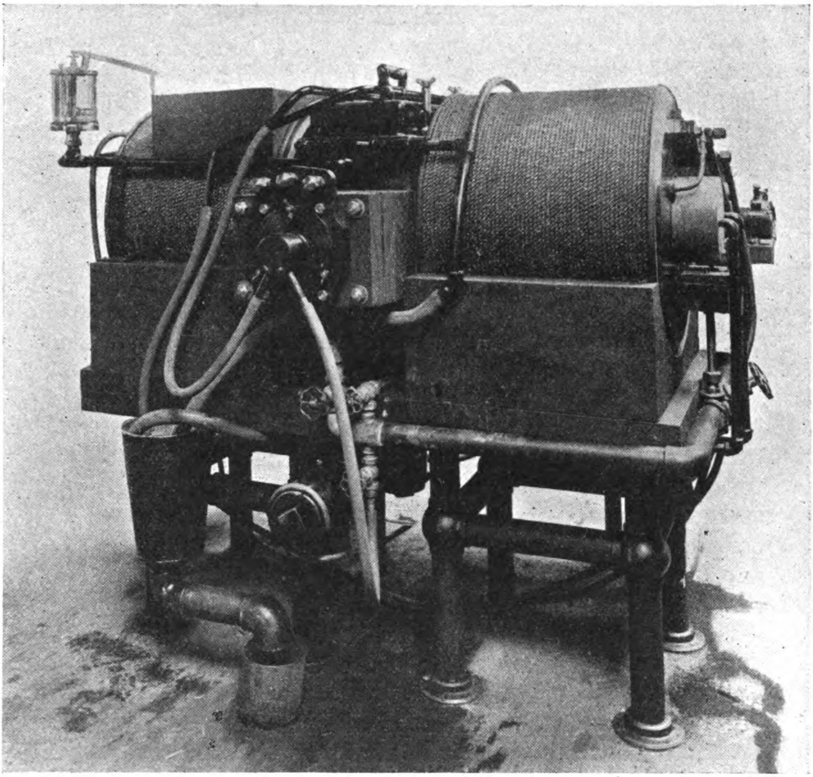


FIG. 190A.—100 KW. Arc Transmitter at San Franscisco.

(By permission of the Federal Telegraph Co., U.S.A.)

radiation, and this, of course, does away with much of the transmitter efficiency obtainable with undamped continuous radiation.

Probably the best known Poulsen stations are those which have worked commercially between San Francisco and Honolulu, a distance of 2100 nautical miles. These are each of 100 KW. size and the aerial at San Francisco is a flat-topped one supported on three lattice masts, one of which is 608 feet high, and the other two 440 feet high, the natural wave length of the aerial being 2300 metres. The arc transmitter is shown in Fig. 190A.

A 60 KW. Poulsen transmitter is installed at the Eiffel Tower Radio Station in Paris, and has been employed on Army traffic during the war.

Marconi System of Continuous Oscillations.—In 1913 the Marconi Co. had developed and brought to a high degree of perfection a system for setting up continuous oscillations and transmitting undamped waves. The method was first fully described by Sen. Marconi in a paper communicated to a scientific society in Rome. The student will remember that the ordinary Marconi system, with a disc discharger, sets up groups of oscillations at great regularity, and that the oscillations in the transmitter aerial circuit are less damped than with a simple spark system. Yet these oscillations, and the resulting ether waves, are in groups separated by intervals of time, and the idea underlying the Marconi continuous wave system is to fill up these intervals of time with other groups of oscillations, set up by other discharge circuits. It is something like using a four-cylinder engine instead of a single-cylinder one; Fig. 191 explains the idea. The lines A, B, C, D, show groups of oscillating discharges set up in four different circuits, arranged in such a manner that the discharges of the different circuits follow each other in a regular sequence. If, then, these discharges are all made to act inductively on a fifth circuit, the resulting oscillations in this circuit will be as shown at E. Attention must here be drawn to an important point in the working of such an arrangement—the discharges must overlap each other *in phase*.

A four-cylinder engine would be useless if the impulses of steam or gas in the cylinders were not properly timed; timed to occur in sequence and to occur at the proper point of the stroke. Similarly our oscillating discharges must overlap in phase, that is to say, referring to Fig. 191, Y must be in the same phase as X, otherwise their effects would neutralise each other. The method adopted by the Marconi Co. to obtain these results is diagrammatically illustrated in Fig. 192. It will be seen that

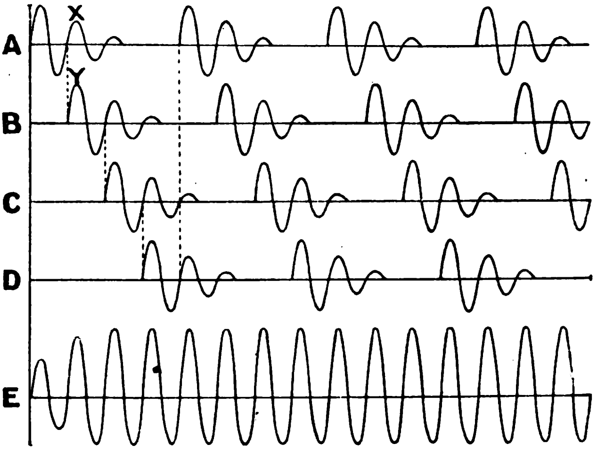


FIG. 191.

four primary circuits are charged in parallel from the source of voltage, or generator G. The spark gaps are metallic wheels with projecting teeth, these wheels being insulated from each other

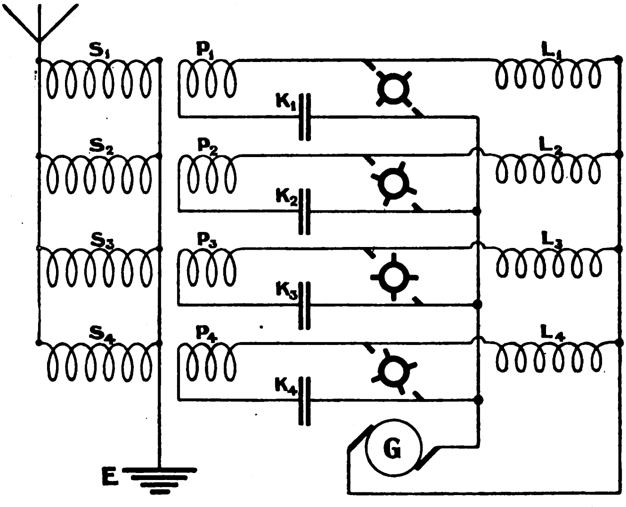


FIG. 192.

though rigidly mounted on the same shaft by which they are rotated. The primary circuits are inductively coupled by four jigger secondaries in parallel to the aerial circuit, and the discs are so arranged that discharges in the four circuits take place in regular succession. Thus, the discs having a certain velocity, the interval between a discharge from one circuit and that of the circuit which follows it is *exactly equal to one or more periods of complete oscillations in the aerial circuit.* At a certain disc speed the oscillation impulses overlap each other in exact phase. The aerial circuit may be coupled to the four primary circuits through the medium of an intermediate circuit; the timing in either case is done by small auxiliary spark gaps and circuits joined to the main discharge circuits; to avoid confusion these are not shown in the diagram of Fig. 192.

Lepel System.—This system was invented by Baron Von Lepel of Berlin, and stations equipped on the Lepel system in Belgium, France, and the West Indies have attained a considerable success in operation, so that a short description of the particular apparatus used may prove interesting.

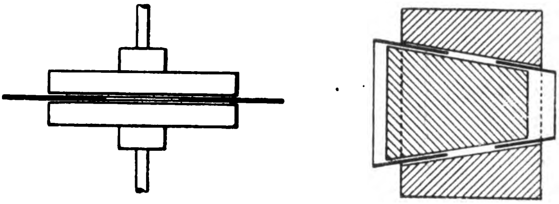


FIG. 193.

The Lepel discharger is really a form of quenched spark gap, and in the patent specification it is stated that the electrodes are a very small distance apart and equal at all points of the same. They may be made of two metallic discs or two metallic cone surfaces as shown in Fig. 193, the distance between the electrodes being so small as to be broken down by a discharge at the working voltage, so that the action would seem to be a mixture of spark and arc discharge. Thus, if 220 volts are used, the electrodes are only a fraction of a millimetre apart. The discharge is prevented from coming to the edges of the electrodes by very thin paper washers which project out beyond the edges of the electrodes; these washers are gradually burnt away on their inner edges and have to be renewed. For small power the electrodes need not be cooled; otherwise they can be cooled by water circulation and in any case cooling will aid the oscillation characteristics as it does in the Poulsen arc. The aerial circuit may be direct coupled to the spark gap or coupled by an oscillating transformer; in either case the power in the oscillating circuit is found to be increased by having an auxiliary oscillating circuit in parallel with it. The connections would then be as in Fig. 194 (*a*) for direct, (*b*) for inductive coupling of the aerial, the auxiliary oscillating circuit being shown dotted in each case.

It is to be noted that when the auxiliary circuit is not used the oscillations in the aerial are practically undamped, the spark gap giving off a faint hissing sound; when, however, the auxiliary circuit is connected up, the values of its inductance and capacity can be so chosen that the oscillations across the spark gap causes it to give out a musical note—it is then identical with a Duddell musical arc and the transmitter acts like a high note sparking transmitter. Thus the Lepel system can be used on either practically undamped waves or highly syntonised damped waves, and the Lepel receivers are fitted with alternative apparatus suitable for the reception of signals on either system.

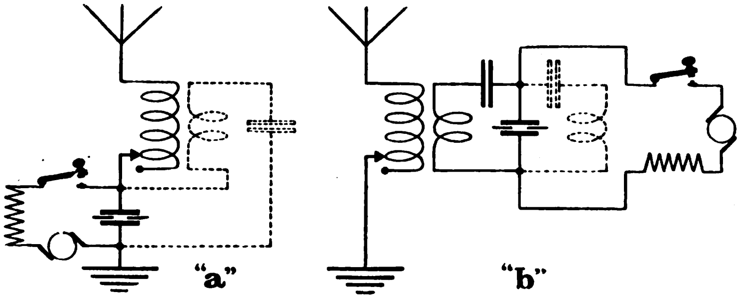
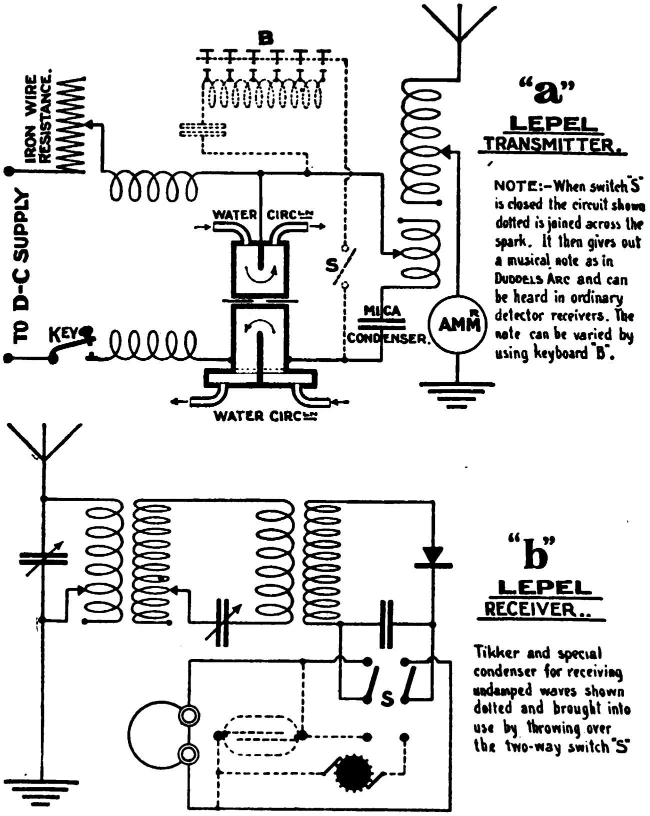


FIG. 194.

In Duddell's musical arc the note given out depends on the frequency of the oscillating circuit shunted across it; if its inductance or capacity is changed the note given out by the arc is changed. In the Lepel transmitter the inductance of the auxiliary circuit is fitted with a switch keyboard so that by manipulating these keys the spark note can be changed; indeed a tune could be played in the transmitter and heard in the receiver.

The transmitter apparatus actually employed is shown diagrammatically in Fig. 195 (*a*). The spark gap is connected in series with choke coils, manipulating key, and special iron wire resistances, to a 500 volt D.C. supply. The iron wire resistances are enclosed in glass tubes filled with hydrogen; their resistance rises if the current in the circuit increases, hence they tend to steady the supply and prevent damage if the spark should become short circuited. The spark electrodes are of copper and delta metal, made hollow and cooled by water circulation. The main oscillating circuit consists of a condenser with mica dielectric and an inductance coil of copper strip wound cylindrically; coupled to it is the aerial circuit. This is all that is required to emit feebly damped waves, but the auxiliary circuit, shown dotted in the diagram, is also provided, consisting of a condenser with mica



"a"
LEPEL
TRANSMITTER.

NOTE:—When switch "S" is closed the circuit shown dotted is joined across the spark. It then gives out a musical note as in Duddels Arc and can be heard in ordinary detector receivers. The note can be varied by using keyboard "B".

"b"
LEPEL
RECEIVER..

Tikker and special condenser for receiving undamped waves shown dotted and brought into use by throwing over the two-way switch "S"

FIG. 195.

dielectric and an inductance coil with keyboard switch contacts. The use of mica dielectric in the condensers considerably reduces their size for a given capacity, hence the Lepel apparatus is small and compact; while the apparatus is thus simple and comparatively inexpensive the efficiency of transmission is certainly very high, and long distances have been covered with comparatively small transmitter energy.

The Lepel receiver is shown diagrammatically in Fig. 195 (*b*), and is seen to consist of three circuits; the aerial circuit coupled inductively to an intermediate circuit, and the latter coupled inductively to the detector circuit. For receiving damped waves, either from a Lepel musical note transmitter, or from a station using spark or disc discharger, a crystal detector and telephones with blocking condenser are used; when receiving Lepel or other undamped waves a tikker interrupter is joined in series with the telephones and an extra condenser of special construction shunted across them. This change of connections can be quickly effected by means of the throw-over switch shown in the diagram. The special condenser used across the telephones when receiving on undamped waves is known as an "electrolytic condenser"; it consists of two little plates sealed in a glass tube, which is filled with an electrolyte. When current flows across the electrolyte a film of gas is deposited between the plates forming the dielectric of a condenser and since this film dielectric is very thin quite an appreciable extra capacity is shunted across the secondary circuit. The energy is stored up in this condenser until the interrupter allows it to be discharged through the telephone receivers.

Before concluding this Chapter, it may be profitable to review the advantages which are obtained by an efficient method of generating and utilising undamped electrical oscillations of high frequency. These advantages can be set out under the following seven headings:

(*a*) **Less Power Required.**—With undamped oscillations or continuous waves more energy is radiated per second for a given amount of primary energy applied. This means that for a given range less primary energy is required at the transmitter. Apart from transmitter considerations the very high sensitivity of the beat method of reception, used with continuous waves, makes it possible to work over very long ranges with small transmitter energy, as compared with spark-signalling and ordinary detector methods of reception. (See also (*e*) below.)

(*b*) **Less Interference.**—The perfect syntonisation obtainable with undamped waves reduces interference troubles between stations, and increases the commercial value of wireless communications since it increases the number of stations which can be efficiently worked in a given area.

(*c*) **Simpler Apparatus.**—The transmitting and receiving apparatus for undamped waves are less intricate and less costly than those required for spark systems; in the receiving station the detector arrangement has better mechanical features, and is not so easily put out of adjustment.

(*d*) **High Speed of Signalling.**—In sparking systems we have groups of oscillations separated by comparatively long intervals of inactivity (see Chapter XII. and Fig. 79), so that if high speed of transmission is attempted we may not have more than one or two trains of oscillations per dot or dash. With undamped oscillations these periods of inactivity are absent, hence high-speed work is possible.

(*e*) **Wireless Telephony** is only possible with undamped waves, for the variations of the human voice are much more rapid than the succession of wave trains which could be obtained with any sparking system. Besides, even if sparking frequency could be speeded up, the sound of the sparks would be heard superimposed on those of the voice. Wireless telephony has been carried on across the Atlantic with only 500 watts of transmitter energy.

(*f*) **Use of Special Directive Aerials.**—Undamped wave systems lend themselves specially to the use of directive aerials, in which direction of radiated energy is controlled by making the waves of two different aerials interfere with each other.

(*g*) **Less Elaborate Aerials.**—The aerials employed with undamped waves may be comparatively short and low.

In conclusion, the student may be reminded that an ordinary rectifying receiver, such as one fitted with a crystal detector, is not suitable without modification for the reception of undamped wave energy. Such a crystal receiver can be employed on undamped wave working if either of the following three modifications are employed:—(1) a tikker or interrupter is included in the transmitter circuit, (2) a tikker or interrupter is included in the receiver circuit, (3) a local oscillator is coupled to the receiver circuit which will form beats with, or heterodyne, the oscillations induced in the receiver by the ether waves.

The whole subject of Continuous Wave Systems is fully dealt with in Vol. II.

QUESTIONS.

1. Explain clearly why an arc lamp can be used for the generation of oscillating currents.

2. What are the advantages of undamped wave transmission ?

3. In an ordinary spark transmitter direct connection of the aerial and earth to the closed oscillating circuit is not desirable except for small outfits. Why is this ? And why is such a connection permissible with undamped wave transmitters ?

4. Why is it that a receiver equipped with ordinary detector arrangements will not respond to undamped waves ?

5. Explain the theory of the Goldschmidt high-frequency generator.

6. In the Marconi undamped wave system the primary oscillations must overlap each other *in phase.* Why is this, and what would happen if they did not so overlap ?

7. Explain why it is that high-speed radio-telegraphy is only possible with undamped wave systems.

8. Why is the Morse key in a Poulsen transmitter not connected so that it controls the primary energy ?

9. What modifications are necessary in the transmitter of a Poulsen or Lepel system so that the signals may be received on an ordinary crystal receiver ?

10. Why is a Poulsen arc enclosed in an atmosphere of hydrogen, and why is it struck in a strong magnetic field ?

CHAPTER XXI

MISCELLANEOUS APPARATUS

Radio Goniometers.— Under ordinary circumstances and with a vertical aerial at the transmitter the energy will be radiated equally in all horizontal directions, and consequently only a small fraction of the radiated energy is available to act on any one distant receiver. This broadcast radiation of ether strain energy from a station is inefficient and causes interference with other stations working on slightly different wave lengths, hence attention was early given to the problem of concentrating the radiation of long ether waves to a particular direction, in the same manner as the short ether waves of a searchlight beam can be directed by a parabolic mirror.

We have seen that quite early in the development of radio signalling on a commercial scale a partial solution of the problem was provided by the invention of the Marconi Directional Aerial; this was only a partial solution and continuous efforts have been made to evolve a more perfect directional arrangement.

The work of directional radiation has been less developed or adopted than that of directional reception, but it is quite possible that the extended use of valve apparatus will give a new impetus to this important problem.

In 1906 Braun described a method he had tried for getting directional radiation; briefly it consisted in having three vertical aerials erected at the corners of an equilateral triangle; oscillations which differed in phase were induced in these so that their effects in setting up ether strains annulled each other in one direction and aided each other in another direction.

Prof. Artom of Turin was the first to patent the use of directive triangular aerials, and commercial developments of this system were made by MM. Bellini and Tosi.

If an aerial is made up of two wires in the form of a plane vertical triangle, with their upper ends insulated from each other at the top of the mast and the aerial earth terminals of the transmitter connected in series at the middle of the base, we have what is known as a triangular aerial for transmission. In comparison with the distribution of radiated energy from a Marconi directional aerial, as shown in Fig. 112, the radiation from a triangular aerial will be a maximum in the direction of the plane of the triangle; energy will be propagated equally in both directions along this plane and, compared to Fig. 112, the polar curve of radiated energy distribution will be like a figure 8. Even if the aerial is a closed triangle, *i.e.* the two side wires connected together at the top, there will be a strong directional effect in the plane of the triangle. Simple triangular closed radiating loops are likely to become popular for short and medium range work both on spark and C.W. systems; on spark systems the loop may be the inductance effect of the closed circuit, but it is better to have a closed circuit with condenser and inductance of the usual design, and the loop circuit coupled to this by jigger coupling. The size and height of the triangular loop aerial will depend upon the wave length and on the range to be covered. Such a simple triangular loop aerial has also good directive effects for reception, and a moderately high loop on a 40–70 ft. mast, used in conjunction with valve apparatus, will receive over ranges of 500 miles or more. The great advantage of a triangular aerial for reception is that the effects of strays are very much minimised, and the effects of ground discharges practically eliminated.

Bellini-Tosi Compass.—For transmission MM. Bellini and Tosi elaborated the system; they employed two triangular aerials placed at right angles to each other and each with an open apex with a plain vertical aerial at the centre of the triangles. The idea underlying this arrangement is that the distribution of radiated energy from a triangular aerial lies on a polar curve of figure 8 shape and the radiation from a simple vertical wire, being equal in all directions, lies on a circle. By radiating from both simultaneously the curve showing the distribution of radiation will be the resultant of the figure 8 curve and the circle, paying due attention to the direction of radiation in compounding the ordinates of the two curves. Bellini and Tosi showed that the resultant was as curve B in Fig. 196,

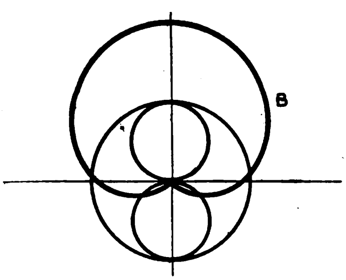


Fig. 196.

and therefore that the energy was nearly all radiated towards one side by the combination.

The energy radiation circle of the vertical wire aerial may not exactly embrace the figure 8 polar curve of energy radiation from the triangular aerial, as has been shown in the Figure.

The arrangement of aerials is shown in Fig. 197; the bases of the two triangular aerials include coils at right angles to each other, and the vertical aerial includes a pivoted coil in which oscillations are induced, for example by coupling it to the closed circuit of a spark transmitter. If the pivoted coil is placed parallel to the coil of one triangle and thus closely coupled to it, its coupling to the other triangle will be nominally zero; then one triangle and the vertical wire will be oscillating and the radiation will be as shown in Fig. 196. On the other hand, if the pivoted coil is coupled tightly to the other triangle the latter will come into action and the first triangle will become inoperative so that the radiation will now be at right angles to its former direction; this means that in Fig. 196 the figure 8 curve and curve B have been shifted round through 90°.

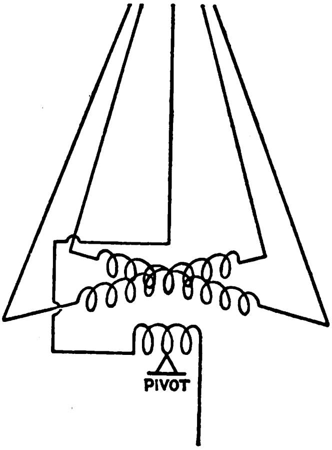


FIG. 197.

For intermediate positions of the pivoted coil both triangles will more or less come into action, and the direction of maximum radiation as shown by curve B will be coincident with the direction of the pivoted coil.

This arrangement has worked most successfully at the French coast stations of Dieppe, Havre, and Barfleur, with aerials 48 metres high and 60 metres side. Ships fitted with similar aerials for reception can take their bearings with good accuracy and so work out their positions in foggy weather when other methods are not available.

For reception the action of the Bellini-Tosi Aerial Compass may be simply described as follows:—

In Fig.198 let the two triangles, with their coils, at right angles to each other be represented by C_1 and C_2, and let the direction from which the ether waves are arriving be denoted by the arrow as shown. Then the currents induced in C_1 by the wave energy will depend upon $\cos\theta_1$, and the magnetic field set up by these currents will also vary as $\cos\theta_1$ and will act along the axis of C_1, *i.e.* along C_2. Similarly the magnetic field set up by the currents induced in C_2 will be proportional to $\cos\theta_2$ ($=\sin\theta_1$) and will be at right angles to C_2. These magnetic fields are shown in Fig. 198 (*b*) and the resultant induced field is seen to be at right angles to the direction of transmission of the waves. If the exploring coil is to embrace all this resultant field and give the strongest signals in the telephones its plane must be at right angles to the resultant field, therefore it must be lying along the direction of transmission.

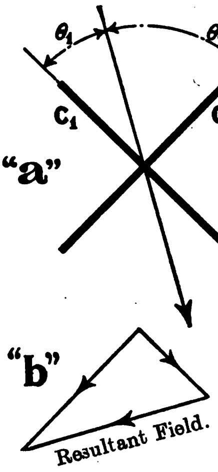


Fig. 198.

From the above it will be seen that maximum current and field is induced in one of the triangular aerial circuits when its plane coincides with the direction of transmission; in this case the plane of the other is at right angles to the direction of transmission, hence no current or field will be induced in it.

Wireless Direction Finder.—The Marconi Co. have designed an instrument for use on board ships, called the "Wireless Direction Finder," based on the Artom and Bellini-Tosi systems. The aerials are two closed triangles with their planes at right angles to each other, each being at 45° to the centre line of the ship. The two apexes of the two triangles are insulated from each other at the top, the insulators being hung from fore and aft stays to the tops of masts.

The centres of the bases of the two triangles pass through the instrument-room and the coils which form the centre of the bases are mounted in an apparatus case. These coils are fixed at right angles to each other; at the centre of each coil is a variable condenser for tuning the two triangular aerials to different wave lengths.

The two condensers are varied simultaneously by a rotation of a single handle, their connections to the coils being shown diagrammatically in Fig. 199. Inside the fixed coils is mounted on a vertical spindle the exploring coil, whose terminals are joined to a carborundum detector, potentiometer, and telephones in the usual manner. As already explained the signals will be strongest when the exploring coil is coincident in direction with that of the transmitting station, and the handle which rotates the coil is fitted with a pointer which moves over a scale, thus indicating the direction of the transmitting station.

In practice it is found that it is not possible to judge the direction of maximum strength of signals with close accuracy, and that it is easier to adjust the goniometer for minimum strength of signals; it is usual therefore to adjust for minimum signals and to make the necessary angle correction to obtain the direction of the transmitter. In this way it is possible to obtain bearings on a transmitter station within 0·5° of accuracy.

One such goniometer will give the direction of a transmitting station, but will not give its actual position; to obtain the latter it is necessary to instal two goniometer stations at a distance from each other and know the length of the base line between them. By taking simultaneous bearings on a transmitting station with the two goniometers and plotting a triangle on the given base line, and with the angles obtained at each end of the base, the apex of the triangle gives the position of the station. The results will be more accurate the longer the base line between the goniometers.

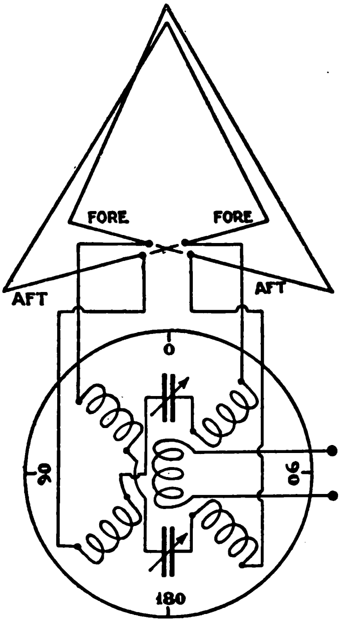


Fig. 199.

During the war goniometers were used in this way by both sides to obtain the positions of all hostile wireless stations; much valuable information was thus obtained as regards positions of headquarters of units, concentrations of infantry or artillery, etc. German Zeppelins obtained their positions continually, during a voyage at night, by transmitting to goniometer stations, who sent in the bearings to a central station where they were quickly plotted and then transmitted to the Zeppelin; each Zeppelin having a distinctive call and paying attention only to the bearings sent particularly to it from the ground station. Of course British and

French goniometer stations also received the bearing calls from the Zeppelins, and by plotting them quickly at a central office the route of flight of each Zeppelin could be followed with great accuracy. It is believed that the great disaster which befel one raid of twelve Zeppelins, when seven of them were destroyed or forced to come down over France, was partly due to a hopeless breakdown in the organisation at the German central station for goniometers, so that individual Zeppelins received wrong bearings and thus eventually became lost and utterly bewildered as to their whereabouts.

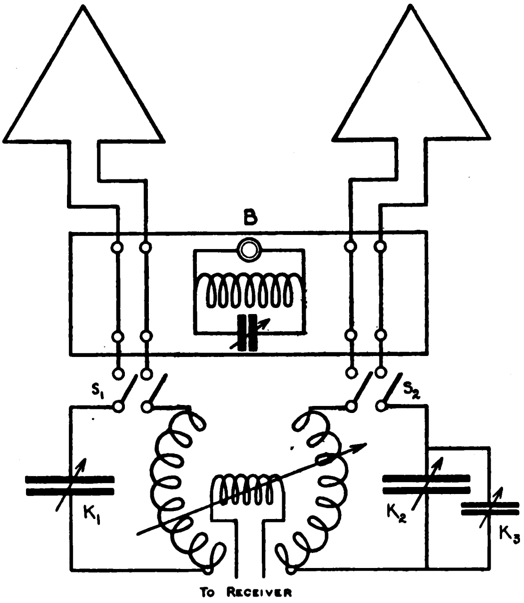


FIG. 200.

Radio-goniometers have been much elaborated by the Marconi Company, and a complete diagram of one is shown in Figs. 200 and 201. In the first place the triangular aerials must be very accurately erected as regards their bearings and fixed so that they cannot move, while precautions are taken that there will be no induction effects in guys, etc. They should be installed in an open plain if possible, to avoid distortion effects on the fronts of the arriving ether waves by trees, buildings, hills, or other semi-conductors. Surveying instruments are employed to obtain the correct alignment of the triangles, one is usually erected with its plane in the direction N.E. and S.W., the other being accurately at right angles to it. The leads from the aerials are taken horizontally and straight into a box which contains a tuning wavemeter B, from this box short thick wires lead to double pole switches and to the goniometer proper. To tune to a given wave length one of the switches, say S_2 in Fig. 200, is opened, and with S_1 closed that aerial is tuned by means of the condenser K_1; S_1 is then opened and S_2 is closed and the other side tuned by means of the condenser K_2. To get the two sides accurately in tune with each other it is usual to have a very small variable condenser K_3 in shunt with either K_1 or K_2 as shown, so that accurate adjustments can be made. The two sides are exactly balanced and in tune when, with both S_1 and S_2 closed and the wavemeter buzzing, minimum signals are obtained with the exploring coils exactly in the half-way position as regards the fixed coils. For long wave

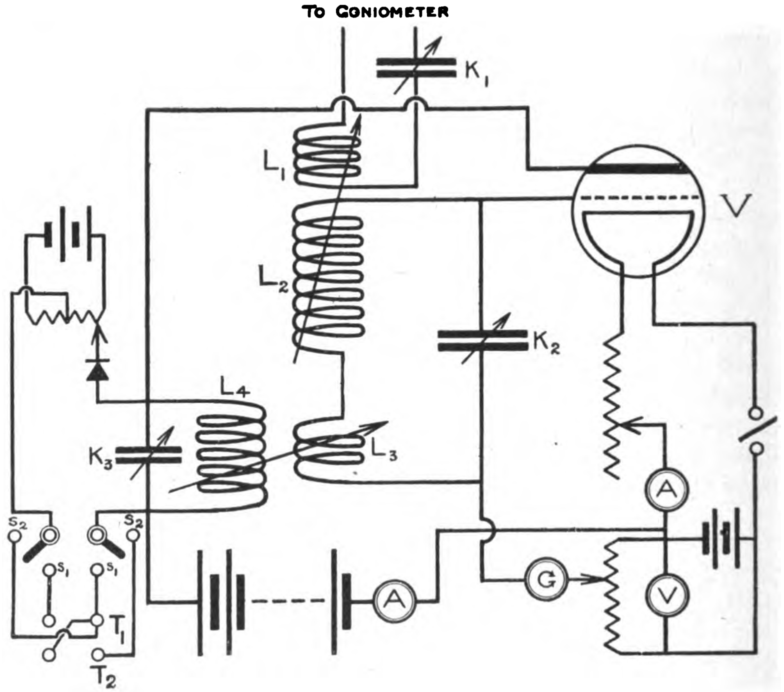


Fig. 201

work the condensers would be connected in shunt to the fixed coils and not in series as shown. By leaving one of the switches open the other triangle can be used as an ordinary loop aerial with good directional effects.

The type of receiver circuit used by the Marconi Company with Direction Finders is shown diagrammatically in Fig. 201; the leads from the exploring coil are brought to a coupling coil L_1 in series with a tuning condenser K_1 which usually consists of four Billi condensers. This couples the goniometer to an intermediate circuit consisting of a loading coil L_2, a coupling coil L_3, and four Billi condensers K_2. Coupled to the intermediate circuit is the closed circuit L_4 and a single Billi condenser K_3, across which the ordinary carborundum detector circuit is connected.

The oscillations of potential set up in the intermediate circuit are impressed on the grid filament circuit of a Round Valve V; this produces oscillations in the current of the plate circuit which includes the coil L_4 of the final circuit; thus the valve amplifies the oscillations in the final circuit and greatly increases the strength of the signals. This is an adaptation of Round's No. 16 Circuit which is fully described in Volume II., dealing with Valves and Valve Apparatus. The detector is connected to the telephones through two switches; when the switches are on the contacts S_1 two pairs of telephone receivers (high resistance) can be connected up to the four terminals in series, but when the switches are put to the contacts S_2 then only the terminals T_1 and T_2 are connected. These can be connected to a step-down telephone transformer for the purpose of using low resistance telephone receivers, or they may be connected to a valve amplifier.

Simple Direction Finders.—Where valve heterodyning reception is employed, which allows of very loose coupling between the aerial circuit and the closed circuit of a receiver, it is possible to get a good directional effect with a single triangular aerial. The top of the triangle can be slung on a swivel from a hemp rope stretched between two masts, while the bottom of the aerial is supported on a short wooden mast passing through the roof of the reception-room and standing on a ball-bearing footstep. The mast can be rotated by means of a handle and with it the triangular aerial. The mast has fixed to it a pointer passing over a compass card on a table round the mast. The whole aerial construction may be very light, the aerial being an equilateral triangle of about 30 feet sides for wave lengths up to 800 metres. For longer wave lengths two or more turns of wire may be put on the triangle.

A variable condenser is connected in series or in parallel with the aerial for tuning short or long wave lengths, and the whole coupled loosely to any valve receiver with a three-valve note amplifier behind it, as shown in Fig. 202.

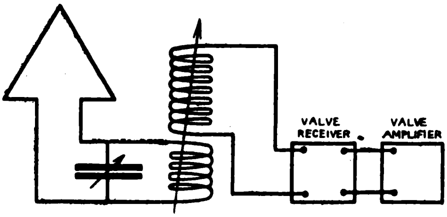


Fig. 202.

As will be described in Volume II. good directional results can be obtained with sensitive valve apparatus by using a pivoted coil inside the reception room instead of an aerial.

Fessenden's Interference Preventer. — Dr. Fessenden has designed many pieces of wireless telegraphy apparatus, his system being used by the National Electric Signalling Co., U.S.A. Many of the United States stations and ships use his patents, and a large station at Arlington, U.S.A., is equipped with his apparatus. His heterodyne detector has already been described in these pages (p. 326). Dr. Fessenden has patented an arrangement for cutting out atmospherics, or Xs, or stations interfering with the signals from the station whose message it is desired to receive. A diagram of connections is shown in Fig. 203. The aerial is joined to the primaries of two coupling coils A and B in parallel with each other, and thence to earth. The primaries and secondaries of the two couplers are alike in all respects but the secondaries are so joined that their actions oppose each other. The detector D, potentiometer P, telephones T, and secondary condenser K_s are joined up in the usual manner.

The side A is tuned to the wave length which is to be received, side B being disconnected while this tuning is carried out; side B is then switched in parallel with A and its aerial condenser varied until disturbing signals are cut out. When this takes place the currents induced in the aerial by ether waves not in tune with side A divide equally between P_A and P_B; but the secondaries being opposed to each other the detector and telephones are not affected. When waves are received to which A is tuned the current passes almost entirely through the tuned side A, therefore currents are induced in its secondary circuit and act in the detector and telephones; the coil S_B under these conditions simply acting as a portion of the wiring of the detector circuit. Atmospheric effects will divide equally between the two sides and thus their action on the telephones is greatly weakened. It can easily be realised that tuned signals would be weakened by this arrangement if the tuning of A and B did not differ by a certain minimum percentage, so that the selectivity obtainable is limited; in other words, stations differing by about 2–3 per cent. in wave length from the one in communication cannot be tuned out without weakening the signals from the station in communication.

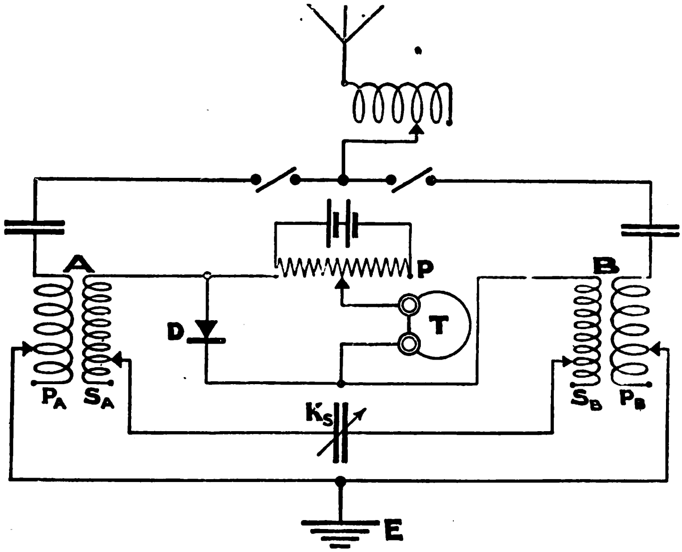


FIG. 203.

Marconi patented an interference preventer which involved the use of two aerials and a rotating machine, but it had not much commercial application. The Marconi Company relied more upon the use of an intermediate circuit for selectivity, and on the employment of two balanced detectors for cutting down interference from strays and from highly damped transmitters.

A type of interference preventer, known as a rejector, has been used with some success; as shown in Fig. 204 it consists of a variable condenser K_1 of comparatively large capacity forming a closed circuit with an inductance L_1 which consists of only one or two turns of thick copper wire. This circuit forms a shunt to the tuned portion of the aerial circuit as shown; oscillations at the frequency to which the aerial is tuned will go through the tuned aerial circuit, but strays or oscillations at a different frequency will find less impedance in the rejector circuit and so will mainly pass through it instead of through the coupling coil to the secondary circuit.

With such rejectors properly proportioned it is possible to have two receivers on the same aerial and pick up signals simultaneously on different wave lengths, each receiver being shunted with a rejector as shown above.

If a valve is generating oscillations and its circuit is coupled to an aerial circuit it will lower the resistance of the aerial to oscillations at the valve frequency, introducing what is called a negative resistance effect at this frequency. The aerial may have a high resistance in series with it and therefore a high resistance to oscillations of all frequencies except that one on which the generating valve introduces the negative or neutralising resistance. Pupin and Armstrong have patented a method of employing a valve, or valves, on these lines to cut down interference from Xs, or strays; this will be described in Volume II.

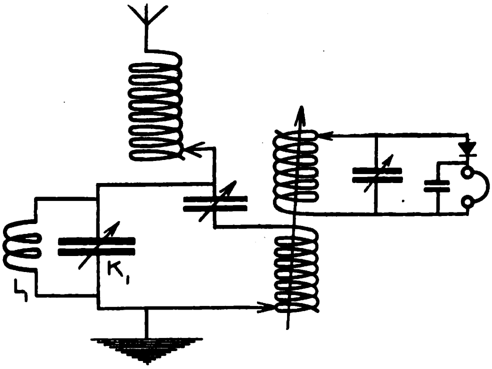


Fig. 204.

Telefunken Double Receiving Switch.—It is usual to have a pair of telephone receivers, one for each ear, mounted on a head-piece; the receivers being joined in series or in parallel according to the resistance and detector used. If it is desirable that two persons can receive the message simultaneously, one receiver can be mounted on each of two head-pieces, but of course this decreases the audibility for each person. Two complete receiver sets can be joined in series across the telephone terminals on the receiver apparatus, but this also will decrease the loudness of the signals to each listener.

The reception of two different messages simultaneously on the same aerial is a more difficult problem ; this will require that two different receiver sets should be connected to the aerial, and that the messages be transmitted at different wave lengths. Any given aerial will only receive one wave length with maximum efficiency, and the more the two received wave lengths differ from each other the less efficient is the reception of one of them. Also if two receivers are connected to the same aerial they are electrically coupled and must therefore interfere with each other to some extent.

The Telefunken Co. have designed an arrangement by means of which two different messages at different wave lengths can be received on the same aerial simultaneously, or one message received by two operators on two different receivers. A diagram of this double receiver switch is shown in Fig. 205, and its action is very simple. A tongue T is caused to vibrate very rapidly (about thirty times a second) by means of a magnet M and local battery, the tongue itself providing the intermittent contact. At the end of the tongue is an insulated spring piece joined flexibly to the aerial; as the tongue vibrates this spring piece connects the aerial to each of the two receivers alternately. The vibration is so rapid that each receiver is connected to the aerial three or four times during the reception of a dot, so that the intensity of sound in the telephones is almost as great as if one receiver alone were permanently connected to the aerial. Thus the receivers, not being electrically connected, have no interfering action on each other, and the same message is received equally well on both of them. Two different messages at different wave lengths can be received simultaneously, but of course the aerial is more efficient to one of these wave lengths than to the other.

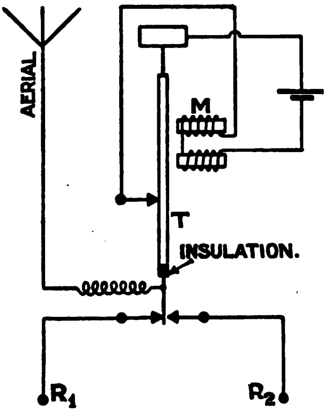


FIG. 205.

Brown Telephone Relays.—These relays have been designed by Mr. S. G. Brown, 4, Gt. Winchester Street, London, E.C., and will magnify receiver circuit currents about twenty times. That known as type " G " is designed to manipulate, with relay action, local currents of 25–35 milliamperes, while a design with a single magnet is specially suitable for small currents in radio receivers. An outline of the " G " type is shown in Fig. 206, its circuits and connections in Fig. 207.

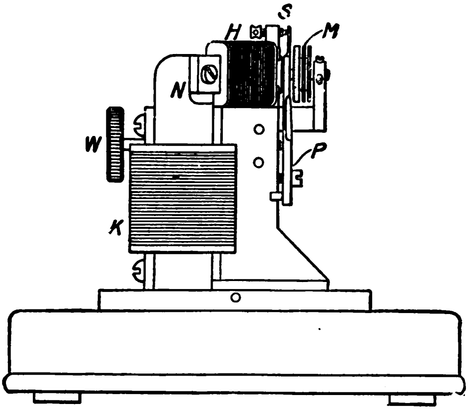


Fig. 206.

The relay consists of a permanent magnet N, with pole pieces H, the latter being wound with coils, H, through which the receiver current flows from the terminals A; a 2 mfd. condenser is connected in series with A to keep out steady currents. A steel reed, P, held by a screw, is fixed in front of the poles of the magnet; its distance from the poles being adjusted by means of the screw W. When the reed is on the point of dropping against the magnets, that is to say when its elasticity is just balanced by the magnetic pull, it is in its most sensitive position. S is a stop screw to prevent the reed

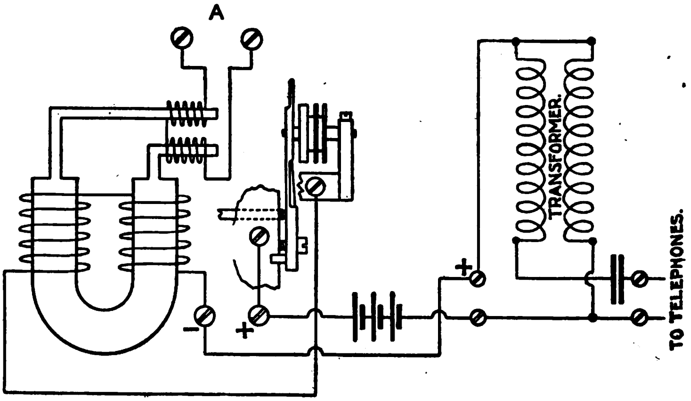


Fig. 207.

from coming into contact with the pole faces, as it would then stick to them; the reed when in use must not touch S, otherwise its oscillations would be damped.

M is a sealed microphone chamber containing two carbon-faced electrodes and nearly filled with fine carbon granules. The front of this chamber is screwed firmly into the reed, and the back is held by three grub screws in the insulated arm. The microphone is in series with a regulating winding K on the limbs of the magnet; by the telephonic reaction of this coil the magnifying power of the instrument is intensified.

The accessories to be used with the instrument are a 6-volt battery, a small transformer, a condenser of tinfoil and paper pattern, and the telephone receivers of about 120 ohms resistance.

The diagram of connections shows that the receiver currents flow through the coils H on the poles of the permanent magnet; these coils, as it were, taking the place of the coils of the telephone receivers. In this case, however, instead of a diaphragm in front of the poles we have the steel reed. The contacts in the microphone (at the back of and fixed to the reed) are joined in series with the local battery, the primary of the transformer, and the intensifying coils on the magnet. The vibrations of the reed act on the carbon granules in the microphone and cause telephonic changes of the current in the local circuit, which currents flow through the primary of the transformer. Currents are therefore induced in the secondary of the transformer, which act on the telephone receivers connected to it.

Thus very weak receiver currents cause vibrations of the reed, and through it much stronger impulses of local current are made to act on the telephones. A second relay may take the place of the telephones, that is to say two or even three relays may be joined in series, and thus the magnification of current effects greatly increased. Mr. A. Campbell Swinton, using three Brown relays in series at a demonstration before the London Radio-telegraphic Society, made the Eiffel Tower signals audible to the whole audience in a large room. By the use of Brown relays feeble receiver currents can be so magnified that the message may be printed on a tape machine or otherwise recorded.

While the type " G " relay just described is best adapted for commercial work another type " A " has been designed which will make distinctly audible signals which are quite inaudible in telephone receivers used alone. Referring to the diagram of this relay, shown in Fig. 208, the reed P is set as closely to the magnet HK as possible, if necessary thin tissue paper being used to ensure that they are slightly separated. Screwed to the reed is a flat contact O of carbon, highly polished, while carried on the hinged arm L is the top contact consisting of a blunt point of iridium screwed into the coarse adjusting screw J. The contact pieces are opened to an infinitesimal amount to form the microphone by means of a fine adjusting screw W, also by the action of the local current which passes through the contacts and the self-regulating winding K. The local current thus assists to form the microphone and steady the adjustment, its amount being regulated by the fine adjusting screw worked from the mill head W.

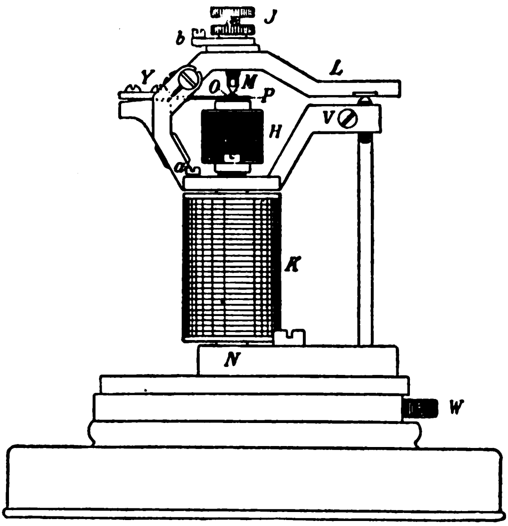


Fig. 208.

The auxiliary apparatus and the connections of this relay are similar to those required for the type "G," a blocking condenser with variable capacity from 0·0025 to 0·01 mfd. being joined across winding H, (terminals A), $1\frac{1}{2}$ volts being used in the local circuit; a milliammeter is also used in the circuit so that the relay may be adjusted until the local circuit current is from 8 to 12 milliamperes; then the relay should be in its most sensitive condition. The telephone receivers are of 120 ohms resistance.

A third type of relay (type "W") has been designed which is the most sensitive of all, and can be used for recording; it, however, requires more attention than the "G" or "A" types, and has to be very carefully protected from vibration. Indeed with all the relays vibration effects must be avoided otherwise it will be impossible to adjust them to their most sensitive condition.

Since the development of valve amplifiers microphonic relays have been largely discarded as signal intensifiers, but it is quite possible that the principle of their action may find some other useful application in wireless circuits.

Einthoven String Galvanometer.—The range of a given size of radio transmitter has been greatly increased since the time when coherer detectors were used in conjunction with a Morse tape machine or siphon recorder. This increase of range is partly due to the development of very sensitive detectors and telephones, operating on infinitesimal currents, but it is clear that when these are used the speed and accuracy of reception is dependent on the skill of the operator. Much time is often wasted in the repetition of messages or phrases not properly understood at the receiving end; also fast transmitting is not feasible with code or cipher messages. Therefore an early demand arose for some method of automatic reception which could be used with the most sensitive detectors; a demand which brought about the development of the Brown telephone relay and the Telefunken sound intensifier, with either of which the received currents were made to control local currents in such a way that a siphon recorder can be used. It would be more desirable, however, to have an instrument which could simply take the place of the telephones, or of both detector and telephones; an ordinary sensitive mirror galvanometer will not do because its moment of inertia would prevent it from responding to the rapid pulsations of current set up in the receiver circuits. An instrument suitable for the purpose must be so delicate as to give a clear deflection, or reading, on currents of one microampere or less; its moving part must have negligible moment of inertia, and the part of the instrument through which the current flows should have negligible self-induction and capacity. It should be absolutely aperiodic in its moving system so that it will respond clearly to each impulse of a rapid pulsating current.

So far the only instrument designed to meet the above conditions, and give satisfactory results when directly working on receiver currents, is the Einthoven galvanometer. It is employed by the Marconi Co. in their transatlantic stations, the messages being automatically recorded on a photographic strip with a clearness and definition at high speeds which fulfils all requirements. This galvanometer was designed by Prof. Einthoven of Leyden, and is made by the Cambridge Scientific Instrument Co., England, to whom the author is indebted for the illustrations and particulars herewith given.

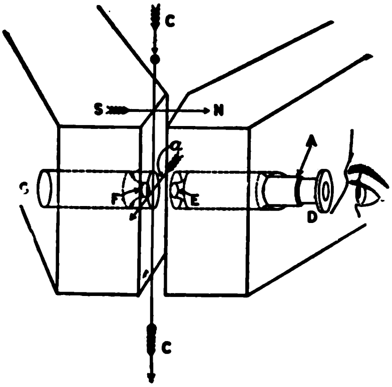


FIG. 209.

A diagram of the instrument is shown in Fig. 209; it consists of a very powerful electromagnet with poles (N) and (S) separated only by a very narrow gap. In this gap is fixed the string CC through which the detector current passes. This string, therefore, takes the place of the coils on the telephone receivers, or of an ordinary galvanometer. When a current passes through it the string is deflected across the field in the direction shown by the arrow. The small movement of the string can be observed by means of a microscope A, passing through a circular aperture bored in the poles. For wireless telegraphy purposes, a beam of light is passed through the hole from an arc lamp or lantern, so that the string stretches across the beam. Its motion, or instantaneous position, can then be photographed by making a photographic film pass in front of the aperture from which the beam emerges at the other side of the magnet. A view of the Einthoven galvanometer is given in Fig. 210.

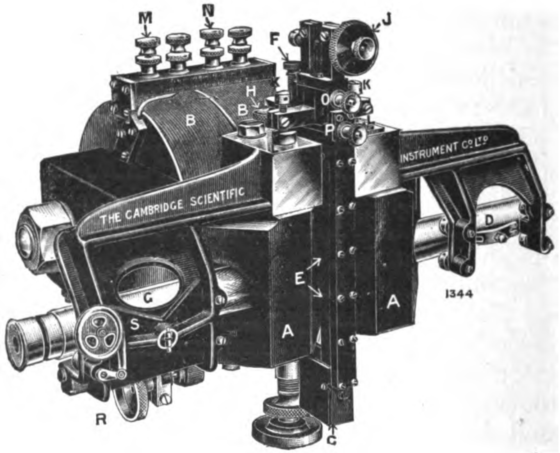


FIG. 210.

In the most sensitive designs the string is made of a fibre of quartz or glass on which is put a light coating of silver; the periodic time of vibration of the string depends on its tension, which can be adjusted by means of a micrometer screw, and, with glass or quartz fibres, can be varied between the aperiodic state and $\frac{1}{300}$ second. The resistance of these fibres is from 2000 to 10,000 ohms. A less sensitive design is fitted with silver or aluminium wire strings; these have a resistance of 6 or 8 ohms and have a longer periodic time, hence they are not so suitable for work with rapid current pulsations.

As seen through the microscope a quartz fibre instrument gives a deflection of 6 mms. with one microampere, so that if a lantern and photographic films are used the instrument is readable with still smaller currents. Unfortunately the Einthoven galvanometer is rather too delicate for ordinary commercial usage; it is also expensive, a complete outfit costing about £100. Its great field of usefulness will probably be in the accurate measurements of receiver currents, and research work on atmospherics, daylight effects, or other phenomena of like nature. Many of the instruments are at present employed for these purposes.

Telefunken Sound Intensifier.—This is an instrument which was developed some years ago by the Telefunken Co. The theory of its action is very similar to that of the Brown relay already described; it is, however, much more elaborate in construction and requires more delicate adjustment. It consists practically of three tuned microphonic circuits in cascade as shown in the diagram of connections in Fig. 211.

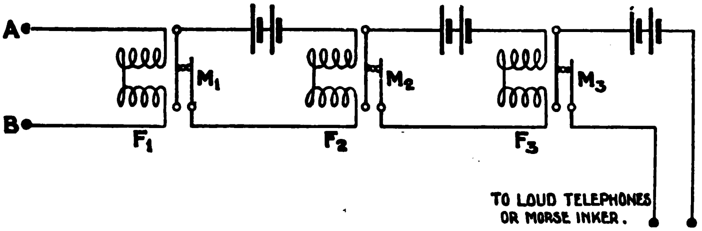


FIG. 211.

The terminals, AB, are connected to the receiver circuit, so that the currents rectified by a detector flow into the high resistance windings of an electromagnet, F, instead of through the coils of the usual high resistance telephone receivers. In front of this magnet is a small armature which has the same vibration frequency as the sounds to be magnified, and the vibrations of the armature are communicated to a small microphonic contact, M_1. It will be seen that the magnet and armature correspond respectively to the coils and diaphragm of a telephone receiver. The microphonic contact, M_1, interrupts a local current flowing from a battery to a second electromagnet, F_2, so that larger current pulsations are set up in F_2 than those in F_1. The currents in F_2 act on a tuned armature and contact, M_2, and the action is repeated through a third set.

Thus the receiver currents can be made to cause large impulses of local currents, and the last of these acts on a loud speaking telephone or on a Morse inker outfit. Since the armatures respond best to currents whose frequency is equal to their own vibration frequency this instrument can be used to give good selectivity and cut out stations not in tune; two intensifiers can be used simultaneously on the same aerial to receive messages if the notes differ in pitch by 20 per cent. or over.

The instrument must not be subjected to vibration, therefore in mounting it for use elaborate precautions are taken; on board ship it is suspended from a well-sprung and damped universal joint.

Hot-wire Ammeter.—This is the only type of instrument suitable for use in the aerial circuit to measure the effective value of the currents oscillating in the aerial. The construction of an ordinary form of hot-wire ammeter is shown in Fig. 212, from which it can be seen that most of the current to be measured flows through a manganin shunt, S, and a small definite fraction of the current flows through the fine platinum silver wire W. The current flowing through this wire heats it slightly so that it increases a little in length and sags. Attached to the hot wire is a phosphor bronze wire, B, whose other extremity is fixed; attached to the phosphor bronze wire is a single fibre of silk, which passes round a small ivory or brass pulley and has its other end fixed to a steel spring X. The pulley is mounted on a spindle pivoted in jewelled screws: the spindle also carrying the index pointer and a light sheet of aluminium, A.

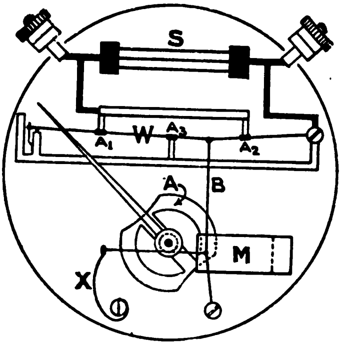


FIG. 212.

The action of the instrument is very simple: when current flows through the wire W it sags slightly, the sag is taken up by the phosphor bronze wire which in its turn sags, lessening the pull on the silk fibre attached to it so that the latter is pulled a little to the left by the steel spring. As the silk fibre moves to the left it causes a slight turning movement on the little pulley, and the spindle in turning carries the index across the scale of the instrument.

The heating effect, the sag, and, therefore, the turning movement, are directly proportional to the square of the current; hence the movement of the pointer across the scale is proportional to the square of the current, and thus the scale can be calibrated to read amperes. The heating effect is independent of the direction of the current through the wire so that the instrument can be used on direct current or current alternating at low frequency. It is seen that magnetic effects or electrostatic effects do not disturb, or enter into, the working of the instrument. As the pointer moves across the scale the aluminium disc moves between the poles of a strong permanent magnet M; this causes eddy currents to be produced in the disc which have a braking effect on any movement, and prevent any unnecessary vibratory motion of the moving system; thus the pointer when deflected remains steady and the reading can be taken accurately.

The type of hot-wire ammeter described is suitable for alternating current measurements if the frequency is not too high, but with high frequency currents, such as obtain in the aerial circuits of wireless transmitters, some modification of the design is necessary to obtain accuracy. For currents above 5 amperes the hot wire would be subdivided into two or three portions in parallel with the shunt, current being led into it as shown at A_1, A_2, and A_3; on high frequency currents this would cause the instrument to read too low.

It is better, then, to have no shunt, and instead of a hot wire, have a number of extremely thin (0·01 mm.) platinum-iridium strips, arranged in parallel; the whole of the current to be measured dividing evenly through the strips, which are carried on a heavy block of metal to absorb the heat and prevent the temperature from rising above a fixed maximum value.

Fig. 213 shows such an instrument made by the Union Electric Co., Ltd., in which the parallel strips can be seen, also the arrangement of permanent magnet and aluminium damper. The pointer can be adjusted to zero by a screw, accessible from the outside of the case, and the working parts of the instrument are mounted on a marble base.

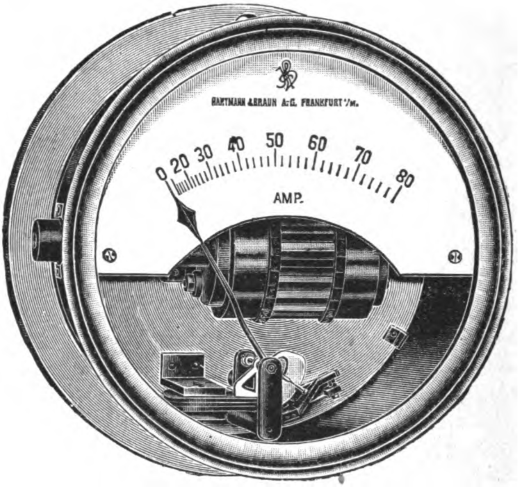


FIG. 213.

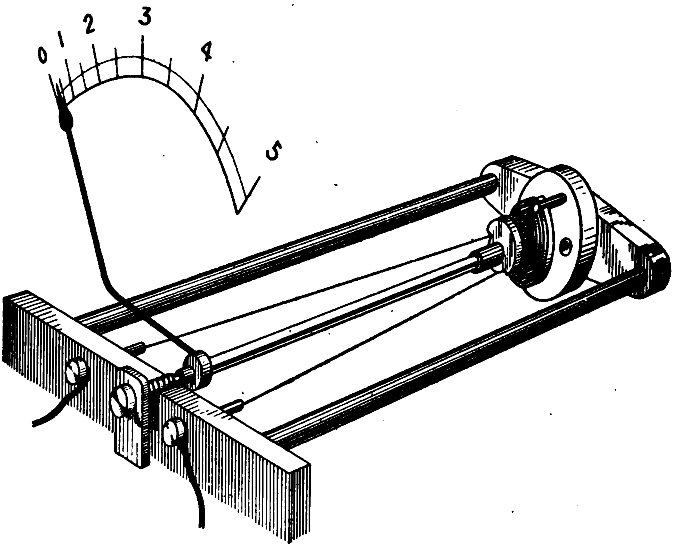


FIG. 214.

A type of hot-wire ammeter patented by the Marconi Co. is shown in the diagram of Fig. 214, and requires little explanation:

The hot wire is stretched round an angular cam on a glass spindle supported in jewelled centres; the rotation of this spindle being controlled by a helical spring at the back. When the current heats the wire its elongation allows the spring to rotate the spindle and the pointer moves across the scale. With this design it is possible to have a more uniform scale than with the ordinary type of hot-wire instruments. The ammeter construction is simple and it is very suitable for use in aerial circuits.

Moving Coil Ammeters and Voltmeters.—For wireless receiver circuits, especially those fitted with valves and potentiometers, miniature instruments such as those made by the Weston Electrical Instrument Company are very suitable. The Weston instruments are dead beat and are fitted with light tubular metal pointers the weight of which is under 0·26 gramme (4 grains). The light weight and low moment of inertia of the moving parts of the Weston instrument make it suitable for use in any position subject to vibration. They can be obtained with two scale ranges, or as combined Volt-Ammeters, and are fitted with a press button switch. This type of instrument is shown in Fig. 215; it has been much used by the Marconi Co. in their valve receiver apparatus.

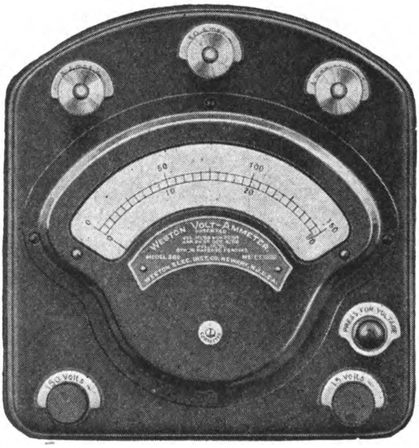


FIG. 215.—Weston Double-range Volt-Ammeter.

CHAPTER XXII

SOME MEASUREMENTS IN RADIO-TELEGRAPHY

In this Chapter a description will be given of some of the more important tests and measurements which can be made on transmitter and receiver circuits or apparatus; it will not include measurements involving the use of valve apparatus, as these will be dealt with in Volume II., nor will it include methods involving the use of expensive laboratory instruments.

The testing of insulation, resistance, voltage drop, broken circuits, etc., is fully described in electrical text-books, and therefore will not be dealt with in this Treatise.

Wavemeters.—Most of the important tests of wireless apparatus require the use of a wavemeter; this consists of a closed oscillatory circuit made up in a small and portable form, and arranged so that it can be used either as a transmitter or as a receiver of ether wave effects.

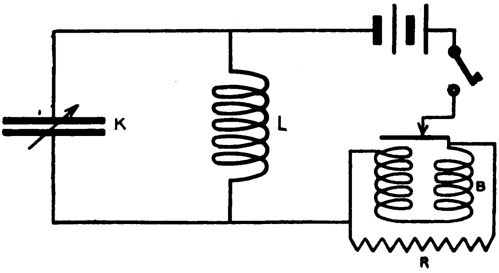


Fig. 216.

It will be remembered that if L and K are the inductance and capacity respectively of a wave generating circuit, of low resistance, the wave length of the ether strain disturbance set up is $59{\cdot}6\sqrt{LK}$, or approximately $60\sqrt{LK}$; also if a receiver circuit is tuned sharply to respond to ether waves its electrical periodicity will be equal to that of the waves, and therefore the wave length is determined by the values of L and K in the receiver circuit.

Suppose a closed oscillating circuit to be made up with a variable condenser K and an inductance coil L as in Fig. 216, and that across the coil a battery of two dry cells, a key, and small buzzer interrupter are connected as shown in the Figure. When the key is pressed current flows through the coil L, building up in it a magnetic field; when the interrupter breaks the circuit this magnetic field in collapsing induces a high voltage which charges up the condenser, and the condenser then gives a discharge which oscillates in the circuit KL with a frequency determined by the values of K and L. The ether around is strained and the wave length of the strain effect is $59{\cdot}6\sqrt{LK}$.

The action of the interrupter or buzzer is to make and break the current so that the oscillations are set up in trains as long as the key is closed.

Shunted Buzzer.—Referring to Fig. 216 when the interrupter breaks the circuit there will be induced in the buzzer coils B a large E.M.F. of induction, which will tend to make the current spark across the interrupter. Thus the break at the interrupter would not be complete; the energy stored up in the coil L will flow round this way rather than through the condenser, so that the oscillations are damped out. To avoid this the coils of the buzzer are shunted by a resistance, R, through which the self-induced voltage in B at the break will send a current rather than across the interrupter; there will now be no sparking at the interrupter, and the only circuit through which the energy induced in L can discharge itself is through the condenser K. This method of preventing sparking at the buzzer interrupter contacts is better for the present purposes than the usual one of connecting a small condenser across the make and break; if such a condenser were used it would provide a path for some of the energy stored up in the coil L. It must be carefully noted that the shunt resistance is across the buzzer coils and not across the make and break; for the usual size of buzzer the resistance of the shunt is from 10 to 14 ohms.

It will be seen that the shunt R is a path for battery current when the key is closed, hence if it has a low resistance it may take so much current that the buzzer will not act unless the battery voltage is increased; on the other hand if the resistance of R is too high the object for which it is connected across the buzzer coils will not be attained. The resistance shunt generally consists of a small bobbin of silk-covered German silver or platinoid wire, mounted on the base of the buzzer. A suitable buzzer is very easily made, in fact if nothing else is available the coil wound cores and trembler armature of an electric bell will serve, but such a buzzer will only give a low harsh note. Figs. 217 and 218 show two methods of making buzzers; in Fig. 217 a core of soft iron is wound with silk-covered No. 20 S.W.G. copper wire and mounted on an iron frame; a thin sheet of steel is fixed in front of one end of the core by screws on a bent up portion of the iron frame. A small platinum contact is riveted into this steel reed armature and a similar contact is mounted on the end of an adjustable screw carried on a brass supporting pillar. In Fig. 218 the armature is a thin steel piano wire attached at one end to a piece of clock spring and at the other end to a tension adjusting screw. The steel wire is about 2 inches long and has a small platinum or silver contact folded on it to make contact with the adjusting screw. This buzzer will give a very high note, the pitch of which can be adjusted by means of the tension screw.

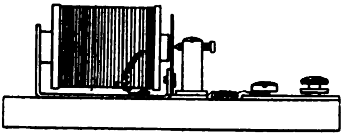


Fig. 217.

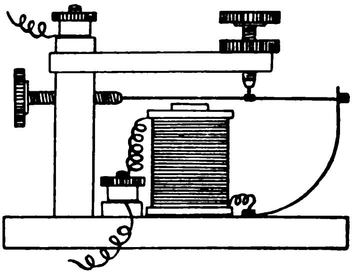


Fig. 218.

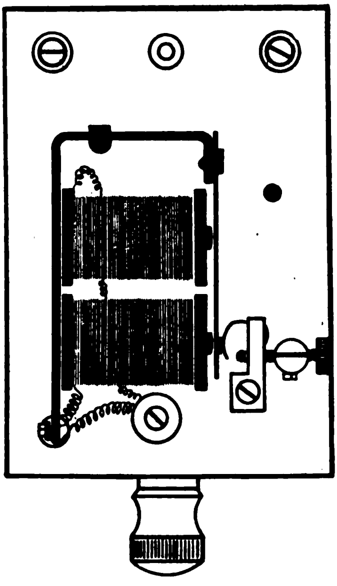


Fig. 219.

Buzzers are very troublesome when the contacts stick and give only intermittent buzzing; this trouble is greatly minimised by using contacts similar to those on buzzers designed by the Telefunken Co. and illustrated in Fig. 219. The adjustable screw carries a comparatively heavy metal counterpoise to which is attached, by means of a small screw, a fine silver or platinum wire making contact with the platinum contact on the thin steel armature. This buzzer is fitted with a small resistance coil shunted across the magnetic coils and has a high note which is very distinctive. Even if a wavemeter is not available the adjustment of detectors and the sensitiveness of receiver apparatus can always be tested by means of a buzzer; it may also be employed to set up weak oscillations in a transmitter aerial circuit, in order to determine the wave length of the latter by means of a reception wavemeter placed near it.

Marconi Wavemeter.—A portable wavemeter is of simple construction and not difficult to use; one of the Marconi wavemeters consists of a square wooden frame 5″ × 5″ × 0·7″, wound with 25 turns of No. 24 silk covered wire, the coil having an inductance (L) = 0·175 mhy. approx. This coil is shunted across a variable condenser of the moving vane type with ebonite dielectric, whose capacity has a maximum value of about 0·011 mfd. The condenser is about 2″ deep and 4″ diameter, and has graduations on the ebonite top; a brass pillar carries an index finger which indicates the value of capacity in use as the vanes are rotated. Across the terminals of the condenser is joined a carborundum crystal detector in series with a pair of telephone receivers; the crystal being simply held between two spring brass fingers. The whole apparatus is mounted in a box 9″ × 6″ × 4½″ deep. The connections are shown in Fig 220 (*a*); the coil is in two sections so that either the whole or only a part of the inductance can be used. When the whole coil is used with the maximum value of the capacity the wavemeter will have a certain maximum wave length and a certain range, but, since wave length depends on $\sqrt{L}$, we see that *if ¼ of the coil is used the range of the meter will be ½ of its first range,* hence the Marconi meter has two plug contacts to the coil, which gives two ranges.

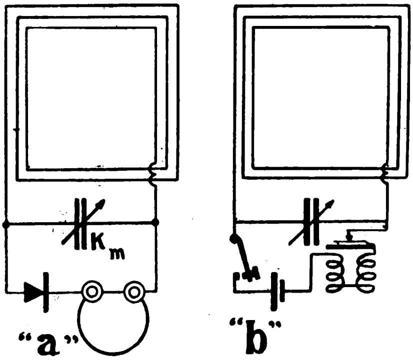


FIG. 220.

When arranged as shown in Fig. 220 (*a*), the wavemeter acts as a receiver; as thus arranged it will respond to and measure the wave length of a transmitting circuit near which it is held.

If the detector and telephones are replaced respectively by a cell and small buzzer as shown in Fig. 220 (*b*), the meter will then act as an oscillator or transmitter; this can be held near a receiver circuit so that the wave length of the latter may be obtained by noting the value of the wavemeter circuit when tuned to it.

Since wave length $= 59{\cdot}6\sqrt{\text{LK}}$ if L is kept constant, $59{\cdot}6\sqrt{\text{L}}$ is a constant for the instrument. Thus if $\text{L} = 175{,}000$ cms.

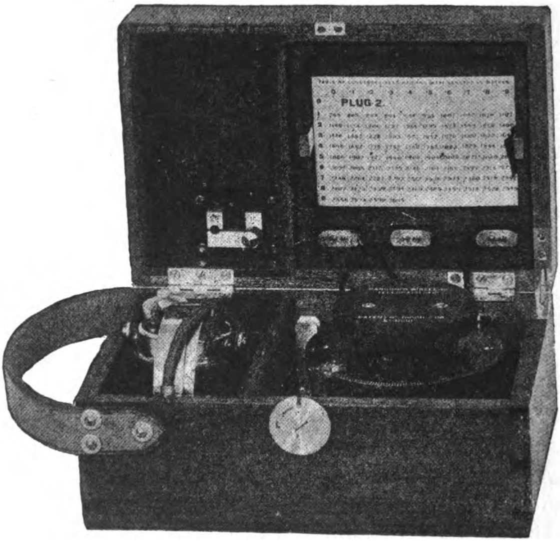


FIG. 221.

$59{\cdot}6\sqrt{\text{L}} = 24{,}900$ approx., therefore wave length $= 24{,}900\sqrt{\text{K}}$ metres, so that each value of capacity of the meter condenser corresponds to a certain wave length. Therefore the graduations of the condenser could be marked directly in wave length values, but it is more usual to number the divisions 1, 2, 3, etc., and obtain the corresponding wave lengths from a card or curve. The range of the meter might be varied by changing the inductance coil, having a set of coils for the purpose and a card of wave length values for each coil. This wavemeter is shown in Fig. 221; the coil and plug contacts are seen in the lid.

The wavemeter used by the Telefunken Co. is shown in Fig. 222 and a diagram of the connections in Fig. 223. The variable capacity K is connected to an inductance L_1 in the case of the instrument, this inductance consisting of four coils of fine enamelled wire, and connected to a switch whose handle is seen on the near side of the case, by means of which one or more of the coils can be joined in series with the condenser. This closed circuit is inductively coupled to the circuit whose wave length is to be measured by means of the circuit consisting of the two coils L_2 and L_3, connected in series by long insulated and leather-covered leads. These are flat coils embedded in ebonite; L_2 slides into grooves at the side of the instrument and is coupled to L_1, while L_3 is held near the circuit under test. A helium tube H glows when the circuits are in resonance, and if L_2 is loosely coupled to L_1 a sharp indication will be obtained. A buzzer, mounted on the top of this wavemeter, is seen in the top right-hand corner; with

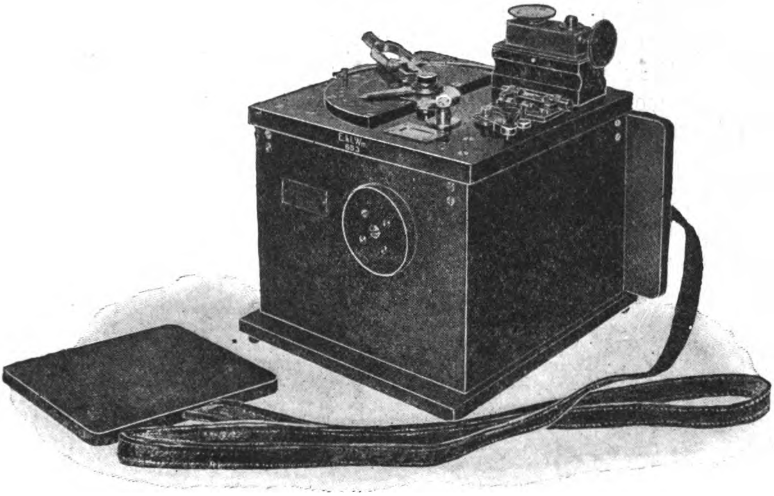


FIG. 222.

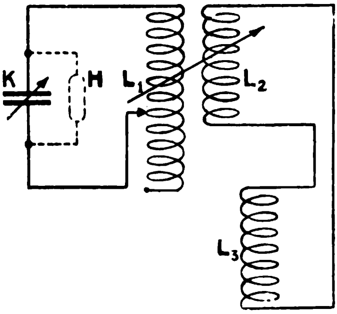


FIG. 223.

this buzzer the meter can be used for such measurements as wave length of receiver circuits, sensitiveness of detectors, coupling, and pitch of note. These tests will be described later.

The Telefunken Co. also make a more elaborate instrument, as shown in Fig. 224; the black disc, mounted on a flexible support seen on the right, is a flat spiral inductance coil encased in ebonite, and connected by flexible leather-covered leads to the variable condenser. Six such coils of different inductances are supplied with each instrument; some of these are seen in the foreground of the picture.

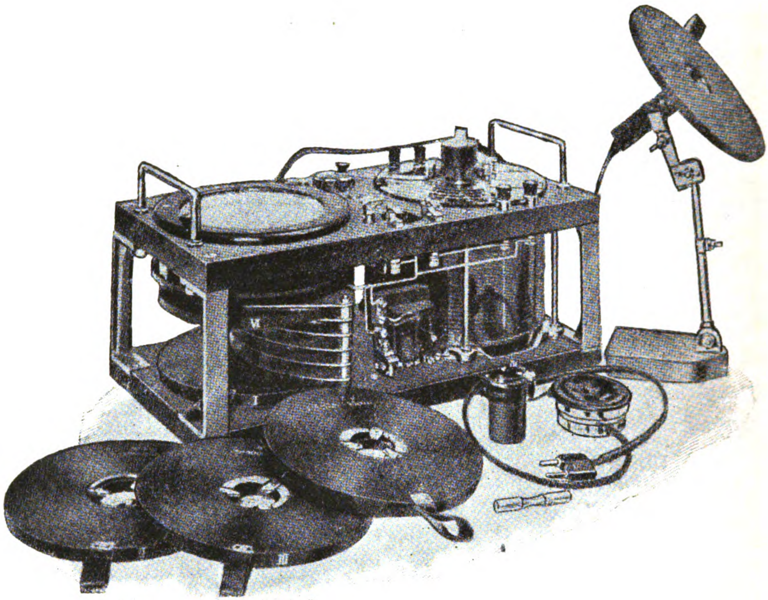


FIG. 224.

The diagram of connections is as shown in Fig. 225, in which it is seen that resonance is obtained by changing the capacity until a maximum reading occurs on the hot-wire ammeter A, which is connected as a shunt to a part of the inductance.

Instead of the hot-wire ammeter a helium tube H can be used to note the point of resonance, or through the point 4 of the switch K a detector D and telephones G can be used. S is a micrometer spark gap to protect the condenser which it shunts.

When the switch K is on point 2 a buzzer B is connected to a battery to supply intermittent currents to the condenser circuit, and when the switch is on point 3 it can be used as an ordinary tapping key to send Morse signals, using the buzzer and battery. Thus the wavemeter can be used for other auxiliary purposes, such as those already referred to in connection with the simpler instrument.

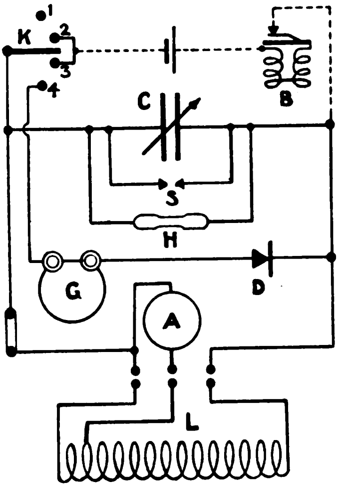


Fig. 225.

It will be seen that a wavemeter is very easy to construct, in its simplest form consisting only of a fixed coil, a variable condenser, a detector and telephone receivers; all who work at radio-telegraphy should try to possess one, as the experiments which can be carried out with it are both interesting and instructive, while its use will lead to a very clear knowledge of the actions taking place in transmitter and receiver circuits.

If the wave length range of a wavemeter is obtained by means of a variable condenser the latter should be very rigidly constructed for portability, otherwise its capacity values will vary and the wavemeter will require constant re-calibration. Good reliable condensers are expensive but only good ones can be relied upon; rather than use a cheap condenser it is better to obtain the variation of wave length by means of a variometer change of inductance. A variometer can be designed to be very constant under conditions of portability, and it is comparatively inexpensive. Fig. 226 shows the diagram of a wavemeter made by Messrs. Muirhead and Co., London, under patent, and to the design of Prof. J. S. Townsend.

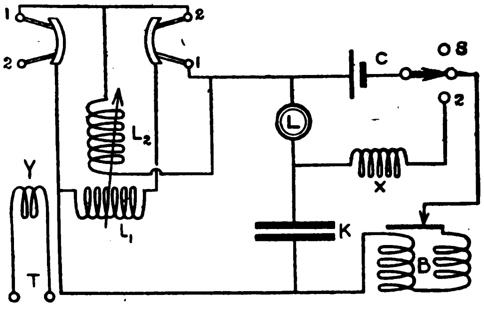


Fig. 226.

The coils L_1 and L_2 form a variometer, L_2 being capable of rotation through 180° inside the frame of L_1. When the two-way switch is placed in the position 1 the coils are in parallel for short wave length range; when the switch is in position 2 the coils are in series for long wave length range. For use as a transmitter a buzzer B is connected through a switch S and dry cell C across the variometer; for use as a receiver a small 2 volt electric lamp L is connected in series with a small condenser K across the variometer. The lamp will be most sensitive if its filament is already heated, and for reception the switch is put on the contact 2 so that the dry cell C heats the filament to a dull red, through the choke coil X which prevents the high frequency oscillations from getting through the lighting circuit.

To use the wavemeter as a generator of weak oscillations, for testing receiver circuits, the buzzer is switched on and the wavemeter, placed near the receiver, is employed in the usual manner. To use it as a receiver the lamp filament is heated and the wavemeter placed near the transmitter circuit to be tested; when the meter is adjusted to be in tune with the latter the lamp filament will brighten up considerably and the tuning adjustment will be found to be quite sharp. If the oscillating currents in the transmitter aerial circuit under test are very weak the earth should be disconnected, and the small coupling coil Y of three or four turns, mounted in the wavemeter, should be included in the aerial circuit by connecting the aerial and earth to the terminals T.

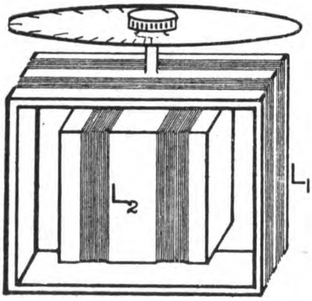


FIG. 227.

For a wavemeter giving a range of wave lengths from 750 to 3000 metres the coil L_1 could be wound with about 48 turns of No. 20 S.W.G. enamelled copper wire, on a rectangular frame 3″ × 3¾″ × 1¾″ wide, and the coil L_2 with 60 turns of No. 20 on an inner pivoted frame 2¼″ × 2¾″ × 1¾″ wide. The arrangement of the coils is shown diagrammatically in Fig. 227. Instead of the small lamp a small neon or vacuum tube may be employed, in which case the cell B would only be required in the buzzer circuit.

A more sensitive arrangement would be to have a small micro-ammeter or galvanometer in series with a crystal detector.

It may be noted that this design of wavemeter eliminates the expense of telephone receivers as well as that of a good variable condenser.

Measurement of Capacity.—The capacity of a circuit has very different values for steady and for high frequency currents, therefore capacity measurements on wireless apparatus should always be carried out with oscillating currents. Thus one size of Moscicki condenser has a capacity of 0·00354 mfd. when measured with steady current, but its capacity is only 0·00272 mfd. when measured with an alternating current whose frequency is 175,000 cycles per second. (N. W. M'Lachlan, at British Association, Sept. 1916.) There may be occasions in which it is desired to know the capacity of a condenser or circuit for steady currents, and two simple steady current methods are given below in (1) and (2):—

(1) This method is simple but not very accurate, and requires the use of a mirror ballistic galvanometer. A ballistic galvanometer is one whose moving system is comparatively heavy, *i.e.* it has a comparatively large moment of inertia, so that when a transient current is discharged through its coil the moving system does not start to move until the discharge is complete; the resulting deflection is then proportional to the full discharge.

A standard condenser is first charged by connecting it to a standard cell, such as Clarke's cell, whose E.M.F. is accurately known. The charge $Q = KV$ microcoulombs if K is in microfarads and V in volts. By means of a two-way switch the condenser is then discharged through the galvanometer and the deflection (d_1) noted. The discharge which will give unit deflection is therefore $\frac{KV}{d_1}$ microcoulombs; this is known as the constant of the galvanometer.

Now connect the unknown capacity (K_x) to a known E.M.F., which will have to be fairly high if the unknown capacity is small in order to have a readable deflection on the galvanometer when the condenser is discharged through it. The E.M.F. of charge should be measured with an accurate voltmeter. Discharge the condenser through the galvanometer as before and note the deflection (d_2). The discharge $(Q) = K_x V_2$; it is also equal to $d_2 \times$ microcoulombs to give unit deflection—

$$\therefore K_x V_2 = d_2 \times \frac{KV}{d_1} \quad \therefore K_x = \frac{d_2 V}{d_1 V_2} K \text{ microfarads.}$$

Note that if the same E.M.F. is used to charge both the standard and the unknown condenser—

$$K_x = \frac{d_2}{d_1}\frac{V_1}{V_1}K = \frac{d_2}{d_1}K \quad \text{or} \quad \frac{K^x}{K} = \frac{d_2}{d_1}$$

Thus the calculations are simplified, and indeed the experiment made more accurate, if a standard condenser of small capacity is available, so that the same E.M.F. may be used to charge both the known and the unknown capacity. Therefore it is advisable to make a standard small capacity with air dielectric, the plates being exactly parallel and as symmetrical as possible, so that the capacity can be accurately calculated from the formula—

$$K = \frac{A \text{ sq. cms.}}{4\pi t_{\text{cms.}} \times 900{,}000} \text{ mfds.}$$

The standard capacity may be made with stiff brass or aluminium sheets, square or circular, and separated by thin small washers of ebonite, mica, or glass, the washers being all of exactly the same thickness. Leads should be soldered to the plates and to terminals mounted on a mahogany or other hard wood case which encloses the condenser. Three or four such condensers, ranging from 0·001 to 0·005 microfarad should, if possible, be kept for testing purposes.

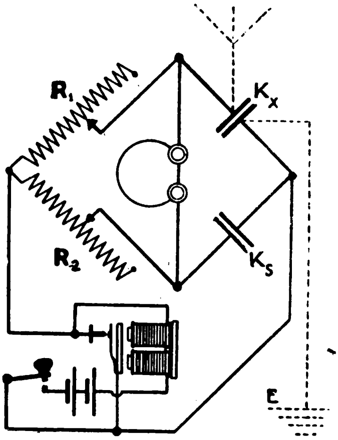


Fig. 228.

(2) The capacity of a condenser can be measured by a bridge method which is a modification of De Sauty's method. The condenser of unknown capacity, a standard condenser (K_s) of approximately similar capacity, and two *non-inductive* resistance boxes are joined as shown in Fig. 228; an arrangement which is similar to the usual Wheatstone bridge connections for measuring resistance. A telephone receiver is used instead of a galvanometer, and a buzzer worked by a battery and key is connected to the other two corners of the bridge. The resistances, R_1 and R_2, are variable by means of

plugs of contacts, and their values are changed until the least sound is heard in the telephone receiver.

Then— $$\frac{K_x}{K_s} = \frac{R_1}{R_2} \quad \text{or } K_x = K_s \times \frac{R_1}{R_2}$$

The connecting wires should be short and the contacts good so that the resistance of these is negligible. If the condensers have different dielectrics it will be impossible to balance so as to get complete silence in the telephone, owing to the fact that their dielectric hysteresis effects are unequal, but it should be possible to get a result correct to within a very small percentage. The buzzer should be a high note one, requiring small battery power to work it. The capacity of an aerial circuit may be measured by this method, replacing the condenser K_x by the aerial and earth wires as shown dotted in Fig. 228.

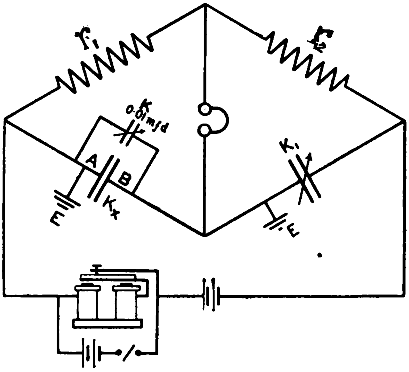


FIG. 228A.

(3) Wien has given another method which can be conveniently used for the measurement of aerial capacity; a diagram of the connections is given in Fig. 228A. If an aerial capacity K_x is to be measured, K_1 is connected up to the bridge and one terminal earthed as shown; the earth terminal of the aerial is connected up to the bridge at A leaving the remainder of the aerial free.

K_1 is set to some suitable value K_a and a balance for silence in the telephones is obtained by adjusting r_1, r_2, and K. The remaining terminal of the aerial, or unknown capacity K_x, is now connected up at B and a new balance obtained by changing K_1 from K_a to K_b.

Then the unknown capacity $K_x = (K_b - K_a)\frac{r_2}{r_1}$

This method eliminates any error which would be introduced by earth capacity effects.

(4) When a standard condenser of known capacity is available, an unknown condenser of the same order of capacity may be determined by means of a wavemeter.

Make up an oscillating circuit with the standard condenser (K_s) and an inductance coil, connecting across it a buzzer circuit as in Fig. 229. Place this near a wavemeter fitted with a detector and telephone receivers; press the key and tune in the wavemeter; let the wave length be λ_1. Now replace the standard condenser with the unknown capacity by means of the throw over switch and tune in the wavemeter again to the new wave length λ_2.

$$\text{Then} \quad \frac{\lambda_2}{\lambda_1} = \frac{59{\cdot}6\sqrt{L_x K_x}}{59{\cdot}6\sqrt{L_x K_s}} \quad \text{or } K_x = \left(\frac{\lambda_2}{\lambda_1}\right)^2 \times K_s$$

(5) When a coil of known inductance (L cms.) and an accurate wavemeter are available, an oscillating circuit can be made up with the coil and the unknown condenser (K_x) as in Fig. 229, and

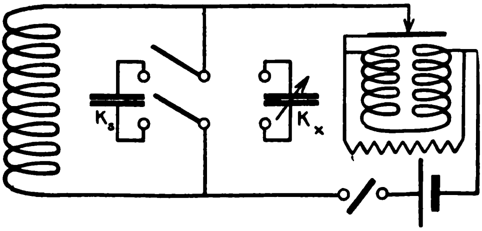


Fig. 229.

the wavemeter tuned to be in resonance with this circuit. Suppose the wave length is λ, then $K_x = \dfrac{\lambda^2}{(59{\cdot}6)^2 L}$ mfds.

In carrying out these experiments with small condensers the connecting wires should be as short as possible, and substitution should be made by means of a two-way throw-over switch as shown in Fig. 229. The wavemeter may be used as a transmitter, and a detector and telephones connected across the oscillating circuit under test.

Measurement of Inductances.—(1) One of the best laboratory methods of measuring the inductances of coils is that known as Anderson's method with modifications introduced by Prof. Fleming.

The coil, whose coefficient of self-induction is to be measured, is first balanced in a Wheatstone bridge box, so that its resistance for steady currents is obtained in the ordinary way—see Fig. 230 (*a*). In obtaining this balance the precaution should be taken to close the battery key before the galvanometer key, otherwise a kick of the galvanometer will take place when the battery key is closed, this kick being caused by inductive action in the coil.

When the galvanometer shows no deflection

$$\frac{\text{res. of coil}}{\text{res. S}} = \frac{\text{res. P}}{\text{res. Q}}$$

When balance has been obtained, modify the circuit as shown in Fig. 230 (*b*), *i.e.* replace the galvanometer by a telephone receiver, and join in series with it an adjustable resistance (r), which should be a plug-box resistance, or at least one which is non-inductive. Join a standard condenser (say $\frac{1}{3}$ microfarad) as shown: most laboratories will contain such a standard, or, if not, a standard can be made with metal plates and ebonite dielectric as already described. Join an ordinary buzzer in series with the battery, and with some resistance in r, note the sound heard in the telephone when its key is closed. It may be necessary to increase the battery volts for this part of the experiment, but not more than 4 or 5 volts should be used owing to the small sizes of wires in the resistance boxes.

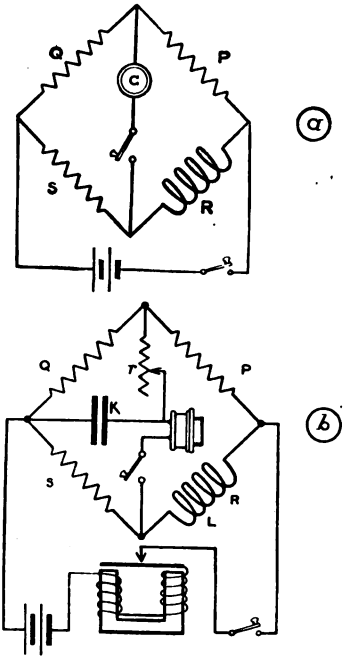


FIG. 230.

Now adjust the resistance r until the least sound is heard in the telephone—this will easily be discernible, and it is not necessary that there should be no sound; when the least sound is obtained the bridge is then balanced for inductive currents, and the self-induction coefficient is calculated from the formula—

$$L = K_{\text{mfds.}}\{r(R + S) + QR\} \text{ microhenrys.}$$

This method can be used both for the inductances of sending coils and receiving coils; the proof of the formula is rather complicated and need not be given here. The student should check his results by calculating the inductance of the coil, using a suitable formula based on the dimensions and shape of the coil, as already given in Chapter VII.

(2) Connect the coil to a standard known capacity and oscillate this circuit by means of a buzzer, key, and battery as shown in Fig. 229. With the detector and telephones on the wavemeter place it near the circuit and tune in, noting the wave length (λ).

$$\text{Then} \qquad \lambda = 59{\cdot}6\sqrt{L_x K_s} \quad \text{or } L_x = \frac{\lambda^2}{(59{\cdot}6)^2 K_s} \text{ cms.}$$

Check the result by connecting a detector and telephones across the oscillatory circuit, and buzzing the wavemeter.

(3) If a standard capacity is not available, but a coil of known inductance is at hand, the unknown inductance can be found by a substitutional method similar to that described for measuring an unknown capacity. Make up an oscillating circuit with any condenser and (1) the known inductance, (2) the unknown inductance; find the wave length of the circuit in each case by means of a wavemeter, then :—

$$\frac{\lambda_1}{\lambda_2} = \frac{59{\cdot}6\sqrt{L_s K}}{59{\cdot}6\sqrt{L_x K}} = \frac{\sqrt{L_s}}{\sqrt{L_x}} \quad \text{or } L_x = \left(\frac{\lambda_2}{\lambda_1}\right)^2 L_s \text{ cms.}$$

(4) A very good method of measuring an inductance is that due to D. Owen; it has the advantages that there is no frequency term in the balance, so that any form of buzzer can be employed, and that any size of inductance can be measured provided there is sufficient known resistance available.

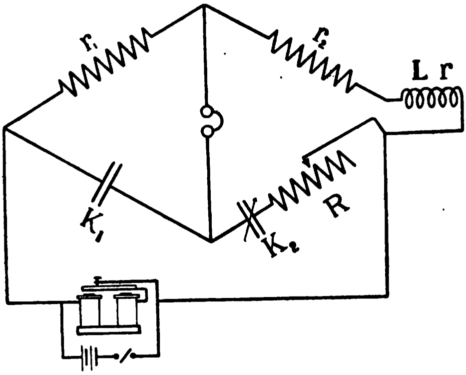


FIG. 230A.

The circuit is made up as shown in Fig. 230A; the unknown inductance L, of resistance r, is connected in series with r_2 in one arm of the bridge, whilst an adjustable resistance box R is connected in series with a variable condenser K_2 to form another arm. The best ratio of r_1 to r_2 will depend on the value of L.

To make the measurement the buzzer is switched on and K_2 roughly adjusted to give minimum sound in the telephones. Then the value of R is adjusted whilst K_2 is slightly varied, until values of R and K_2 are found to give zero or the minimum of sound in the telephones.

Under these conditions :—

$$K_1r_1 = K_2(r_2 + r)$$

and

$$L = K_1r_1R = K_2(r_2 + r)R$$

Determination of Aerials.—It is very important that the resistance and capacity of an aerial should be known, also its natural wave length when unloaded, for the efficiency of transmission and reception greatly depends on the comparison between these values and the corresponding ones for the whole aerial circuit. Apart from its importance the determination of an aerial provides an interesting and instructive exercise for the student, and leads to a very clear conception of proper aerial design and location.

As a first approximation the natural wave length of an aerial should always be roughly calculated ; thus if it is an L or T type aerial its fundamental wave length is about 4·8 times its actual length. Then if the aerial is tuned by a coil in series the length of the wire in the coil should be measured or calculated, and the fundamental wave length of the tuned aerial roughly calculated by taking four times the total length of the wire in the aerial and coil. These results will be useful for checking calculations made on results obtained by experiment, and they will prevent the possibility of arriving at very wrong conclusions.

Aerial Wave Length.—The natural wave length of an aerial can be obtained by connecting it directly to earth and loosely coupling to it an ordinary buzzer circuit. It may be necessary to include in the aerial a couple of small turns of wire to hold near the buzzer for coupling effect, but if these are small they will not introduce any great error. The wave length is measured by holding a wavemeter, fitted for reception, close enough to the aerial to just give sufficient strength of signals for accurate adjustment of the wavemeter.

An experimental method of determining aerials is shown in Fig. 231 ; an artificial aerial is made up with a variable condenser (K), inductance (L), and resistance (R), and connected to one side of a throw-over switch, the aerial circuit being connected to the other side of the switch.

To the middle of the switch is connected a coil C loosely coupled to a buzzing wavemeter W; C may have in series with it a loading coil L_1 if the wave length of the wavemeter is long compared with that of the aerial, otherwise L_1 may be shorted or discarded. A detector and telephones are connected across the coupling coil. The method simply consists in first tuning the aerial circuit, with C and L_1 in series, to the wavemeter wave length and noting the strength of signals in the telephones, then switching over to the artificial aerial and adjusting K, L, and R until the same strength of signals is obtained. The values of K, L, and R will then give respectively the equivalent capacity, inductance, and resistance of the aerial on that wave length.

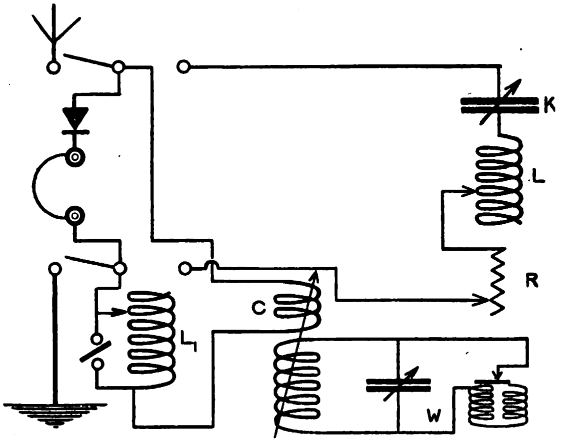


Fig. 231.

Equivalent Inductance of an Aerial.—If L_0 is the equivalent inductance at zero frequency and L_1 the inductance at any wave length λ_1, then $L_1 = \dfrac{L_0(1 - \cos\left(\frac{\pi\lambda}{2\lambda_1}\right)}{\frac{\pi\lambda}{2\lambda_1}}$, where λ is the fundamental wave length of the unloaded aerial.

The following two methods, due to Dr. W. Eccles, may be employed for obtaining L_0:—

(*a*) Connect an inductance at the bottom of the aerial and adjust it until the wave length λ_1 is $1{\cdot}84\lambda$, where λ is the wave length of the unloaded aerial. Then the inductance of the coil L is equal to L_0. For this experiment a variometer is very useful.

(*b*) Tune the aerial to a wave length λ_1 by means of an inductance coil at the bottom of the aerial, exciting the aerial by means of a buzzer, and using a wavemeter to get the resulting wave lengths. Measure also the wave length λ of the unloaded aerial, and the inductance, L, of the coil.

When the loading inductance is fairly large compared with the inductance of the aerial the following equation is approximately true :—

$$\lambda_1 = \frac{\pi}{2} \times \left(\frac{6L + L_0}{6L}\right)\sqrt{\frac{L}{L_0}} \times \lambda$$
$$= \frac{\pi}{2}\sqrt{\frac{L}{L_0}} \times \lambda$$

Equivalent Capacity of an Aerial.—1. If K_0 is the equivalent capacity at zero frequency then its capacity at any wave length λ_1 is given by $K_1 = K_0 \frac{\sin\left(\frac{\pi\lambda}{2\lambda_1}\right)}{\frac{\pi\lambda}{2\lambda_1}}$, where λ is the fundamental wave length of the unloaded aerial. The sines and cosines of angles will be found in Appendix III.

Dr. W. Eccles gives the following three methods of determining K_0 in his "Handbook of Wireless Telegraphy and Telephony," p. 121 :—

(*a*) Connect a condenser (K) whose capacity is much greater than K_0 in series at the bottom of the aerial, excite oscillations in the latter by a buzzer and measure the wave length λ_1; also measure the wave length λ of the unloaded aerial; then $K_0 = \frac{2{\cdot}5K(\lambda - \lambda_1)}{\lambda}$.

(*b*) Insert a variable condenser at the bottom of the aerial and adjust until $\lambda_1 = 0{\cdot}774\lambda$; then $K_0 = K$.

(*c*) Tune the aerial to several wave lengths shorter than λ, by means of a variable condenser connected in series just above the earth connection, and note the values of λ_1 corresponding to the values K of the condenser. If K is greater than K_0 the following formula is approximately true :—

$$\lambda_1 = \lambda \times \frac{10K - 4K_0}{10K}$$

therefore
$$K_0 = \frac{5K(\lambda - \lambda_1)}{2\lambda}$$

2. A simple method involving the use of an oscillating valve for determining approximately the capacity of an aerial at any wave length may be given here :—

(*a*) Connect an accurate variable condenser in series with a hot-wire ammeter across the coil in the plate circuit of an oscillating valve, and note the current in the ammeter.

(*b*) Connect the aerial and earth in parallel with, or to the terminals of, the condenser and reduce the condenser until the current is the same value as before. Since the capacity of the aerial and earth is in parallel with the variable condenser the reduction of the latter gives approximately the capacity of the aerial circuit at the wave length on which the experiment was carried out.

3. Measure the fundamental wave length (λ_0) of the aerial with a shunted buzzer and wavemeter, then connect a condenser of known capacity K in series with the aerial near the earth connection and measure the new wave length λ. Thus obtain $\frac{\pi}{2} \times \frac{\lambda_0}{\lambda}$, call this an angle ϕ in radians and obtain $\tan\phi$ from Tables; $\frac{K_0}{K} = -\frac{\tan\phi}{\phi}$ and the capacity of the aerial $K_0 = -K\frac{\tan\phi}{\phi}$.

To Measure or Adjust the Wave Length of the Transmitter Closed Circuit.—Remove the connections of aerial and earth and remove the jigger secondary as far as possible from its primary; send oscillating discharges through the closed circuit in the usual manner and hold a wavemeter near enough to be loosely coupled to the circuit. The wavemeter being switched over to reception tune it in until it receives maximum strength of signals. For adjustment to a given wave length set the wavemeter at that wave length and listen in its telephones; vary the adjustments of the transmitter closed circuit until signals are a maximum on the wavemeter. The more loosely the wavemeter is coupled to the circuit under test the less will its inductive action interfere with the frequency of the circuit under test.

To Measure or Adjust the Wave Length of the Aerial Circuit.—Remove the secondary of the jigger as far as possible from the primary and excite oscillations in the aerial circuit by connecting one or two turns of the aerial inductance in the circuit of a shunted buzzer as shown in Fig. 232. With the wavemeter adjusted for reception hold it near enough to the aerial circuit to receive signals and adjust wavemeter for sharpest tuning. If it is desired to tune the aerial circuit to a given wave length set the wavemeter at that wave length, and vary the tuning adjustments of the aerial circuit until signals are of maximum intensity in the wavemeter.

Oscillations may be excited in a Marconi aerial circuit fitted with an earth arrester by connecting the two sides of the earth arrester across the make and break of a fairly strong buzzer, but this is liable to give only flat tuning.

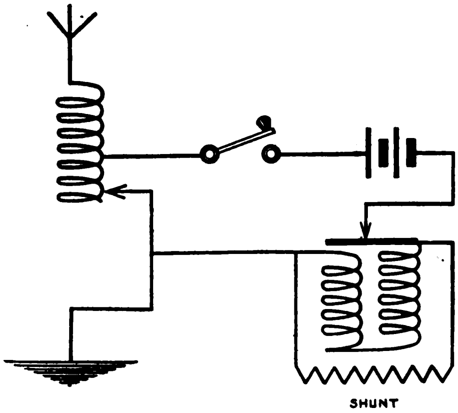


FIG. 232.

To Measure Degree of Coupling of a Transmitter.—Tune the closed and aerial circuits of a transmitter independently and as accurately as possible to a given wave length (λ); then couple them by means of the jigger in the usual manner, starting with fairly tight coupling. With the wavemeter adjusted for reception hold it at a distance from the aerial circuit such that signals are just received when the transmitter key is pressed, and tune it in for best strength of signals. It will be found that a maximum of signal strength will be given on two different adjustments λ_1 and λ_2 on the wavemeter, neither of these being the wave length (λ) to which the circuits are tuned, and one will be a stronger maximum than the other. Then degree of coupling—

$$K_k = \frac{\lambda_2 - \lambda_1 \times 100 \text{ per cent.}}{\lambda} \text{ approx.}$$

The experiment should be repeated for different degrees of coupling, and the coupling adjustments of the transmitter thus calibrated. Radiation on two wave lengths with coupling not loose is best observed with a valve wavemeter.

To Find the Wave Length of a Distant Transmitting Station.—Tune the receiver until the signals from the distant station are of maximum strength in the telephones. Place a buzzing wavemeter near the receiver and adjust wavemeter until its signals are heard best in the receiver circuit; the wavemeter is then adjusted to the same wave length as the distant station.

The wavemeter may show two wave lengths to which the receiver responds, either of which may be the wave length of the distant station. To find which is the correct one reduce the inductance of the receiver aerial circuit, and if the distant station cannot now be heard the longest wave length value is the correct one.

To Obtain the Resonance Curves of Receiving Circuits.—The receiver circuits are first coupled fairly closely and the telephone receivers shunted by an adjustable graduated resistance, such as a slider potentiometer wire, as shown in Fig. 233. A buzzing wavemeter is placed near the receiver so that the latter will receive fairly strong signals from it.

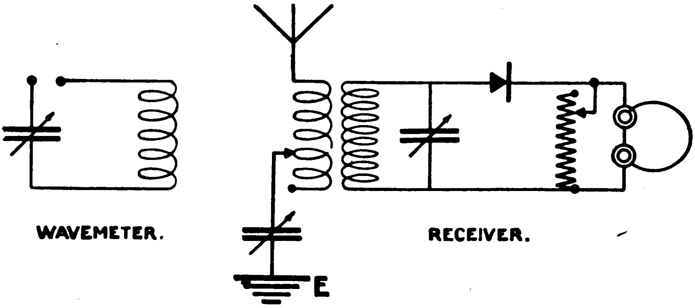


Fig. 233.

(*a*) The receiver is first tuned to any given wave length by means of the wavemeter with the full shunt resistance across the receiver telephones. The shunt resistance is now reduced until the signals are just audible, and the value of the resistance now in use is noted.

(*b*) The wavemeter is next adjusted to a lower wave length and the shunt resistance on the telephone receivers again adjusted so that signals are just heard. The tuning adjustments of the receiver are not varied during the experiment.

(*c*) The wavemeter is adjusted to a higher wave length and the shunt resistance is adjusted as before to give just audible signals.

(*d*) The experiment is repeated for adjustments of the wavemeter to various wave lengths, increasing and decreasing, the limit being reached in either case when no signals are heard even with full value of shunt resistance.

The telephone current at each adjustment is inversely proportional to the shunt resistance and a curve should now be drawn connecting wave lengths and inverse value of shunt resistance; this curve will show how the intensity of the telephone currents varies with the wave length, *i.e.* it shows how a receiver with any given tuning and coupling responds to energy received on different wave lengths. The experiment should be repeated with different degrees of coupling of the receiver circuits, and the curves will be as shown in Fig. 234, where curve A is the result of tight coupling and curve B that given by looser coupling. Instead of the shunted telephones a thermo-galvanometer or thermo-ammeter may be used if available, in which case the detector currents are read off directly on the instrument.

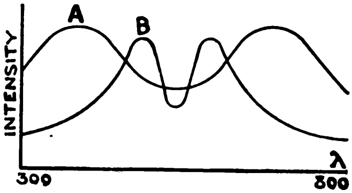


FIG. 234.

To Obtain the Characteristic Curve of a Crystal Detector.—For this experiment a sliding potentiometer of 200–400 ohms is required; the slider should be graduated and the wire connected through a reversing switch to a battery of one or two dry cells.

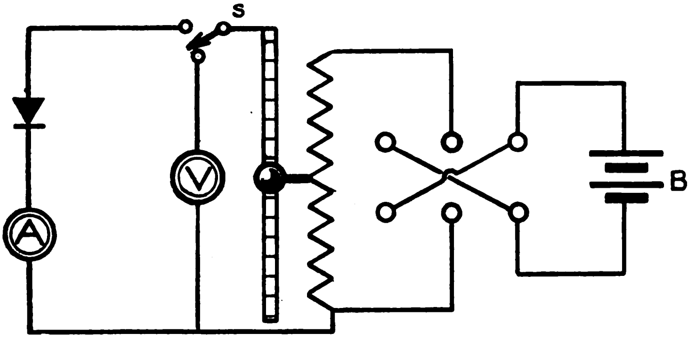


FIG. 235.

The connections are shown in Fig. 235. B is a battery of 2 or

3 dry cells, V a high resistance voltmeter connected through switch S, and A is a micro-ammeter or sensitive galvanometer.

For a carborundum detector B should be about 3 or 4 volts and A is a micro-ammeter; for a perikon detector B need not be more than 2 volts and A is preferably a sensitive galvanometer. Set potentiometer voltage to some value measured by closing switch S to the voltmeter, then switch on to the detector circuit and read the current in A. Repeat this for various values of voltage applied and plot a curve connecting voltage applied with detector current or galvanometer deflection; reverse the battery and repeat the experiment for current through the detector in the opposite direction.

Carborundum crystals can be quickly compared in this way, mounting them for test between two metal clips as in a Marconi wavemeter; the steeper the curve rising from the sensitive point at the bend the better is the rectifying properties of the crystal.

Simple Test of Circuits for Continuity.—Wireless circuits, especially receiver circuits, have to be frequently tested for continuity when it is suspected that a break has occurred for example in a tuning coil, reactance coil, or telephone transformer winding. A very delicate and portable tester can be made by connecting a dry cell in series with one ear-piece of a fairly high resistance telephone receiver. Hold the receiver to the ear and connect the circuit across the coil or other apparatus under test. If there is no broken circuit a click will be heard in the receiver when it is connected or disconnected; if there is a break in the circuit no click will be heard. This tester is very portable and as sensitive as any galvanometer method; if the ear-piece is of high resistance there is no danger of sending excessive testing currents through fine wire coils, such as the windings on telephone or intervalve transformers.

Audibility of Signals.—The strengths of signals may be compared by connecting an adjustable non-inductive shunt across the telephone receivers, and adjusting the value of the shunt until signals are just audible. If C is the value of the current pulses in the telephones when unshunted and R_t the effective telephone resistance at the pulse frequency, C_1 the telephone current which will give just audible signals and R_s the corresponding resistance of the shunt, then—

$$\frac{C}{C_1} = \frac{R_t + R_s}{R_s}$$

and this ratio is called the audibility of the signals. If a thermo-ammeter or thermo-galvanometer is available it would be used instead of the shunted telephones and the currents under different conditions read directly off the instrument.

This method may be employed for comparing the sensitiveness of detectors or of telephone receivers.

Measurement of Damping Decrement.—In a wireless transmitter we have two circuits; each has its own decrement of damping, and the damping decrement of the radiated waves is different from both the component decrements. In general, when two circuits are coupled, waves are radiated at two wave lengths, which differ according to the degree of coupling, and it can be proved that the train of shortest wave length is the most damped. We have seen that in practice the coefficient of coupling is chosen so that the two wave lengths very approximately coincide.

Now, according to Wien, if the decrements of the closed and open circuits are δ_1 and δ_2 respectively, and k is the coefficient of coupling, the decrements of the two radiated wave lengths are—

$$D_1 = \frac{\delta_1 + \delta_2}{2\sqrt{1-k}} \text{ and } D_2 = \frac{\delta_1 + \delta_2}{2\sqrt{1+k}}$$

Thus, suppose the closed circuit has a decrement of 0·18 and the aerial circuit a decrement of 0·05, while the coefficient of coupling is 20 per cent. or 0·2; then

$$D_1 = \frac{0{\cdot}18 + 0{\cdot}05}{2\sqrt{1 - 0{\cdot}2}} = \frac{0{\cdot}23}{1{\cdot}78} = 0{\cdot}13$$

$$D_2 = \frac{0{\cdot}18 + 0{\cdot}05}{2\sqrt{1 + 0{\cdot}2}} = \frac{0{\cdot}23}{2{\cdot}2} = 0{\cdot}105$$

The longest wave has the smallest decrement; the smaller the coupling the more nearly do the wave decrements and wave lengths coincide to one value in each case.

It will be seen from the above that, to obtain the damping decrement of any train of waves, it is necessary to find the coefficient of coupling, and the sum of the decrements of the closed and aerial circuits. The coupling coefficient can be found by means of a wavemeter, using the method already described; it therefore remains to find some method for determining $(\delta_1 + \delta_2)$.

Unfortunately this is difficult to obtain accurately with ordinary sparking systems, because the frequency is never quite constant, and the decrements do not exactly follow a logarithmic law. With arc or other undamped oscillators $\delta_1 = 0$, and the determination of radiation decrement can be made with some accuracy in such a case. Damping decrement can be determined with sufficient accuracy for practical purposes by the following method :—

Obtain a resonance curve of the circuit, in other words find the strength of the currents received in a wavemeter on various wave lengths. These will be proportional to the ether energy carried at the various wave lengths : if the circuits of the transmitter are well tuned and loosely coupled the curve of energy will be a sharp peaked one, as described in the chapter on Coupled Circuits.

To find the resonance curve a special form of wavemeter is used ; in this the telephone receivers and detector are connected across the inductance by a sliding contact, as shown in Fig. 236. When such a circuit is inductively coupled to a transmitter circuit, and tuned to it, oscillating currents will flow through the wavemeter circuit ; as they flow through the turns of the induction coil they will cause a difference of potential to be set up across them. This difference of potential will send currents through the detector and telephones, and sounds will be heard in the latter. The less current oscillating in the wavemeter coil the less is the potential induced in each turn, therefore more turns must be joined across the telephone circuit to give a certain strength of sound. *In other words, for a certain strength of sound in the telephones the strength of the currents in the wavemeter are inversely proportional to the number of turns of the coil used across the telephones*, or $C \sim \frac{1}{n}$.

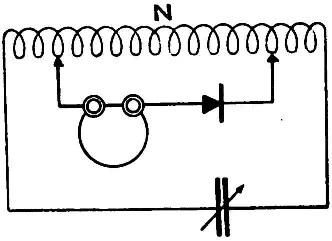


FIG. 236.

The strength of sound usually adopted is that which can be just heard. The experiment is carried out as follows :—

(*a*) Tune wavemeter to the transmitting circuit and adjust the slider on the coil until the sound is just heard in the telephones ; let the number of turns tapped be n_1, then current strength in wavemeter $\sim \frac{1}{n_1}$. Also wave length $= 59{\cdot}6\sqrt{LK}$, but L is a constant, $\therefore \lambda \sim \sqrt{K}$.

(*b*) Decrease K a little, and adjust slider again to just get a sound in the telephones—it will require more turns now, since the wavemeter is slightly out of tune and hence the oscillating currents in it are decreased; note n_2 and K_2.

(*c*) Repeat for different values of K above and below sharp tuning value. The currents in the meter are proportional to $\frac{1}{n_1}$, $\frac{1}{n_2}$, $\frac{1}{n_3}$, etc., and are set up by tuning to wave lengths which are proportional to $\sqrt{K_1}$, $\sqrt{K_2}$, $\sqrt{K_3}$, etc.; hence if we plot a curve having $\sqrt{K_1}$, $\sqrt{K_2}$, etc., as abscissæ and $\frac{1}{n}$, $\frac{1}{n_2}$, etc., as ordinates, it will be of the same shape as the currents set up in the meter plotted against wave lengths, therefore it shows relatively the amounts of energy in the ether at different wave lengths. We shall see presently that it is not necessary to plot the actual values of the receiver (*i.e.* wavemeter) currents, nor of the wave lengths. The curve when plotted is as shown in Fig. 237.

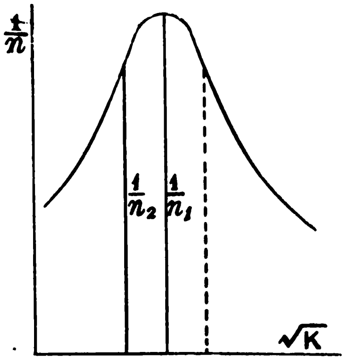


FIG. 237.

Now V. Bjerknes has proved that if D_1 is the transmitter decrement, and d_m the wavemeter decrement, and if C_1 is the resonating current in the wavemeter when in tune at λ_1, and C_2 the current in the wavemeter when it is a small percentage out of tune, then—

$$D_1 + d_m = \pi\left(1 - \frac{\lambda_1}{\lambda_2}\right)\frac{1}{\sqrt{\left(\frac{C_1}{C_2}\right)^2 - 1}}$$

Since the wavemeter decrement can be made very small we may in such case neglect it, so that we may say—

$$D_1 = \pi\left(1 - \frac{\lambda_1}{\lambda_2}\right)\frac{1}{\sqrt{\left(\frac{C_1}{C_2}\right)^2 - 1}}$$

But $$\frac{\lambda_1}{\lambda_2}=\frac{\sqrt{K_1}}{\sqrt{K_2}}=\sqrt{\frac{K_1}{K_2}}, \text{ and } \frac{C_1}{C_2}=\frac{\frac{1}{n_1}}{\frac{1}{n_2}}=\frac{n_2}{n_1}$$

therefore $$D_1=\pi\left(1-\sqrt{\frac{K_1}{K_2}}\right)\frac{1}{\sqrt{\left(\frac{n_2}{n_1}\right)^2-1}}$$

From the curve two readings are taken, corresponding to values of $\sqrt{K}$ and $\frac{1}{n}$ which are respectively a little above and a little below the values of accurate tuning; the difference of wave lengths corresponding to these values should not be more than about 4%. From the values of $\sqrt{K}$ and $\frac{1}{n}$ thus chosen an average value of D_1 is obtained which is approximately accurate for the wave length of resonance.

The instrument has been called up to the present a wavemeter and could be used as such, but since this special design is suitable for measuring decrements it may be called a "decremeter."

Instead of the telephone and detector some special form of high frequency galvanometer, such as a thermo-galvanometer, might be used; in general it is not so sensitive as the telephone and detector arrangement, and the decremeter would have to be held close to the oscillating transmitter to obtain suitable readings. In the above formula it is seen that we require only ratios of currents and ratios of wave lengths, also it is not necessary to know the actual currents and wave lengths, since the ratios are equal to $\frac{n_2}{n_1}$ and $\sqrt{\frac{K_1}{K_2}}$ respectively.

Marconi Decremeter.—This instrument, as its name implies, is used for measuring the decrement of damping in an oscillating circuit. At the same time it is constructed so that it can be used as a wavemeter; also for the determination of capacities, self-induction coefficients, mutual induction, and degree of coupling. It is, in fact, a combination of wavemeter and decremeter, with special terminals for inserting inductances and capacities when it is desired to measure them. The connections as a decremeter are shown in Fig. 238.

To use the instrument :—(*a*) Turn the switches over to side A, and tune the meter by means of the condenser as accurately as possible; do not touch the condenser afterwards. (*b*) Turn the switch to side T; this cuts out small inductance coil L_2, which changes the wave length of the meter 4 per cent.; the telephones are now across 32 turns of the main coil, and the meter is put in such a position that weak signals are heard in it. (*c*) Turn switch over to A again; the meter is again in tune and the slider is varied until the signals in the telephones are of same strength as in (*b*). Let the number of turns now tapped by the slider be *n*, then, neglecting decrement of the meter—

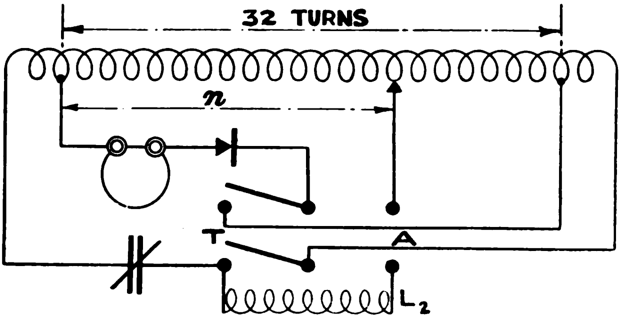


FIG. 238.

$$D = \pi\left(1 - \frac{\lambda_1}{\lambda_2}\right)\frac{1}{\sqrt{\left(\frac{32}{n}\right)^2 - 1}} = 0{\cdot}04\pi\frac{1}{\sqrt{\left(\frac{32}{n}\right)^2 - 1}}$$

It is easily seen that each number of turns (*n*) tapped by slider corresponds to a certain decrement, since it is the only variable in the above formula; therefore the slider can be provided with a scale from which the decrement can be read off directly.

When the signals are very damped, or with coupled circuits, it is best to obtain the decrement by plotting the resonance curve, which can be done in the usual manner with the Marconi decremeter. In this case the switches should be kept in the position A all the time, the position of the slider and the capacity being varied as already described for this test.

The diagram of a later type of Marconi decremeter is shown in Fig. 239. A portion of the inductance is in the form of a square coil, by which the meter can be inductively coupled to the circuit under test. Switch S is a double throw reversing switch, while the double two-way key (K) on one arm changes the decrement circuit, and on the other changes the telephone circuit.

(*a*) With switch at F and key at 1, L_3 is cut out and the telephones are across *n* turns.

(*b*) With switch at F and key at 2, L_3 is in and telephones are across 32 turns.

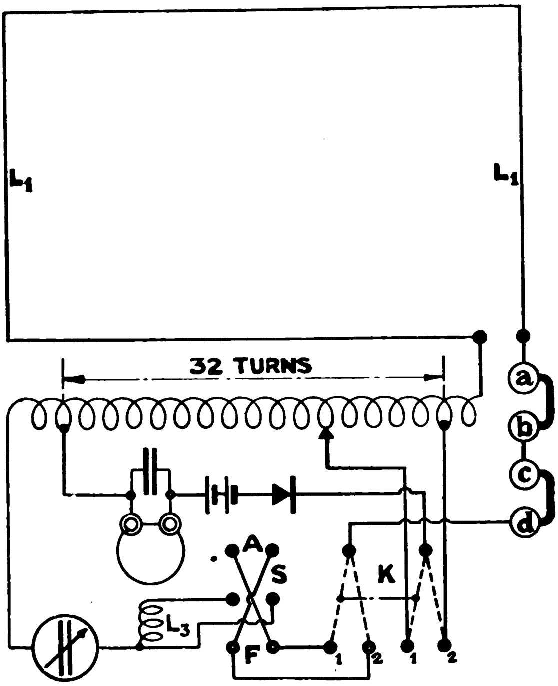


FIG. 239.

(*c*) With switch at A and key at 1, L_3 is in and telephones are across *n* turns.

(*d*) With switch at A and key at 2, L_3 is out and telephones are across 32 turns.

To measure a small capacity: Tune up for wave length with switch at A and key at 1 or 2; then join unknown capacity in parallel with variable capacity and vary latter until resonance occurs again, but do not vary slider. Since the wave length is the same in each case $60\sqrt{LK_1} = 60\sqrt{L(K_2 + K_x)}$

$$\therefore K_x = K_1 - K_2$$

Larger capacities can be measured by taking the link out at *ab* and joining them in series with C; do experiment as before; then $K_1 = \frac{1}{K_2} + \frac{1}{K_x}$.

To measure a self-induction take the link out at *ab* or *cd*, join the self-induction to be measured in the break thus made, and repeat as for finding a capacity, then—

Fig. 240.

$$LK_1 = (L + L_x)K_2. \quad \therefore L_x = L\left(\frac{K_1}{K_2} - 1\right)$$

To measure the coefficient of mutual induction of two coils join one in *ab*, the other in *cd*, and measure the inductance L_x as in previous paragraph; $L_x = L_1 + L_2 + 2M$. Then reverse the connections of the coil in *cd* and measure again; the new result L_y is equal to $L_1 + L_2 - 2M$. Thus $L_x - L_y = 4M$, so that M can be calculated. Fig. 240 shows this Marconi Decremeter.

CHAPTER XXIII

SECONDARY CELLS AND BATTERIES

As has been described in Chapter II. a *molecule* of a compound is a combination of atoms of two or more different elements. Thus two atoms of hydrogen (H) united with one atom of oxygen (O) forms a molecule of water (H_2O); this molecule has a different formation to that of the atoms with which it is composed; the distribution of electrons in it is different so that water has chemical and physical characteristics which are entirely different to those of either hydrogen or oxygen.

In a similar way one atom of lead (Pb) unites with two of oxygen to form lead peroxide (PbO_2); two atoms of hydrogen (H) one of sulphur (S) and four of oxygen form a molecule of sulphuric acid (H_2SO_4); one atom of lead one of sulphur and four of oxygen, when combined, form a molecule of lead sulphate ($PbSO_4$).

The formation of compound molecules is sometimes spoken of as the intermarriage of atoms; it is probably due to an electrical affinity between them, which may only occur when they are subjected to some physical stress. Thus oxygen unites with iron fairly easily to form the familiar iron oxide known as rust, but hydrogen atoms will unite with those of oxygen, to form molecules of water, only when the mixture is subjected to the violent action of the passage of an electrical discharge through it.

In some cases the compound thus formed is staple, in others it is unstaple and easily broken up; thus water (H_2O) is a staple compound, but hydrogen peroxide (H_2O_2), in which two atoms of hydrogen have united with two of oxygen, is unstaple and easily loses its extra atom of oxygen, thus changing into water.

It is a well-known fact that pure water has a very high electrical resistance but the addition of a few drops of sulphuric acid in solution brings down its resistance and it becomes a fairly good conductor.

The reason is that in a solution of this nature a continual disassociation and reassociation is taking place, so that at any given moment, in such a solution, there will be not only molecules of H_2SO_4 but also a number of broken up molecules, the broken up parts being called *ions* (from the Greek word "Ion," a wanderer).

Thus in a weak solution of sulphuric acid in water there will be the molecules of H_2SO_4 and a considerable number of disassociated molecules forming ions of H_2 and ions of SO_4; some of these combine again to form H_2SO_4, while some further molecules of H_2SO_4 break up into ions; this action is going on continuously so that, according to the strength of the solution, there will always be a certain number of ions per cubic centimetre. The electrical conductivity of the solution depends on the number of ions present, therefore on the strength of the solution up to a certain point. The same action occurs in other solutions, such as a solution of common salt in water, or a solution of copper sulphate in water.

The ions are always tending to recombine because in themselves they are not a staple electrical combination, just as a body charged positively or negatively is not in a normal condition as regards distribution of electrons. Some of the ions correspond to positive charges, others to negative charges; thus when a molecule of H_2SO_4 (sulphuric acid) breaks up into ions, the H_2 ion carries a positive charge, the SO_4 carries a negative charge. It is the electrical attraction between positive and negative charges which makes them recombine, but by suitable electrical pressure they can be driven further apart and will then carry their respective charges with them.

When a plate of zinc, copper, lead, carbon, or any other conductor is put into a weak solution of sulphuric acid the intimate contact between the plate and the solution sets up between them a difference of electrical pressure or potential, the plate attaining a lower potential than the solution, *i.e.* the plate is at negative potential with respect to the layer of solution with which it is in contact.

If a plate of zinc and a plate of, say, carbon are put simultaneously into such a solution, without touching each other, they each come to negative potential with respect to the solution, but the zinc is more negative than the carbon, so that the latter is positive with respect to the zinc. The difference of potential can be measured by a voltmeter and will be found to be about 1 volt; it depends not only on the plates used, but also on the solution used and on the strength of the solution. Thus if the plates of zinc and carbon were put into a saturated solution of sal-ammoniac the difference of potential between them would be about 1·4 volts. The potential is independent of the size of the plates.

In a diagram a cell is generally represented by a long and a short line parallel to each other, the long line representing the positive plate and the short line representing the negative plate.

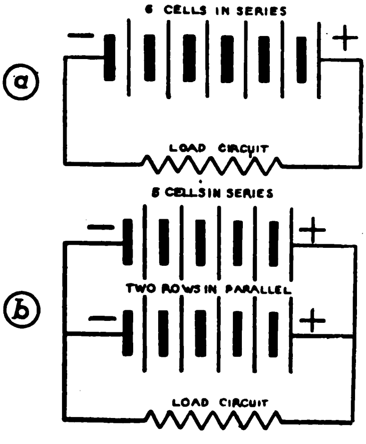


Fig. 241.

Batteries of cells in series and in parallel are thus diagrammatically shown in Fig. 241 (*a*) and (*b*).

If each cell gives two volts, then in Fig. 241 (*a*) the voltage applied to the load circuit is $6 \times 2 = 12$ volts; whereas in Fig. 241 (*b*) it is $5 \times 2 = 10$ volts and connecting more rows in parallel would not increase this value.

The voltage of a battery is determined by the number of cells in series and is not increased by joining similar rows of cells in parallel with it.

Theory of Secondary Cells.—If two plates of lead are put into a sulphuric acid solution they would be equally electro-negative with respect to the solution; there would be no difference of potential between them and thus the combination would not form a primary cell. But if some other material is put on the surface of one of the plates there will then be two dissimilar contacts with the solution, since it is only the surface which forms a contact, and a difference of potential will exist between the plates. The chemical symbol for lead is Pb from the Latin word "Plumbum."

In Fig. 242 two lead plates are shown in a solution with 10 per cent. of sulphuric acid in water; the solution contains ions of H_2 and SO_4. Suppose a battery of primary cells is connected to the plates, so that one plate is at positive potential the other at negative potential as is shown. The H_2 ions will be attracted to the negative plate, the SO_4 ions to the positive plate, and each group will give up their respective charges to the plates. Dissociation of the molecules of the (H_2SO_4) into ions is continually taking place in the solution, therefore as long as the electrical potential is applied to the plates the ions will carry their charges as described. This constitutes what is called a flow or current of electricity in the solution and, from the analogy with water, the direction of flow is taken to be from high pressure to low, from positive potential to negative ; in other words, the direction of the positive flow. Thus a charging current is said to flow from the outside battery through the solution in the direction of the arrow C. The hydrogen gas will mostly rise through the solution as bubbles and go off into the atmosphere, but the SO_4 ion is chemically very active, so much so that it attacks a molecule of water (H_2O) unites with the hydrogen (H_2) in it to form H_2SO_4 (sulphuric acid), expelling the oxygen (O). Eventually therefore hydrogen gas appears at the negative plate and oxygen gas at the positive plate, and as long as the outside potential is applied it is really molecules of water which are broken up to supply this hydrogen and oxygen. The oxygen gas is itself active enough to chemically unite with the lead on the surface of the positive plate and form with it peroxide of lead (PbO_2).

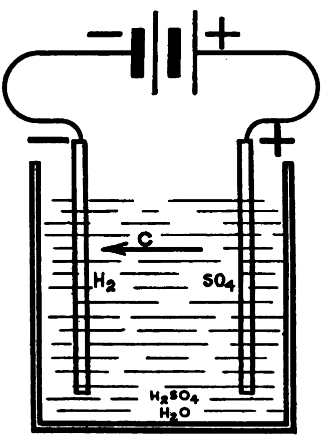


FIG. 242.

After the current has passed for some time in this manner there will be formed a layer of lead peroxide on the surface of the positive plate, so that now there are not two surfaces of lead in contact with the solution, but a surface of lead at the negative plate, with some bubbles of hydrogen gas sticking to it, and a surface of lead peroxide on the positive plate. When measured by a voltmeter the difference of potential of these surfaces will be found to be something over 2 volts ; a source of E.M.F. similar to a primary cell has thus been formed, but because a chemical action is first necessary a cell of this kind is called a " Secondary

Cell "—sometimes an "Accumulator," but the latter term is not theoretically correct as it implies accumulation of electricity.

The chemical action during the charging of a cell is seen to be somewhat complex, but it can be written with sufficient accuracy as follows :—

$$\underset{\substack{-\\ \text{(Plate)}}}{\mathrm{Pb}}+\underbrace{2H_2+2SO_4}_{\text{(ions)}}+\underset{\text{(Water)}}{2H_2O}+\underset{\substack{+\\ \text{(Plate)}}}{\mathrm{Pb}}=\underset{\substack{-\\ \text{(Plate)}}}{(Pb+H_2)}+\underset{\substack{\text{(Sulphuric}\\ \text{acid)}}}{2H_2SO_4}+\underset{\substack{+\\ \text{(Plate)}}}{(PbO_2)}$$

It is seen that during the charging of the cell some water is used up in the solution and some sulphuric acid formed, thus the specific gravity of the solution rises. The specific gravity of water is 1, of sulphuric acid 1·78, and of the solution or mixture used in these cells it is about 1·200.

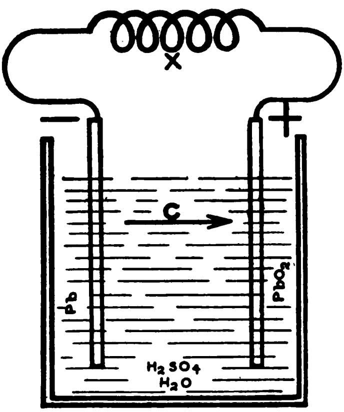


Fig. 243.

It must be remembered that the voltage of a cell depends entirely on the nature of the surface in contact with the solution, on the nature of the solution, and on the strength of the solution. *It does not depend on the size of the surfaces, and small plates will give the same voltage as large ones.* The size of the plates only determines the strength of the current which can be passed through the cell on charge or discharge, just as the size of a wire conductor depends on the current it has to carry.

A lead plate secondary cell when charged consists of a surface of lead forming the negative plate, and a surface of lead peroxide forming the positive plate, both being in contact with a solution of sulphuric acid in water, of specific gravity 1·200, and the combination giving a difference of potential of just over 2 volts at the terminals of the plates.

The action which accompanies the discharge of a cell such as this will now be considered. Referring to Fig. 243 let an outside circuit (X) be connected to the terminals of the cell; a current will flow, its positive direction being from the positive plate through the circuit to the negative plate, and from the negative plate across the cell to the positive.

Note that the discharge current flows through the cell in the opposite direction to the charging current; as before it is carried across the cell by ions, and these ions will enter into chemical actions with the plates and solution after delivering their respective charges.

The resulting chemical action in the cell may be written as follows:—

$$\underset{\text{−Plate}}{Pb} + \underbrace{H_2 + SO_4}_{\text{Ions}} + \underset{\text{Sulphuric acid}}{H_2SO_4} + \underset{\text{+ Plate}}{PbO_2} = \underset{\text{On − plate}}{PbSO_4} + \underset{\text{Water}}{2H_2O} + \underset{\text{On + Plate}}{PbSO_4}$$

The chemical formula shows that during discharge some sulphuric acid is used up out of the solution and some water formed, so that the specific gravity of the solution is lowered; at the same time a certain amount of lead sulphate is formed on the surface of both positive and negative plates. If the action or discharge was allowed to go on, until all the surface of both plates was covered with lead sulphate, there would not be two dissimilar surfaces and thus the difference of potential of the plates would be reduced to zero. For reasons which will be given later this is never allowed to happen as it would ruin the plates.

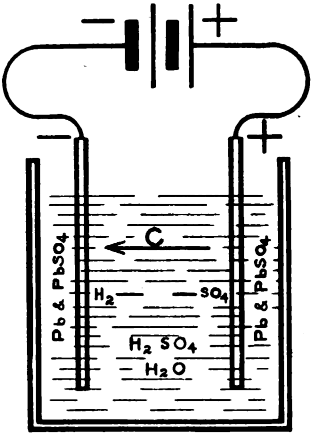


FIG. 244.

When the E.M.F. of the cell has dropped to about 1·85 volts or the specific gravity of the solution to 1·185 the cell should be charged up again. In this and all subsequent charges the chemical action is not the same as during the first charge as there is now lead sulphate on the surface of the plates to be dealt with and, in fact, eliminated. The conditions are shown in Fig. 244. The charging current flows across the cell from positive plate to negative plate, carried as before by the ions, each train of ions entering into chemical action after completing their task. The resulting chemical action is—

$$\underset{\substack{\downarrow\\ \text{On −}\\ \text{plate}}}{PbSO_4} + \underset{\substack{\downarrow\\ \text{Water from}\\ \text{the solution}}}{2H_2O} + \underset{\substack{\downarrow\\ \text{On +}\\ \text{plate}}}{PbSO_4} = \underset{\substack{\downarrow\\ \text{On −}\\ \text{plate}}}{Pb} + \underset{\substack{\downarrow\\ \text{Sulph. acid}\\ \text{into the}\\ \text{solution}}}{2H_2SO_4} + \underset{\substack{\downarrow\\ \text{On +}\\ \text{plate}}}{PbO_2}$$

Thus the lead sulphate on both plates is reduced, the negative surface becoming a pure lead surface again while the lead peroxide on the positive surface is renewed; water is used up out of the solution, and sulphuric acid formed, so that the specific gravity rises; at the same time the renewal of the differences of the two surfaces raises the difference of potential. When the latter is again over two volts and the specific gravity is again 1·200 the charge is complete. If the charging current is still kept on after the completion of the above chemical action no harm will ensue; all that will happen is that the oxygen gases set free at the positive plate, finding no more lead on its surface to combine with and form lead peroxide, will rise to the surface and escape as bubbles. This, in fact, is one method of determining when a cell is fully charged—it is said to be fully charged when it is gassing freely.

During the first few times that the cell is charged and discharged the chemical action on the plates sinks deeper, and the surfaces become more spongy; this has the effect of artificially increasing the size of the surface, thus increasing the amount of chemical action which can take place and so, for a given current, prolonging the charge and discharge.

Practical Construction of Lead Plate Cells.—The negative plates in ordinary secondary cells are generally of the "Pasted" type, sometimes called the "Faure" type, after the French scientist who first introduced the process. In this the plate is moulded as a skeleton framework of horizontal and vertical ribs, consisting of lead stiffened by adding a small percentage of antimony. Between these ribs are little square grids, with tongues of lead projecting in such a way that when the ribs are filled with a soft lead paste the projecting tongues key the paste in, and prevent it from shaking out of the grids. The paste with which the grids are filled is made by mixing some oxide of lead, such as litharge, with sulphuric acid; by chemical action this mixture produces a paste of grey spongy lead which hardens when dried in the grid.

The positive plates have to withstand greater chemical reactions than the negative ones, since at each charge a coating of lead peroxide is formed on them; thus they are usually of stouter construction, and are not pasted. They are of the "Formed" type, sometimes called the "Planté" type after the French scientist who first introduced the method of forming the plates; sometimes they are called "Tudor" plates as the design of plates almost universally adopted now was first introduced by the Tudor Company. The plate is moulded lead, with horizontal and vertical ribs stiffened by a little antimony ; it is thicker than the negative and between the main ribs the interstices are filled in, not with paste but with lead, the surface of which is crinkled in such a way that it provides pockets, or brackets, to hold the lead peroxide which will be formed on the surface. A section of one type of plate is shown in Fig. 245 ; by a construction such as this not only is the lead peroxide less likely to fall off the surface of the plate, but also the active surface is greatly increased ; thus the side of the plate whose dimensions give it an area of 1 sq. foot may have 10 sq. feet of active surface on which chemical action can take place.

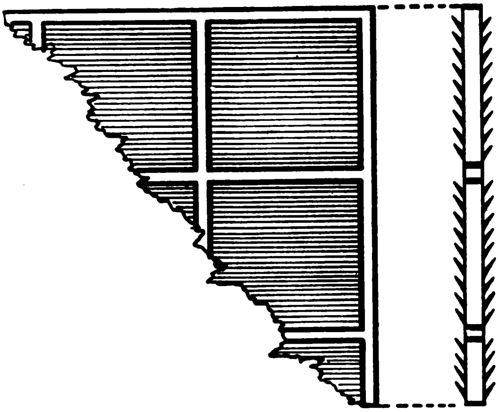


FIG. 245.

The process of "Forming" the plates is carried out by the manufacturers as follows :—

A number of the moulded leaden positive plates are all connected together to form one large positive plate, and this is put into a tank containing the proper solution of sulphuric acid, with a corresponding large negative plate, which for this purpose may be simply a sheet of lead. Charging current is then passed through and the positive plates have a certain amount of lead peroxide formed on them. The charging current is then switched off and a discharge current taken from the cell, so that some of the lead peroxide on the positive plates is reduced to lead sulphate. Charging current is then passed through again, and the process of charge and discharge repeated several times. At each charge the formation of lead peroxide on the surface of the plate increases, as the chemical action strikes deeper into the fissures and the surface becomes of a more spongy nature: thus the active surface is increased, and with it the quantity of electricity which can be put in on charge and taken out on discharge when these plates are subsequently used in cells. The above process of charge and discharge is known as "Forming" the plates. With new cells the formation of the plates is not thoroughly complete when they leave the manufacturers, and the capacity of a new secondary battery will gradually increase for the first few weeks in which it is used regularly on charge and discharge by the owner.

Thus positive plates always come from the manufacturer with a coating of *chocolate-coloured* lead peroxide on them, negative plates with a *grey* paste of spongy lead in their grids; it is by these colours that they can be distinguished.

In some batteries made for special purposes the plates are not designed as here described; a description of them will be given later.

The containing vessel of a secondary cell is generally of glass, celluloid, or other transparent material so that the condition of the plates can be seen; the plates should be placed close together so as to keep the resistance of the path of the current through the solution, from plate to plate, as low as possible. In order that the plates should not touch and short circuit, two or more "Separators" of glass rod, ebonite, wood, or other insulating material are placed between them. The plates should be supported well clear of the bottom of the containing vessel, because sediment will gradually heap up at the bottom, having fallen from the surface of the plates; this sediment is liable to make a connection from positive to negative plates and thus short circuit them. The cells should be examined regularly for this purpose, and the sediment removed when necessary. In a large stationary battery the plates are moulded with side lugs by means of which they hang on the top edges of the glass containing vessel and are several inches clear of the bottom.

In small cells the same object is accomplished by moulding two or three raised ribs on the bottom of the glass to support the plates, or, if in celluloid cases, using bars of glass, ebonite or other insulator for this purpose.

Size and Number of Plates.—The size of the positive and negative plates is determined by the strength of the normal discharging current which it is desired to take out of the cell.

Generally the current will be from 4 to 7 amperes per square foot of positive surface, but in small cells and in cells with plates made specially strong, such as are used for traction purposes, the current density can be increased beyond this. For purposes of portability it is not usual, except in the case of very small cells, to have only one positive and one negative plate on a cell; the requisite size is obtained by joining a number of positive plates together to form one positive plate, and a number of negatives together to form the negative plate; the number and size of the plates may vary, but there must be the required area of positive surface to deal with the current.

The positive and negative groups are made up by burning a lead strap to the plates, and they are then arranged in the cell as shown in Fig. 246. The plates on the outside are always negative ones and, since the two outer surfaces of these plates are not facing positive surfaces, there is always one more plate in the negative group than in the positive group, and the number of plates in a cell is always an odd number. Generally in the case of small portable batteries the normal discharge current is marked on it.

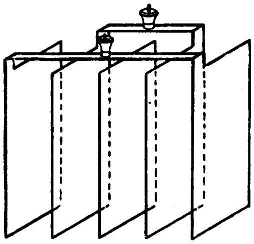


FIG. 246.

Number of Cells in a Battery—Regulating Cells.—The number of cells required in series in a battery is determined by the fact that a discharge can safely continue until the voltage per cell has dropped to 1·85. Thus if 100 volts are required the number of cells must be $\frac{100}{1\cdot85} = 54$. But when the battery is fully charged each cell is giving at least 2·2 volts per cell, so that 100 volts is then obtained by the use of only 46 of these cells; as the voltage of these gradually falls during discharge the remaining cells can be switched in to keep the total voltage up to 100. The cells thus used in a battery are known as regulating cells; it is seen that they are not discharged as much as are the main cells in the battery, consequently on the subsequent charge they will rise to their full voltage before the others, and switching arrangements can be adopted to cut these cells out one by one as they become charged and gas freely. A simple arrangement of charge and discharge switch is shown in Fig. 247. At the beginning of the charge the charge side of the switch is put at A so that all the cells are in circuit, the regulating cell X will be charged first;

when it is seen to be gassing the switch is put on the next contact, and so on, until all the regulating cells are charged, when the remainder of the battery should finally all come up to the gassing point together. Similarly, on discharge from the battery to the load, the discharge side of the switch is put at B where 47 cells are switched on and should give 100 volts. As the voltage of these cells gradually falls off the discharge switch is moved across, bringing in the regulating cells until the whole lot are on the load.

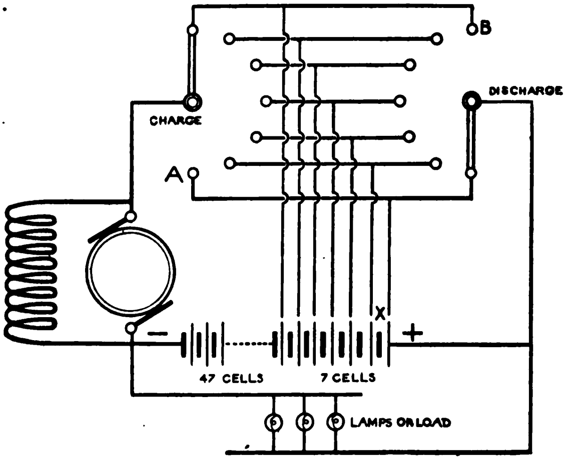


FIG. 247.

The full 100 volts will thus be kept on until the voltage has dropped to 1·85 volts per cell, when a new charge should be given.

Small portable batteries are usually reckoned at 2 volts per cell; thus a battery of 6 cells is called a 12 volt battery. In good condition, however, it must not be forgotten that after a complete charge the voltage is 6×2·2 = 13·2 volts, and may be even higher if the battery is used immediately after the charge has ceased, or if the solution has been made too strong. Similarly the voltage of a 3 cell battery may rise to over 7 volts when fully charged. The rise and fall of voltage in a lead plate cell during charge and discharge are as shown in Fig. 248. Dealing first with the charge curve and assuming that the cell has been discharged until its voltage has fallen to 1·85 volts, the charge curve will start at 1·85 volts. It will quickly rise to 2 volts as soon as some of the lead sulphate on the plates has been reduced, and it will remain at 2 volts until as much lead peroxide as possible is formed on the positive plates. At the end of the charge when the cell is gassing freely the voltage will have risen to 2·5 volts. This high value is mainly due to a local concentration of the solution round the plates; it will be remembered that during charge sulphuric acid is formed by the reduction of the lead sulphate on the plates; this acid tends to lie close to the plates so that round them the specific gravity of the solution is higher than in the general body of the cell. If the cell is allowed to stand for a time after the charge ceases, or is moved about, the solution will mix up, and the voltage will fall to 2·2 volts, which is the normal value for a healthy cell when fully charged.

It may therefore be taken that the discharge curve will start at 2·2 volts; it will rapidly fall to 2 volts as current is drawn from it, and then more slowly fall to 1·85 volts when it is time to charge up again.

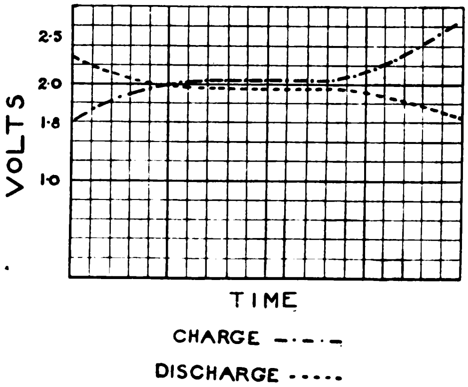


Fig. 248.

The curves in Fig. 248 assume that normal charge and discharge currents are used; if heavier currents are employed the corresponding curves will slope more rapidly, or the time taken for charge or discharge will be decreased.

Sulphating.—It has been described that during the discharge of a cell or battery lead sulphate is formed on both positive and negative plates; this must not be allowed to go too far, a fact which is the main consideration in stating that a new charge must be given when the E.M.F. has dropped to 1·85 volts per cell. If the cells are charged up again this sulphate is easily reduced by the chemical action which accompanies the charge, but if they are allowed to run down too far, even if they are left to stand idle too long, *a hard white sulphate* is formed which is very difficult to remove by subsequent charging. The formation of this white sulphate is known as *sulphating*, and is to be carefully avoided as it is liable to cause a permanent deterioration of the cells. The plates of the cell are heated to a certain extent by the passage of the charge or discharge current; they thus tend to expand but the white lead sulphate does not expand easily, and if there is any on the surface of the plates it does not expand with the plate, therefore tends to tear the paste out of the grids of the negative plates, or the lead peroxide underneath it out of the pockets on the positive plates. It is a bad conductor and, as remarked before, is not easily reduced by the chemical action accompanying the charge, hence any portion of a plate covered by white sulphate is out of action; its presence amounts to a reduction of the size of the plates and therefore of the capacity of the cell or battery.

If cells are allowed to stand idle for any length of time, even if no current is being taken from them, sulphuric acid in the solution will be acting on the plates and sulphating will result. To arrest this sulphating, cells which are not in use should be given a charge for an hour or two at least once a fortnight.

Again, if the level of the solution in the cell is allowed to fall below the tops of the plates, the exposed parts of the plates will become sulphated because the sulphuric acid creeps up over them, and as they are not in the current path they do not get any effects of a charge.

Lastly, if the solution is made too strong there is every likelihood of the plates becoming sulphated, and too much care cannot be taken to see that the solution is kept at the correct specific gravity.

When a new battery is received from the makers the solution should never be put into the cells until everything is ready to commence the first charge; sulphating commences immediately the solution is put in the cells and is only arrested by the charge.

Voltage of Charging Unit.—The voltage of the unit required to charge a battery must always be greater than that of the battery itself, since some voltage is required to get the charging current through the resistance of the circuit. To take an example, suppose a battery of 40 cells in series has to be charged, the voltage of each cell being down to 1·85 volts; then the battery E.M.F. is 74 volts. If the resistance of the battery and leads to the dynamo is, say, 2 ohms and the charging current 15 amperes, the drop of potential in the resistance is 30 ohms. Thus the charging dynamo will require to have a voltage of 74 volts to overcome the battery voltage, and 30 volts to drive the current through the resistance; it will therefore require to generate a terminal potential difference on this load of 104 volts.

As the voltage of the battery rises during charge the charging current will be decreased, unless the dynamo voltage is raised in proportion. Thus suppose the dynamo voltage is kept at 104; when the battery is fully charged and gassing freely its voltage will have risen to 2·5 per cell, *i.e.* 100 volts, so that there is now only 4 volts left to send current through the 2 ohm resistance of battery and leads, therefore the charging current is reduced to 2 amperes. If we wish to keep it up to 15 amperes we must raise the dynamo voltage to $100 + 15 \times 2 = 130$ volts.

First Charge of a New Battery.—When a new battery has to receive its first charge it is essential to make certain that the engine and dynamo, or other charging unit, are in a condition to work more or less continuously for 50 or 60 hours, and that at least there will be a non-stop run of about 12 hours' duration. Also the connections should be carefully traced to see that the positive of the dynamo goes to the positive of the battery and negative to negative; time is not wasted in thoroughly satisfying oneself on this point. When all is ready for closing the switches, and not before, the solution is put into the cells and the charge commenced.

At first, in spite of the charge, the specific gravity of the solution will fall, showing that sulphating of the plates is taking place, but the charge will eventually arrest this providing that it is not stopped during the first 12 or 15 hours. Then, if necessary, a stop may be made, but it is much better to carry on as long as possible without stopping.

It will be found that the cells do not start gassing, (showing that the charge is complete), until the charge has continued for 50, 60, or even 70 hours, the actual length of first charge depending on the condition of the plates as delivered by the manufacturers.

The first discharge of a new battery should be made of short duration, in fact during the first week or two charge and discharge should follow each other at short intervals, paying no attention to the rated capacity of the battery in ampere hours; these cycles of chemical action and reaction are completing the "Forming" of the positive plates and gradually bringing up the ampere-hour capacity of the cells. The positive plates should soon assume a rich chocolate colour while the negative ones are a clean pale grey. At the end of the charge all the cells should arrive at the gassing stage together; if one or more cells show no signs of gassing the charge should be continued until they do so, (it will do no harm to the other cells), and subsequent steps taken to bring all the cells into synchronism.

Defective Cells. —If a cell shows no signs of gassing when the charge of the remainder of the battery is complete, or if it shows signs of sulphating, with white patches on the plates, or is otherwise defective, it should be cut out of the discharge circuit so that it receives one or more charges in succession, but is not discharged. When trying to get a defective battery into good condition it is well to reduce the charging current and not hurry the charge; a heavy charging current is more likely to damage the plates of a defective cell than to improve them. Provided the strength of the solution has been carefully checked the best thing to do with a sluggish cell is to subject it to a persistent, but not violent, chemical action of charge.

The Solution.—The solution is carefully prepared by the manufacturers from pure sulphuric acid and pure water. The sulphuric acid should be free from all impurities, such as iron or arsenic, which are liable to be present, and the water should be distilled to free it from similar metallic salts. The presence of these salts in the solution will cause local action in the cells and will deteriorate the plates.

The strength of the solution sent out by different manufacturers with a new battery varies slightly, but as a general rule it may be taken that its specific gravity in a fully charged cell, or in a new cell about to go on first charge, should be 1·200. When the cell is discharged to the safe limit the specific gravity will have fallen to 1·185.

Where cells are open at the top and evaporation can take place they should be constantly examined and the solution never allowed to fall below and expose the tops of the plates. The quantity should be renewed from time to time so that the level is kept well above the tops of the plates; *this renewal should be made by adding distilled or other pure water only*, for it is only the water in the solution which evaporates.

When the solution in a cell or battery gets spilled out or leaks away it must be renewed by *a solution of the proper strength*, and the greatest care must be taken to see that it *is* the proper strength. If, as is most likely, the battery is discharged or the plates slightly sulphated when the refilling takes place, the added solution should not have a specific gravity of 1·200 but something less than this and about 1·190.

This point must be emphasised strongly, especially in working with portable batteries where constant renewals of the solution are required; the whole tendency is to make the added solution too strong. On charge the battery will soon rise to a voltage well above 2 volts per cell and all appears well. But the high voltage is due to the strength of the solution and the battery volts are high before the charge is properly complete or the plates in good condition; on discharge, or when standing idle, the relatively strong solution sets up more than usual sulphating of the plates.

When mixing a fresh solution to put into the cells care must be taken that the water is put into the glass, or other mixing vessel, before the sulphuric acid; if the acid is put in first then the first contact of the water with it will set up great heat, so that the vessel, if of glass, will be broken, the strong acid solution spilled, and everything it touches corroded. By putting the water into the vessel first and then slowly pouring in the acid the solution is weak at first, the chemical action slow, and consequently the heat generated is not very serious.

Capacity of a Battery.—The capacity of a battery is generally reckoned in ampere-hours, that is to say the product of the discharge current which it will give and the number of hours during which it will give it before the volts have dropped to the safe limit. Thus if a battery, after a completed charge, gives 5 amperes of discharge current for 10 hours before the volts have dropped to 1·85 per cell, the capacity of the battery on this discharge is $5 \times 10 = 50$ ampere-hours.

The capacity of a battery depends on the rate of discharge and afterwards falls off as this rate is increased; a battery which gives 4 amperes for 10 hours will not give 5 amperes for 8 hours, it will probably give 5 amperes for 7 hours, 6 amperes for 5 hours, and 8 amperes for 3 hours. Thus its capacity values at the rates of discharge of 4, 5, 6 and 8 amperes are 40, 35, 30 and 24 ampere-hours respectively. If the discharge is only at the rate of 1 ampere it might be expected to give it for more than 40 working hours, but if possible a charge should be given before the time represented by this has elapsed, in order to make certain that sulphating will be arrested. In fact it is always best practice to charge a battery as often as possible and not wait until it has reached the limit of discharge; this will ensure that the plates are kept in a nice healthy condition and avoid having, at times, to rush the charge of a battery with heavy currents which tend to strain the plates.

Charge and Discharge Current.—According to the total area of positive or negative active surface in a cell there is a certain value of what is called "normal" charging current. To hasten a charge the current may be increased above the normal value. The maximum current which it is safe to use in this way is about 50 per cent. greater than the normal. It is best to avoid using heavy currents as they heat up the plates abnormally, and the latter then tend to bend or "buckle." The chemical action is liable to be too violent, disintegrating the surfaces, and the local concentration of acid round the plates during charge becomes accentuated, so that the voltage is artificially increased. Thus the charge may not be properly completed when the indications of the voltmeter and gassing lead to the conclusion that they are fully charged.

A less value of current than the normal may be used to charge a battery, in which case the time taken to complete the charge will be correspondingly increased.

Similar considerations apply to "Discharge"; a heavier current than the normal may be drawn from the battery for a short time, but if it is more than 50 per cent. greater than the normal there is danger of buckling or disintegrating the plates.

The voltage of a battery from which a discharge current 30 to 50 per cent. greater than the normal value is taken will generally fall fairly rapidly, with consequent reduction of current.

If given a short rest it may be found that the voltage has to some extent risen again.

The temporary undue lowering of voltage is caused by local weakening of the solution near the surfaces of the plates. During discharge water is formed in the solution by the chemical action set up at the surface of the plates; if the discharge, and with it chemical action, is rapid there will be greater amount of water near the plates than in the general body of the solution. Potential is due to contact effects between the solution and the plates, so that this weakening of the solution near the plates causes the E.M.F. to fall off.

When given time to mix up the battery E.M.F. will therefore tend to rise a little. A battery should always be charged until the charge is complete, and the cells are gassing freely, before it is attempted to use it on discharge. By this means only can a proper check be made of the number of ampere-hours' charge and discharge, for it is imperative that no more ampere-hours are taken out on discharge than are put in on charge. Every battery should have a charge and discharge schedule, and none should be left for more than a fortnight without a charge, even if it has not been used since its last charge.

Cells in Series and in Parallel.—When cells are joined in series, or when two or more batteries are joined in series to obtain a necessary voltage on charge or discharge, if possible the cells should be all of the same size. If it is not possible to have them all of the same size then the charge or discharge current must be the normal value for the smallest cell or cells.

Cells are connected together to make up a battery either by burning on lead bars which connect the positive group of one cell to the negative of the next, or by means of lead pins and lead nuts fastening through holes in projections on the top of the groups. No metal other than lead should be used in terminals or connections for cells where it would be exposed to the acid fumes.

When cells or batteries are connected in parallel, so as to increase the current which can be used for charge or which can be taken out as discharge, care must be taken to see that they are all of the same voltage. For example if a 6-volt battery is connected in parallel with an 8 volt one, the first battery, instead of helping the second one may actually be a load on it and draw current from it, so that the 8-volt battery is charging the 6-volt one at the same time as it is supplying current to the load.

Charging Dynamos.—The dynamo used for charging batteries must be a shunt-wound one ; if a series one is used, or one having a series winding on the poles as well as a shunt winding, *i.e.* a compound dynamo, there is a likelihood that the polarity of the machine may be reversed. Thus in Fig. 249 (*a*) the armature of a shunt dynamo is shown sending current to a battery to charge it, at the same time supplying current to its own shunt winding,

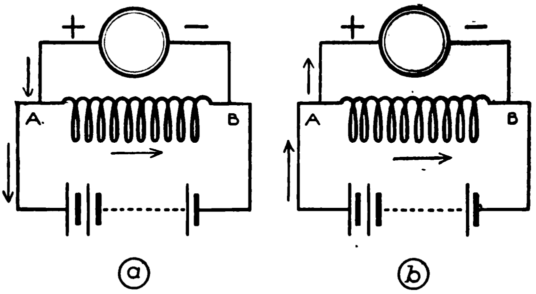


Fig. 249.

which current flows from A to B. Suppose that for some reason, such as a falling off in speed, the dynamo voltage falls below the battery voltage, a current will then flow from the battery to the dynamo. As shown in (*b*) part will go through the armature, part through the shunt coil, and it is seen that the latter current flows through the coil from A to B, *i.e.* the same direction as before, so that the polarity is not reversed. The armature current is reversed therefore the machine will run as a motor driven by the battery.

Fig. 250 shows the conditions with a series wound dynamo. When it is charging the battery, as at (*a*), the current flowing to the battery passes through the pole coils in the direction from A to B. But if by any chance the dynamo voltage falls off, below that of the battery, then the current will flow from the battery to the dynamo as in (*b*), and it is seen that now the direction of the current in the pole coils is reversed, and is from B to A. Thus the excitation of the dynamo is reversed and before its speed is pulled up its generated volts will be reversed as shown. The dynamo and battery are now in ordinary series, with positive of one to negative of the other, on what is practically a short circuit, so that there is danger of the dynamo armature being burnt out and the battery damaged unless the fuses blow in time to save them.

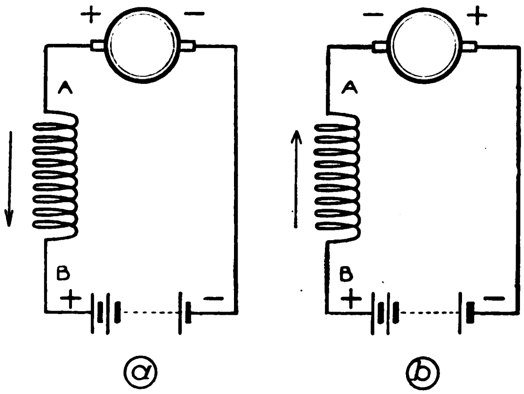


FIG. 250.

For this reason a series wound dynamo is never used for charging batteries, and if a compound wound dynamo is required to charge a battery it should be provided with switching arrangements so that the series or compounding coils can be cut out while so employed.

Automatic or Reverse Current Cut-out. — As already explained, if the speed of a shunt dynamo falls off for any reason while it is charging a battery, so that its E.M.F. drops below that of the battery, a reverse current will flow from the battery to the dynamo, and will tend to drive it as a motor. If by any chance the switch is closed between the two while the dynamo is at rest, then a heavy discharge current would flow from the battery to run the dynamo as a motor, and with it drive the engine.

The heavy starting current would probably injure the battery. To avoid this an automatic cut-out is placed in the circuit between the battery and the dynamo; the cut-out is so designed that it breaks the circuit when the current from the dynamo falls to zero and before a reverse current can flow from the battery.

Charging Small Batteries from Electric Light Mains.—Small batteries can be charged by connecting them in series with one of the leads going to light lamps, no matter what the voltage of the system may be, as long as it is a direct current system. Thus Fig. 251 shows the wiring of three lamps from the bus bars on a Distribution

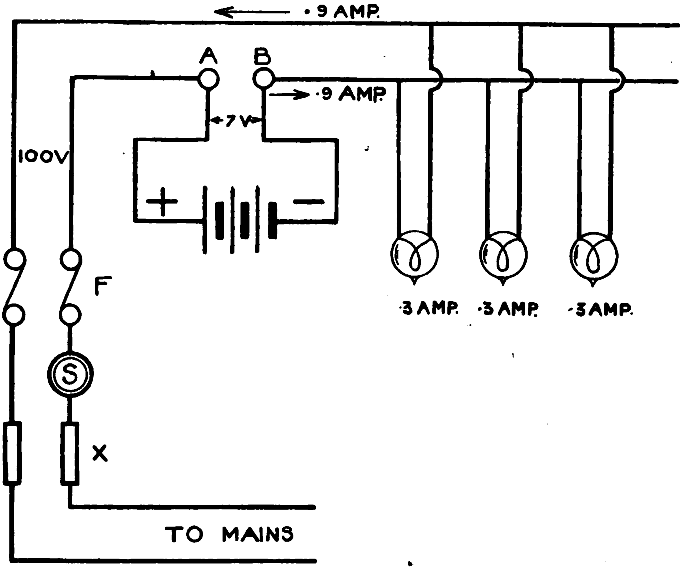


FIG. 251.

Box at X, through switch S and double pole fuse F. It is represented as a 100 volt system and each lamp is represented as taking 0·3 amp. which would be nearly correct if they were 25 c.p. Tungsten filament lamps. If it is required to charge a 6 volt battery one of the mains going to the lamps is broken at AB and the battery joined in series with it, *care being taken that the current flows through the battery in the right direction, i.e.* from positive to negative. Now the 0·9 amp. total current going to light the lamps will flow through the battery and charge it ; if the resistance of the battery is such that 0·9 amp. cause a drop of potential of 1 volt and the voltage of the battery is 6 volts, then the total drop of volts in the battery is 7 volts. This means that of the total 100 volts, 7 volts will be used in the battery and 93 volts left to light the lamps ; the latter will be a little less brilliant than on full voltage, but the difference is scarcely appreciable in this case. It is seen that no matter what the voltage of supply is, the battery takes just the voltage required to charge it. A connecting link could be put across AB ; this is removed and replaced by the battery when it is required to charge the latter.

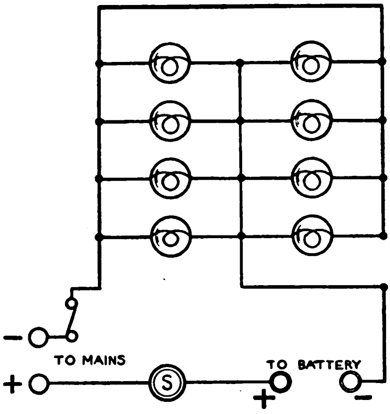
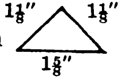


Fig. 252.

By having more lamps, or lamps of larger candle-power, the current would be increased, and thus the time taken to complete the charge decreased.

It is essential to know the correct polarity of the mains ; this can be simply done if a *moving coil* ammeter is available, since its terminals are marked + and —, and it will only give a deflection when connected up correctly. Without the battery or link connect the ammeter across AB in Fig. 251 and mark the end + to which the + terminal of the ammeter is connected when it gives a reading on switching on the lamps. Another method is to connect two strips of lead to A and B and insert them in dilute sulphuric acid. Switch on the current for a few minutes and then note which strip of lead has a brown chocolate coating on it ; this will be the one connected to the + end of the wires.

A small charging board can be made on this principle so that batteries may be charged off any direct current supply. It would be wired as shown in Fig. 252, where a number of lamps in parallel are connected in series with the battery, switch, and fuse on the mains. By taking lamps out the current can be reduced, by inserting lamps of larger candle-power the current can be increased. The lamps simply take up the volts not used in the battery; thus suppose the mains are a 100-volts supply, the battery a 60-volt one, of resistance 3 ohms, and the current 2 amps. Then the drop of volts in the battery is $60 + 3 \times 2 = 66$ volts, and the lamps only get 34 volts, so that they will now only glow dull red. If the battery is a 6-volt one and ½ ohm resistance with the same current it will take $6 + 2 \times \frac{1}{2} = 7$ volts, and the lamps will get 93 volts.

Fuller Block Cell. Type BL.—*Plates.*—The positive plate is of the pasted type, triangular in section  and 5″ long.

A paste of what is virtually lead peroxide is surrounded by fine glass fibre and enclosed in a thin perforated celluloid case.

The negative plate is also a pasted plate, similar in size to the positive, but it is not enclosed in glass fibre and celluloid. There are two positive and two negative sections in each cell arranged as in Figure 253.

The capacity of the cell is 20 ampere-hours, and its charging rate is 2 to 4 amperes. The BL Type cell has a celluloid container 2½″ × 2½″ × 6⅜″ outside dimensions.

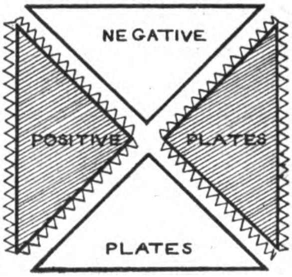


FIG. 253.

Three cells, forming a 6-volt battery, are contained in a wooden box 9⅛″ × 4″ × 8¾″; total weight 13 lbs.

Five cells, forming a 10-volt battery, are contained in a box 14″ × 4″ × 9″; total weight 26 lbs.

Edison Cell. — The active materials in an Edison cell are nickel oxide on the positive plate, iron on the negative, and a 21 per cent. solution of caustic potash mixed with a small percentage of lithium hydrate.

The positive plates are composed of perforated steel tubes which contain alternate layers, in very thin flakes, of nickel hydroxide and pure nickel. The tubes are reinforced with steel rings and mounted in a steel frame, the whole being heavily nickel-plated. This construction is shown in Fig. 255.

The negative plate is also a steel plate with rectangular perforated pockets filled with powdered iron oxide, the whole being pressed together in dies and nickel-plated.

The plates are separated by specially fitted thin rods of vulcanite, the same material being used to keep the plates from the sides of the containing vessel, and a vulcanite rack supports the plates on the bottom. The containing case is nickel-plated inside and out to prevent rusting.

The cell is made up in a watertight metal case and is therefore unspillable if the filling cover is closed. During charge water of the solution is given off as gas, therefore the filling cover should be left open, also the water must be replaced from time to time in the solution so as to keep the latter about half-inch above the tops of the plates. A higher level of the solution than this will cause it to froth over on charge.

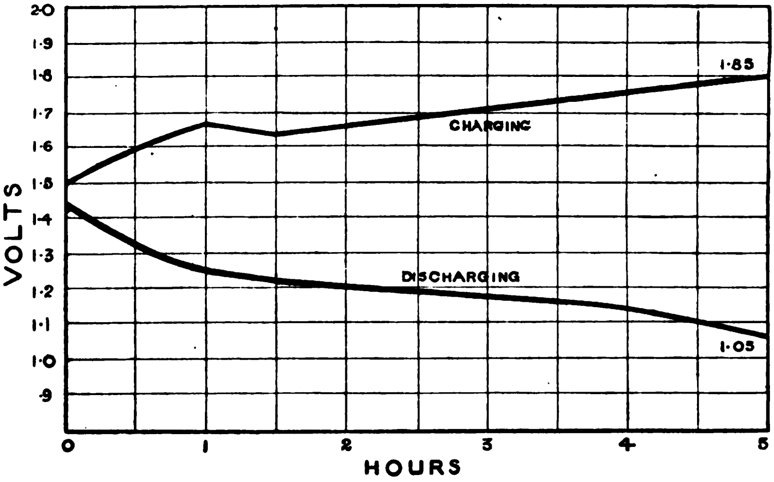


FIG. 254.

The specific gravity of the solution should be about 1·200; after 10 or 12 months' use it may be expected to fall, and when, after a full charge, it reads only 1·160 on testing with a hydrometer it should be emptied out and fresh solution immediately poured in. Always discharge the battery completely before renewing the solution; then give a 12 hours' charge at normal rate.

The efficiency of an Edison cell is not greater than 60 per cent., while that of a lead cell may be 75 per cent.; this is not an important point where portable batteries are concerned.

Never put acid in an Edison battery, nor use utensils that are contaminated with acid solutions; you may ruin the battery, as it is very susceptible to organic impurities of the solution.

Never bring a lighted match or flame near the battery.

If the solution gets spilled it must, of course, be made up with standard renewal solution which will have a specific gravity of 1·250; this falls to 1·200 when mixed with the weaker solution in the cell.

The capacity in ampere-hours improves with use during the first 8 or 10 months, when it may begin to fall off, an indication that a renewal of the solution is necessary.

Voltage.—The voltage averages 1·25 volts per cell, the value varying very greatly during discharge. The maximum value of the voltage is about 1·85 volts, and the cell can be discharged until its voltage is zero. The charge and discharge curves are shown in Fig. 254.

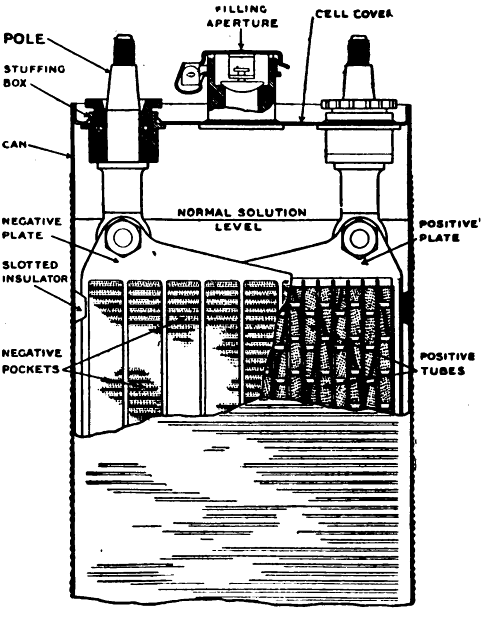


Fig. 255.

The construction of the plates and the general assembly of the parts in an Edison cell are clearly shown in Fig. 255.

Advantages of Edison Cells.—(1) They can be totally discharged without injury.

(2) Provided the temperature of the solution does not rise above 115° F. the charging current can be greatly increased in order to hurry a charge. Thus it may be double the normal current for about an hour, treble the normal current for about half an hour or even four times normal current for a quarter of

an hour. This is sometimes very convenient for hurrying up a charge.

(3) They can be discharged with currents as high as six times normal for short periods without injury. (It is, however, desirable that the size of the cell should be chosen so that the load current does not exceed 25 per cent. above normal rating.)

(4) The cells are mechanically very strong and will not be injured by rough mechanical usage.

(5) The solution is an alkali, not an acid one; an alkali solution has not the same corrosive effect as an acid one on metals, etc., with which it comes in contact.

Disadvantages.—(1) The volts curve on charge or discharge has a much greater slope than that of a lead plate cell. When charging it is necessary to start with a current about 50 per cent. above normal so that as it decreases, due to the rise of the battery voltage, it will average the normal value throughout the charge. Otherwise a continual adjustment of the rheostat would be necessary to keep the current at normal.

On discharge some method of control is necessary if it is desired to have a constant voltage.

HINTS ON BATTERIES.

1. The charging voltage must always be greater than the nominal voltage of the battery; how much greater depends on the charging current required and the resistance of the battery and leads.
2. Never try to get more ampere-hours out of a battery than are put into it.
3. Never let the solution fall below the tops of the plates.
4. If the solution gradually evaporates make up with pure water only.
5. If the solution leaks away or is spilled, make up with fresh solution, but carefully avoid having this too strong—its specific gravity should not be greater than 1·200.
6. When connecting up batteries for a charge be careful to see that the positive of the battery is connected to the positive of the leads, and negative to negative.
7. Avoid the use of cells of different sizes in series or in parallel.
8. When putting a battery on charge if possible always have in series with it a fuse which will blow with double the normal charging current.
9. Try always to have a battery in such a condition that all the cells start gassing simultaneously on charge.
10. Periodically take portable batteries out of their wooden cases and see that the sediment is not shorting any of the plates at the bottom of the cells, and that the solution covers the tops of the plates.
11. If a battery is not in use give it a short charge at least once a fortnight.
12. Never empty the solution out of a battery because it is not in use. The plates will become sulphated; act as in No. 11.

APPENDIX I

INTERNATIONAL MORSE CODE

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Figures.

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6 ▬ ▪ ▪ ▪ ▪
7 ▬ ▬ ▪ ▪ ▪
8 ▬ ▬ ▬ ▪ ▪
9 ▬ ▬ ▬ ▬ ▪
0 ▬ ▬ ▬ ▬ ▬

Punctuations.

Full stop ▪ ▪ ▪ ▪ ▪ ▪
Semicolon ▬ ▪ ▬ ▪ ▬ ▪
Comma ▪ ▬ ▪ ▬ ▪ ▬
Colon ▬ ▬ ▬ ▪ ▪ ▪
Interrogation ▪ ▪ ▬ ▬ ▪ ▪
Hyphen ▬ ▪ ▪ ▪ ▪ ▬
Apostrophe ▪ ▬ ▬ ▬ ▬ ▪
Inverted commas ▪ ▬ ▪ ▪ ▬ ▪

Short Figures.

1 ▪ ▬
2 ▪ ▪ ▬
3 ▪ ▪ ▪ ▬
4 ▪ ▪ ▪ ▪ ▬
5 ▪ ▪ ▪ ▪ ▪
6 ▬ ▪ ▪ ▪ ▪
7 ▬ ▪ ▪ ▪
8 ▬ ▪ ▪
9 ▬ ▪
0 ▬

Other signals.

Repeat (something not understood) ▪ ▪ ▬ ▬ ▪ ▪
Underline (before and after words or phrase) ▪ ▪ ▬ ▬ ▪ ▬
Preliminary call signal ▬ ▪ ▬ ▪ ▬

Understood ▪ ▪ ▪ ▬ ▪
Error ▪ ▪ ▪ ▪ ▪ ▪ ▪ ▪
Cross (+), also end of transmission ▪ ▬ ▪ ▬ ▪
Invitation to transmit ▬ ▪ ▬
Wait ▪ ▬ ▪ ▪ ▪
"Received" signal ▪ ▬ ▪
Double dash (=) ▬ ▪ ▪ ▪ ▬
End of work ▪ ▪ ▪ ▬ ▪ ▬

Spacing and length of signals.

1. A dash is equal to 3 dots.
2. Space between signals in one letter is equal to 1 dot.
3. Space between letters is equal to 3 dots.
4. Space between words is equal to 5 dots

APPENDIX II

CALL LETTERS OF STATIONS

THE calls allotted to the radio stations of the various countries commence with the letters of the alphabet as follows :—

A	
B	British Navy Stations.
C	Chili.
CN	Morocco.
CR	Portugal.
E	Spain.
F	France and Colonies.
G	British P.O. Stations.
I	Italy and Colonies.
J	Japan.
K	Alaska, Hawaii.
L	Norway.
LI	Argentine.
M	Marconi Co. Stations.
A	United States.
OA	Peru.
OH	Austria-Hungary.
OQ	Belgium, Belgian Congo.
OU OX	Denmark.
P	Holland and Colonies, Brazil.
R	Russia.
S	Brazil.
V	British Colonies.
W	United States.
X	China.
XA	Mexico.

The calls of some stations in Great Britain and important stations in other countries are given below :—

Whitehall	BYA
Cleethorpes	BYB
Dover	BYL
Sheerness	BYK
Wick	BYG
Cullercoats	GCC
Folkestone	GUR
Heysham	GHH
Land's End	GLD
Newhaven	GNF
Carnarvon	MUU
Poldhu	MPD
Clifden	MFT
Chelmsford	MZX
Eiffel Tower	FL
Boulogne	FFB
Cherbourg	FFC
Dieppe	FFI
Havre	FFU
Coltano	ICI
Rome	IDO
Petrograd	TSR
Madrid	EGC
Nordeich	KAV
Eilvese	OUI
Nauen	POZ
Scheveningen	PCH
Malta	BYY BYZ
Sayville	WSL or SYL
Tuckerton	WGG
Glace Bay	GB

APPENDIX III

TRIGONOMETRICAL RATIOS, ETC.

Angle.	Radians.	Sine.	Tangent.	Co-tangent.	Cosine.		
0°	0	0	0	∞	1	1·5708	90°
1	·0175	·0175	·0175	57·2900	·9998	1·5533	89
2	·0349	·0349	·0349	28·6363	·9994	1·5359	88
3	·0524	·0523	·0524	19·0811	·9986	1·5184	87
4	·0698	·0698	·0699	14·3006	·9976	1·5010	86
5	·0873	·0872	·0875	11·4301	·9962	1·4835	85
6	·1047	·1045	·1051	9·5144	·9945	1·4661	84
7	·1222	·1219	·1228	8·1443	·9925	1·4486	83
8	·1396	·1392	·1405	7·1154	·9903	1·4312	82
9	·1571	·1564	·1584	6·3138	·9877	1·4137	81
10	·1745	·1736	·1763	5·6713	·9848	1·3963	80
11	·1920	·1908	·1944	5·1446	·9816	1·3788	79
12	·2094	·2079	·2126	4·7046	·9781	1·3614	78
13	·2269	·2250	·2309	4·3315	·9744	1·3439	77
14	·2443	·2419	·2493	4·0108	·9703	1·3265	76
15	·2618	·2588	·2679	3·7321	·9659	1·3090	75
16	·2793	·2756	·2867	3·4874	·9613	1·2915	74
17	·2967	·2924	·3057	3·2709	·9563	1·2741	73
18	·3142	·3090	·3249	3·0777	·9511	1·2566	72
19	·3316	·3256	·3443	2·9042	·9455	1·2392	71
20	·3491	·3420	·3640	2·7475	·9397	1·2217	70
21	·3665	·3584	·3839	2·6051	·9336	1·2043	69
22	·3840	·3746	·4040	2·4751	·9272	1·1868	68
23	·4014	·3907	·4245	2·3559	·9205	1·1694	67
24	·4189	·4067	·4452	2·2460	·9135	1·1519	66
25	·4363	·4226	·4663	2·1445	·9063	1·1345	65
26	·4538	·4384	·4877	2·0503	·8988	1·1170	64
27	·4712	·4540	·5095	1·9626	·8910	1·0996	63
28	·4887	·4695	·5317	1·8807	8830	1·0821	62
29	·5061	·4848	·5543	1·8040	·8746	1·0647	61
30	·5236	·5000	·5774	1·7321	·8660	1·0472	60
31	·5411	·5150	·6009	1·6643	·8572	1·0297	59
32	·5585	·5299	·6249	1·6003	·8480	1·0123	58
33	·5760	·5446	·6494	1·5399	·8387	·9948	57
34	·5934	·5592	·6745	1·4826	·8290	·9774	56
35	·6109	·5736	·7002	1·4281	·8192	·9599	55
36	·6283	·5878	·7265	1·3764	·8090	·9425	54
37	·6458	·6018	·7536	1·3270	·7986	·9250	53
38	·6632	·6157	·7813	1·2799	·7880	·9076	52
39	·6807	·6293	·8098	1·2349	·7771	·8901	51
40	·6981	·6428	·8391	1·1918	·7660	·8727	50
41	·7156	·6561	·8693	1·1504	·7547	·8552	49
42	·7330	·6691	·9004	1·1106	·7431	·8378	48
43	·7505	·6820	·9325	1·0724	·7314	·8203	47
44	·7679	·6947	·9657	1·0355	·7193	·8029	46
45	·7854	·7071	1·0000	1·0000	·7071	·7854	45
		Cosine.	Co-tangent.	Tangent.	Sine.	Radians.	Angle.

The functions of angles larger than 90° can be obtained as follows :—

Sin $(90+\theta)=\cos\theta$
Sin $(180+\theta)=-\sin\theta$
Sin $(180-\theta)=\sin\theta$
Sin $(270+\theta)=-\cos\theta$
Sin $(270-\theta)=-\cos\theta$
Sin $(360+\theta)=\sin\theta$
Sin $(360-\theta)=-\sin\theta$

Cos $(90+\theta)=-\sin\theta$
Cos $(180+\theta)=-\cos\theta$
Cos $(180-\theta)=-\cos\theta$
Cos $(270+\theta)=\sin\theta)$
Cos $(270-\theta)=-\sin\theta$
Cos $(360+\theta)=\cos\theta$
Cos $(360-\theta)=\cos\theta$

Tan $(90+\theta)=-\cot\theta$
Tan $(180+\theta)=\tan\theta$
Tan $(180-\theta)=-\tan\theta$
Tan $(270+\theta)=-\cot\theta$
Tan $(270-\theta)=\cot\theta$
Tan $(360+\theta)=\tan\theta$
Tan $(360-\theta)=-\tan\theta$

Examples :—Sin 125° $=\sin(180-55)^\circ=\sin 55^\circ=0{\cdot}8192$.
or Sin 125° $=\sin(90+35)^\circ=\cos 35^\circ=0{\cdot}8182$,
Tan 310° $=\tan(270+40)^\circ=-\cot 40^\circ=-1{\cdot}1918$.

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