HOW TO BECOME A WIRELESS OPERATOR

A PRACTICAL PRESENTATION OF THE THEORY OF ELECTRICAL WAVES, THEIR PROPAGATION, AND THEIR ADAPTATION TO WIRELESS COMMUNICATION, INCLUDING SIMPLE AND CLEAR INSTRUCTIONS HOW TO OPERATE WIRELESS DEVICES AND HOW TO COMPLY WITH GOVERNMENT REQUIREMENTS FOR OPERATORS

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INTRODUCTION

FOR those who are interested in electrical matters or who are now gaining their livelihood in some branch of the electrical field, for instance, telegraph operators, power-house attendants, and the like, there are few subjects so fascinating as that of wireless telegraphy. Likewise there are few subjects with so much seeming mystery that are in reality so exceedingly simple. It is scarcely to be wondered at that man's recently achieved ability to communicate over long distances without the aid of the fixed lines of communication so long considered indispensable should appeal to the uninitiated as the crowning mystery of electrical science. Yet there is so little real mystery involved that many boys of fifteen have not only mastered wireless telegraphy but have actually constructed many of the sending and receiving instruments.

¶ With the exception of amateurs operating receiving stations only, all operators are licensed by the Federal Government and must pass an examination to demonstrate their fitness to hold the license for which they apply. Eight licenses are issued as follows:

1. Commercial Extra First Grade—chief operators for large passenger ships and shore stations.
2. Commercial First Grade—assistant operators as above; so high an operating speed is not required.
3. Commercial Second Grade—still lower sending and receiving speeds permissible.
4. Commercial Cargo Grade—taken by officers of cargo ships that do not carry a regular operator.
5. Experiment and Instruction Grade—for experimenters and scientists.
6. Amateur First Grade.
7. Amateur Second Grade.
8. Commercial Temporary Permit—usually issued to an operator for one voyage of a vessel only.

¶ There are three methods by which the student can acquire the knowledge necessary to pass the required examination. He (or she) may attend a telegraph school, of which there are a number in various parts of the country; he may attend the Marconi School of Instruction in New York, at which instruction is gratis for those intending to enter the Marconi service upon graduation; or with a few hours home study a day and the aid of books such as this one, he may fit himself to pass the examination with comparatively little effort or expense and without disturbing his usual routine duties. This book is intended for the great number to whom attendance at school is impossible and to whom the acquirement of the necessary knowledge in any other way than by home study would be difficult.

¶ A great many works have been published on various phases of the subject, but none of them has been specifically planned to give the reader in concise form a knowledge of principles and operation that will enable him to enter the field commercially. In the present work, neither the history nor the mathematics of the art have been touched upon. So far as possible, it is a manual for those intending to become operators, whether for personal instruction as amateurs or in the commercial field. Any experienced telegrapher by devoting a few hours a day to the subject can equip himself with the necessary knowledge in three or four months or even less. Those who have had no experience in any branch of telegraphy will find six months to a year necessary.

¶ Reference is made from time to time to various standard works on the subject. If the student wishes to become familiar with the scientific aspect of radio communication, he will find them of great value. Many can be found in the various public libraries.

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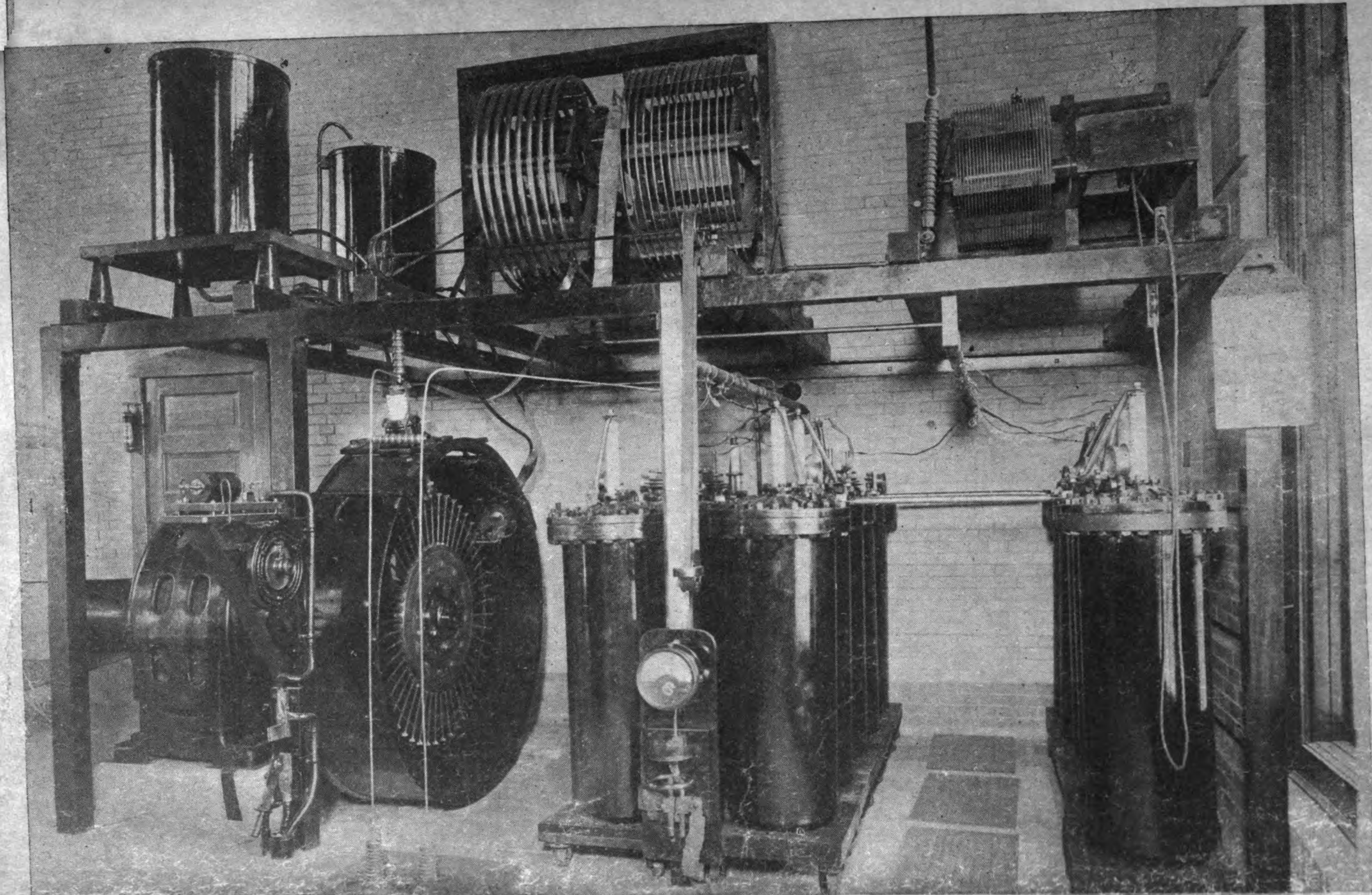


TRANSMITTING APPARATUS FOR THE WIRELESS STATION AT RADIO, VIRGINIA

HOW TO BECOME A WIRELESS OPERATOR

FUNDAMENTALS OF WIRELESS TELEGRAPHY

Discovery of Electric Waves. The fact that electrical energy could be transmitted by means of a wire or other conductor was known for many years before it was discovered that energy in the same form could also be transmitted through the air without any connecting wires—in other words, that electrical energy could be *radiated* as well as conducted along a given path. This discovery was made by several scientists at different times almost a century ago, but it was not until the work of Hertz in 1888 that practical means of radiating electrical energy and detecting its presence at a distance were devised. This was accomplished by generating electromagnetic waves which, in honor of the discoverer, are often referred to as Hertzian waves.

Water Analogy. To form a clear conception of how these waves are employed as a means of communication, the familiar mechanical analogy of the action of waves in water is resorted to as an explanation of the theory of wireless telegraphy. When a stone is dropped into a pool of water a well-defined series of waves is radiated from a common center due to the depression caused in the surface by the weight of the stone, the rush of water to fill this depression, and the inertia of the water, which causes the motion to continue once it has been established. The fall of the stone sets into motion a whole series, or train, of waves which travel outward concentrically until the force which originated them is expended or until they reach the edges of the pool, when it is of limited dimensions.

Nature's Wireless. Lightning is a common example of the transfer of huge quantities of electrical energy from one point to another without any tangible connecting medium and that it is the same in character as the electromagnetic waves radiated by the transmitter of a wireless set is evidenced by the fact that the receiving instruments respond to it in the same manner as to the waves sent out for purposes of communication. A lightning discharge is caused by what is termed a difference of potential, either between the earth and the upper strata of the air or between different strata of the latter.

Just as in the case of the stone dropped into the water, a train of waves is radiated and they continue to travel outward from their point of origin until the force back of them is exhausted. Both are examples of the release *at random* of a certain amount of energy which is dissipated without accomplishing any useful purpose. It will be apparent that if the energy is to be of any value as a means of communication, provision must be made for controlling its release at the sending station and that means must also be provided to cause the waves thus radiated to manifest their presence at the receiving end.

To make this clear, the simile of the wave motion in water may be carried further. Instead of the loose stone simply dropped into the water, a plunger of definite weight and dimensions on the end of a rod provided with means by which it can be plunged into the water and withdrawn at a certain time interval is used. By setting this into action, waves of definite characteristics can be radiated from this crude analogy to a sending station and different trains of waves can be caused to follow one another periodically. It can readily be understood that even with such a crude device a fairly close approximation to the dots and dashes of the Morse code could be produced in the form of wave trains.

Detecting Waves. A lightning discharge makes its presence known by the flash and the rending crash caused by the sudden release of such a tremendous amount of electrical energy, but the fact that these phenomena constitute merely the visual and audible manifestation of the radiation of this energy in the form of electromagnetic waves was not definitely known until a method of detecting the presence of these waves had been discovered.

If the means of causing waves to radiate over the surface of a pond be operated in the dark, the time interval at which they follow one another cannot be seen and the signals will be meaningless. Consequently, a detector that will respond to the succeeding trains of waves with the same time constant as that with which they are radiated is indispensable.

This detector may take the form of a pivoted vane or [illegible]lly only at right angles to the advancing waves and immersed to about [illegible]en to its length in the water so as to receive the full force of the wave striking against it. If the arm of the vane through which the pivot passes be extended and have attached to it a pointer arranged to move over a scale or a hammer designed to strike against a gong, it will be apparent that the passing of the waves may be caused to give either a visual or an audible indication at the receiving end. While the waves will be weaker, in proportion to the distance they have traveled, when they reach the detector than they were when they left the transmitter, they will still possess the same characteristics, that is, they will still be of the same length and the succeeding trains of waves will be separated by the same time interval as when they left the transmitting station. The response of the detector will accordingly be a reproduction on a reduced scale of the movements of the transmitter. If the latter be plunged into the water three times with a 10-second interval and after 30 seconds has elapsed be plunged in three times with a 20-second interval, the response of the detector will be of the same periodicity and the signal might be likened to three dots, space, three dashes.

Essentials of Wireless Method. In a rudimentary form, the foregoing analogy illustrates the method of communication employed in wireless telegraphy. First, there must be a means of generating and radiating electromagnetic waves at the sending station and these waves must be given definite characteristics. Second, there must be a means of detecting these waves at the receiving station and the detector must be so arranged that it will respond to waves of the character radiated by the sending station. In the simile employed, the time interval between the trains of waves has been given as an illustration of their definite character. This, of course, does not apply in the same sense to the electromagnetic waves of wireless telegraphy, as the characteristics given to a wireless wave are its length and frequency. (The wave length is a measure of the frequency.) The former determines the adjustment necessary at the receiving station for its proper reception, while the latter affects the pitch, or sound, produced by the wave in the receiving instruments. It is a peculiarity of the human ear the wa... esponds better to faint sounds of high pitch than to those di... lower frequency, so, within the range of audibility, the higher the frequency the better. Frequencies considerably above the range of audibility are also employed, but in such cases special means must be used at the receiving station to make them audible.

In actual practice, the time interval mentioned refers merely to the spacing, or separation, of letters and words and is the same in character as that ordinarily employed in telegraphy.

Distances and Wave Lengths. Just as the stone dropped in the water causes a concentric series of waves, so the wave trains sent out by the transmitting station radiate in all directions from it. The distance to which any station can transmit is defined by the diameter of a circle of which it is the center. Messages sent from Arlington (officially Radio), Virginia, have been received simultaneously in Paris and in Hawaii. Unlike land telegraphy, however, long-distance transmission is a question of the power employed at the sending station. It is also influenced very largely by the length of the wave radiated, as a short wave is absorbed and, therefore, is not effective for long-distance transmission.

Differences in wave lengths employed in wireless telegraphy frequently raise many puzzling questions in the mind of the beginner. For example, if the sending station must transmit a wave of a certain length, what is to prevent other stations than the one for which it is intended also receiving the message? If several transmitting stations are sending messages at the same time on the same wave length, how is the receiving station to distinguish the one intended for it?

Tuning Waves for Secrecy. There is nothing to prevent any receiving station from picking up messages, whether intended for it or not. Secrecy can only be insured by the use of a telegraphic code so that the message cannot be deciphered as read. By the use of what is known as a wave-length code, the reception of the message itself is made difficult. It will be apparent that the receiving station must be *tuned* to respond to the wave length of the transmitting station. But if the latter changes its wave length radically on the completion of each word, stations other than those for which the message is intended will naturally only respond to those parts of the message for which they happen to be in tune at the time.

Preventing Interference between Wave Trains. The second question represents one of the greatest problems of wireless telegraphy and is known as interference. Wave lengths have been standardized for the different classes of stations. Amateurs are not permitted to use a wave length in excess of 200 meters; commercial ship stations must send waves of 300 or 600 meters or between these limits; naval ships waves of from 600 to 1600 meters; while the high-power and transatlantic stations employ waves ranging from 2500 to 10,000 meters and these are often of a frequency not audible without special receiving apparatus owing to the waves themselves being *undamped.* But even where several stations using the same wave length are transmitting at the same time, means have been provided whereby a receiving station can distinguish the message intended for it above the others. The latter cannot be eliminated entirely but they may be suppressed to a degree which permits of the desired message being read clearly, just as an operator in a busy office can distinguish the message coming in on his own sounder despite the simultaneous clatter of a hundred other instruments, which to an unitiated person represents nothing but a confusion of sounds. These points are all taken up in detail in succeeding sections.

Nature of Waves. In so far as the term "wireless telegraphy" relates to the absence of connecting wires between stations, indispensable to other methods of electrical communication, it is appropriate, but, as a great deal of wire is used in the apparatus of every wireless telegraph installation, it is hardly descriptive. Communication is carried on by means of electromagnetic waves of high potential *radiated* through the ether so that the term "radiotelegraphy" is more apt and has been officially adopted by all government publications. In order to obtain a clear understanding of what is meant by radiating an electromagnetic wave, it is necessary at the outset to have a well-grounded conception of waves and wave motion.

Motion through a Body. The popular idea of a wave is that of motion of a body, for example, a wave in water is generally considered to be an actual forward motion of a portion of the surface of the water. Where surf is breaking on a beach this is the case to a certain extent, but the action of the surf does not represent a true wave. The latter can only be seen several miles off shore where, if one were to watch a small boat or log floating upon the surface of the water, it would be seen to rise on the crest and fall into the trough of the wave without making any progress toward the shore, that is, wave is *motion through a body* which, after it passes, leaves the body in the same state as before. This may also be demonstrated by a long piece of string held taut and snapped sharply at one end. A well-defined wave will be seen to travel along the entire length of the string and, upon reaching the other end it will not cease abruptly but will start back along the string. The number of times this movement will be reflected depends upon the amount of energy originally imparted to the string.

The continuing action of the wave, which lasts until the energy causing it is expended, may be shown much more clearly in a long piece of light rope suspended vertically and made fast at the upper end only. A flag halyard or the long line depending from a painter's scaffold form excellent subjects for the experiment. By grasping the lower end and giving the rope a sharp snap at right angles to the body, a sinuous wave will quickly travel to the upper end, its speed depending upon the sharpness of the snap causing it and its length upon the manner in which it is set in motion as well as upon the length of the rope itself. Upon reaching the upper end, the wave will start downward and, if sufficient energy has been employed, will travel back to the lower end, although greatly diminished in size and speed, and will again start upward, continuing until damped out. In fact, its size will be seen to decrease rapidly from the moment it starts. This decrease in size affords an analogy to *damping* in an electromagnetic wave, to which reference is made later.

Wave Measurements. In the same manner a wave in the ocean at some distance from the shore is motion through the water. The water rises and subsides, as may be noted by the fact that a floating chip rises and falls with the wave but is not carried forward perceptibly by it, unless there happens to be a current in the same direction. The wave passes *through* the body of water, leaving the surface the same after it has passed. A number of waves following one another is known as a wave train. The distance from the crest of one wave to that of the one preceding or following it is the wave length. The number of waves that pass a given point in a second is the wave frequency, while the speed with which a train of waves passes the same point per second is the velocity of the waves. These terms are all employed in connection with electromagnetic waves, the length and frequency representing the characteristics of the wave. The velocity is always the same, being equivalent to that of light, as explained under "Electromagnetic Waves", page 112.

Wave Motion. In order that wave motion may be set up in any body or medium, the medium must possess the properties of elasticity and inertia. Elasticity is that property by virtue of which bodies resume their original form or volume when the force which altered that form or volume ceases to act. Inertia is that universal property of matter by reason of which it tends to resist any change of motion or rest. Air possesses perfect elasticity in that it resists compression and, once compressed, quickly returns completely to its original state when the force causing the compression is removed. It likewise is possessed of inertia in that a body of still air resists a force tending to set it in motion and, when once moving, also resists those natural forces which tend to bring it to rest again. Its motion does not cease immediately when the force causing it is removed, but by virtue of its inertia continues a certain distance after the force has ceased to act upon it.

ELEMENTARY ELECTRICAL PRINCIPLES

STATIC AND CURRENT ELECTRICITY

Importance of Knowledge of Subject. A knowledge of electrical principles will prove a great aid in facilitating progress in the early study of wireless telegraphy, and it will be advisable, even for those well versed in the laws governing the everyday use of direct currents and low-frequency alternating currents, carefully to review this part of the work. The high-frequency currents employed in wireless telegraphy are not subject to the same laws in every instance and are, moreover, utilized in ways radically different from those common to commercial practice.

Static Phenomena. *Positive and Negative Charges.* The term electricity is derived from the Greek *elektron,* meaning amber, because it was found that when a lump of amber was rubbed briskly with a piece of silk both objects become electrified, or charged. Before being rubbed together the silk and the amber have no effect on each other when brought close together, but after they have been charged by friction it will be found that they attract each other. In cold dry weather after a brisk rubbing this attraction is quite strong. But another piece of silk that has been charged by friction against amber will repel the first piece and the same is true of the two lumps of amber. The silk is said to be positively charged and the amber negatively, and as it has been shown that the two objects have no effect upon each other before being charged, it is evident that it is the electrical charges on these objects that attract and repel each other and not the objects themselves.

Because it is produced by friction, the electrical charge resulting is often termed frictional electricity, which is more descriptive than correct. If, after being charged, the objects are not brought into contact with a conductor of any kind, they remain in this electrified state; in other words, the charge *stands,* and it is accordingly referred to as static electricity, to distinguish it from dynamic electricity, to which reference is made later. The positive charge of the silk is represented by the plus (+) sign and the negative charge of the amber by the minus (−) sign.

Charging and Discharging Bodies. When oppositely charged bodies are brought together they are not only attracted but also *discharged.* The opposite charges of the two bodies have neutralized each other and have ceased to exist, at least so far as the previously electrified state of the objects is concerned. By holding one of the electrified bodies close to a wire or other metal connected with the ground, a minute spark accompanied by a faint crackle will accompany the discharge, the latter taking place from the object to the earth. If, instead of being discharged by either of these methods, the electrified object be placed in contact with a conductor connected to the earth, the charge will leak away without giving any indication of its passing. When discharged directly to another object, the size of the spark produced increases with the extent of the charge. A discharge accompanied by a distinctly audible spark is termed one of high potential. To effect the discharge, it is not necessary to bring the objects in actual contact with each other, and the greater the distance through which the sparking occurs, the higher the potential.

Silk and amber have been cited as familiar instances of bodies capable of being electrically charged since they lend themselves very readily to electrification upon being rubbed. But all bodies, regardless of their nature, may be electrified. By briskly stroking the fur of a cat in cold weather a distinct crackling will be heard. The cat's fur becomes negatively charged and the hand of the person rubbing it positively charged. The static nature of the charge on any object that has been electrified may be readily demonstrated by permitting an interval of several minutes to elapse and then presenting another object to it, whereupon the discharge will be evidenced by a spark.

Dynamic, or Current, Phenomena. *Static and Dynamic Electricity Identical.* It was long considered that there was a difference in character between static and dynamic electricity, that is, that there were two different classes of electricity, so to speak. As the term implies, dynamic electricity is electricity in movement, a current of electricity usually being said to *flow* from one point to another. But whether it be in movement or quiescent in the form of an electrical charge on a body, representing kinetic energy in the first instance and potential energy in the second, it is one and the same thing in different states. There is also more or less misconception prevalent regarding dynamic electricity, in that it is popularly assumed to represent only a current produced by a dynamo or generator. The current from a dynamo may be utilized to charge a condenser and the charge of the condenser is then static electricity, while a current from a battery is dynamic electricity quite as much as that produced by a generator, so that it is the state or condition of electricity and not the method of its production that makes the distinction. In wireless telegraphy, dynamic electricity is utilized to produce static electricity in the form of a charge in a condenser and it is the distinctive nature of the discharge of the latter under certain conditions, known as an oscillatory discharge, which generates the electromagnetic waves that are radiated to form the means of communication between distant points.

Potential. Reference has already been made to the size of the spark produced upon discharge being dependent upon the potential of the charged bodies. If it be desired to transfer heat from one body to another, the amount of heat transmitted will depend upon how much hotter the first is than the second. Thus heat transmission, or conduction, is a measure of the difference of temperature. In the same manner, the rapidity of the flow of water from one level to a lower level is a function of the difference in levels. The greater the head, or height, of the upper body of water, the more rapid will be its transference to the lower level when released. In either case there may be said to be a difference of pressure. Potential is electrical pressure and, in order that current may flow, there must be *difference of potential,* that is, an electromotive force, usually abbreviated to e.m.f. or to E. It will be apparent that the greater the difference of potential, the greater will be the current passing from the point of high pressure to that of lower pressure, as illustrated by the increased size of the spark previously cited. Just as the head of water is measured in pounds pressure per square inch, so electrical pressure, or potential, is measured in *volts.*

Conductors. To transfer heat from one body to another the objects must either be brought into close proximity with each other or into actual contact, depending upon the difference of temperature. In the former case, the heat transference is said to take place by convection; in the latter, by conduction. In the same manner, a path must be provided for the flow of electricity and the nature of the path that can be utilized will depend upon the difference of potential. A highly charged condenser will discharge itself through the air gap intervening when a conductor is brought within a fraction of an inch of its terminal; no actual contact is necessary. But to cause a current to flow from a [illegible] cell, actual metallic contact must be made with both o[illegible] terminals. In the former case, there is a difference of potenti[illegible] many thousand volts with which to break down the air g[illegible] the latter, only 1½ volts.

It will be apparent from this that certain substances provide a much better path for electricity than others. Such substances are known as conductors and in this class are all the metals, carbon, acids, salt water, and the like. Naturally, these are not all equally good conductors. Pure annealed silver heads the list and is utilized to form a standard by which others may be compared. Its conductivity is given as unity (1) and the comparative effectiveness of other materials as conductors is known as their specific conductivity. For example, pure copper is next to silver and its specific conductivity is 0.92 to 0.94, varying with its purity and softness. Silver not being practically available, pure copper is sometimes given a specific conductivity of 1. From this point, the ability of metals as conductors of electric current ranges downward to such as iron, steel, and nickel, which have such a low specific conductivity that they are known as conductors of high resistance and are utilized chiefly for their ability to resist the passage of the current. Other substances that are conductors are carbon and water, the latter as ordinarily used. Distilled water is practically an insulator and becomes a conductor in proportion to the impurities it contains; the addition of alkalis or acids to it renders it a good conductor.

The ability of a particular substance as a conductor, however, is not dependent solely upon its character but also upon the amount of the substance employed for the purpose. A piece of pure copper wire will conduct a current 20 to 30 times better than a piece of hard steel wire of the same size, from which it follows that if the steel be made 20 to 30 times as large as the copper wire, it will conduct the same amount of current with the same facility as the copper. This is true of all conducting materials in proportion to their respective specific conductivities.

High-Frequency Conductors. Direct currents and low-frequency alternating currents, such as are employed commercially, utilize the entire cross-section of the wire or other conducting material for their passage. The most commonly employed frequency is 60 cycles, or 120 alternations, per second. A high-frequency current, such as employed in wireless telegraphy, is one having not less than 500 cycles, or 1000 alternations, per second. From this minimum the high-frequency currents employed range up to millions of alternations per second. High-frequency currents do not "soak into" the conductor, so to speak, but travel on its surface only, or, as it is termed, produce a skin effect. Copper is a good conductor of high-frequency currents while iron is an exceedingly poor one. But it was found that by copperplating an iron wire it became an equally good conductor even though the plating was little more than a surface coating, not exceeding one millimeter in thickness; in other words, the copperplating on the iron wire conducted the current with no greater resistance than the solid copper wire. Copper tubes or flat strips presenting the maximum surface are accordingly better conductors of high-frequency currents than solid wires of the same material. As stranded conductors present a greatly increased area of surface for the same diameter, connections of this kind are usually employed between the receiving instruments. One type of stranded conductor, called *litzen-draht* wire, is composed of a number of enameled copper magnet wires separately insulated from one another, twisted together in basket weave and the whole covered by a single braided silk covering. The tubes and strips are used for transmitting circuits where a much greater volume of current as well as high potential must be transmitted. Helices and oscillation transformers are examples of their use.

Insulators. It will be evident from the conductivity values given above that there are a number of substances which are not conductors at all. Such substances are known as insulators in that they prevent the passage of the current. Glass, wood, hard rubber, fiber, silk, porcelain, cotton, and dry air are familiar substances of this nature. Their effectiveness varies just as that of the various conductors does, while it also varies with their condition. None of the materials mentioned is a good insulator when wet, though in the latter condition it is not the insulator itself that conducts the current but the water on its surface. The effectiveness of the materials as insulators is also dependent upon the quantity of material, the insulators being proportioned to the difference of potential to which they are subjected. It has already been mentioned that the high-potential discharge of a condenser will bridge a gap of dry air. The moment the discharge passes, it renders the air of the gap conducting and the insulation is then said to be *broken down*. In the same manner, a thin sheet of hard rubber used to insulate two conductors between which there exists a great difference of potential will be punctured, whereas a sheet several times as thick would serve as a good insulator. In the case of a current of high potential flowing in the two conductors in question, the breaking down of the insulation would be manifested by an electrical discharge bridging the gap between the wires through the hole made in the hard rubber. This is termed an *arc* and it can only be ruptured by moving the conductors farther apart or by shutting off the flow of current. The formation of an arc is destructive to the conductors themselves as well as to the insulation, as it transfers metal from one to the other in the direction of the current flow.

Resistance. The difference between the conducting abilities of different substances has already been pointed out as well as the fact that this property varies with the amount of material employed as well as its nature. Resistance is accordingly said *to vary inversely as the cross-sectional area of the conductor and directly as its length.* For example, 1000 feet of No. 10 wire (see Table I) presents a resistance of slightly over 1 ohm to the passage of the current; the same length of No. 16 wire (having one-fourth the area) has a resistance of more than 4 ohms; while the resistance of No. 40 wire (having one-thousandth the area) is practically 1 ohm per foot. To wind a resistance coil of 10 ohms would accordingly require only 10 feet of No. 40 wire and almost 10,000 feet of No. 10 wire.

Mechanical resistance, as in the case of the loss of pressure in water flowing through pipes, is caused by friction. Electrical resistance is considered to be molecular friction in the atoms of the conductor and it produces heat just as mechanical friction does. The extent of the rise of temperature in a conductor depends entirely upon the proportion that its size, and, consequently, its current-carrying ability, bears to the amount of current that is sent through it. Resistance, however, is also caused by poor contacts, dirty contact surfaces, and improperly made joints in the conductors. In any case, power is being wasted and, with the infinitesimally small currents that must be relied upon to operate the receiving instruments in wireless telegraphy, losses that would

TABLE I

American Wire Gage (B. & S.)

No.	Diameter		Circular Mils	Ohms per 1000 Ft.	No.	Diameter		Circular Mils	Ohms per 1000 Ft.
	Mils	Mm.				Mils	Mm.		
0000	460.00	11.684	211600.0	0.051	19	35.89	0.912	1288.0	8.617
000	409.64	10.405	167805.0	0.064	20	31.96	0.812	1021.5	10.566
00	364.80	9.266	133079.4	0.081	21	28.46	0.723	810.1	13.323
0	324.95	8.254	105592.5	0.102	22	25.35	0.644	642.7	16.799
1	289.30	7.348	83694.2	0.129	23	22.57	0.573	509.5	21.185
2	257.63	6.544	66373.0	0.163	24	20.10	0.511	404.0	26.713
3	229.42	5.827	52634.0	0.205	25	17.90	0.455	320.4	33.684
4	204.31	5.189	41742.0	0.259	26	15.94	0.405	254.0	42.477
5	181.94	4.621	33102.0	0.326	27	14.19	0.361	201.5	53.563
6	162.02	4.115	26250.5	0.411	28	12.64	0.321	159.8	67.542
7	144.28	3.665	20816.0	0.519	29	11.26	0.286	126.7	85.170
8	128.49	3.264	16509.0	0.654	30	10.03	0.255	100.5	107.391
9	114.43	2.907	13094.0	0.824	31	8.93	0.277	79.7	135.402
10	101.89	2.588	10381.0	1.040	32	7.95	0.202	63.2	170.765
11	90.74	2.305	8234.0	1.311	33	7.08	0.108	50.1	215.312
12	80.81	2.053	6529.9	1.653	34	6.30	0.160	39.7	271.583
13	71.96	1.828	5178.4	2.084	35	5.61	0.143	31.5	342.433
14	64.08	1.628	4106.8	2.628	36	5.00	0.127	25.0	431.712
15	57.07	1.450	3256.7	3.314	37	4.45	0.113	19.8	544.287
16	50.82	1.291	2582.9	4.179	38	3.96	0.101	15.7	686.511
17	45.26	1.150	2048.2	5.269	39	3.53	0.090	12.5	865.046
18	40.30	1.024	1624.1	6.645	40	3.14	0.080	9.9	1091.865

otherwise be negligible are serious. Resistance also plays a very important part in the generation of electromagnetic waves, for unless it is kept below a well-defined relation to the other characteristics of the circuit the discharge of the condenser is not oscillatory in nature.

Relative and Specific Resistance. All substances resist the passage of electric current to a certain extent, ranging from a minimum for the metals up to the maximum represented by those materials known as insulators. Just as silver is adopted as the standard for the specific conductivity of materials so it is also used in measuring *relative resistance,* the unit chosen being the resistance of a 1-inch cube of annealed silver at 32° F. or, in the metric system, of a centimeter cube, Table II. For instance, the relative resistance of soft iron is 6.4, or practically six and one-half times as great as the resistance of silver, while that of lead is 13.05. The *specific resistance* S of a substance is the actual resistance in ohms of one cubic inch or one cubic centimeter of the material. For example, the last two columns of Table II show the

TABLE II

Resistance of Chemically Pure Substances at 32° F. in International Ohms

Metal	Relative Resistance	Resistance of a Wire 1 Foot Long 0.001 Inch in Diameter	Resistance of a Wire 1 Meter Long 1 Millimeter in Diameter	Specific Resistance in Microhms	
				Cu. In.	Cu. Cm.
Silver, annealed	1.000	9.023	0.01911	0.5904	1.500
Copper, annealed	1.063	9.585	0.02028	0.6274	1.594
Silver, hard drawn	1.086	9.802	0.02074	0.6415	1.629
Copper, hard drawn	1.086	9.803	0.02075	0.6415	1.629
Gold, annealed	1.369	12.35	0.02613	0.8079	2.052
Gold, hard drawn	1.393	12.56	0.02661	0.8224	2.088
Aluminum, annealed	1.935	17.48	0.03700	1.144	2.904
Zinc, pressed	3.741	33.76	0.07143	2.209	5.610
Platinum, annealed	6.022	54.34	0.1150	3.555	9.032
Iron, annealed	6.460	58.29	0.1234	3.814	9.689
Lead, pressed	13.05	117.7	0.2491	7.706	19.58
German silver	13.92	125.5	0.2659	8.217	20.87
Platinum-silver alloy (⅓ platinum, ⅔ silver)	16.21	146.3	0.3097	9.576	24.32
Mercury	62.73	570.7	1.208	37.05	94.06

specific resistance expressed in microhms (millionth ohms). The total resistance of a conductor accordingly varies directly as its length and its specific resistance and inversely as its cross-section. It would take twice as much soft-iron wire as it would of lead wire of the same size to present the same resistance to the current. Resistances connected in series are cumulative, that is, the resulting resistance is the sum of their resistances.

Resistances in Multiple. It will be apparent that connecting resistances in parallel, or multiple, affords an increased conducting area for the current so that the total resistance of several resistances in multiple is less than that of the smallest in the circuit. The total, or joint, resistance is thus equal to the reciprocal of the sum of the resistances.

To calculate the resistance of a conductor, it is only necessary to take the product of its specific resistance in ohms times its length in inches and divide by its cross-section in square inches; that is

$$R = S\frac{L}{A}$$

In th

nonin *High-Frequency Resistance.* It has already been stated under

natin head "High-Frequency Conductors", page 11, that high-frequency currents, such as the oscillatory discharge of a condenser, do not flow uniformly through the entire cross-section of the conductor but merely penetrate the surface to a very slight degree. Surface area rather than cross-section is accordingly the most important factor in the resistance of a conductor to a high-frequency current. This increased resistance to a high-frequency current as compared with a direct current or low-frequency alternating current is termed the skin effect, the oscillatory current being densest at the surface owing to the inductive effects which are proportional to the frequency. At very high frequencies a tube presents the same resistance to the oscillatory current as a solid rod of the same diameter would, because the current does not utilize even the full thickness of the walls of the tube. Owing to the increased inductive effect the resistance of an iron tube or rod would be correspondingly greater than similar conductors of copper. The great difference between the resistance of a conductor to a direct current and its resistance to one of high frequency is apparent from the instance cited by Rupert Stanley* in which the resistance of a No. 22 copper wire one meter long is 0.0431 ohm for direct current and 0.1207 ohm for a current having a frequency of 1,000,000 oscillations per second.

Noninductive Resistance. Every conductor possesses inductance, but, as it is essential that the inductance of the circuits employed in wireless telegraphy always be a well-defined quantity under close control of the operator, it is often desirable to employ a noninductive resistance. Resistance varies directly with the length of the conductor and inversely as its size, therefore, wire of small diameter is employed and to utilize it in the most convenient form it is wound in the shape of a coil; to prevent the great increase in the inductance of the circuit that this would otherwise bring about, the wire is doubled back on itself at its middle portion to form two strands and these are wound simultaneously, thus forming two spirals of an equal number of turns. The current, in traversing the entire coil, must flow through one spiral in one direction and in the opposite direction in the other sp[illegible] thereby nullifying the inductive effects of one spiral by th[illegible]esist- the other. A carbon rod, upon which a sliding contact bears [illegible] the [illegible]y the

* See Textbook of *Wireless Telegraphy.*

to bring more or less of it into the circuit, is another example of a noninductive resistance, as the amount of inductance in a carbon rod is so slight as to be negligible.

Ohm's Law. From the definitions of the electrical units it will be seen that all are closely related. Thus an ampere is that amount of current which a potential of one volt will force through a resistance of one ohm; in order to increase the current passing through this amount of resistance, the voltage must be increased, that is, doubling the voltage doubles the current, or the current increases in direct proportion to the potential. In the same manner, increasing the resistance decreases the current proportionally. Given a unit circuit through which one ampere is flowing under the pressure of one volt, the addition of one ohm of resistance cuts the current to one-half ampere; or, if it be desired to force one ampere of current through this circuit, the potential must be raised to two volts. From this interrelation of all three factors, electromotive force, or potential, current flow, and resistance, there has been deduced what is known as Ohm's law: *the strength of the current in a circuit is directly proportional to the electromotive force and inversely proportional to the resistance,* or *the electric current in a conductor equals the electromotive force divided by the resistance.*

Application of Ohm's Law. Ohm's law is fundamental and forms the basis of all electrical calculations, so that the student should become thoroughly grounded in its applications; without this it will be found difficult to form a clear conception of electrical circuits and the interrelation of the three factors upon which the energy carried by them depends. This relation is usually expressed

$$\text{amperes} = \frac{\text{volts}}{\text{ohms}}$$

or, using the symbol I for current, E for potential, and R for resistance

$$I = \frac{E}{R}$$

In this form Ohm's law applies only to direct-current circuits or noninductive alternating-current circuits. When inductive alternating circuits are involved, the law must be modified before being applied. It will be further apparent from this interrelation that, given any two factors, the third may readily be found, that is

$$E = I \times R$$

and

$$R = \frac{E}{I}$$

Applying the last equation to a practical case, take a 16-c.p. carbon-filament lamp, which on a 110-volt circuit requires 0.5 ampere to bring it to incandescence. Then

$$R = \frac{110}{0.5} = 220 \text{ ohms}$$

In case the resistance of the lamp and the voltages of the circuit are known

$$I = \frac{110}{220} = 0.5 \text{ ampere}$$

If the resistance and the current were the known factors, we would have

$$E = 220 \times 0.5 = 110 \text{ volts}$$

Assume now that it is desired to produce twice as much light from the bulb on the same circuit, then the problem is to find how much resistance the filament should have in order to pass the additional amount of current required. I will then be 1 ampere, E will equal 110 volts, and from Ohm's law, we have

$$R = \frac{110}{I} = 110 \text{ ohms}$$

In other words, *halving the resistance doubles the current.* Take the reverse instance in which it is desired that the lamp consume one-half as much current as the 16-c.p. bulb. Then

$$R = \frac{110}{0.25} = 440 \text{ ohms}$$

that is, *doubling the resistance halves the current.*

Examples. 1. If the e.m.f. applied to a circuit is 4 volts and its resistance is 2 ohms, what current will flow?

By the formula for current

$$I = \frac{E}{R} = \frac{4}{2} = 2 \text{ amperes}$$

Ans. 2 amperes

2. What voltage is necessary to cause a current of 23 amperes to flow through a resistance of 820 ohms?

By the formula for e.m.f.

$$E = RI = 820 \times 23 = 18860 \text{ volts} \qquad \text{Ans. 18,860 volts}$$

3. The e.m.f. applied to a circuit is 110 volts, and it is desired to obtain a current of 0.6 ampere. What should be the resistance of the circuit?

By the formula for resistance

$$R = \frac{E}{I} = \frac{110}{0.6} = 183+ \text{ ohms} \qquad \text{Ans. 183 ohms}$$

Series Circuits. In the examples just cited only a single resistance has been inserted in the circuit. Now taking a problem directly applicable to wireless telegraphy, suppose a wireless

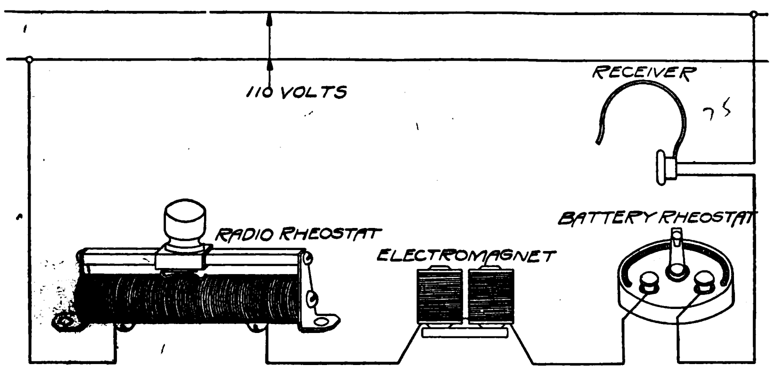


Fig. 1. Typical Series Circuit in Wireless Work

receiver of 75 ohms resistance, a De Forest audion rheostat of 10 ohms, an electromagnet of 125 ohms, and an adjustable radio rheostat of 10 ohms are connected in series in a 110-volt circuit as shown in Fig. 1. The total resistance in the circuit will evidently be equivalent to 220 ohms; that is, the same as that of the single 16-c.p. bulb of our original problem, and the current passing through all parts of the circuit will be 110÷220, or 0.5 ampere. The voltage drop, or fall of potential, over the whole circuit is 110 volts. Then the difference of potential between the terminals of each resistance must be that voltage which will drive 0.5 ampere through the given resistance, that is, the voltage drop at the receiver terminals is 0.5×75, or 37.5 volts. Similarly, the voltage drop at the audion rheostat terminals is 0.5×10, or 5 volts;

across the electromagnet terminals the voltage drop equals 0.5×125, or 62.5 volts; and across the radio rheostat terminals the drop is 0.5×10, or 5 volts, making a total of 110 volts.

This gradual fall of potential, or *drop* as it is commonly called, throughout a circuit, enters into the calculations for the size of conductors or mains supplying currents to distant points. The resistances of the conductors cause a certain drop in transmitting the current, depending upon their sizes and lengths, and it is therefore necessary that the voltage of machines at the supply station shall be great enough to give the voltage necessary at the receiving stations and also the additional voltage lost in the conducting mains.

Parallel Circuits. Suppose the audion battery rheostat and the radio rheostat of our previous example are so connected that the current is able to flow through the two resistances simultaneously, that is, *in parallel.* The voltage drop across these two resistances will evidently be equal to the full voltage of the circuit, 110 volts, and, as there are now two channels of equal resistance for the flow of the current, the amount of flow will be doubled and the resistance halved. If the two resistances are not equal, *the current will divide inversely as the resistance.*

If all four resistances are wired in parallel, four paths for the current are now offered. The current passing through each will vary as the resistance. For example, the current through the receiver will be $\frac{110}{75}$, or nearly 1.5 amperes; that through the audion rheostat and radio rheostat will be $\frac{110}{10}$, or 11 amperes each, that through the electromagnet will be $\frac{110}{125}$, or about 0.9 ampere, making a total of 24.4 amperes now flowing through the joint circuit. If the resistances of all four were equal, that is, if each were one-fourth of 220 ohms, the current would then divide equally among them, for, in each case, the relation of voltage to resistance would be $110 \div 55$, or 2 amperes; that is, 2 amperes would pass through each. In all these examples, in order to simplify the illustration, the resistance of the circuit itself has not been taken into consideration.

MAGNETISM

Comparison of Magnetism and Current Electricity. Magnetism and electricity are manifestations of the same force in different forms, as is readily evidenced by a few simple experiments. In fact, in the passage of a current, whether along a conductor or through the ether in the form of electromagnetic waves, the two are always present. In other words, a flow of current always creates a *magnetic field* which surrounds the conductor, the lines of force of this field being at right angles to the direction of the current flow.

Fig. 2. Bar Magnet

Certain forms of iron ore are magnetic as they occur in nature. One variety is called magnetite (Fe_3O_4) and pieces of it are natural magnets. They will attract scraps of iron or steel and when rubbed on a piece of hard steel will cause it to become permanently magnetic. The first artificial magnets were employed in the earliest forms of the compass (origin uncertain but the earliest records outside of the Chinese are about the twelfth century) and must have been made in this way. Artificial magnets are now made with the aid of the electric current and they are many times more powerful than could be produced with the aid of a lodestone, or natural magnet. A bar magnet is shown in Fig. 2, while Fig. 3 represents a horseshoe magnet, which in slightly different forms is used in direct-current measuring instruments, Figs. 53 and 54, as well as in the head telephones used for wireless receiving.

Poles of Magnet. By dipping a bar magnet into iron filings as shown in Fig. 4, a regular mass of the filings will be found to cling to the ends of the bar, the mass being greatest at the extremities and tapering toward the center, while at the center itself the filings are apparently not attracted at all. The ends of the magnet at which its strength is apparently concentrated are termed the poles of the magnet, as a magnet when freely suspended will always assume an approximately due north and south position,

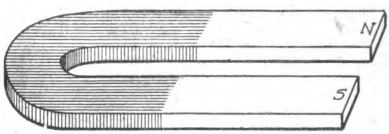


Fig. 3. Horseshoe Magnet

the ends are termed north, or N, and south, or S, poles, respectively. Such a suspended magnet is in effect a compass and the plane in which it comes to rest is the *magnetic meridian.* For the earth is itself a great magnet with an S pole near the geographical north and an N pole near the geographical south. This accounts for the directive force of the earth when a magnet is free to rotate on its axis.

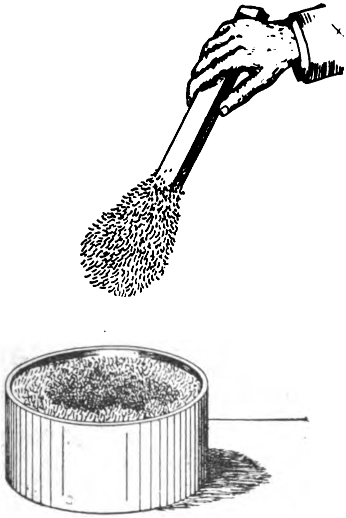


Fig. 4. Location of Poles of Magnet

Magnetic Attraction and Repulsion. Filings or scraps of iron or steel are equally attracted by either pole of the magnet, but if a piece of hard steel has been in contact with the magnet it will be found that thereafter there is no longer the same attraction regardless of the polarity. The piece of hard steel has become a magnet itself with its own north and south poles. If the magnet then be suspended so as to move freely, Fig. 5, it is found that if the two north poles are brought together, the suspended magnet will move away from the stationary one. If the north pole of the stationary magnet be presented to the south pole of the suspended magnet, they will attract each other and will adhere. This is known as the law of magnetic attraction and is expressed *like poles repel and unlike poles attract.* This is the principle on which the wattmeter operates except that instead of magnets there are employed certain electromagnetic fields, the strength of which varies in accordance with the voltage and amperage flowing in the windings setting up these fields. It is also the principle employed in the direct-current

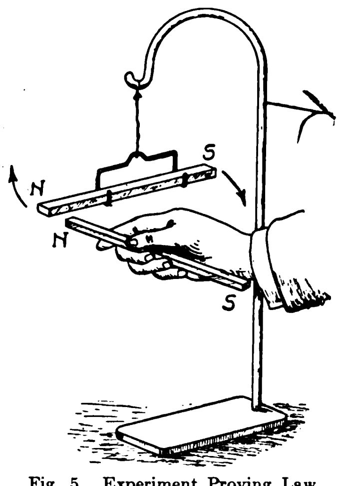


Fig. 5. Experiment Proving Law of Magnetic Attraction and Repulsion

voltmeter and ammeter, a permanent magnet being used to create one magnetic field while the other is electromagnetic and depends for its strength on the voltage or current.

Magnetic Substances. Iron and steel are the only common metals which are strongly magnetic. Nickel and cobalt are attracted by strong magnets, while bismuth, antimony, and some other metals are repelled, though the repulsion is weak, so that until recently iron and steel were the only metals whose magnetic properties were sufficiently strong to make them of any value as magnets. Some alloys of nonmagnetic materials, such as copper, manganese, and aluminum, make comparatively strong magnets. These are known as Heusler alloys. They are composed of copper, manganese, and aluminum in various proportions; the composition exhibiting the best magnetic properties is 14.3 per cent aluminum, 28.6 per cent manganese, and 57.1 per cent copper.

Permanent Magnets. When a piece of hard steel has been brought within the influence of a magnet, it is found to have retained a certain percentage of the magnetism which attracted it. By stroking the magnet with the hard steel the percentage of magnetism retained is greatly increased; in fact, the steel bar becomes almost as powerful a magnet as that from which it obtained its magnetism. It is then known as a permanent magnet for, unless subjected to heating or hammering, it retains its magnetism almost indefinitely. By bringing a piece of soft iron within the field of influence of a permanent magnet or in actual contact with it, the iron also becomes magnetic. It will in turn attract other magnetic metals and follows the law of magnetic attraction when another magnet is presented to it. But, as soon as it is withdrawn from the permanent magnet, it loses practically all except what is termed residual magnetism, which is so weak that the iron is to all intents and purposes no longer magnetic. Soft-iron can thus form only a temporary magnet. The property of steel which causes it to resist magnetization and, once magnetized to retain its magnetism, is known as its retentivity. Hard steel possesses this property to a greater extent than any other metal.

Permeability. Magnetic lines of force are said to permeate the air or any substance within the influence of the magnetic field.

The permeability of air at atmospheric pressure is unity in this respect, and the ease with which magnetic lines of force are conducted by different substances with relation to air is expressed in figures and is termed their magnetic permeability. Thus this factor for air is 1, while for pure wrought iron it is 3000, that is, a piece of this iron will transmit 3000 times as many magnetic lines of force as an air gap of the same dimensions.

Electromagnets. Some of the experiments mentioned as demonstrating the identity of electricity and magnetism are as follows: When current is passed through the windings of a telegraph sounder or relay, the soft-iron cores of the coils become strongly magnetic, as does also the armature, which is attracted. Instead of the soft-iron armature ordinarily provided, one of hard steel is substituted and the current passed to convert it into a permanent magnet. Then the sounder s disconnected from the battery and connected to a galvanometer. If the armature is vibrated rapidly by mechanical means, a current of electricity will be induced in the coil windings the strength of which will be indicated by the reading of the galvanometer. The faster the magnetic armature is moved up and down, the stronger this current will be.

By taking a bar of iron or steel and winding several turns of insulated wire around it and then passing a current from a battery through this wire, the bar becomes magnetic, one end of it being the positive, or plus, or north, pole of the magnet, and the other end, the negative, or minus, or south, pole of the magnet, these terms being used interchangeably. If the bar is of iron, breaking the circuit causes the magnetism to disappear instantly; if of steel, the bar has become converted into a permanent magnet and by connecting the coil to the galvanometer and then inserting and withdrawing the bar magnet rapidly the galvanometer needle will be deflected. The coil with the iron bar in it is an *electromagnet,* since it is only magnetic while a current is passing through the windings. The polarity of such a magnet may readily be determined by bringing close to it another movable magnet, such as a pocket compass. Let the needle come to rest and then present the north pole of the latter to one end of the electromagnet. If the needle continues to point in the same direction and gives evidence of being strongly attracted, the end to which it is being held is the south pole of the electromagnet. Approach the north pole of the compass to the other end of the electromagnet and the needle will be deflected sharply, demonstrating magnetic repulsion. The bobbins, or coils, of telegraph sounders and relays are common forms of electromagnets as are also the field coils of a dynamo. A polarized relay is an example of the use of a permanent magnet (the armature) in conjunction with an electromagnet; another very common example of this is the magneto used for ignition on automobiles, the fields consisting of permanent magnets while the armature is an electromagnet. An electromagnet, however, does not necessarily comprise both a winding and a core. An electric current in a conductor sets up a magnetic field about the conductor and by winding the conductor in the form of a coil, this magnetic field is greatly increased, so that the coil alone becomes an electromagnet. In this form, it is known as a solenoid. By inserting a bar of iron in the coil the magnetic effect becomes much greater, since the permeability of the iron is many times that of the air otherwise occupying the hollow of the coil.

Magnetic Field. The magnetic effect produced about a conductor or existing in a magnet exerts its influence in a well-defined direction, and in the case of an electromagnet this is always at right angles to the current producing it. The existence of this field may be demonstrated by placing a bar magnet under a piece of glass, Fig. 6, and scattering some iron filings on the glass. By tapping the latter and tilting it first one way and then the other to bring all the filings within the influence of the magnet, they will arrange themselves symmetrically as illustrated, indicating the existence of a well-defined magnetic strain or force. This is a graphic illustration of the field of influence of a magnet, usually termed the magnetic field. This field is most powerful at the poles, as will be noted by the attraction of the filings at the N and S points, representing the north and south poles of the magnet. The field existing about a single pole of the magnet may be demonstrated by bringing one of the poles up under the center of the glass, as illustrated in Fig. 7.

Magnetic Flux and Circuit. Referring further to Fig. 6, it will be noted that the filings have arranged themselves as if to indicate a rotary movement taking place between the north and south poles of the magnet, and this is also equally apparent in the case of the magnetic field existing about a conductor carrying a current, Fig. 8, and in the field about a coil, Fig. 9. In all these

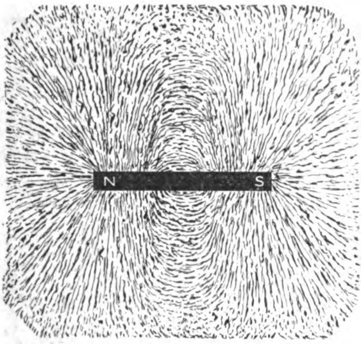


Fig. 6. Field of Force about Bar Magnet

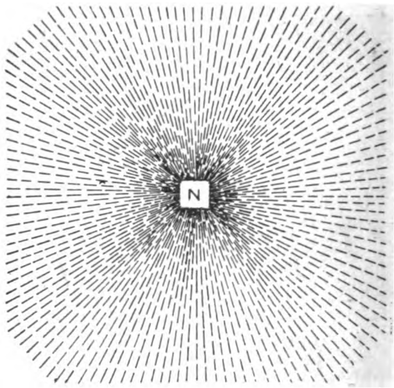
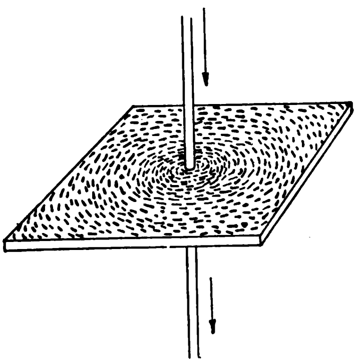


Fig. 7. Field of Force about Single Magnetic Pole

instances, the arrangement of the filings indicates the distribution of what are known as the lines of magnetic force, while their apparent rotation shows the direction of *magnetic flux*, or flow of these lines of force from one pole to the other, which is termed the



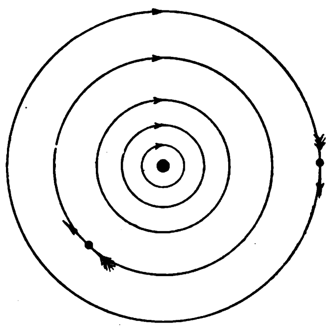


Fig. 8. Field of Force about Conductor Carrying Current

magnetic circuit. Just as the electric current flows from the positive terminal of a battery to the negative, the magnetic lines of force flow from the north to the south pole.

Magnetic Induction. A test would show that all the filings used in the experiment, Fig. 6, had become temporary magnets and that each was possessed of two unlike poles, the same as the bar magnet itself. Thus the ends of the filings closest to the north pole of the magnet would show a negative, or south, polarity, while those closest to the south pole of the magnet would show the reverse. Magnetism has been *induced* in the filings and they continue to act as magnets themselves as long as they remain in the magnetic field. If the field be an electromagnetic one, then any iron within its field of influence may be converted into a magnet by induction by turning the current on or may be as quickly demagnetized by turning the current off. This is the principle by which a strong magnetic field is created in the secondary of an induction coil (transformer) or in the secondary of a wireless oscillation transformer.

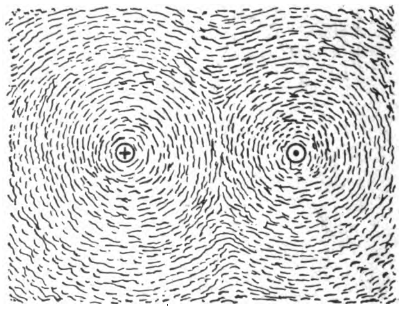


Fig. 9. Field of Force about Coil

Magnetic Saturation. As the current flowing through the windings of an electromagnet is increased, the strength of the resulting magnetic field is found to increase in proportion. However, as the magnetizing force increases, the lines of force in the field tend to reach a point beyond which no further increase of current produces any greater strength in the magnetic field. There is apparently no limit to the magnetization of air, but when other magnetic substances, such as iron, reach this maximum they are said to be saturated—borrowing a term commonly used to designate a solution formed from fresh water into which salt has been poured until it will no longer dissolve. Beyond this point the iron will not hold any more magnetism regardless of the amount of current producing it. Magnetization is accompanied by the production of heat and rapid changes of the magnetizing force occasion slight sounds, as will be noted in the operation of large electric generators. The heating effect is minimized by building up the cores of electromagnets of many small parts instead of making them solid. Thus the cores of the field poles and the armature of a generator are made of hundreds of sheets of thin iron with shellac or thin paper between them to act as an insulator, while the cores of induction coils are made up in the form of a bundle of very fine wires rather than as a solid bar. This construction minimizes what are known as eddy currents, which cause the heating of the metal, and has the further advantage of decreasing the time necessary to bring the core to the point of saturation and to demagnetize it again.

Solenoid. The direction of the exciting current and that of the resulting magnetic force bear the same relation to one another as the travel and rotation of an ordinary right-hand screw thread. Consequently, if the conductor be looped instead of straight, the lines of magnetic force will surround it as illustrated in Fig. 10. The magnetic field of such a loop, if outlined with the aid of filings or explored with a pocket compass, will be seen to retain the general character of the field surrounding a straight conductor, so that all the lines of force leave by one face and return by the other, the entire number passing through the loop. Hence, one face of the loop will be equivalent to the north pole of a magnet and the other face to the south pole. The loop will act exactly as if it were a thin disc magnetized. By winding a number of these loops to make a hollow coil there is formed a *solenoid*, Fig. 11. Exploring its field shows that the lines of force pass directly through the center or opening of the coil, leaving by one end and returning at the opposite end, as indicated by the dotted lines which represent the magnetic circuit of the solenoid. While these lines are drawn uniformly, the number of lines of magnetic force is very much greater at the ends, or poles, of the solenoid than at the center. The direction taken by these lines of force is from the north pole to the south pole outside of the coil and from the south pole to the north pole inside of it, but the polarity of the coil itself, which is responsible for this direction, depends upon that of the current flow.

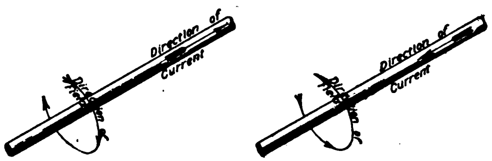


Fig. 10. Direction of Magnetic Lines about Conductor

If the arrows shown on the coil were reversed to indicate that the current was flowing in the opposite direction through the windings, the right-hand end of the solenoid would then be the north pole instead of the south. The strength of the magnetic field about a solenoid is directly proportional to that of the current flowing in its windings. By placing a soft-iron core in the hollow of the coil so that its end extends in part way, the solenoid being held vertically, a current passed through the latter will instantly draw the core up into the coil and hold it there. If direct current is employed the core will remain in place as long as the current flows, but the moment the current is shut off the core loses its magnetism and will again drop out. With the core held in place by its magnetism, reversing the current through the coil would merely change its polarity, but if it were of steel it would be forced out since like poles repel. The principle of the solenoid is employed in automatic motor starters to operate electromagnetic switches.

Effect of Iron Core. Inserting a soft-iron core in the hollow of the solenoid greatly increases the number of lines of force, or magnetic flux, due to the much higher magnetic permeability of iron as compared with air; in other words, iron is a very much better conductor of magnetism than air. The presence of the iron core in the solenoid also greatly increases what is known as its self-induction, which is explained under the head "Inductance, or Self-Induction", page 34.

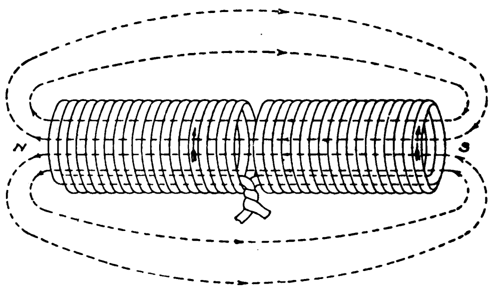


Fig. 11. Magnetic Field about Solenoid

INDUCTION

Simple Induction Principle. *Current Induced in Coil by Magnet.* It has been pointed out that when one end of a bar of iron is brought into contact with a pole of a magnet, the bar also becomes a magnet, the polarity of the end in contact being opposite to that of the permanent magnet. Magnetism has been *induced* in the iron bar, but it ceases as soon as the bar is withdrawn from the field of the permanent magnet. If, instead of a plain bar, a coil *C*, Fig. 12, whose terminals are connected to a galvanometer or current detector is placed in the field of the magnet, the needle of the galvanometer will deflect momentarily and return to rest. When the coil is suddenly withdrawn from the magnetic field, the needle will again deflect but in the opposite direction. There is no reaction apparent as long as the two remain motionless. A current has been induced in the windings of the coil by thrusting the coil into the field of the magnet and then withdrawing it, thus cutting the lines of magnetic force of the magnet.

Current Induced in Coil by Another Coil Bearing Current. Now take a coil, Fig. 13, and, connecting it in circuit with a battery and switch, place this coil close to another coil which is connected to a galvanometer. On completing the circuit by closing the switch, a movement of the galvanometer needle will be observed; opening the switch will cause a second movement of

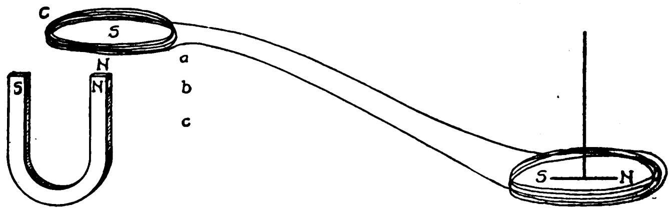


Fig. 12. Diagram Illustrating Principle of Electromagnetic Induction

the needle in a direction opposite to the first. When the circuit was closed the current created a magnetic field about the coil connected to the battery. The lines of force of this field were cut by the stationary coil near by and a current was induced in its windings. This cutting of the magnetic lines only occurred either when a movement of the magnetic field took place, Fig. 12, or when the magnetic field was rising or falling in strength, as was the case when the battery circuit was made or broken.

If, while coil *A*, Fig. 13, is inside of *C* and has a steady current flowing in it, we insert a core of soft iron into *A*, we shall make *A* a strong electromagnet, thus greatly increasing the magnetic flux through *C* and inducing a current in *C* which *opposes* these magnetic changes, that is, a current in *C* opposite to that in *A*. Upon removal of the soft-iron core, the induced current in *C*, for the same reason, will flow in the *same* direction as that in *A*.

Thus we see that the currents induced in *C* are made greater by using stronger currents and a soft-iron core in *A*.

In all cases, *the induced current in a coil is due to the change in the number of lines of magnetic force (flux) through the coil.*

On making the current in the primary coil, the current induced in the secondary coil is opposite in direction to that in the primary.

On breaking the current in the primary coil, the current induced in the secondary coil is in the same direction as that in the primary.

Dynamo, or Right-Hand, Rule. In the above discussion of induced currents, reference was made to the change of direction

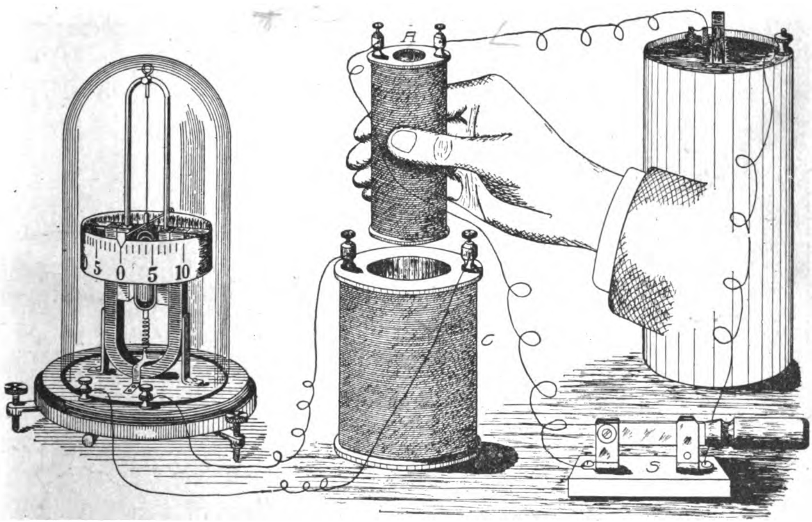


Fig. 13 Experiment Illustrating Currents Induced by Currents

of the current with the change of direction in which the lines were cut. This has been clearly laid down in a rule known as the dynamo rule, as follows: *If the* ***forefinger*** *of the* ***right hand*** *points in the direction of the magnetic lines, Fig. 14, and the* ***thumb*** *in the direction in which the conductor is cutting these lines, then the* ***middle finger,*** *held at right angles to both thumb and forefinger, will point in the direction of the induced current.*

Dynamo Principle. A dynamo is essentially nothing but a coil of wire rotating continuously between the poles of a magnet. Thus, suppose that starting with the coil in the position shown in

Fig. 15, it be rotated through 180 degrees from left to right as one looks down upon it. During the first half of the revolution, the wires on the right side of the loop are cutting the lines of force as they move toward the reader, while the lines on the left side are cutting the same lines as they move away from the reader. Hence, by applying the dynamo rule, we find that a current is being generated which flows down on the right side of the coil and up on the left side. It will be seen that both currents flow around the coil in the same direction. The induced current is stronger when the coil is in the position shown in Fig. 16, because there the greatest number of lines of force is being cut. Just as the coil is being moved into or out of the position shown in Fig. 15, it is moving parallel to the lines of force and hence no current is induced, since no lines of force are being cut. As the coil is now moved through the last 180 degrees of a complete revolution, both sides are cutting the same lines of force as before, but they are cutting them while moving in a direction opposite to that in which they were first moving, hence the current generated during this last half is opposite in direction to that of the first half. If the coil is continuously rotated in the field, therefore, an alternating current is set up in it, which reverses direction every time the coil passes through the position shown in Fig. 15. This is the essential principle of the alternating-current dynamo. The direct-current dynamo differs from the alternating-current dynamo, only in that a so-called commutator is used for the purpose of changing the direction of the current in the external circuit every time the coil passes through the position shown in Fig. 15, so that the current always flows in the same direction through this external portion of the circuit

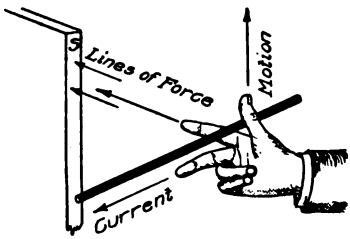


Fig. 14. Illustrating Dynamo, or Right-Hand, Rule

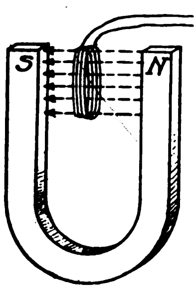


Fig. 15. Position of Coil for Weakest Induced Current

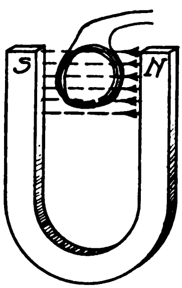


Fig. 16. Position of Coil for Strongest Induced Current

in spite of the fact that in the rotating coil it changes direction every half-revolution.

Transformer Principle. If, in the experiment illustrated by Fig. 13, coil *A* is lowered into coil *C* and a current that is rising and falling in opposite directions (an alternating current) is substituted in coil *A* for the constant current of the battery, a similar current induced in the windings of coil *C* will be indicated by the galvanometer. But the current induced in coil *C* will rise and fall, or alternate, in a direction opposed to that in coil *A*. This represents the fundamental principle of the transformer. It is also evident that to induce a current in a conductor, the latter must either cut the lines of force by its movement through the field of the magnet or the magnetic field itself must be successively created and destroyed. If the magnetic field, or what is the same thing the current setting it up, remains constant no reaction takes place. It should also be noted that the position of the second coil relative to that of the first is a factor; if, instead of being parallel, the two coils are at right angles to each other, the current induced in the second coil will be greatly reduced. The reason for this will be clear upon noting the magnetic circuit of the solenoid as shown in Fig. 11. In such a position only one end of the second winding would be cut by the magnetic lines of flux from the first winding.

Mutual Induction. In the foregoing experiments in connection with Fig. 13, mention has been made only of the reaction brought about in coil *C* due to electromagnetic induction. But it has been pointed out that when a current from the battery is sent through coil *A* so that the magnetic field is rising, the induced current in coil *C* is in the *opposite direction.* When the circuit is broken and the magnetic field is falling, the galvanometer shows that the induced current is then *reversed* so that it is flowing in the same direction as the initial current in coil *A*. It accordingly induces a current in coil *A*. This is termed mutual induction and it is a most important factor in the control of the electromagnetic waves radiated from the sending station of a wireless set. Circuits placed in inductive relation to one another mutually react, and the strength of this reaction depends upon their relative positions and upon the distance separating them. If they are close to each other, their mutual induction is at a minimum when they are placed at right angles to each other. This is taken advantage of in the design of the oscillation transformer.

Inductance, or Self-Induction. *Inertia Analogy.* A direct analogy to self-induction exists in what is known as inertia in mechanics. All bodies, whether solid or gaseous, possess inertia, which is the property of resisting any change of rest or motion. For an engine to set a railway train in motion takes many times the effort, in pounds per ton of draw-bar pull, that it takes to keep the train moving when it has once started rolling. And when it is traveling at good speed, a great deal more force is required to bring it to a stop than is required to continue hauling it at that speed. In other words, it resists either starting or stopping and the power necessary to overcome this resistance is all out of proportion to the amount of energy necessary to maintain the train in motion. An everyday illustration of inertia, the force of which will at once be apparent, is to be found in the action of a passenger alighting from or jumping on a street car. When the car is traveling at full speed, the passenger must jump in the same direction that it is proceeding and run with it for a short distance before he can overcome his own inertia; when he is standing on the street and attempts to board a speeding car, he must also run along with it until his inertia of movement approaches that of the car before he can safely jump on it.

Application to Coil. When a conductor is in the form of a coil the magnetic field set up around it by a current is greatly increased and by placing an iron core in the coil the strength of this field is still further increased. But the iron resists magnetization to a certain extent so that the field does not reach its maximum strength until the core has become magnetically saturated. This is the electrical equivalent of the inertia that must be overcome in starting a train. When the magnetic field is at its maximum it similarly resists any drop in its strength, which corresponds to the inertia of movement that must be overcome by the brakes in stopping the train. As an increase or decrease of current in the conductor causes a similar variation in the number of lines of force in the magnetic field, so any change in the current will induce an electromotive force in the conductor.

This property which opposes both the building up and the dying out of the current is called self-induction when the induced e.m.f. is in the *same* circuit in which the current change takes place. The induced e.m.f. is the momentary e.m.f. which is set up in the opposite direction to the change that is taking place and it is this e.m.f. induced in the circuit which keeps the current down. Inductance is a property of the circuit itself—not of the electric current or voltage—and it depends entirely upon the shape and size of the circuit and upon the magnetic permeability of the surrounding medium. The term inductance is accordingly rather freely used in wireless telegraphy to designate any conductor in the form of a coil used either in the sending or receiving circuits of a wireless set. A coil, however, may be wound noninductively by reversing the direction of each alternate turn, as explained under "Noninductive Resistance", page 16. With direct current, self-induction only occurs when the circuit is made or broken or when the strength of the current changes; with alternating current, which is not only periodically reversing in direction but at the same time is rising and falling in strength, the self-induction is likewise rising and falling and changing in direction. The electrical inertia thus set up is taken advantage of in the design of the choke coils, or reactance coils, employed to control alternating currents.

Laws and Measurement of Inductance. This self-induced e.m.f. is always in a direction opposing the change of current which produces it. If the current is increasing, the induced e.m.f. is opposed to the inducing current, thus tending to prevent the increase of current. When the current is decreasing, the induced e.m.f. is in the same direction, thus tending to prevent its falling off. All conductors possess this property of self-induction but that of a coiled wire is much greater than that of a straight wire. The inductance of a coil without a core is practically constant for a constant magnetic field. Inserting an iron core in the coil greatly increases its inductance because of the greater permeability of iron than air; that is, the iron core affords a much easier path for the passage of the magnetic lines of force than the air core, consequently, a much greater percentage of the leakage lines pass through the iron core. Inductances used in the circuits employed in wireless telegraphy are always made without cores as excessive self-induction is an undesirable factor. Their diameter is also large in proportion to their length and they consist usually of only single layers of wire to prevent the coils from acting as electrical capacities or condensers and because high-frequency currents travel only on the surface of the conductor.

Coefficient of Inductance. The self-inductive effect set up in a coil or any conductor depends upon the rate at which the current is changing. As a basis for comparison and calculations, a rate of change of *one ampere per second* is defined as unity and is termed the coefficient of inductance. The unit of inductance is the *henry* (so named after Professor Henry, an American scientist), and to have an amount of inductance representing one henry, a circuit must be of such dimensions that a change of one ampere of current per second will induce in it an e.m.f. of one volt. To do this the current of one ampere must create in the circuit a magnetic field consisting of 100,000,000 lines of force, so that the henry may further be defined as a unit representing the cutting of 100,000,000 lines of force in a circuit in which a current is rising and falling at the rate of one ampere per second. The symbol for inductance is the letter L.

The henry is naturally too large a unit to be employed for practical purposes in wireless telegraphy, so inductances are measured in subdivisions of one thousandth and one millionth of a henry, known respectively as millihenrys and microhenrys. Inductance is also measured in centimeters, 1000 centimeters being the equivalent of one microhenry, so that quantities expressed in one unit can readily be transformed into the other, either by dividing or multiplying by 1000.

Calculations for Self and Mutual Inductance. The formula for calculating self-inductance is

$$L_s = \frac{4\pi^2 N^2 r^2 \mu}{10^9 l}$$

in which L_s is the inductance in henrys; N is the number of turns; μ (Greek letter mu) is the permeability of the core; l is the length of the core in centimeters; and r is the mean radius of the coil.

The formula for calculating mutual inductance is

$$L_m = \frac{4\pi^2 N_1 N_2 r^2 \mu}{10^9 l}$$

in which N_1 is the number of turns on one coil; N_2 is the number of turns on the other coil; and r is the radius of the inner coil in centimeters. This formula will hold for two coils wound on the same magnetic core and having about the same diameter. It will be noticed that this formula is the same as that for self-inductance, except that instead of squaring the total number of turns in both coils the number of turns in one coil is multiplied by the number of turns in the other.

GENERATORS

Classes of Generators. Electromagnetic induction is the basic principle of operation of the generator, or dynamo-electric machine, designed to transform mechanical into electrical energy. Generators are of two general types, one designed to produce an alternating current which reverses periodically and rises from zero to a maximum in each direction, while the second produces a direct current, that is, one which always flows in the same direction in the external circuit and at a constant rate, depending upon the load.

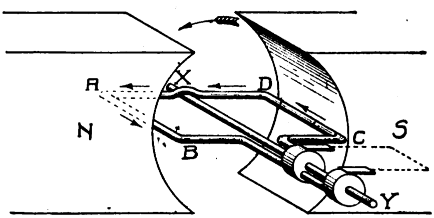


Fig. 17. Elementary Principle of Generator

Elementary Dynamo. *Method of Producing Current.* Whenever lines of magnetic force are cut by a conductor, an e.m.f. is induced in the conductor the strength of which is dependent upon the speed and the number of conductors cutting the magnetic field. For example, in Fig. 17, which illustrates the principle of the dynamo, if the loop of wire will produce an e.m.f. of one volt at a speed 100 revolutions per minute, this e.m.f. may be increased to two volts either by revolving the coil at 200 r.p.m. or by adding another coil. *ABCD* represents a coil, consisting of a single turn, arranged to rotate in the field of the permanent magnet whose poles are indicated by N and S. Each end of the coil is connected to a collector ring, the rings being mounted on the shaft and insulated from one another. Brushes for conducting the e.m.f. induced in the coil to the external circuit bear upon these collector rings. This is an alternating-current generator in its simplest form and thousands of this simple type are employed for ignition on motor cars as well as in the old hand-ringing type of telephone; they are known as magnetos because permanent magnets in horseshoe form are used to provide the magnetic field. In commercial alternators the magnetic field is produced by field coils, which are excited by some outside direct-current source, usually a d.c. generator termed the exciter.

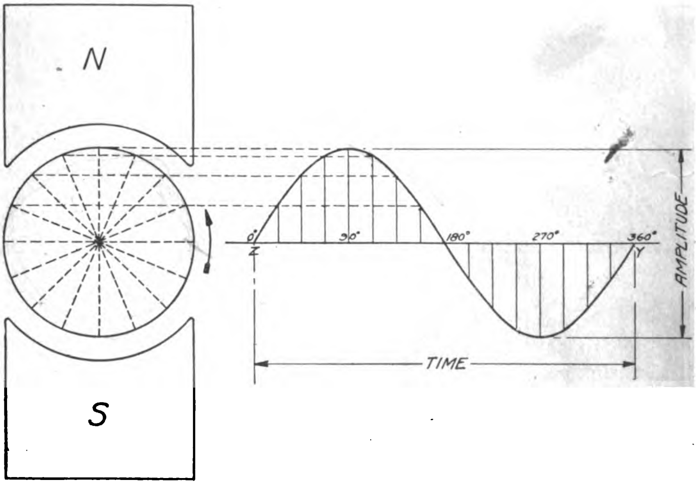


Fig. 18. Curve Showing Variation of E.M.F. in One Revolution of Generator Armature

Current an Alternating One. Referring to the illustration, Fig. 17, if the coil be rotated to the left, as indicated, it will have an e.m.f. induced in it in the direction shown by the arrows. The e.m.f. induced in *AB* and *CD* will be of maximum value at the position shown, as the conductors are then cutting the magnetic flux at right angles and are consequently passing through a greater number of lines of force than at any other part of the revolution. Note that as *CD* moves up *AB* moves down, and *vice versa,* across the magnetic flux, so that the e.m.f. induced in all parts of the loop at any instant is flowing in one direction. As the coil approaches the vertical position, this e.m.f. decreases as the number of lines of force being cut is diminishing until, when the coil is perpendicular, both the cutting of the magnetic flux and the generated e.m.f. are at zero. Continuing the rotation, the rate again increases until at 180 degrees it is once more at a maximum. The cutting, however, in this second quadrant and the one following is in the opposite direction to that occurring in the first quadrant, so that the direction of the e.m.f. generated has been reversed. At the end of the third quadrant the generated e.m.f. again reverses to the original direction and rises to a maximum at the starting point. Plotting this through an entire revolution gives the curve shown in Fig. 18 which represents the rise and fall of e.m.f. during one complete cycle. If the cycle had required one second for its completion, the frequency of the generator would be one cycle. Alternating-current generators in general commercial use have a frequency of 60 cycles, or 120 reversals of current, per second. For wireless service, generators having a frequency of 60, 240, and 500 cycles are in common use, while, for wireless telephony, a.c. generators of special design having a frequency running into the thousands or hundreds of thousands of alternations per second are employed. The frequency of an a.c. generator depends on the number of field poles and the speed of the armature in revolutions per second.

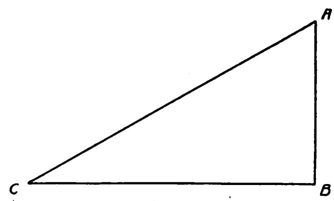


Fig. 19. Triangle Showing Sine Relation

Plotting Curve of Current. In the rise and fall of a current during a complete cycle, the e.m.f. as plotted in Fig. 18 is said to describe a *sine curve* and an e.m.f. of this character is often referred to as a sinusoidal e.m.f. The different values of the angle in degrees and the corresponding time in seconds are both shown to scale on the *abscissa,* or horizontal line, so that *zy,* which represents a complete cycle, also gives the frequency of the current. If the time consumed in the completion of this cycle is $\frac{1}{60}$ second, the frequency is 60 cycles; if $\frac{1}{500}$ second, 500 cycles. The vertical lines, termed the ordinates of the curve, are a measure of the *amplitude* of the e.m.f. or current wave, as the case may be. The reason for terming this a sine curve is because the rise of the curve is proportionate to the sine of the angle made by any of the ordinates at its junction with the abscissa *zy,* the maximum ordinate or radius of the circle being unity. In the right-angle triangle ABC the ratio of AB to AC, Fig. 19, is the sine of the angle ACB, that is, $\frac{AB}{AC}$ equals sine ACB. An alternating current, the rise and fall of which is represented by such a sine curve, is termed a simple harmonic, or periodic, current.

Alternating-Current Generators

Commercial Types. While Fig. 17 represents the basic principle of the alternator, in practice, the machine is naturally built

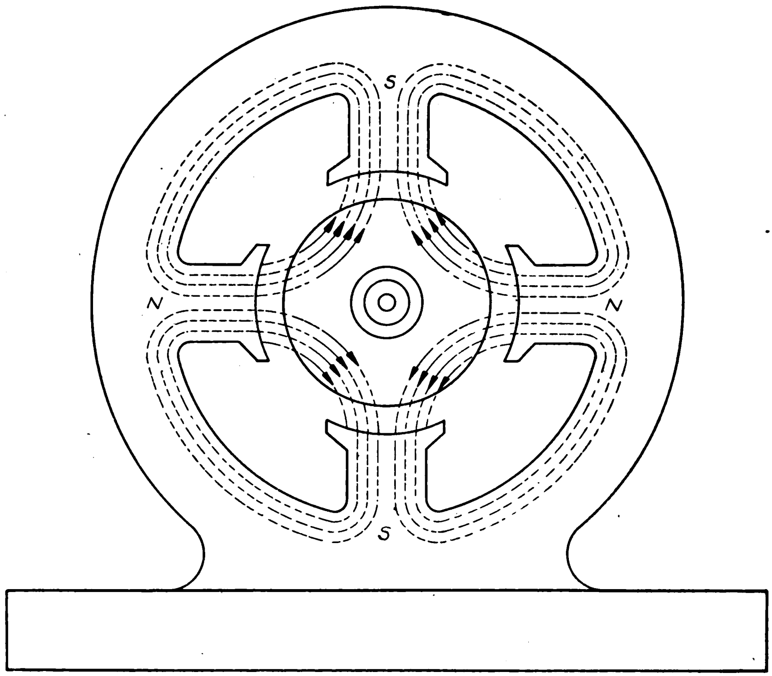


Fig. 20. Magnetic Flux in Alternator

with a multipolar field in order that the desired frequency may be attained without excessive speed. Electromagnetic fields are also employed in place of the permanent magnets indicated, though the latter are used extensively in ignition and telephone magnetos. In Fig. 20 is illustrated the distribution of magnetic flux through the armature and field poles of a simple machine of this type during one revolution, while the complete circuits of a small alternator are shown in Fig. 21. From the latter, it will be noted that a complete cycle occurs during the time in which the armature is revolving past each pair of pole pieces. These pole pieces are magnetized by coils which are excited by a small direct-current generator, so that in the alternator there is no electrical connection between the armature and the fields.

The armature is also wound with a great many turns of wire all connected in series with one another so that the e.m.f. generated

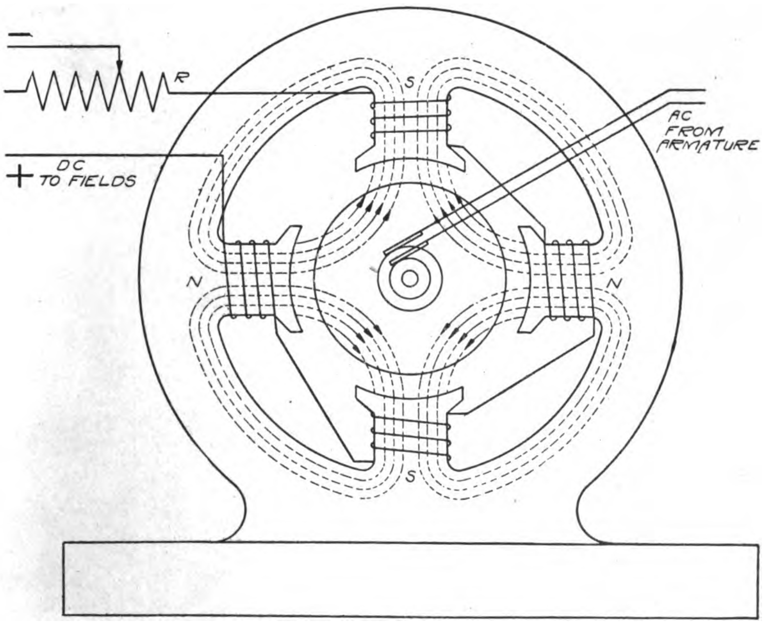


Fig. 21. Complete Circuits of Alternator; Direct Current Exciting Field, Alternating Current Flowing Out of Armature

in them is cumulative, exactly as in the case of a number of battery cells connected in series. The waves of e.m.f. and current flow from the alternator through two collector rings, as illustrated on the elementary machine, the voltage depending upon the number of poles, the speed of rotation, and the strength of the magnetic field. For commercial service, alternators are wound to generate current at 110, 220, 1100, 2200, and 6600 volts or intermediate voltages. The generator end of the motor-generator set generally employed in marine wireless sets is usually wound for 100 to 500 volts and to charge the condensers of the oscillatory circuit the potential is stepped-up by means of a transformer to 15,000 to 30,000 volts.

Factors Influencing Output. As the output of the generator depends upon the strength of its fields and the speed of rotation of its armature, means are provided for varying these two factors. The strength of the fields is proportional to that of the current in amperes times the number of complete turns in the windings of the coil on the whole piece, in other words, the number of *ampere-turns*. One ampere of current flowing through ten turns of wire is the equivalent of ten amperes flowing through one turn; hence, a large number of turns are made in the windings, and as this is a fixed quantity the strength of the field can only be varied by varying the strength of the current. A *rheostat*, or variable resistance, is accordingly inserted in series between the source of exciting

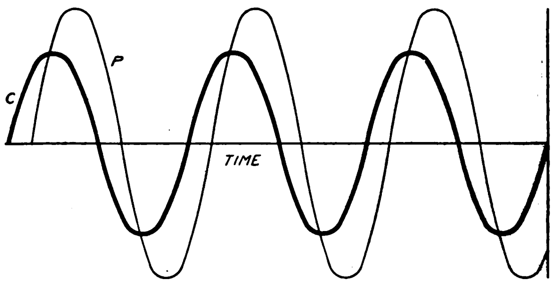


Fig. 22. Current *C* and Potential *P* Curves Showing Phase Displacement; Voltage Leading Current

current and the field windings of the alternator. By increasing the amount of resistance in the circuit through the movement of the arm of the rheostat, the current is weakened, and *vice versa*. To increase the output to the maximum, the resistance is reduced to a minimum and the speed of the alternator increased by raising the speed of the driving motor with the aid of a rheostat in the field circuit of the motor. In commercial service, alternators are of two general types, revolving-field and revolving-armature machines, the former being employed in wireless practice. In Fig. 22 are illustrated the current and voltage curves of a small a.c. generator such as is used in wireless sets.

Effective E.M.F. and Current. Alternators are rated in kilovolt-amperes (k.v.a.), but, as both the voltage and current are constantly varying from zero to a maximum value, it will be apparent that these maximum values cannot be taken in calculating the true output of the machine. For example, when an alternator is rated to produce current at 110 volts, it will indicate such a potential on a voltmeter or will light lamps designed for that voltage; this voltage is termed the effective voltage, or effective e.m.f. This effective value is 0.707 of the maximum so that in the case of the 110-volt machine, the maximum would be 110÷0.707, or 155 volts. The constant 0.707 is called *the square root of the mean squares* because it can be found by squaring a number of instantaneous values in a cycle, finding the average of these squares, and then extracting the square root; the effective value of the potential is, therefore, often referred to as the *root mean square voltage* and that of the current as the *root mean square amperage.*

Phase and Phase Displacement. While the alternating current follows the same sine curve in rising from zero to maximum and in falling again, this current curve does not always coincide with the voltage curve. It may either precede the voltage curve, in which case the current is said to *lead* the e.m.f., passing through its reversal in advance of the latter; or it may follow, in which case the current is said to *lag.* When the two curves coincide, the current and the e.m.f. are said to be *in phase* with each other; when the current leads the e.m.f. or lags behind it, the difference between the two is known as the phase displacement. The amount of the phase displacement depends upon the relation that the values of inductance and capacity in the circuit bear to each other and may be as great as 90 degrees. An instance in which the current curve is leading that of the voltage is illustrated in Fig. 22. This leading characteristic is taken advantage of in the rotary spark gap, or so-called disc discharger, to cause the discharge to occur at a moment when the voltage of the alternator is low so that excessive strains on the insulation of the windings of the machine are avoided.

For commercial use, alternating-current generators are usually built with three independent sets of windings on the armature and are known as three-phase alternators. Only single-phase machines are used in wireless work.

Direct-Current Generators

Changing Elementary Dynamo into D. C. Type. From the explanation of the principles of the elementary dynamo already given, it is plain that the e.m.f. and the current as induced in

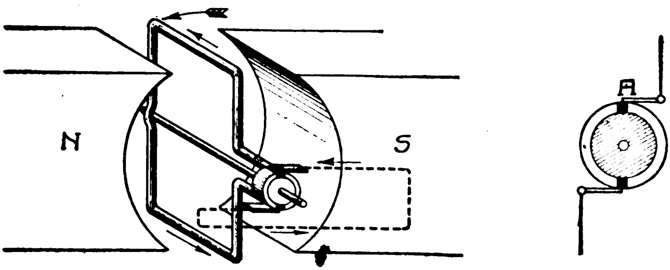


Fig. 23. Simple Form of Generator Showing Arrangement of Brushes in Contact with Commutator

the windings of the armature of the machine are always of an alternating nature owing to the fact that in its revolution the armature is successively passing pole pieces of opposite polarity. To convert these alternating impulses into a direct, or continuous, current flowing in one direction, it is necessary to add a commutator to the generator. A commutator in its elementary form is illustrated in Fig. 23. It may be imagined as consisting of a brass tube which has been sawed in half longitudinally, the halves being mounted on an insulating rod of wood or hard rubber, which, in turn, is mounted on the shaft of the machine so as to turn with it in the same manner as the collector rings of the alternator. This insulating rod and the cuts in the tube serve to insulate the two halves of the commutator from each other. To lead the current into the outer circuit, brushes bear on this commutator, and, in order that they may bear smoothly throughout the revolution, the spaces in the periphery of the commutator are also filled with insulating material, usually mica in commercial practice. The relative positions of the various parts of the commutator and the brushes are shown at *A*, Fig. 23.

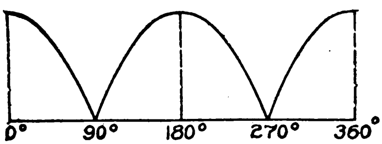


Fig. 24. E.M.F. Curve with Commutator

Pulsating Current. Against this commutator, at diametrically opposite points, press a pair of metallic springs, or brushes, which *lead* the current due to the generated e.m.f. to the external circuit If, as in Fig. 23, these brushes are so set that each half of the split tube, or segment of the commutator, moves out of contact with one brush and into contact with the other at the instant

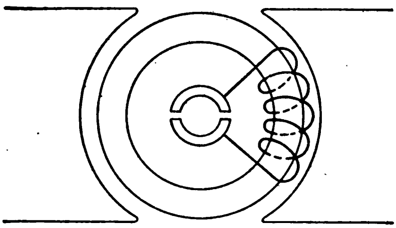


Fig. 25. Armature with Single Pole

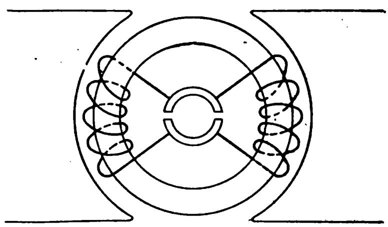


Fig. 26. Two-Pole Armature

when the coil of the armature is passing through the positions where the rate of cutting is at the minimum (as indicated in the end view *A*), an unidirectional current will be produced, but it will be of a pulsating nature, as indicated by Fig. 24. This would also be the case if, instead of the single turn of wire, a coil wound on an iron core of the ring type be used, as shown in Fig. 25, the only effect of this change being to increase the e.m.f. by increasing the number of times the winding cuts the lines of force of the magnetic field. Assume that two coils are wound on the core and connected to the commutator bars. This will give the construction shown in Fig. 26, usually referred to as an *armature*. The two coils are connected in parallel and while the voltage generated by these two coils will be no greater than that of the single one in the previous illustration, the current-carrying capacity of the winding has been doubled. The current generated by this form of armature, however, would still have the disadvantage of being pulsating. Adding another set of coils to the armature, Fig. 27, would produce

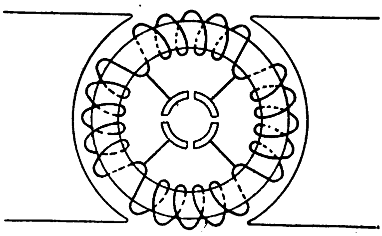


Fig. 27. Four-Pole Armature

a more continuous current, as one set of coils (the two in a horizontal plane) would be at the position of maximum magnetic flux while the others would be at the minimum, corresponding to the zero point of the sine wave alternating current. But this current.

would not be sufficiently steady for practical purposes as there would be four distinct pulsations per revolution. Consequently, to generate a steady continuous current, it is necessary to increase still further the number of coils on the armature with their corresponding commutator segments. Adding to the number of pole pieces in the fields also has the effect of steadying the current.

Commutator. The commutator consists of a number of copper bars, or segments, corresponding to the number of slots in the armature core. These segments are separated by sheets of insulating material, such as mica, or are molded integrally with an insulating compound and are firmly held together by a clamping device consisting of a metal sleeve with a head having its innerside

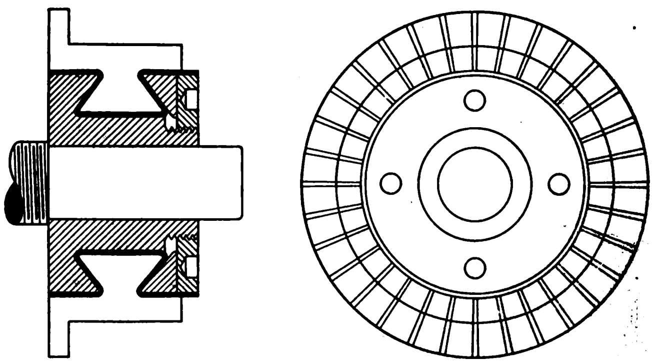


Fig. 28. Sectional and End Views of Commutator
Courtesy of The Horseless Age, New York City

undercut at an angle, a washer similar in shape to the head of the sleeve, and a nut that screws over the end of the sleeve, Fig. 28. The sleeve is surrounded by a bushing of insulating material, and washers of the same material are placed between the assembly of the commutator bars and the two clamping heads. This illustrates but one form of construction though it will serve to make clear the essential principle that each bar must be completely insulated from every other bar of the commutator as well as from the shaft and the clamping sleeve. After assembling, the commutator is turned down in the lathe to a true-running cylinder and then sandpapered on its outer surface to present a perfectly smooth and clean bearing surface for the brushes. At the inner end of the commutator, that is, the end nearest the armature windings, the commutator bars are provided with lugs, as shown in the illustration. These lugs are slotted and the armature leads, or terminals of the coils on the armature core, are soldered to them. The commutator is a part of the motor-generator with which the wireless operator soon becomes well acquainted as it requires more or less frequent attention to keep it in good condition. The nature of this attention is described later.

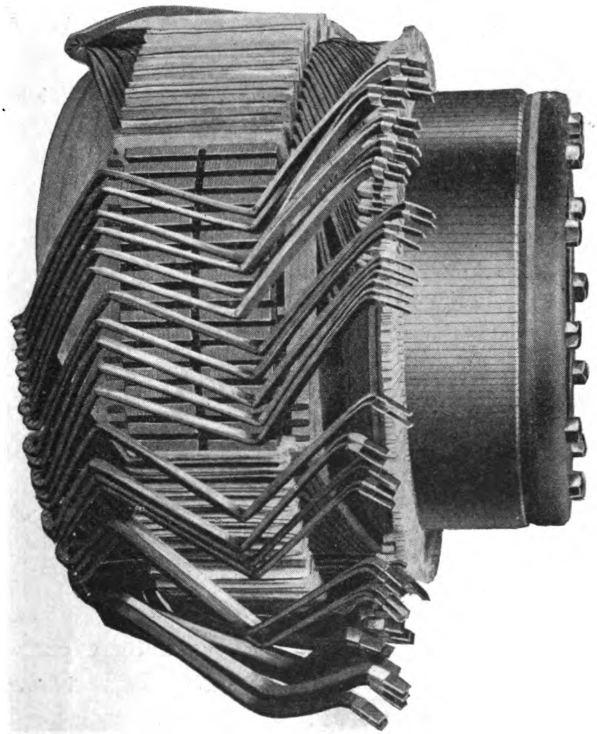


Fig. 29. Fort Wayne Armature Partly Wound, Showing Formed Coils

Armature Windings. In the simple illustrations given to show the method of generating an e.m.f. in the armature winding and leading this to the external circuit, what is known as the ring type of armature is shown. This is an inefficient type because half the length of the winding—that inside the ring—does not cut any lines of force and hence does not aid in generating the current. Consequently, a slotted, or drum, form of armature is employed, consisting of a large number of thin discs of iron or soft steel with paper or a coat of shellac separating them to minimize eddy currents in the metal. These discs are punched out by dies in a form somewhat similar to a toothed wheel and the wire is either wound directly in these slots or is *form wound,* that is, wound on a wooden form corresponding to the position the completed coil will take when in position on the armature core. After the necessary length of wire has been wound on this wooden form, the turns are all taped together and varnished or impregnated with an insulating compound and then baked. The punchings, or laminations, constituting the core are assembled on the shaft of the generator and are put together under considerable pressure so as

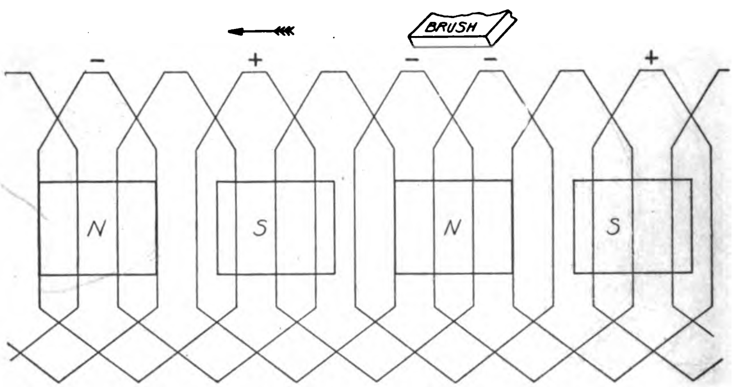


Fig. 30. Lap Winding of Armature as Developed on Plane; One Brush for Each Pole of Field

to form practically a solid piece of metal. A direct-current armature in the process of winding is shown in Fig. 29. This is a drum-wound armature. What is known as a lap winding is illustrated as developed on a plane, Fig. 30. By tracing any one of the coils, it will be noted that it laps back on itself and its terminal is connected to the adjoining commutator bar from that at which it started. With this type of generator a brush is required for each pole piece in the field. A more intricate form of winding, known as wave winding, is illustrated in Fig. 31. In this it will be noted that the current passes through a coil under each of the field poles so that there are but two paths through the armature and only two brushes are needed regardless of the number of field poles. The lap-wound type of armature is generally employed in motors used in wireless sets.

Brushes. The e.m.f. and current induced in the armature windings are led through the brushes which bear on the commutator to the outer circuit and to the fields in direct-current generators to excite them. Originally these brushes were made of plain strips of copper, later, laminated copper brushes and brushes of copper wire gauze were employed, but all of them caused rapid wear with excessive sparkling, so that carbon brushes are now universally employed; in some cases copper is embedded in the carbon when a brush of low resistance is desirable. The brushes bear directly against the face of the commutator, either with a blunt squared end or at a slight angle, and are held in place

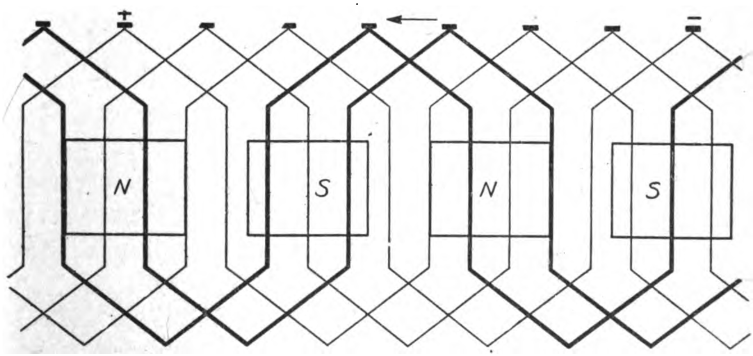


Fig. 31. Wave Winding of Armature as Developed on Plane, Two Brushes Only; Heavy Lines Indicate Path of Current through Armature

by springs on the brush holder so as to press against the commutator with a certain amount of pressure. Ordinarily, the brushes are made of a uniformly smooth and homogeneous compound of carbon, soon acquire a glazed surface at their bearing ends, and wear almost indefinitely with very little attention, but occasionally a gritty brush will be found. Such a brush scratches the commutator surface, wears unevenly, and causes trouble, which is indicated by sparking. Since both the resistance and current-carrying capacity of different brushes vary considerably, replacements should only be made with brushes designed for the machine, except in cases of emergency. Badly worn commutators result from the use of improper brushes and likewise from too heavy or too light a spring pressure.

Neutral Point for Brushes. Where an electric motor is designed for variable speed and load, as in wireless service, the brushes are mounted on a rocker arm which is adjustable, so that they can always be placed at the neutral points of the magnetic field. Unless this is done, excessive sparking is liable to occur at the commutator.

Types of D. C. Generators. *Series-Wound Type.* In an alternator it is necessary to excite the field, or, in other words, render it magnetic, from an outside source of direct current, whereas all direct-current generators are *self-excited,* that is, all or a part of the current induced in the armature is led around the field windings in order to magnetize the field poles. In the case of the simplest type of generator, the armature is connected directly in series with the fields, so that all the current produced by the machine flows through them, Fig. 32. The series type of generator has so many shortcomings that it has long been obsolete, except possibly for a few special purposes.

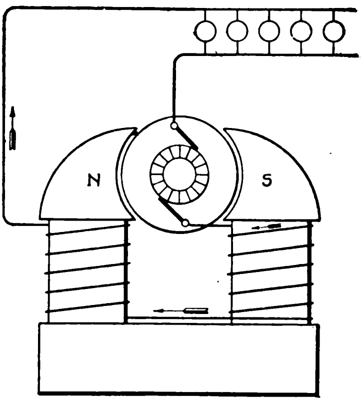


Fig. 32. Diagram Showing Series-Wound Generator

Shunt-Wound Type. As has been mentioned under "Parallel Circuits", page 20, the current in a circuit divides in accordance with the resistance in the different parts of that circuit. By making the field windings of the generator of comparatively high resistance, with reference to the external circuit which the generator is to supply, and connecting the fields in shunt with the armature, the amount of current flowing in the fields is determined by the voltage at the brushes and the resistance of the field winding. If a shunt generator runs at constant speed, as more and more current is drawn from the generator, the voltage across the brushes falls slightly. This fall is due to the fact that it requires more and more of the generated voltage to force this increasing current through the windings of the armature, that is, the armature *IR* drop increases. This leaves a smaller part of the total e.m.f. for brush e.m.f. and then when the brush voltage falls, there is a slight decrease in the field current, which is determined by the brush voltage. This causes the total e.m.f. to drop a little, which still further lowers the brush potential. These two causes combine to gradually lower the brush pressure (voltage), especially at heavy overloads. The shunt-wound generator is shown diagrammatically in Fig. 33. A small part of the total current, the exciting current, is shunted through the fields. The shunt-wound generator gives a fairly constant voltage even with varying loads. Its voltage may be kept more nearly constant by providing extra resistance in the field circuit, which may be cut out either automatically or by hand as the brush potential falls.

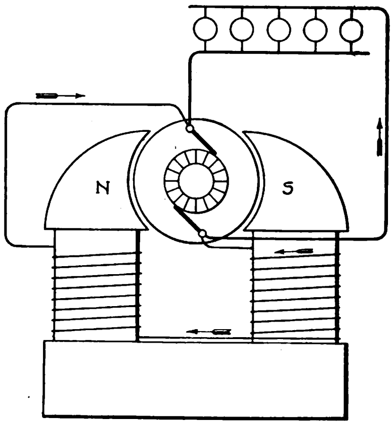


Fig. 33. Diagram Showing Shunt-Wound Generator

Compound-Wound Type. To cause a substantial increase in the number of lines of force in the magnetic field with an increase of load, it is necessary to supply considerably more current to the field coils. This is accomplished by adding to these field coils a few turns of heavy wire in series with the armature so that all the current from the latter passes through them. The magnetic flux now increases with the load since it is directly affected by the current demanded by the increased load. This combination of the shunt and series coils on the fields is termed a compound-wound generator and is in very general use. When the series winding opposes the shunt winding, it is termed a differentially-wound type. The connections of the two windings with the armature and their relation to the external

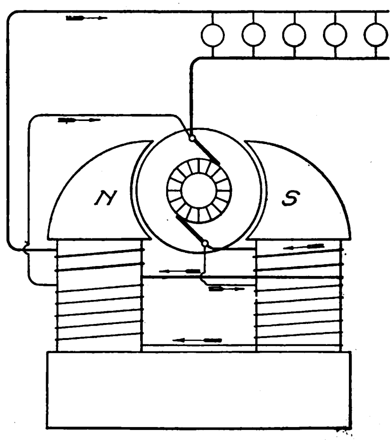


Fig. 34. Diagram Showing Compound-Wound Generator

circuit are illustrated by Fig. 34. For purposes of simplicity, a bipolar type of generator is shown in these illustrations. With the exception of very small units, such as automobile lighting and charging generators, the bipolar is an obsolete type, practically all generators now being multipolar, in which the field frame is a circular casting from the inner face of which the poles protrude to form the armature bore. Pole pieces or ends are put on the poles after the coils are in place so as to almost inclose the armature.

ELECTRIC MOTORS

Similarity between Generators and Motors. A machine that is designed to convert mechanical energy into electrical energy or the reverse is technically a *dynamo-electric machine.* When the armature of the machine is rotated by an external source of power, it is called a generator. When the machine has a current sent through it from a battery or another generator, converting electrical energy back into mechanical energy, it is called a motor. From this it is evident that a generator and an electric motor are fundamentally the same and that by a reversal of the conditions a generator may be converted into a motor, and *vice versa.*

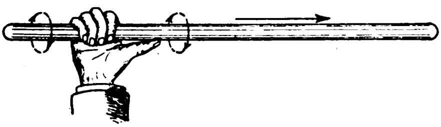


Fig. 35. Direction of Flow of Magnetic Lines about Wire

Types of Motors. Being the counterparts of electric generators, electric motors differ in type according to their windings, as already explained with reference to generators. Thus the series-, shunt-, compound-, and differentially-wound motors are similar to generators of the same types. But while the series-wound generator was of very limited application and has long since become obsolete, the series-wound motor is in very general use, being employed for railway use and for automobile starting motors. It is not, however, used in wireless work.

How Rotation Is Produced. In Fig. 35 is shown a straight wire carrying an electric current. Now, electricity in *motion* always produces a magnetic field at right angles to the current accompanying it. Hence, a magnetic field surrounds the conductor, Fig. 35, and if one looks along the wire in the direction in which the current is flowing, the magnetic field is whirling around the wire in the direction we would turn down a right-hand screw. The best rule for determining the direction of these whirls is the *thumb rule* (for straight wire). *If we grasp the wire with our* ***right hand*** *so that the* ***thumb*** *points in the direction of the current, the* ***fingers*** *will point in the direction of the magnetic field.* Notice that these magnetic whirls are *circles* and not *spirals*. Fig. 36 shows cross-sectional view of this wire and its magnetic field represents the way the field would appear if we looked at the end of the wire with the current going away from us.

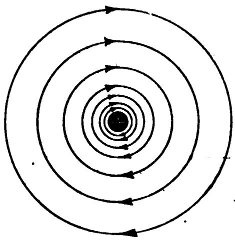


Fig. 36. Field about Wire Bearing Current

Fig. 37 represents a wire lying in a magnetic field and carrying no current. If the polar surfaces of the field are large and close together, the magnetic lines pass straight from one to the other; they are not distorted, whether the wire is at rest or in motion. This is the condition in the air gap of a dynamo or motor when no current is flowing in the armature conductors. When, however, a current flows, it sets up a magnetic field of its own about the conductor, as shown in Fig. 36, and this field distorts the original field in which the conductor lies, making the magnetic lines denser on one side and less dense on the other. This is shown in Fig. 38. Since the magnetic lines of a field endeavor to straighten and shorten themselves, the result of this distribution is a force upon the wire, pushing it in the direction of the arrow; and this is the principle of the electric motor.

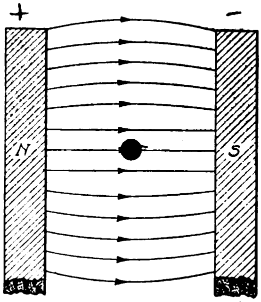


Fig. 37. Diagram Showing Wire Placed in Magnetic Field but Bearing no Current

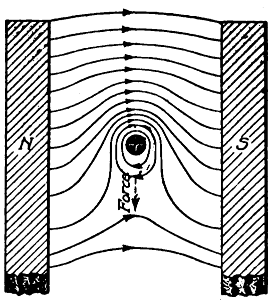


Fig. 38. Effect on Magnetic Field when Current Flows in Conductor of Fig. 37

The fact that the lines are denser on one side of the wire is due to the circular shape of the field, which causes the direction of the force lines on one side of the wire to be exactly opposite to the direction of those lines on the other side. In Fig. 36, notice that the lines above the wire flow to the right, below to the left. When this wire is placed in a uniform field, flowing to the right, Fig. 38, the lines above the wire, flowing to the right, join those of the field flowing to the right and thus strengthen the field above. Those below the wire, flowing to the left, neutralize some of those of the field flowing to the right and weaken the field below the wire. A strong field above the wire and a weak field below results in a force urging the wire down as previously seen.

Motor, or Left-Hand, Rule. The relation between the directions of force, current, and magnetic lines can easily be remembered by Fleming's rule as applied to motors: *Let the* ***forefinger*** *of the* ***left hand*** *point in the direction of the magnetic lines of force and the* ***middle finger*** *in the direction of the current sent through the wire; the* ***thumb*** *will then point in the direction of the mechanical force acting to move the wire.*

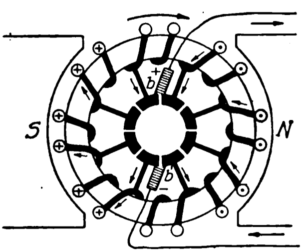


Fig. 39. Diagram Showing Analysis of Motor Operation

To analyze the operation of a motor, such as that shown in Fig. 39, suppose a current from an outside source is first sent around the coils of the field magnets and then into the armature at b'. Here it will divide and flow through all the conductors on the left half of the ring in one direction and through all those on the right half in the opposite direction. Hence, in accordance with Fleming's motor rule, all the conductors on the left side are urged upward by the influence of the field and all those on the right side are urged downward. The armature, therefore, will begin to rotate, and this rotation will continue so long as the current is sent in at b' and out at b; for, as fast as the coils pass either b or b' the direction of the force acting on them changes. The left half is therefore always urged up and the right half down. The greater the strength of the current, the greater the force acting to produce rotation.

Counter-E.M.F. A motor armature, although being rotated by means of current supplied by an external source of power, is revolving in the magnetic field of the poles and is, therewitch fulfilling conditions previously mentioned as necessary for the generation of an e.m.f. But this e.m.f. is in a direction opposite to that of the potential of the current which is operating the motor. Consequently, it opposes the operating e.m.f. and is termed the counter-e.m.f. This, together with the fact that copper has a positive temperature coefficient, that is, its resistance increases as it becomes warmer, explains why the apparent resistance of a motor is so much greater when it is running than when it is standing idle. The counter-e.m.f. approaches in value the line e.m.f., or voltage, at which current is being supplied to the motor.

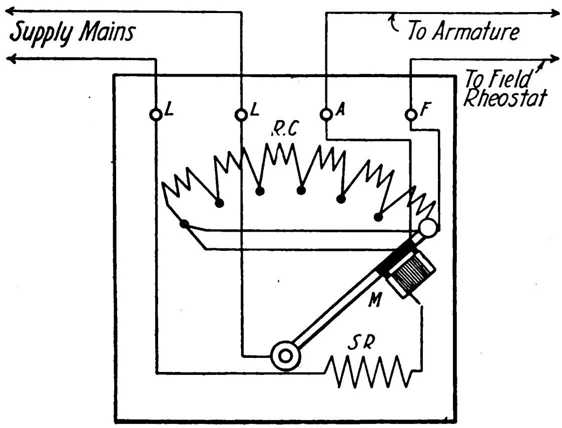


Fig. 40. Wiring Diagram of Typical Motor Starter, Showing Handle in Full-On Position

It can, of course, never quite equal the latter for, in that case, the two opposing electromotive forces would neutralize each other and no current would flow.

Necessity for Motor Starter. For the reason just stated the motor cannot be started simply by closing a switch and throwing the current on full. The resistance of the armature standing idle is so low that there would be a rush of current and the circuit-breaker or the fuses or both would operate to protect the motor. Therefore, a motor starter must be employed. This consists of a rheostat, or variable resistance, in which, by the movement of the switch handle, the resistance coils are successively cut out of the circuit until the motor is receiving the full strength of the current. As there are a number of contacts on the rheostat, the motor of t cquired its full speed by the time all the resistance is cut out. Fig. 40 is a diagrammatic illustration of the resistance coils and connections of a motor starter, while the starter circuit is shown

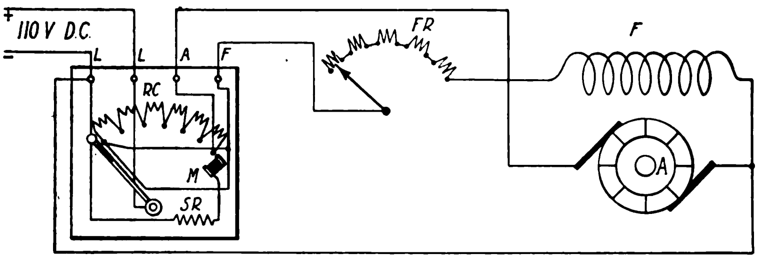


Fig. 41. Motor Starter Circuit—*LL*, Line; *A*, Armature; *F*, Field; *FR*, Field Rheostat; *SR*, Starter Resistance in Series with Holding Magnet *M;* *RC*, Resistance Coils of Starter

in Fig. 41. It will be noted that the starting handle must be moved over the contacts against the pull of a strong spring and that this handle also has mounted on it a soft-iron armature which,

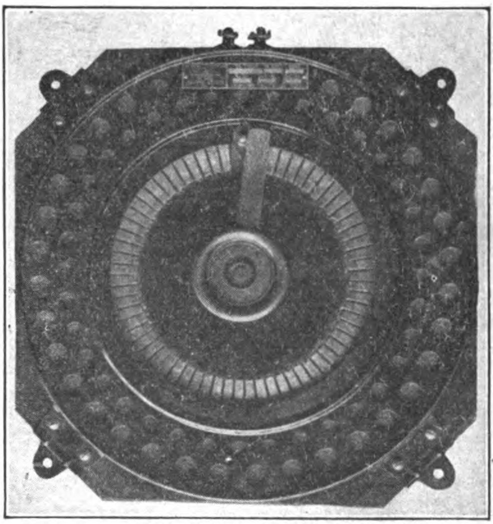


Fig. 42. One Type of Field Rheostat Used for Both Generator and Motor in Wireless Installations
Courtesy of Cutler-Hammer Manufacturing Company, Milwaukee, Wisconsin

when the handle is at the full-on position, makes contact with the pole pieces of an electromagnet mounted on the face of the starting resistance. The coil of this electromagnet is connected in series with the line and with an additional resistance in the starter itself which limits its current to that required to hold the switch handle against the pull of the spring. It will be evident that, in case of a failure of the current, the core of this electromagnet will no longer be excited and the switch handle will fly back to its starting point under the influence of the spring. As this starting point is a dead contact, no current can pass through the motor circuit until the starting switch has again been moved over the rheostat contacts by hand. The connections *LL* on the starter are for the supply circuit *A* to the armature of the motor and to its field *F*. In starting up a motor, the handle of the switch must be moved slowly but continuously over the contacts; if moved too rapidly the armature of the motor will not have sufficient time in which to develop the necessary counter-e.m.f., while if a pause is made on the contacts the resistance coils are liable to be burned out through overheating, as they are only designed to be kept in circuit a short time. In the center of the complete starter circuit are the coils of a rheostat *FR*, shown also in commercial form in Fig. 42, which are used for the purpose of alterating the speed of the motor.

MOTOR-GENERATOR

Function of Motor-Generator in Wireless Work. Electromagnetic waves as used in wireless transmission are generated by

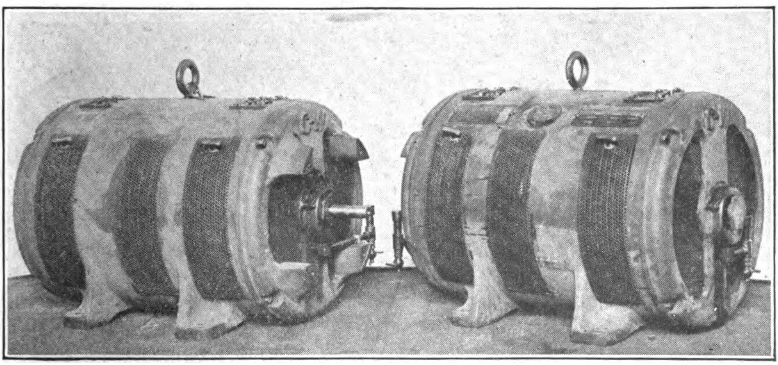


Fig. 43. Two-Kilowatt Five-Hundred Cycle Motor-Generator as Used on Marconi Ship Installations
Courtesy of Crocker-Wheeler Company, Ampere, New Jersey

means of alternating current at a high potential, but since in ship stations the source of supply is the direct-current lighting generator of the steamer, means must be employed for converting the current from direct current to alternating current. It is then stepped-up to a high voltage through a transformer, the principles of which are explained in another section. As the most efficient method of conversion is a motor-generator, the direct current from the dynamo of a ship is employed to run a d.c. motor which in turn operates an a.c. generator. The fact that these

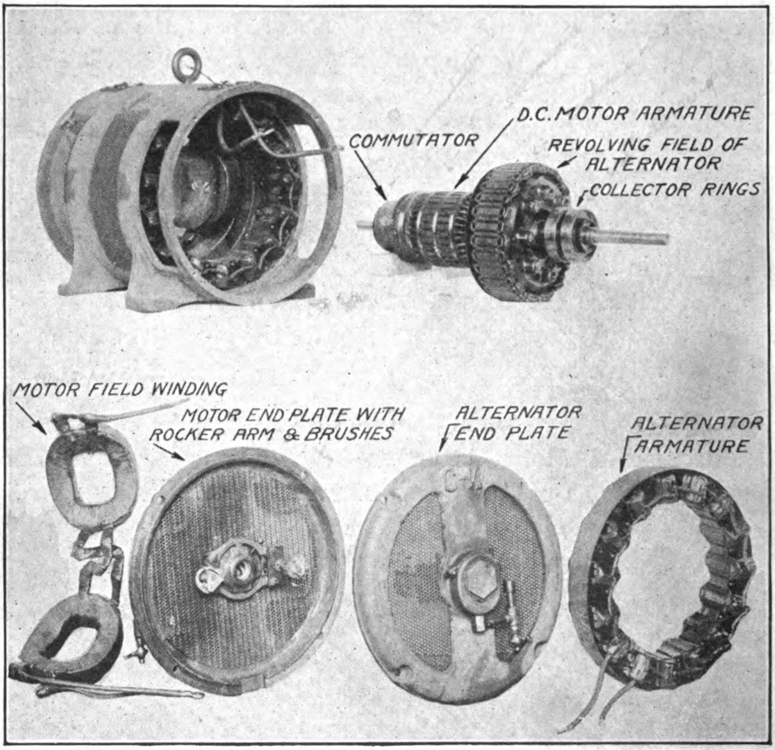


Fig. 44. View of Crocker-Wheeler Two-Kilowatt Motor-Generator Parts

two units are usually combined in one, the armatures of both the motor and the generator often being mounted directly on the same shaft, accounts for the term motor-generator.

In Fig. 43 is illustrated the Crocker-Wheeler 2-kilowatt 500-cycle motor-generator, as employed in many of the Marconi ship installations, and in Fig. 44 the same machine is shown dismantled to illustrate its component parts. The driving motor is usually of the shunt-wound type, which may be coupled either to a simple- or a compound-wound alternator, though compound-wound motors are also employed. In Fig. 45 are shown diagrammatically the circuits of the two machines, the a.c. generator being at the top, while the d.c. motor is at the bottom. Current for exciting the fields of the alternator is taken directly from the supply circuit which also feeds the motor. The latter receives direct current at 110 volts and its speed is varied by means of the rheostat in series with the field; increasing the amount of resistance in circuit increases the motor speed, and *vice versa,* since the

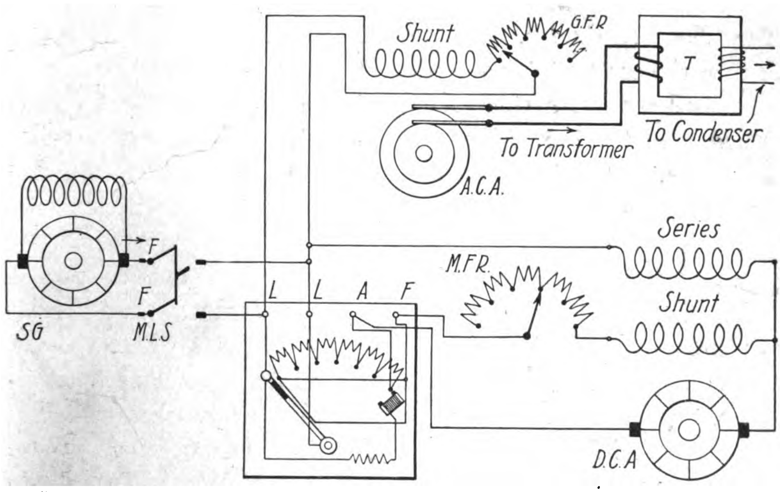


Fig. 45. Complete Circuit of Motor-Generator with Compound-Wound Motor—*MFR*, Motor Field Rheostat; *GFR*, Generator Field Rheostat; *DCA*, Motor Armature (Direct Current); *ACA*, Alternator Armature; *SG*, Ship Generator; *MLS*, Main-Line Switch; *FF*, Fuses; *T*, Transformer

greater the resistance of the field as compared with that of the armature, the greater the amount of current passing through the latter. The alternator generates alternating current at voltages varying from 110 to 500 volts, and the current has a frequency of 60, 120, 240, or 500 cycles, according to its design. The care of the motor-generator is an important part of the wireless operator's duties and in the government examinations considerable value is accorded the answers to questions on this part of the transmitting set.

Care of Motor-Generator. *Commutator.* Owing to the fact that it has a commutator, the motor end of the unit will require more of the operator's attention than the generator. The most frequent form of attention required will be cleaning the commutator periodically and inspecting it in operation from time to time to note whether or not the brushes are sparking. This sparking must be kept down to the minimum at all times for, if it is allowed to increase, it will burn the commutator so badly that the efficiency of the motor will be greatly reduced and the armature will have to be removed from the machine to turn the commutator true again.

The commonest cause of sparking is a collection of dirt, usually carbon ground off from the brushes and dirt from the air, both combining with any excess oil to form a pasty mixture that is an excellent conductor. When a sufficient amount of this collects between the commutator segments it is liable to short-circuit them and may burn out a coil. High mica, as it is sometimes termed, consisting of the protrusion of one of the insulating separators of the commutator bars above the surface of the latter, will cause excessive sparking and will quickly ruin the brushes if not remedied. Some other causes of sparking are hollows or grooves in the commutator due to uneven wear; brushes out of position in the neutral field; grounded or short-circuited coil in either the armature or field; brushes worn down to a point where they are too short to be held against the commutator by the springs with sufficient pressure; unevenly worn brushes or brushes that have become stuck in their holders so that they cannot move.

Cleaning. Parts that are regularly kept clean will rarely fall into bad condition, because such a tendency will be noted before it has gone far enough to cause any damage. In the majority of instances, sparking will be due to an accumulation of dirt and oil on the commutator and the latter will be more or less blackened. A strip of fine sandpaper passed around the squared end of a piece of wood and held lightly against the commutator as it is revolving, taking care to treat the entire surface equally, is the best remedy for this. *Never use emery cloth.* Emery is metallic and therefore conducting, so that particles of it lodging between the commutator bars would short-circuit them. For the same reason, emery must never be used in cleaning any of the switch points of the starter, the rheostats, or the collector rings of the alternator. Brushes that have worn unevenly but not to the point requiring replacement should be *sanded-in.* Take a strip of sandpaper slightly wider than the brush itself, disconnect the pigtail connection of the latter to the rocker arm, draw the brush back and insert the sandpaper face up under the brush. Hold the sandpaper in this position and turn the motor over slowly. The brush will thus be sanded down to the exact contour of the surface of the commutator. In case new brushes do not bear evenly all over their surfaces, they should be given the same treatment before being put into service.

All contact surfaces, such as the switch points of the motor starter and of the field rheostats of the motor and generator, and the collector rings of the generator should be kept free from dirt and given an occasional cleaning with fine sandpaper, preferably worn, so that it takes off as little copper as possible. Discoloration, however, is not always an indication of the necessity of cleaning. In service, a commutator usually assumes a purplish hue, sometimes shading into an orange tint, and takes on a hard glassy surface. It is then in the best of condition and should not be touched with the sandpaper as it would only destroy this glaze which serves to protect the copper. When in this condition any dirt should be cleaned off with a soft rag with a little oil on it. The commutator itself, however, should never be oiled.

Care of Connections. Armature and field connections, particularly the former, should be inspected from time to time to see that none of them is coming loose. In starting the motor, the switch handle should be given a slow even movement over the contacts of the starter. In case the circuit-breaker operates or the fuses blow out, the connections should be inspected before attempting another start unless, of course, this has been due to starting too quickly. The bearings of both members and the field frame of the generator should be felt with the bare hand occasionally to detect any signs of overheating. If the bearings should be so affected, it would be due to failure of the oil or lack of alignment caused by wear, while in the case of the field frame it would indicate that an excessive amount of current was being taken from the generator. Further instructions covering the care of the motor-generator are outlined in the section giving examination questions and answers, page 270.

STUDY OF CIRCUITS AND THEIR PROTECTION

Definition of Circuit. The conducting path necessary to equalize a difference of potential is termed a circuit, and the current is said to flow from the point of high to that of lower potential. A simple circuit is accordingly composed of the source of current, as a battery or generator, the apparatus to which this source of current is connected, such as a lamp, and the conducting wires between the two. If there be any break in the conductors, the circuit is said to be *open;* if all connections are made so that the current passes through the circuit, it is said to be *closed.*

Series Circuit. Simple series circuits are illustrated in Figs. 46 and 47, the only difference being in the number of lamps in circuit. It will be evident that the current must pass from the battery through each lamp in turn to complete the circuit, and that a break at any part of the circuit will open it and extinguish all the

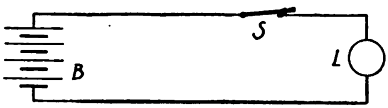


Fig. 46. Simple Closed Series Circuit—*B*, Battery; *S*, Switch; *L*, Lamp

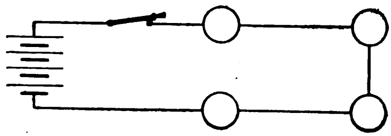


Fig. 47. Lamps and Battery in Series Circuit

lamps. The latter are *in series* with the battery, and the cells of the battery itself are also connected in series.

To distinguish this from the other forms of circuits, it must be borne in mind that in equalizing a difference of potential the current flows from the positive terminal of the battery through the circuit to the negative terminal. In the case of a series circuit, the current accordingly flows through each lamp in turn; each receives all the current in the circuit at a potential proportioned to the resistance of the lamp itself. Consequently, in the first circuit shown, the lamp receives all the current from the battery at the full voltage. In the circuit with four lamps, each lamp receives all the current but at only one-fourth the voltage.

Multiple, or Parallel, Circuit. If the four lamps, Fig. 47, are rearranged so that the wire from the positive terminal of the battery is connected to one side of each lamp and the wire from the negative to the other side of the lamps, as shown in Fig. 48, they are said to be *in multiple,* or *in parallel.* A voltmeter added to the circuit, as illustrated in Fig. 49, is said to be shunted across the circuit. In this new arrangement of the lamps, all receive the full voltage of the battery but the amount of current passing through each lamp is proportionate to its resistance. Incandescent lights are usually wired in parallel, so if a 110-volt lamp be inserted in a circuit of this voltage it will burn brightly, but if a 220-volt lamp be inserted in the same circuit it will only glow very dimly as its resistance is twice as great as that of the lower voltage lamp and it does not permit sufficient current to pass to light it to full incandescence.

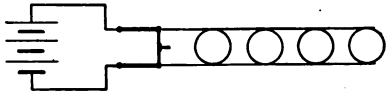


Fig. 48. Lamps and Battery in Multiple Circuit; Switch Opens Both Circuit Leads

Multiple-Series Circuit. On the other hand, if a 110-volt lamp be inserted in a 220-volt circuit, it will immediately be burned out, because the voltage is twice as large as that for which the resistance of the lamp was designed. As resistances in series are cumulative, however, several groups, each consisting of two 110-volt lamps in series, may be connected across the 220-volt circuit and, as a result, the lamps will light as usual. This is termed a multiple-series, or parallel-series, circuit and the series part of it may consist of any number of lamps or other pieces of apparatus whose total resistance is sufficient to permit only enough current to pass to operate them. For example, the low-voltage series lamps used for decorative purposes have a resistance which will cause a drop of 14 volts in the circuit. Consequently, to form one group, eight of these lamps must be connected in series and the group connected as one unit across the terminals of the 110-volt circuit. A smaller number will be burned out, while a larger number will not light to full brilliance.

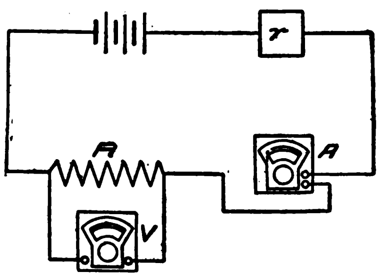


Fig. 49. Diagram Showing How Voltmeter is Shunted in Circuit

Series-Multiple Circuit. A series-multiple, or series-parallel, circuit is one wherein a number of minor circuits are first connected in parallel and then several of the parallel-connected minor circuits are connected in series across a source of e.m.f. as in Fig. 50. This method of connection is seldom used.

Shunt Circuit. A shunt circuit is a *divided* circuit, that is, practically a circuit on a circuit, and is really one form of multiple circuit. Voltmeters are always connected in this way, that is, *shunted* across the line, since they are designed to measure the potential only and require a minimum of current for this purpose. If a voltmeter be connected into a circuit in series by mistake, very little current can be drawn from that circuit beyond the instrument, as the high resistance of the voltmeter will prevent its passage. The shunt-wound fields of motors and generators are also familiar examples with which the student will have to acquaint himself. The speed of a shunt-wound motor may be decreased below normal by a rheostatic controller in series with its armature and may be increased above normal by means of a rheostat in series with its field winding. The latter rheostat is known as a field rheostat and, to be effective, must have a high

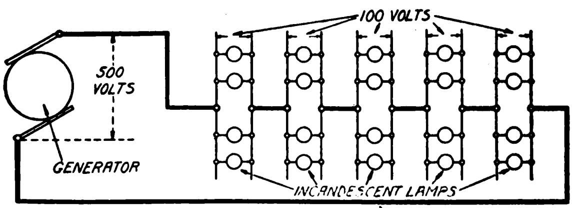


Fig. 50. Diagram Showing Incandescent Lamps in Series-Multiple Circuit

resistance owing to the small current which flows through the shunt field winding. The ammeter shunt is another familiar example of this type of circuit, the function of which is explained under the head "Measuring Instruments," page 71.

Short-Circuits. Where a shunt, or by-path, of negligible or comparatively small resistance is established around any part of an electric circuit, through which so much of the current passes as to virtually cut out the parts of the circuit to which it acts as a shunt, a short-circuit is said to exist. Referring to Fig. 48, should one of these lamps burn out and the broken filament fall across the wires leading into the bulb, the lamp becomes short-circuited and, as its resistance is now but a small fraction of that of the other lamps, all the current in the circuit will immediately pass through this easier path, causing the circuit-breaker to open, or, failing this, the fuses will blow out, thus protecting the generator.

Grounds. Should one of the wires of the circuit just mentioned lose its insulation at a point which permitted it to come into contact with a conductor (any conducting material) connected with the earth or with the other side of the circuit, a short-circuit would also result, but to distinguish it this form of short-circuit is termed a ground. The circuit is then said to be *grounded* and the protective devices in the circuit will operate. A ground is accordingly a short-circuit but all short-circuits are not necessarily grounds. For example, when an accumulation of carbon dust from the brushes of a direct-current motor or generator collects between the commutator bars, the latter become short-circuited. When the failure of the insulation of part of the armature or field winding allows it to come into contact with the core a ground results.

Open and Closed Circuits. In the use of direct current as ordinarily employed, an open circuit is one in which there is a gap, or opening, in the circuit, as by the opening of a switch or a break in any part of the circuit, such as a parted connection or a broken wire. A closed circuit represents a complete conducting path around which the current may flow to light lamps, run motors, or the like. But in connection with the circuits employed in wireless telegraphy, these terms are used in an entirely different sense. When low-voltage direct current is employed, a condenser connected in series in the circuit would open it; no current could pass. This would also be true were a spark gap inserted in the circuit. With high-frequency alternating currents, however, this is not the case. The transformer, condenser, and spark gap, which are utilized to generate the high-frequency oscillatory current and which would represent a circuit open at two points to a low-voltage direct current, constitute what is termed the closed circuit in wireless telegraphy. The oscillation transformer, inductance, aerial, and short-wave condenser, which do not constitute a circuit of any type for direct current, constitute what is known as the open, or radiating, circuit of the transmitting set. As low-voltage direct current, low-voltage alternating current, and high-potential high-frequency alternating current are all used at the same time in the generation and radiation of electromagnetic waves for wireless telegraphy, this distinction must be borne in mind in applying the terms open and closed to the different circuits used.

Protective Devices. Mention has been made under the head "Parallel Circuits", page 62, of the fact that the current in a circuit divides in accordance with the amount of resistance in its various branches and the reason for this is explained in the section, "Ohm's Law", page 17. It will be apparent that the resistance at that point where a short-circuit or ground takes place in the circuit will be so much less than that on any other path which the current might take, that all the current in the circuit will be diverted. The source of current supply, such as the generator or storage battery, is then said to be on a *dead short-circuit.* There will accordingly be a rush of current through this shorter path of low resistance that would burn out the windings of the generator or ruin the battery, unless means were taken to prevent it. The provisions made for protecting the apparatus in a circuit take various forms, depending upon the method by which they are designed to operate, although their function is the same in every instance, that is, to open the circuit immediately in the case of direct current.

Circuit-Breakers and Fuses. To protect the generator, there are circuit-breakers and fuses on each side of the line. The former consist of a solenoid, plunger, and spring-controlled switch. The switch is normally closed against the tension of this spring and the winding of the solenoid is such that, with the normal current passing, the plunger does not move. With an increase above a certain limit, however, the plunger is strongly drawn up, tripping the release of the spring and causing the circuit to open automatically. Fuses are a second line of defense and their function is to open the circuit in the case the circuit-breaker fails to operate. They consist of soft alloys which will melt at low temperatures. The amount of fuse wire employed is closely calculated to carry a certain safe percentage above the normal current before reaching the fusing point, so as to permit the circuit-breaker to operate if it will. Circuit-breakers are employed because they act more quickly than fuses and because necessity of replacing the fuses every time the circuit is overloaded is thus avoided. Fuses are known as cartridge, plug, or plain wire fuses according to the form they take.

No-Voltage Release. For reasons that have already been explained, under "Necessity for Motor Starter", page 55, a direct-current motor above a certain minimum size cannot be started by simply throwing the switch, which would send the entire current in the circuit through the armature of the motor at once. The motor must be started by increasing the current gradually through a resistance and it is also necessary to prevent the full-load current from reaching the motor in case the circuit has been broken and the current is then turned on again. To prevent this, the starting box, or rheostat, is provided with a no-voltage release. The switch handle of the starting box carries a soft-iron

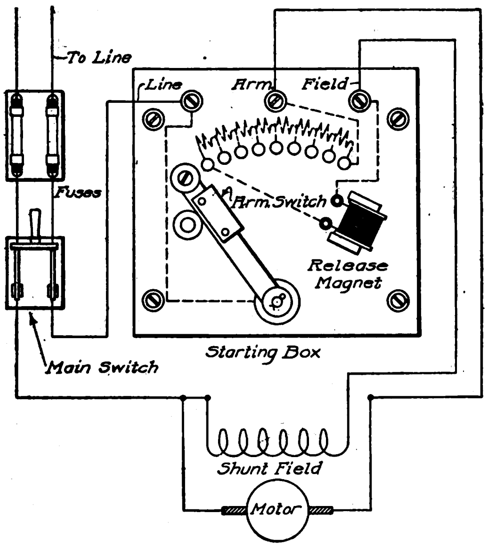


Fig. 51. Wiring Connections for Starting Box of Shunt-Wound Motor

armature which makes contact with the pole piece of an electromagnet on the box when the switch is in the full-on position. This electromagnet is wound to a high resistance and is connected in shunt with the main circuit so that it depends upon the voltage of the latter to excite it and attract the armature of the switch handle against the pull of a spring on the latter. When the circuit is broken the electromagnet loses its attraction for its armature, permitting the switch handle to be pulled back by the spring. In Fig. 51 is shown a motor-starting box on which the details of the no-voltage release are apparent.

Automatic Cut-Out. By studying the workings of the storage battery, as given later, it will be seen that it is not necessary to connect the battery to another circuit to discharge it. If the current in the charging circuit fails, the battery will immediately discharge back through it. To prevent this, a protective device known as an automatic cut-out is employed—it is sometimes termed a reverse-current relay. This consists of two windings, one of high resistance, which is known as the voltage coil and is always in circuit with the generator, and another of a few turns of heavy wire and consequently of low resistance, termed the current coil. A pivoted armature is held away by a spring from the core on which both these coils are wound. This armature is polarized, that is, magnetized, and carries a platinum contact at its free end designed to make or break the battery circuit by being pulled down on another stationary contact. It also carries a second contact designed to put the current coil in series connection with the generator and battery.

When the charging switch is closed, the voltage coil in shunt with the circuit pulls down its armature and the two sets of contacts then close the circuit of the current coil and the charging circuit to the battery so that the current flows through the latter. In case the generator current fails, the battery reverses and discharges through the current coil of the automatic cut-out. But as the polarity of the magnetism depends upon the direction of the current, this reversal causes the core of the electromagnet to become of the same polarity as its armature and, since like poles repel, the armature is forced away from the core, thus opening the battery circuit and that of the current-carrying coil at the same time. This will also take place when the voltage of the battery, due to the completion of its charge, reaches a value in excess of that of the charging current. A protective device is sometimes used in connection with the ampere-hour meter whereby the charging current is cut off when the meter reaches its maximum reading.

A.C. Devices. *Kick-Back Preventers.* As an alternating current fluctuates both in direction and intensity, it is not subject to the same laws as a direct current and does not lend itself to control in the same manner. By reason of their mutual inductance, the transformer windings will sometimes permit heavy surges of high-potential current to run back to the generator circuit; as these would cause damage to the generator, they must be guarded against. The protective devices employed take two forms. In one case, they consist of condensers in series shunted across the line and a ground connection between the condensers to the earth so that the high-potential current induced in the primary of the transformer will charge these condensers and they will, in turn, discharge to the ground without doing any damage. These surges of high-potential current are known as kick-backs, and the shunted condensers with their ground connection are known as kick-back preventers. Instead of the condensers, a high-resistance rod is also employed, being connected in the same manner.

Choke Coil. The second and more commonly employed form in commercial practice is the choke coil, or reactance coil. Under the head "Inductance", page 34, it is pointed out that oscillations will not take place in a circuit having a high resistance or in one having excessive inductance (self-induction). As the choke coil is wound on a soft-iron wire core of high permeability, its self-induction is at a maximum and it will not permit the high-potential high-frequency current to pass. The same principle is also employed as a lightning arrester though, in this case, no core is necessary in the coils. A high-frequency choke coil (air core) is sometimes inserted in series with each side of the primary circuit of the transformer.

ELECTRICAL MEASUREMENTS

Practical Electrical Units. It was early apparent that a uniform system of measurements for the application of electricity was of the greatest importance and absolutely necessary for the development of the science. Accordingly, in 1893, at the International Electric Congress, in Chicago, a system of international units was adopted, based on the centimeter-gram-second (c.g.s.) system. The absolute units based on this system are of little use for practical purposes, consequently, practical units defined as follows were adopted.

Volt. The standard volt is defined as $\frac{1}{1.0183}$ of the voltage of a standard Western cell. It is the unit of electromotive force.

Ohm. The standard ohm is the resistance of a column of pure mercury 106.3 centimeters long of uniform cross-section and weighing 14.4521 grams.

Ampere. The standard ampere is the rate of flow of a steady current which one standard volt pressure forces through one standard ohm resistance. It is the unit of current strength.

Watt. The watt is the unit of power. It is the energy expended per second by an unvarying electric current of one standard ampere under an electric pressure of one standard volt. It is equal to one joule per second.

Joule. A joule is the amount of work required to raise the potential of one standard coulomb of electricity one standard volt.

Coulomb. The coulomb is the unit of quantity of electricity. It represents the quantity of electricity that would pass in one second through a circuit conveying one standard ampere. In other words, it is an ampere-second.

Farad. The farad is the unit of capacity and is such capacity of conductor or condenser that a standard coulcomb of electricity is required to produce therein a difference of potential of one standard volt.

Henry. The henry is the unit of self-induction. It is the value of the induction in the circuit when an electromotive force of one volt is induced in the circuit by a current varying at the rate of one ampere per second.

Ampere-Hour. The ampere-hour is used in connection with storage batteries in preference to the watt to express the capacity of the battery. It is the flow of a current of one ampere for one hour.

Small Units. For wireless work some of the above units are too large. Consequently, they are divided into a thousand or a million parts denoted respectively by the prefixes *milli* and *micro.* Thus milliampere means one thousandth ampere and microvolt or microfarad means one millionth volt or farad.

Electrical Horsepower. There is another unit, termed electrical horsepower, which is used in rating motors, principally. This unit represents the expenditure of energy at the rate of 33,000 foot-pounds per minute, or 550 foot-pounds per second, one foot-pound representing the amount of work done in raising a weight of 1 pound to a height of 1 foot against the force of gravity. One watt of electrical energy is the equivalent of 0.73 foot-pound, so that 746 watts are the electrical equivalent of one horsepower and 1000 watts, or one kilowatt, are the equivalent of 1.34 h.p. The equivalent in horsepower may readily be obtained by multiplying the current in amperes by the voltage and dividing by 746. Thus if 15 lamps, each taking one ampere, are connected in a 110-volt circuit, the energy consumed represents 1650 watts, or slightly over two horsepower. The horsepower rating of a motor may readily be obtained in the same way, but it must be borne in mind that electric motors are capable of standing excessive overloads for short periods, so that taking the product of the normal amperage by the potential of the circuit does not give the maximum horsepower output of which the motor is capable.

Classification. Electromotive force, usually abbreviated e.m.f. and denominated potential, or voltage, is measured by a voltmeter, current flow is measured by an ammeter and power by a wattmeter. Wireless sending apparatus is rated by the kilowatts of energy which it is capable of radiating and ranges from ½ kilowatt for small ship stations up to many hundred kilowatts for the large transatlantic stations. Current used for lighting and power purposes ashore is charged for by the kilowatt-hour and is recorded by a kilowatt-hour meter.

Measuring Instruments

Electroscope. An electroscope is used to indicate the presence of a static charge on a body. It consists of two strips of gold leaf hung inside a wide-mouthed bottle or flask from a conductor inserted through the stopper. When a charged body is brought near the end of the conductor protruding through the stopper, the pieces of gold leaf will move apart at their lower ends and stand at an angle to each other, thus affording a demonstration of the law of attraction and repulsion, *like charges repel and unlike charges attract.*

Galvanometer. The galvanometer was the first type of electrical measuring instrument developed and, with the exception of the electroscope, was practically the only one used during the long period in which electricity was in the laboratory stage.

The operation of the galvanometer rests upon the law of attraction just given, except that in this case it is magnetic attraction and repulsion—*like poles repel while unlike poles attract.* A simple form of galvanometer, Fig. 52 (known as the D'Arsonval type), consists of a permanent horseshoe magnet between the poles of which is mounted a movable coil with a stationary iron core at its center. The current to be measured is sent through the windings of the suspended coil and sets up a magnetic field about it, the direction of current flow being such that the polarity of this magnetic field is the same as that of the field of the permanent magnet. Mutual repulsion, accordingly, takes place so that the coil tends to rotate so as to place itself at right angles to the poles of the permanent magnet. The object of the iron core in the coil is to strengthen the magnetic field set up by the current. As the strength of this field is proportionate to the current causing it, the rate of flow of the latter is directly indicated by a pointer attached to the coil and arranged to travel over a calibrated scale. This is but one type of galvanometer, more elaborate instruments, whose precision is such that they will measure currents as small as one-millionth of an ampere, being used for laboratory measurements.

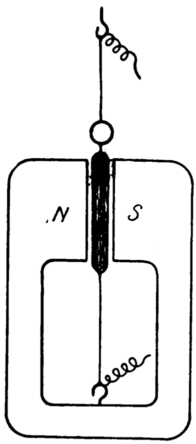


Fig. 52. Diagram of D'Arsonval Galvanometer

Ampere-Turn. The ampere-turn is not a unit of current measurement but refers to the coils or turns of a winding and the effect of the latter in producing a magnetic field. For example, one ampere of current sent through six turns of a coil represents six ampere-turns; to produce the same magnetic effect with a single turn of wire would require six amperes of current.

Voltmeter. The principles on which the voltmeter and the ammeter operate will be clear if it is remembered that their movable coils act as does the galvanometer referred to above; that is, when a current is sent through a coil of wire suspended between the poles of a magnet, the coil tends to place itself at right angles to the latter. The coil itself becomes an electromagnet when the current passes through its windings and the principle of attraction and repulsion between like and unlike poles applies. As the coil is pivoted on a practically frictionless bearing, it is free to move under the impulse of the mutually attractive or repellent magnetic fields. By affixing a long needle or pointer to the coil, a very slight movement of the latter is multiplied many times on the scale of the instrument.

This is made clear by Fig. 53, which illustrates the principles of the voltmeter. *M* is a large horseshoe magnet having pole pieces *N* and *S*; *C* is the coil to which the pointer is affixed; *P* is the bobbin on which the coil is wound; the hair spring shown above the coil returns the pointer to zero when no current is passing; and *n* and *s* indicate the polarity of the coil when energized by the current. *R* is a coil wound to a high resistance to keep the current passing through the instrument down to a small value, as very little current is required to operate it. This object is further attained by always connecting the voltmeter in shunt with the circuit, the current passing through the voltmeter thus being limited by its resistance, which is high. Should a voltmeter inadvertently be connected in series with the circuit, it will be found impossible to draw more than a very small current from the circuit owing to the high resistance of the instrument. The coil, or bobbin winding, is connected in series with the resistance. *B* and *B′* indicate the terminals of the instrument, while the arrows show the direction in which the current must pass through the voltmeter to operate it. As a reversal of the direction in which the current passes through the coil reverses the polarity of the magnetic field set up, it will be apparent that reversing the connections would tend to make the pointer move toward the left instead of over the scale; therefore, a deflection of

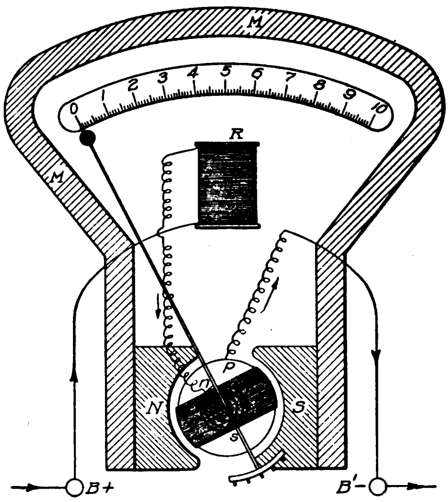


Fig. 53. Diagram of Voltmeter Principle

the pointer to the left always indicates that the connections have been wrongly made. The instrument illustrated is termed a low-reading voltmeter, in that it is calibrated to read only to 10 volts. For storage-battery testing, the voltmeter is usually made with two scales, one reading to 3 volts by tenths and the other to 110 volts; this instrument has three connections. Care must be used not to connect the 3-volt scale on the 110-volt circuit as this would burn out the entire instrument.

Ammeter. The principle used with the voltmeter is also employed in the construction of the ammeter, but as the ammeter must measure all the current passing through the line, it must always be connected in series—not in parallel as in the case of the voltmeter. However, as an instrument capable of measuring the total current directly would be unnecessarily large, a resistance, which is in shunt with the coil and which carries most of the current, is employed. This is indicated by *rr*, Fig. 54, the remaining letters on the illustration being the same as in the case of the voltmeter. This shunt is of low resistance so that it does not interfere with the passage of the current, only a small portion of the total current passing through the coil. The multiplied movement of the pointer and the calibration of the scale are such that they give a reading of the total amperage without the necessity of passing the latter through the coil itself. For the same reasons as mentioned in the case of the voltmeter, the current must be sent through the instrument in the proper direction and a low-reading instrument must not be connected in a circuit carrying a current greatly in excess of the reading afforded by the scale.

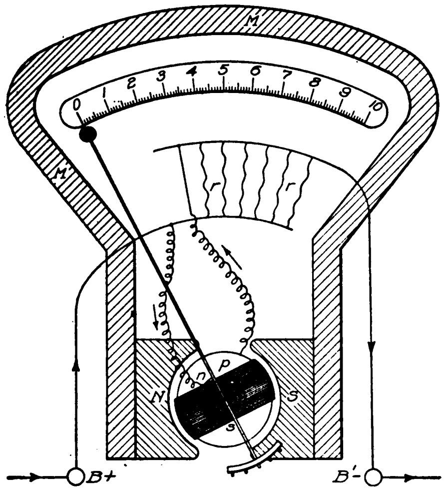


Fig. 54. Diagram of Ammeter Principle

A.C. Voltmeters and Ammeters. The ammeter and voltmeter already described are the types designed for measuring the current flow and potential of a direct current. They are not applicable to alternating-current measurements owing to the fact that an alternating current is constantly changing in value as well as in direction. A meter for alternating currents consists of a stationary coil surrounding a semicylindrical iron core, a brass cylinder, and a second semicylindrical iron core attached to the indicating pointer and normally lying parallel to the first core. The magnetic field set up in the coil tends to revolve the core to which the pointer is attached so that it moves away from the stationary core against the pull of the hairspring. This is but one type of alternating-current meter but it will serve to make clear the principle of operation. With the exception of the difference in the winding of the coil, the instrument is the same for measuring either current or potential. In the latter case, the coil is of fine wire and is connected in series with a high-resistance coil in the instrument, while to serve as an ammeter there is but one coil of much heavier wire.

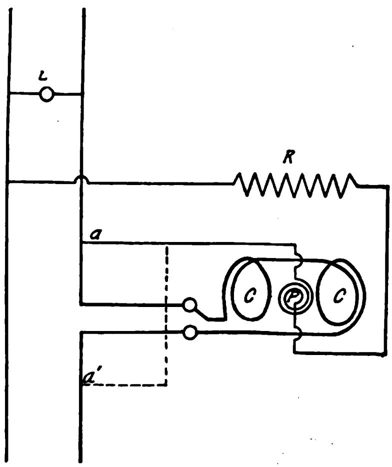


Fig. 55. Diagram of Circuits in Wattmeter

Wattmeter. It will be apparent that as the wattmeter must measure both the potential and the amount of current flowing, it must be connected in both shunt and series with the circuit, the former to measure the voltage and the latter the amperage. These connections are distinguished by employing two large binding posts for the series connection and two smaller binding posts for the shunt connection, so that a wattmeter may always be recognized by the number of posts provided on it. A wattmeter is not necessary in the direct-current circuit of a sending set, as the product of the readings of the ammeter and voltmeter gives this factor at a glance—volts times amperes in direct current giving the power reading in watts. In an alternating-current circuit, the wattmeter is inserted between the alternator and the primary of the transformer. An alternating current varies from zero to a maximum twice in each cycle but, owing to the self-induction of the circuit, the current and the voltage do not reach their maximum values simultaneously; the current curve, as shown on an oscillograph, lags behind the voltage curve so that the product of the two gives only what is termed an apparent power reading. The difference in phase between the two curves is termed the phase displacement.

A wattmeter is practically a combined voltmeter and ammeter and consists of two coils, one of wire of large cross-section connected in series with the circuit, Fig. 55, and known as the current coil, and the other of fine wire known as the voltage coil and connected in shunt with the circuit. As in the case of a voltmeter a high-resistance coil *R* is also connected in series with the voltage coil. When the pointer is at zero these two coils are at right angles to each other; the current coil is stationary, while the voltage coil carries the indicating pointer and is mounted so that it may revolve against the tension of its springs. When current flows through these two coils two magnetic fields are set up and, as the coils are wound to produce opposite polarities in these fields, they are mutually attractive and the current coil tends to make the voltage coil revolve in the same plane with it. The force tending to revolve the voltage coil is proportional to the product of the current and the potential difference so that the scale is calibrated directly in watts; the instrument is so designed that it is not affected by the phase displacement.

Hot-Wire Ammeter. The types of voltmeter and ammeter just described are employed in connection with the low-voltage circuit of the transmitting set to indicate the amount of power supplied to the oscillatory circuit by the motor-generator or other source of power. In order to be certain that transmission is being effected at the maximum efficiency and also as a simple and direct means of indicating resonance, it is necessary to measure the amount of power being radiated by the aerial circuit. In this circuit, however, comparatively small values of current are handled at very high frequencies and high potentials, and as high-frequency currents are not subject to the same laws as those governing low-voltage direct currents or low-frequency alternating currents, the same principles are not available for measuring purposes.

The facts that electrical energy consumed in overcoming resistance manifests itself as heat and that a wire, when heated, will expand in proportion to the increase in temperature constitute the basis of operation of what is known as the hot-wire ammeter. A fine platinum wire is stretched between two supports, Fig. 56. At a point almost midway between the supports a short piece of phosphor-bronze wire is soldered to the platinum wire. The bronze wire is also rigidly supported at its lower end and has attached to it, some distance above this lower end, a fine fiber of silk. This silk fiber passes around a small pulley forming the hub of the indicating pointer and terminates in a small steel spring. The tension of the system keeps the pointer at the zero mark on the scale when no current is passing through the instrument.

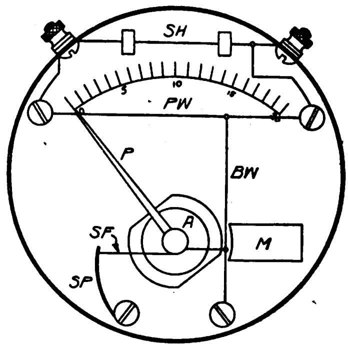


Fig. 56. Diagram of Hot-Wire Ammeter Principle

When the platinum wire is heated by the current, it sags slightly, permitting the tension of the spring to draw the bronze wire slightly out of line and thus causing a partial revolution of the small pulley carrying the pointer. The heating effect and the lengthening of the platinum wire are both directly proportional to the square of the current passing so that the movement of the pointer itself is in the same ratio, the scale being calibrated to read directly in amperes. In the case of the ammeter, it is not necessary to pass the entire current directly through the instrument, therefore a shunt is employed in the same manner, though it is not always used. The actual construction of different makes of hot-wire ammeters will be found to vary more or less from the above but the principle in all is the same. An adjusting screw is usually provided for resetting the pointer at zero to allow for any permanent sag that the platinum wire may take after repeated heating. The hot-wire ammeter is a delicate instrument, a very fine platinum wire and silk fiber being employed and the pointer being mounted in jeweled bearings. It is connected directly in series with the aerial circuit.

Audibility Meter. The audibility meter is based on the fact that if a pair of head telephones in which signals are being received is shunted by a variable resistance and the latter is adjusted until the signals are just audible, the ratio of the current in the telephones to the current in the shunt is an indication of the strength of the signal. The difference in strength between signals transmitted over long distances is often so slight that the human ear is far from being sensitive enough to distinguish between them. An audibility meter, Fig. 57, is accordingly employed, the transmitter being tuned to produce the maximum signals at the receiver and the meter then being shunted across the telephones and the resistance gradually reduced until the signals are just audible. The meter illustrated has 47 resistance coils so adjusted that the audibility is directly indicated by the numbers opposite the contact points. Its range is from 8000 times audibility down to 1, by steps of approximately 20 per cent. For example, if the signal be just audible when 99 per cent of the current flows through the shunt, or meter, and 1 per cent through the telephones, the signal is said to be 100 times stronger than is necessary to produce a barely audible signal. Point No. *1* on the instrument is a blank, that is, it does not connect with any shunted resistance so that the telephones may be left permanently connected with the instrument. One pair of binding posts is provided for connecting the receiving circuit with the detector and the second for connecting the telephone leads. A small inductance coil is placed in the instrument to prevent the low-resistance shunts from changing the conditions in the detector circuit.

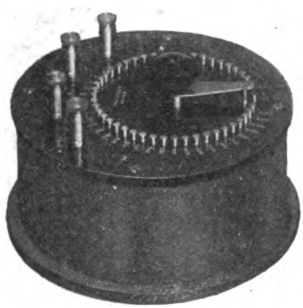


Fig. 57. Audibility Meter
Courtesy of General Radio Company, Cambridge, Massachusetts

Frequency Meter. As explained under "Wave Lengths", page 7, the frequency of the radiated wave is influenced by its length, the shorter the wave, the higher its frequency. This relation is fixed and there is no occasion for providing an instrument to determine the wave length by measuring the frequency, as commercial sets are accurately designed to operate at certain standard wave lengths; the change from one to another is made simply by throwing a switch, so that frequency meters are seldom used in commercial installations. They always form, however, a part of the equipment of the radio testing inspector.

Frahm Type. The Frahm frequency meter indicates frequency through a series of tuned steel reeds, one or more of which are set into rapid vibration through the exciting influence of the alternating current under test, much the same as a tuning fork will excite another of the same rate of vibration. The reeds are firmly mounted in a common base and on the same plate, which supports the reeds, there is rigidly fastened a piece of soft iron in the form of a flat bar which forms the armature of a magnet. When this magnet is excited by an alternating current or by an interrupted direct current, the armature is set in vibration, and that gives a slight movement to the base plate at right angles to its axis, thereby affecting all the reeds, especially those that are almost exactly in tune with its vibrations. The reed which is exactly in tune will vibrate forward and backward through an arc of considerable magnitude and by its greater prominence thus indicate the frequency of the exciting current.

Fig. 58. Wavemeter Complete in Case
Courtesy of General Radio Company, Cambridge, Massachusetts

Wavemeter. A frequency meter, or wavemeter as it is called, Fig. 58, may be constructed practically as a miniature wireless set having closely calibrated inductance and capacity, one or both being variable by accurately determined increments. It consists of a condenser and inductance coil or coils, the latter being made changeable in order to increase the range of the meter. This forms the basis of the set. When used for receiving to determine the length of a received wave, a detector and head telephones are added so that the wavemeter comprises a complete receiving set, with the aid of which the wave length radiated by any sending circuit may be read either directly on a scale or by means of a calibrated chart based upon various adjustments of the inductance or capacity of the meter itself. When used in connection with a means for exciting it, such as a buzzer, battery, and key, it becomes a miniature sending set with the aid of which electro-

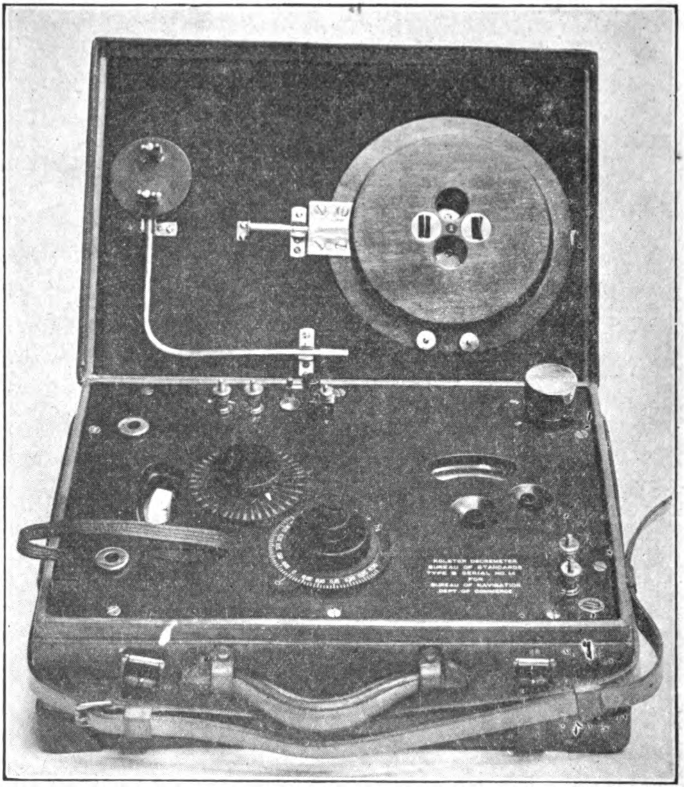


Fig. 59. Kolster Decremeter as Used by Government Radio Inspectors
Courtesy of United States Bureau of Standards, Washington, D. C.

magnetic waves of any length within the range of the meter may be induced in any oscillatory circuit close at hand. The wavemeter is an important adjunct in the operation of wireless sets and therefore a section on "Uses of Wavemeter" is given on page 232.

Decremeter. To comply with the wireless regulations, it is necessary that the transmitting set radiate what is termed a pure wave. In order to do this, as explained later, it is necessary and the decrement of damping should not exceed a certain factor. ce, highly damped wave cannot be sharply tuned and accordingly causes interference with the operation of stations not tuned to the same wave length. The maximum decrement permitted by government regulations is 0.2, but modern commercial sets are designed to have an oscillation decrement much below this so as to insure sharp tuning and a minimum of interference with other stations.

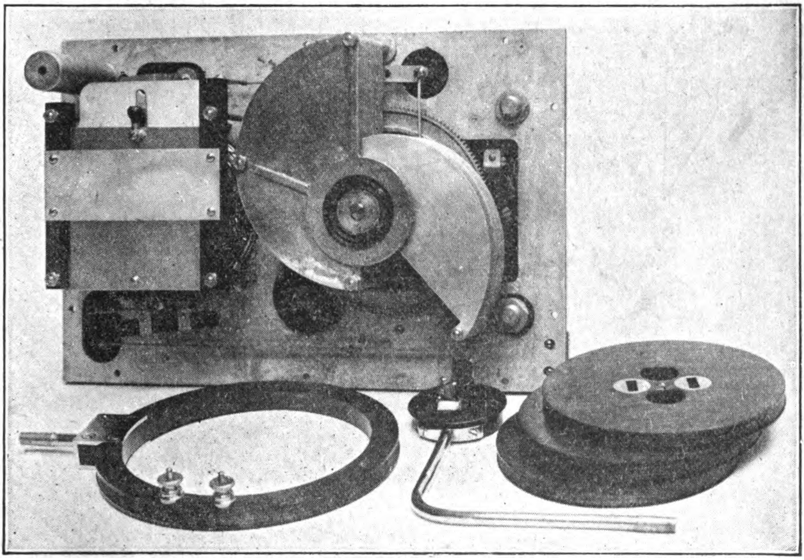


Fig. 60. Parts of Kolster Decremeter Exposed
Courtesy of United States Bureau of Standards, Washington, D.C.

The decremeter is simply a wavemeter provided with a hot-wire wattmeter to permit accurate reading of the current flowing in the wavemeter circuit. Fig. 58 illustrates one form of wavemeter with detector, head telephones, buzzer, vacuum tube (to indicate resonance), variable condenser, and inductance coil. The calibration curves for interpreting the readings are placed in the cover of the box.

The U.S. Bureau of Standards employs the Kolster decremeter for the use of government radio inspectors. In Fig. 59 is shown the complete equipment in its case; in Fig. 60 are shown the variable condenser and the other instruments as they appear fastened to the top cover of the box.

FUNDAMENTAL WIRELESS PHENOMENA

OSCILLATORY DISCHARGE

Relation of Resistance to Capacity and Inductance in Circuit. Whether the discharge from a condenser is a single surge of current in one direction or is oscillatory in character depends upon the

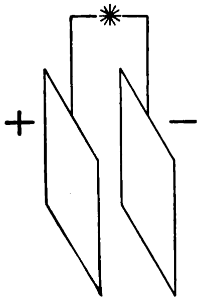


Fig. 61. Elementary Condenser with High-Resistance Circuit

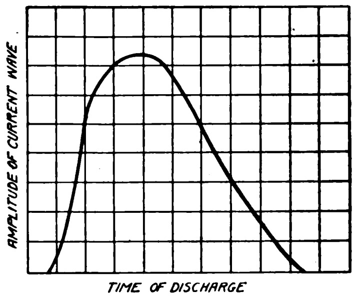


Fig. 62. Curve Showing Unidirectional Discharge of Condenser, Fig. 61

relation that the resistance of the circuit bears to the values of inductance and capacity in the circuit. As already mentioned, *inductance* is produced by a coiled conductor while *capacity* is represented by a condenser; but it must be borne in mind that all conductors have inductance because a current may flow either in or on them; they also have capacity due to their surface. All conductors naturally have resistance and, in the case of an oscillatory circuit, this resistance also includes that of the open space in the circuit, known as the spark gap, or discharger, the resistance of which is an important factor.

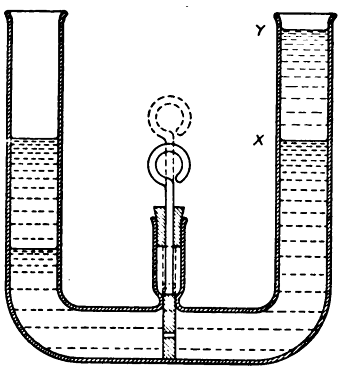


Fig. 63. Mechanical Analogy of Discharge of Condenser

In a charged condenser, assuming a two-plate type to simplify the illustration, one of the opposed surfaces is at a high positive potential while the other is at an equally high negative potential. Let these surfaces be connected by very fine wires the ends of which are gradually brought closer to one another until the discharge takes place, Fig. 61. In such a circuit, the capacity is high and the inductance has a very low value, but the value of the resistance, as represented by the fine conducting wires and the large opening of the gap, is excessive. The discharge of the condenser through such a circuit would accordingly be unidirectional and comparatively slow, the current curve taking the form shown in Fig. 62, in which the vertical line, or ordinate, shows the amplitude of the current wave while the horizontal line, or abscissa, represents the time taken to complete the discharge.

Mechanical Analogy. A simple mechanical analogy to this form of discharge is the passage of water from one branch of a U-tube to the other through a very small opening, Fig. 63, in the disc at the bottom. When water is poured into the left arm of the tube, it runs very slowly through the hole so that when it reaches the common level *X* in the right-hand branch it subsides without further movement. If, with the water all in the left branch, however, the disc be quickly lifted so as to open the full bore of the connecting passage, there is immediately a rush of water from the left-hand to the right-hand branch. Owing to its inertia, the water will rise to the point *Y* far above its original level and will then fall back and rise beyond its former level in the left tube, continuing this alternation from one to the other with gradually decreasing rise and fall during each cycle until the resistance of the walls of the tube plus that of the air causes it to come to rest with half of the water in each branch.

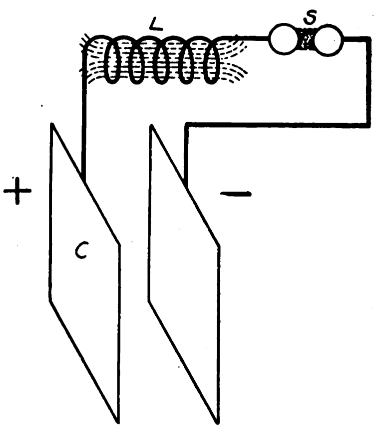


Fig. 64. Discharge of Condenser through Low-Resistance Circuit Having Increased Inductance

Producing Oscillatory Discharge. The pulling out of the disc to open the full bore of the passage is analogous to what takes place in the discharge of the condenser when the resistance of the circuit permits a quick rush of current from it rather than a comparatively slow leakage which does not permit the current to attain any inertia. To bring this about, it is necessary to connect the condenser with heavier wire, make the opening of the spark gap very much smaller, and include in the circuit an increased value of inductance. The terminals of the wires representing the spark gap must also have plane or circular surfaces rather than points, as the discharge tends to leak away through pointed terminals. The resistance of the circuit has now been greatly lessened and its self-induction greatly increased by the additional inductance of the coil.

Influence of Resistance. The action on discharge is then as follows: the condenser, Fig. 64, discharges across the gap *S* through the inductance *L*. But in doing so, it creates a powerful magnetic field about *L* which reaches its maximum at the same instant that the current reaches zero. The energy that was previously represented by the charge of the condenser is now in this magnetic field, less any losses caused by the resistance. But as

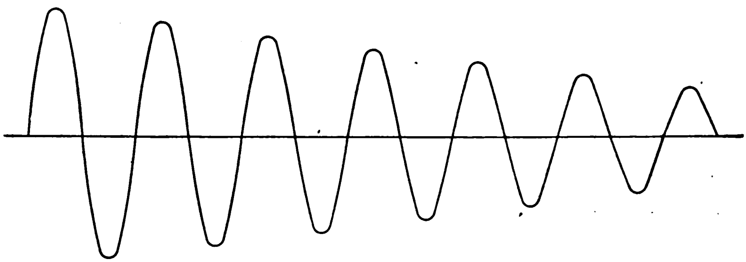


Fig. 65. Curve of Oscillatory Discharge of Condenser, Fig. 64

there is no longer any current to maintain it, the magnetic field is reconverted into an electrostatic field in the inductance and rushes back into the condenser to recharge it in the opposite direction. This alternate conversion from electric to magnetic energy and back again takes place as many times as the inductance and capacity of the circuit are able to overcome its resistance, producing a current curve such as that shown in Fig. 65. Two alternations complete each oscillation, the highest potential attained by the latter representing its amplitude. The time interval between two successive oscillations is their *period*, while the decrease in amplitude from one oscillation to the succeeding one is the *damping*, so that its extent indicates the amount of loss between succeeding cycles.

Oscillation Circuit. The circuit represented in Fig. 66 is an oscillation circuit and, to distinguish it from the aerial or radiating circuit of the transmitting set, it is known as the closed oscillation circuit. In order for such a circuit to be oscillatory in character when its condenser is charged from a source of high-potential alternating current, causing it to discharge through the spark gap, the resistance of the circuit must be *less than twice the square root of the inductance divided by the capacity,* that is

$$R<2\sqrt{\frac{L}{C}}$$

If the resistance is greater than this factor, the circuit will be nonoscillatory, while if it is equal to this value, it will be just oscillatory but, as explained later, the oscillations will be very strongly damped. This is known as the fundamental equation of wireless telegraphy. In actual practice, the various elements of the closed oscillation circuit are connected by copper tubing, flat strips, or heavy stranded wire and the spark gap is very small, even with high power, so that the resistance of the circuit is held down to a very low value.

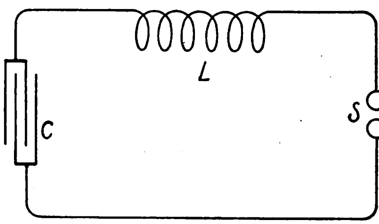


Fig. 66. Closed Oscillatory Circuit

Oscillation Frequency. It has been demonstrated that electricity travels with the same speed as light, that is, 186,000 miles per second (300,000,000 meters), and as the oscillations shown by the curves are all represented by what appears to be a single brief spark, it will be apparent that the rapidity with which these oscillations occur is very great. The number per second is known as the oscillation frequency and it may reach 1,000,000 or more, so that the time element as represented by the abscissa may be 0.000001 second or less. The oscillation frequency of a circuit varies inversely as the square root of the product of the inductance and capacity, the inductance L being measured in henrys and the capacity C in farads. As the frequency is also inversely proportional to the wave length of the oscillation emitted by the circuit, it follows that the wave length of any circuit may be increased by adding either inductance or capacity to the circuit. This increases the time, or period, between two oscillations.

The current in a circuit damps down or dies out when the e.m.f. which established it is removed. In a circuit containing resistance, inductance, and capacity, the frequency of the natural oscillation depends entirely upon the inductance and capacity, provided that four times the inductance is large as compared to the product of the capacity and resistance squared. The damping constant is directly proportional to the resistance and inversely proportional to the inductance.

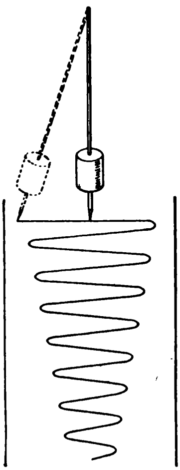


Fig. 67. Curve Traced by Pendulum

Damping. If a pendulum be fitted with a marking point at its lower end and then be held 90 degrees out of the perpendicular and released, this marking point will trace a curve on a band of paper moving beneath it, as shown in Fig. 67. The pendulum will make a long series of oscillations before finally coming to rest. By affixing a plane surface to its suspending cord at right angles to its line of travel and repeating the experiment, the number of oscillations will be greatly reduced and the curve will then be similar to that shown in Fig. 68. The plane has greatly increased the resistance of the air and has caused the pendulum to come to rest in a much shorter time. If, on the other hand, the plane be omitted and the pendulum itself be given a streamline form, its resistance will be less than in the first instance and it will continue to oscillate through a greater number of alternations.

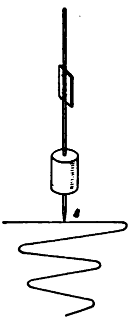


Fig. 68. Curve Traced by Damped Pendulum

The series of oscillations in each case is termed a train and when produced by an oscillatory electric circuit is called a wave train. Because the amplitude of each succeeding oscillation is less than that of the one immediately preceding it, such a wave train is said to be *damped.* As produced by the pendulum with the air-resisting surface attached to it, the train is highly damped, while in the third instance it is only feebly damped. When the amplitude of the wave train is practically constant, it is said to be undamped, or persistent. A highly damped wave train produces what is known as a broad wave in wireless telegraphy and, as such a wave cannot be sharply tuned, it is a disadvantage.

Decrement of Damping. In all the oscillation trains illustrated it will be noted that a fixed ratio of decrease exists between the amplitude of the oscillations in each successive half-period, as measured between any adjacent maxima. This is due to the successive loss of energy at each reversal, or oscillation, a part of the force represented by the charge of the condenser being dissipated in the form of heat in overcoming the resistance of the circuit; therefore, each succeeding oscillation is of smaller amplitude than its predecessor. This decrease is a fixed quantity, varying with the characteristics of different circuits but chiefly in proportion to their resistance, and its rate may be expressed in terms of a logarithmic percentage. The rate of decrease in the oscillations is accordingly termed its logarithmic decrement. As the sharpness of the tuning possible depends upon the wave being of a well-defined length, a highly damped wave is not permissible under government regulations which prescribes a wave with a decrement not exceeding 0.2.

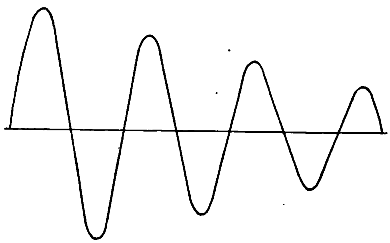


Fig. 69. Highly Damped Oscillation Train

In Fig. 69 is illustrated a highly damped train of oscillations, while one with feeble damping is shown in Fig. 70. By comparing the two it will be apparent that where the damping is slight the number of oscillations for the same amount of energy in the condenser will be much greater than where the oscillations are quickly damped out. To obtain the requisite tuning qualities in the electromagnetic wave to prevent undue interference at the receiving

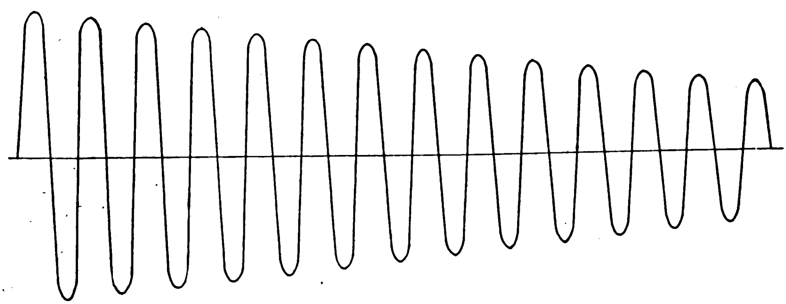


Fig. 70. Feebly Damped Oscillation Train

station, it has been found that the transmitter must produce at least 15 complete oscillations for each spark discharge of the condenser. The decrement, or ratio of decrease, is equal to 2.7183 times δ (Greek letter delta), where δ is the constant for the oscillatory circuit. The quantity 2.7183 is the base of the Naperian system of logarithms, so that δ equals the Naperian logarithm of the ratio between any two successive maximum amplitudes in the opposite direction. The constant δ is termed the logarithmic decrement and is the measure of the damping in any particular circuit.

Standard U.S. Decrement. A wave train composed of 15 complete oscillations corresponds to a decrement of 0.2 for each complete oscillation, which is the reason for the adoption of this decrement in the United States statute. A decrement of 0.2 means that the logarithm of the ratio of damping between any two successive oscillations, as shown in Fig. 69, will be 0.2, but as the number corresponding to the logarithm 0.2 is 1.2, the ratio of decrease between each oscillation will be 1.2 per cent. In other words, each succeeding oscillation will be 1.2 smaller than the one preceding it, for a decrement of 0.2.

This regulation is chiefly aimed at the numerous amateur stations and is designed to prevent them from sending out waves that would interfere with other stations. But as a wave train consisting of but 15 complete oscillations would not be efficient for long-distance sending, commercial sending sets have a logarithmic decrement of but one-fourth or less that prescribed by law. Many of the Marconi transmitters show a decrement of only 0.05, which means that the number of oscillations per wave train is approximately four times as great as for the decrement of 0.2, or over 60 for each spark discharge of the condenser.

Resonance. The foregoing explanation of the method of generating a high-frequency current by means of the discharge of a condenser in circuit with an inductance and spark gap covers briefly what is known as the closed oscillation circuit. In order to utilize this high-frequency current in the form of electromagnetic waves, it must be transferred by electromagnetic induction to a second circuit known as the open oscillation circuit, because it comprises in part the aerial, or antenna, from which the waves are radiated. Both circuits are sometimes referred to as radio-frequency circuits. To effect this transfer most efficiently, it is necessary that both circuits should have the same natural frequency of oscillation. The reason for this will be clear upon considering the action of a simple mechanical analogue.

Mechanical Resonance Illustrated by Pendulum. Assume a suspended pendulum to be fitted with an automatic tapping device designed to impart energy to the pendulum and so arranged that this energy may be delivered to the moving pendulum at any part of its travel, Fig. 71. The tapping device corresponds to the closed oscillation circuit, while the pendulum is the counterpart of the open radiating circuit to which the energy is to be transferred. With the pendulum oscillating at its natural frequency, only a slight tap is needed to maintain it in motion at the same speed if the force be delivered to it at exactly the right moment. This is when the pendulum has reached the limit of its travel in one direction and is just about to start back in the opposite direction. Should the tapper, however, be set to deliver this blow when the pendulum has completed only three-fourths of its travel, a much heavier blow will be necessary to start it back at the same speed and its oscillations will no longer have the same frequency as that of the tapper, that is, the oscillation of the latter will begin before that of the pendulum has been completed.

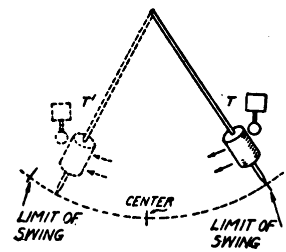


Fig. 71. Mechanical Illustration of Resonance—*T*, Tapper Set to Strike at End of Swing; *T′*, Tapper Set to Strike before Completion of Swing

Resonance of Piano Strings. Another familiar instance of resonance is to be found in the effect of a tuning fork on piano strings. By depressing the loud pedal of a piano, then striking a tuning fork a sharp blow and holding it near the strings, it will be found that while all the strings respond to some extent, one particular string will respond most strongly because its period of vibration is the same as that of the tuning fork so that the two vibrate in unison.

Balancing Inductance against Capacity. To charge the condenser in the closed oscillation circuit, the alternating current must overcome its back pressure, or reactance, which is known as negative reactance, since it opposes the flow of current. But the inductance in the circuit also has reactance and the counter-e.m.f. set up by this tends to aid in charging the condenser so that it is termed positive reactance. It will be apparent from this that, by providing the circuit with an adjustable capacity and an adjustable inductance, the two may be varied so that their opposing electromotive forces will just counterbalance one another and the current then only has to overcome the ohmic resistance of the circuit. Under such conditions, the greatest value of alternating current will flow in the circuit for a given amount of impressed e.m.f.

Spark Gap. To produce a high-potential discharge from a condenser, it is essential that the circuit in which the condenser is placed be provided with a break or opening in it of such length that the condenser cannot discharge across it until the maximum potential is reached. As the resistance of air to the passage of the current is very high, it is not necessary that this opening, or gap, be very long. It is known as the spark gap and to prevent the leakage, or brush discharge, that would occur from points or sharp surfaces, thus dissipating some of the energy before the condenser was discharged, the terminals of the spark gap are in the form of either flat surfaces or spheres. Once the discharge has started, the air between these terminals becomes conductive in proportion to the strength of the current passing. Its conductivity is due to the air becoming *ionized* by the passage of the current and is approximately inversely proportional to the length of the gap.

A small amount of electricity will charge a small condenser to a high potential and if the condenser is connected to a narrow spark gap, the discharge will then take the form of an arc. But by using a larger capacity, a greatly increased amount of current is required to bring it up to the necessary high potential, and to discharge this rapidly, a small spark gap is needed. The less the distance between the terminals of the spark gap, the lower its resistance, so that in an oscillation circuit of large capacity, a small spark gap is desirable to produce feebly damped trains of oscillations.

Oscillation Constant. Mention has already been made of the fact that the chief determining factors of the wave length of an oscillation circuit in which the resistance is practically negligible are inductance and capacity. By increasing either of these, a corresponding increase in the wave length is effected, and if either be decreased, a like decrease in the wave length results. But it is clear that the increase or decrease of the wave length is not proportional to the increase or decrease of C or L, since increasing either only increases the wave length in the ratio of the square root of $2(\sqrt{2})$. Again, by increasing C and decreasing L an equivalent amount, one neutralizes the other and the wave length remains the same. It should be borne in mind that the wave length is always a measure of the oscillation frequency of the circuit. The quantity represented by the square root of the product of the capacity times the inductance, or $\sqrt{CL}$, is therefore termed the oscillation constant. Circuits that have the same oscillation constant are in electrical resonance since they have the same frequency.

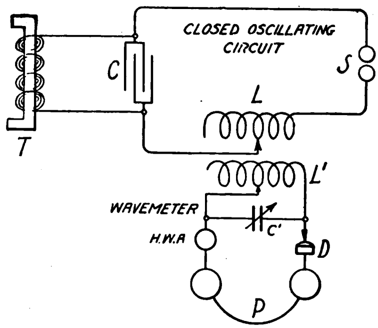


Fig. 72. Diagram Showing Method of Determining Point of Resonance with Wavemeter

An illustration of the method of obtaining electrical resonance in wireless circuits is given in Fig. 72. CSL is the closed oscillation circuit consisting of a fixed condenser which is charged from an alternating-current source of high potential T. S is the spark gap while L is an adjustable inductance, the arrowhead indicating that a greater or lesser number of the turns of the coil may be included in the circuit by moving a sliding contact or a multiple-point switch. The second circuit $L'AC'$ represents a wavemeter, of which A is the hot-wire ammeter, D the detector, and P the head telephones. In this circuit both the inductance L' and the capacity C' are variable. The condenser of the first circuit is discharged through the spark gap while both the inductance and the capacity of the second circuit are adjusted so as to produce the maximum reading of the hot-wire ammeter. When further change in adjustment will give no higher reading, the circuits are oscillating at the same frequency and are then in resonance. This is of great importance in wireless transmission since the maximum amount of energy will be radiated from the open circuit for a given transformer input under these conditions.

CONDENSERS

Electrostatic Capacity. In the sections on "Elementary Electrical Principles", page 8, it was pointed out that certain substances, such as amber and silk, are very readily electrified, or charged. Furthermore, it was shown that when amber and silk are rubbed together, one is charged positively and the other negatively. If either is brought close to another object, it will be discharged. The electricity thus held by a body is termed an electrostatic charge while the amount of this charge that the body is capable of retaining is termed its electrostatic capacity, or simply capacity, which is abbreviated to C in all calculations. All conductors have capacity, the chief measure of which is their surface area, so that the capacity of a wire is naturally small. Consequently, to obtain increased capacity, surfaces in the form of plates are employed.

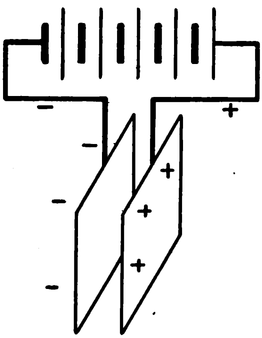


Fig. 73. Diagram of Simple Condenser Charged by Battery Current

Factors Affecting Capacity of Condenser. By connecting two such plates to wires from the terminals of a battery, Fig. 73, then placing these plates close to each other momentarily, as shown, they will become charged. This charge may be evidenced by connecting the plates to a galvanometer, through which they will immediately discharge upon making the connection, the deflection of the galvanometer needle indicating the strength of the charge. Repeat the experiment a second time with the same battery and the same plates, but bring the latter closer together by placing them on opposite sides of a thin sheet of glass. The galvanometer will then indicate that the amount of charge held by the plates has increased. The charge has literally been *condensed* by bringing the oppositely charged surfaces closer together. Hence, an electrical capacity is termed a condenser.

It will also be clear from the above that the capacity of these plates is affected by their proximity as well as by their area. The closer together they are placed, the greater the charge they will hold. If the experiment be repeated a third time with a battery of twice as many cells connected in series, it will be found that on discharge the galvanometer needle again shows a substantially increased deflection. From this it is apparent that a third factor influences the capacity of any conductor, namely, the potential of the charging current. The greater the pressure, under which the charge is applied, the larger the capacity.

This has a simple parallel in mechanics in the capacity of a container. Assuming that the latter has a capacity of one cubic foot; at atmospheric pressure it will hold one cubic foot of air, but by connecting it to an air compressor it may be made to hold as many cubic feet of air as the compressor is capable of forcing into it.

If the experiments be carried further by placing different insulating substances between the plates and then noting the strength of the discharge as shown by the galvanometer, it will be apparent that the capacity of the plates also varies according to the nonconductor as well as to the distance separating them. There are accordingly five factors which influence the capacity of a body: first, its size; second, the proximity of other conductors; third, the distance separating it from these conductors; fourth, the potential of the charging current; and fifth, the nature of the nonconductor separating the capacity areas. All other things being equal, however, the capacity of the condenser will be determined solely by the extent of its surface.

Dielectrics. While the substances thus employed to insulate the opposing surfaces of a capacity from one another are nonconductors of electric currents, they are good conductors of electrostatic lines of force which fill the space separating two charged bodies. In other words, an electrostatic field is created between them in the same manner as a magnetic field is created between the poles of a magnet, the number of lines of force depending on the factors above mentioned. The body separating charged surfaces is known as the dielectric. This may be air, either at atmospheric or a higher pressure, gas, paraffined paper, oil, glass, or other nonconducting substance. The ability of these various substances to conduct the electrostatic lines of force depends upon their nature and varies greatly.

Specific Inductive Capacity. This conductive property of dielectrics is termed the specific inductive capacity of the material, air being used as the standard. For example, castor oil has five times the inductive capacity of air; while glass has six to nine times, depending upon its character. The specific inductive capacity is also known as the dielectric constant and in equations is represented by K. Thus the dielectric constant of castor oil would be 5, that of the best grade of glass 9. This indicates that a condenser in which the dielectric constant is 5 will require five times as much energy to charge it to maximum capacity as the same condenser with air as the dielectric; likewise, upon discharge, the condenser is capable of doing five times as much work, the potential being the same in both cases.

Concentrated and Distributed Capacity. It has been mentioned under the head "Comparison of Magnetism and Current Electricity", page 21, that the flow of a current in a conductor is always attended by the creation of a magnetic field, in which the lines of force are at right angles to the direction of current flow. It is also attended by an electrostatic field, in which the lines of force lie parallel with the conductor and are most strongly in evidence at the ends of the latter. Consequently, every conductor has capacity, the extent of which is governed by the factors already given. In the case of wires, this is known as distributed capacity and, except where the wires are of large size, are placed close together, and have a high-potential current flowing in them, it is small. In the case of surfaces with a very short distance between, the capacity is concentrated. A concentrated capacity is termed a condenser.

Types of Condensers. *Leyden Jar.* A condenser consists of conducting surfaces placed parallel to each other and separated by a dielectric. The familiar Leyden jar is one of the simplest forms, Fig. 74. It consists of a wide-mouthed bottle, or jar, coated to about one-half its height both inside and outside with tinfoil. Connection is made with the outside coating by placing the jar on a metal plate, while a rod terminating in a chain which rests on the inside coating on the bottom of the jar forms the second connection. The capacity areas are represented by the tinfoil coatings, while the glass wall of the bottle forms the dielectric.

Leyden jars were used almost entirely for the transmitting condensers of early wireless sets but, owing chiefly to the great amount of space necessary to obtain the required capacity, they have been abandoned to some extent for more compact forms. In commercial use, however, the tinfoil used on small experimental Leyden jars is replaced by a coating of copper plated on the glass.

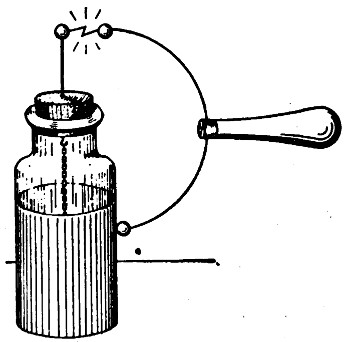


Fig. 74. Leyden Jar Type of Condenser

Commerical Transmitting Types of Fixed Capacity. Modern types of transmitting condensers which must stand very high potentials consist of plates of copper, zinc, or aluminum separated by glass, hard rubber, or oil, which forms the dielectric. They are sometimes embedded directly in an insulating compound which is poured on them in a molten state and which hardens when cold. In Fig. 75 is illustrated a condenser consisting of metal plates with a glass dielectric, while Fig. 76 shows one of the latter type, known as a molded condenser. In order to prevent a discharge around the edges of the plates, the metal surfaces are made considerably smaller than those of the dielectric. It will be apparent that with the plate construction a large capacity may be obtained in a small space. To increase this, the condenser is made in units which may be connected either in parallel or in

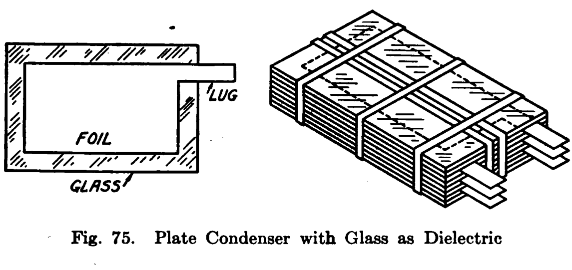


Fig. 75. Plate Condenser with Glass as Dielectric

series, as noted later. Condensers of the above types are used only in the transmitting circuits and they are in every case fixed units, that is, their capacity is not variable except by altering the manner in which the members comprising the complete condenser are connected in the circuit.

Receiving Types of Fixed Capacity. In the receiving circuits, in which both the potential and the currents handled are represented by almost infinitely small values, much simpler forms of condensers may be used. One of these consisting of sheets of tinfoil separated by layers of paraffined paper is shown in Fig. 77.

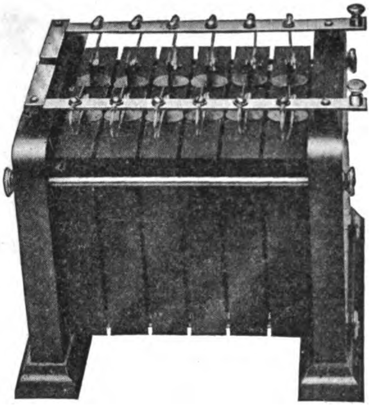


Fig. 76. Molded Condenser Units Mounted in Rack
Courtesy of W. J. Murdock Company, Chelsea, Massachusetts

The extended ends serve as connections for the terminals, the sheets of tinfoil being placed so that the ends, or tabs, extend alternately to the two terminals. In assembling the condenser, a sheet of the paraffined paper is laid down, then a sheet of tinfoil with its tab extending to the right, next another sheet of paper, and then a sheet of tinfoil with its tab extending to the left. The tinfoil, however, should not come as close to the edges of the paraffined paper as is shown in the sketch, at least one-half inch being allowed all around. The pile is completed with a final sheet of the paper. There is accordingly no direct connection between the two groups of tinfoil sheets while the condenser is insulated top and bottom by the waxed paper.

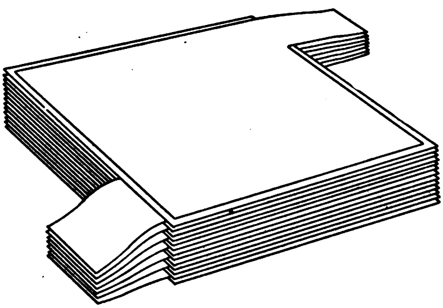


Fig. 77. Simple Tinfoil Condenser with Paraffined Paper as Dielectric

To complete a condenser of this type, the groups of extending tabs are clamped or soldered to connecting wires which are brought out to binding posts, or terminals, on the containing case. The latter may be of either wood or hard rubber, Fig. 78, and after the condenser has been inserted in the case and connected to its terminals, the case is poured full of paraffin wax or some other insulating compound in a molten state so that there can be no relative movement of the leaves or of the condenser as a whole in the case. Where no case is provided, the condenser itself may be solidified by placing a warm laundry iron on the pile. The heat of the iron should only be sufficient to cause the wax to soften, thus allowing the weight of the iron to press it together; if too hot, the wax will run off the paper altogether. When cool the condenser can be further protected by a wrapping of ordinary adhesive tape. Small binding posts can be clamped through the groups of tabs and the latter then doubled back on the condenser itself and thoroughly wrapped with the tape.

Condenser for Code Practice. In the section "Learning the Code", page 247, mention is made of the use of a simple condenser of this kind in connection with an ordinary buzzer and battery to simulate wireless signals for practice. If the student does not wish to make a condenser as above described, one that is suitable for the purpose and that will work equally well on the low voltage and small current employed may be made in a few minutes. Sheets of tinfoil, such as are packed with cigars or candy, and ordinary letter paper for the dielectric will provide suitable materials; the wax paper wrapped around loaves of bread is equally good. Four to six sheets of tinfoil approximately 3 by 5 inches are all that is required but they may, of course, be of any size that is available. If considerably smaller than the dimensions given, use a greater number of sheets; if larger, fewer of them will give the desired capacity. One or more of the sheets may be cut into strips to provide the tabs in case the tinfoil itself is too small to permit this conveniently. After the sheets of tinfoil and paper have been assembled they may be rolled up on a magazine, a round piece of wood, or any other insulator that will provide a support for them and may be kept together by passing a rubber band around them. After pasting up the two groups of tabs, the ends of two flexible pieces of wire, which are long enough to form a connection between

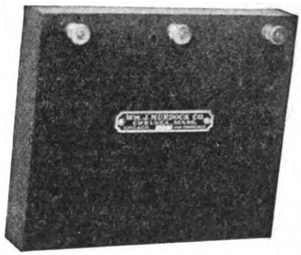


Fig. 78. Murdock Type of Tinfoil Condenser

the buzzer, key, and condenser, should be bared and tightly wrapped, one in each tab; the condenser terminals should then be secured to the body of the condenser with adhesive tape or more rubber bands. This is a rather crude form of condenser but may be made without any expense and will serve the purpose as well as one costing two or three dollars. The capacity of such a condenser is immaterial; one having but two sheets of tinfoil 4 by 6 inches will work well on two dry cells while a greater number only increases the sound in the head telephone—not a particularly desirable feature.

Variable Condensers. *Simple Type.* The types of condensers just described are known as fixed condensers since the area of their opposed surfaces cannot be varied. As the amount of capacity in a high-frequency circuit is one of the essentials governing the

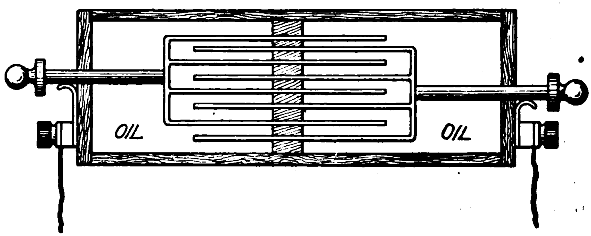


Fig. 79. Simple Type of Variable Condenser

wave length of the circuit, it is desirable that this factor be made adjustable. For this purpose, what is known as a variable condenser is provided. Other things being equal, the area of the opposed surfaces is a direct measure of the capacity of any condenser, so that the variation in capacity is accomplished by making the condenser with one set of surfaces stationary and the other movable in order that the latter may be moved out of the electrostatic field. The principle involved is illustrated by Fig. 79, though in this case both groups of plates are movable. Two groups of four plates each are fastened at their ends to rods, giving a construction somewhat similar to a pair of large forks the tines of which may be brought near each other without touching at any point. In the position shown, they represent almost the maximum capacity of the condenser; by drawing them apart this can be reduced almost to zero. As the specific inductive capacity of oil is very much greater than that of air, the capacity of such a condenser may be increased several times by filling it with oil, as indicated. For instance, if it be assumed that with air as the dielectric the capacity of this condenser is 0.001 microfarad, by filling the case with castor oil, it will be increased to 0.005 microfarad.

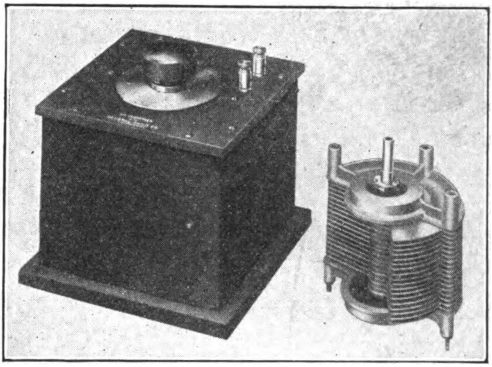


Fig. 80. Korda Type of Air Condenser, Showing Also Plates Dismounted from Case
Courtesy of General Radio Company, Cambridge, Massachusetts

Korda Type. The form of construction just described is not sufficiently compact for use in connection with the cabinet type of receiving sets now generally employed, so the variable condensers employed are of what is known as the Korda type. This consists of a stationary and a movable group of metal plates of semicircular form. The first group is attached to a stationary rod fastened to the cover of the condenser while the second group is attached to a pivoted rod which may be revolved through a half-turn by means of the hard-rubber knob on top of the condenser. The variation of the capacity is indicated by a pointer fastened to the turning knob and passing over a scale which is usually marked in divisions simply indicating the relative increase or decrease of the opposed areas and not representing any particular unit. The construction of this type of condenser will be clear from Fig. 80, the plates being shown outside the box. A condenser of the same type mounted in a glass case is shown in Fig. 81. In the panel or cabinet types of receiving sets generally employed commercially, only the hard-rubber adjusting knobs and their corresponding scales appear.

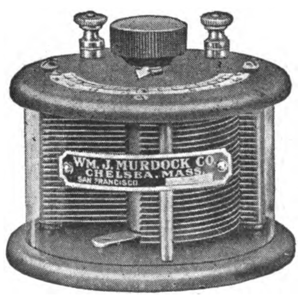


Fig. 81. Korda Type of Air Condenser Mounted in Glass Case

Capacity of Condenser. The unit of capacity is the farad (named after the scientist Faraday). A condenser has a capacity of one farad when it will be charged to a potential of one volt by one coulomb of electricity. The earth acts as one opposing surface of a huge condenser, but as its area is not sufficient to give it a capacity of one farad, it will readily be apparent that the latter is entirely too large a unit for practical purposes, Hence, one millionth of a farad, or microfarad, has been adopted as the practical unit and most of the condensers used in wireless telegraphy have capacities which are but small fractions (represented by three or four decimals) of this unit. Thus a condenser having a capacity of one microfarad is charged to a potential of one volt by one microcoulomb of electricity. The capacity of a condenser is calculated by the formula

$$C=\frac{K\times A\times 2248}{T\times 10^{10}}$$

in which C is the capacity in microfarads; A is the area of the opposed surfaces; K is the specific inductive capacity of the dielectric, or nonconductor, separating the opposed surfaces; and T is the thickness of this dielectric.

As an example, assume that the area of the opposing surfaces of the small experimental condenser described above is 50 square inches, the specific inductive capacity K of the paper dielectric is 5, and the thickness T of this paper is 0.005; then

$$C=\frac{5\times 50\times 2248}{0.005\times 10^{10}}=0.00112 \text{ microfarad}$$

from which it will be apparent that the capacity of a condenser varies directly as the area of the opposed surfaces and the specific inductive capacity of the dielectric and inversely as the distance separating these opposed surfaces, or plates. Thus if K were 10 or the area of the surfaces were 100 square inches, the capacity of this condenser would be doubled; or, these factors remaining the same as given in the above equation, if the thickness of the paper dielectric were 0.0025 instead of 0.005, the capacity would also be doubled.

Action of Condenser. In the description of the induction coil, it was explained that the condenser *absorbed* the back kick, or surge, of current caused by the self-induction of the primary coil when the circuit was broken. When current flows into a condenser, the potential difference of the condenser rises until it equals that of the charging source, so that the moment the voltage of the charging current decreases, the condenser discharges back into the circuit. In the case of the induction coil, the charging current falls to zero, so that the entire charge of the condenser is immediately returned to the primary circuit of the coil when the vibrator recloses it.

Mechanical Analogy. The action taking place in a condenser may be compared with that taking place in a tube, Fig. 82. At one part of this tube a thin rubber diaphragm is inserted, while at a point opposite it a blower is located. When the blower is operated there will be a displacement of the air in the circuit, depending upon the pressure created by the blower and the stretch, or give, of the rubber diaphragm. The moment the blower is stopped the pressure throughout the circuit will again be equalized by the elasticity of the diaphragm bringing it back to its normal plane. But if the pressure be raised beyond the strength of the diaphragm to withstand it, the latter will be broken and the air will circulate around the tube freely. The displacement of the diaphragm caused by the pressure is equivalent to the electrostatic strain set up by the charging current; the back pressure exerted by the diaphragm when the charging pressure ceases is the equivalent of the discharge of the condenser, while the breaking of the diaphragm under excessive pressure is the same as the puncturing, or rupture, of the dielectric of a condenser when subjected to an excessive

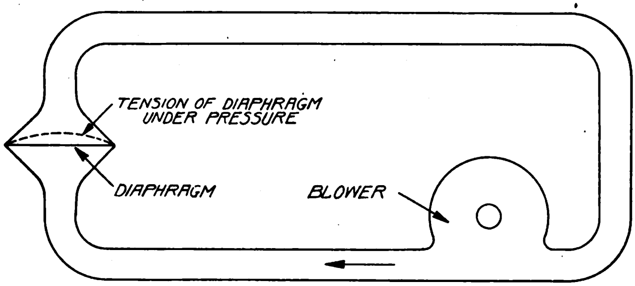


Fig. 82. Mechanical Analogy of Action of Condenser

potential. The latter is caused by separating too far the sparking points of an induction coil or the spark gap in series with the secondary of a transformer; this is the commonest cause of the breakdown of the transmitting condensers in wireless operation.

Condensers in Parallel and Series. Connecting condensers in parallel gives a total capacity equal to the sum of the several units, as this is equivalent to increasing the area of the plates, while keeping everything else constant. But when two single condensers or two parallel groups are connected in series, the resulting capacity is but one-half that of a single unit in the first case or of a group in the second case. For example, to obtain the same capacity as is represented by eight condenser units in parallel, it is necessary to provide two parallel groups of sixteen units each connected in series. Connecting condensers in series has the important advantage of dividing the voltage between them and thus reducing the strain on them by half. For example, if the transformer of a transmitting circuit must be operated at its maximum voltage of 30,000 volts in order to send messages the distance required and the condensers will only stand 25,000 volts, they may be connected in two groups in series-parallel so that the potential which the units of each group will then have to withstand will be reduced to 15,000 volts. Another method of protecting condensers from excessive strain from being operated at potentials above that at which they are rated is to equip them with safety spark gaps similar to those employed for the same purpose on induction coils.

Condenser Discharge. In the small condensers used in the receiving end of the set, the charges are so small that the condenser does not discharge without connection actually being made with its terminals. But where high potentials are employed, as in the transmitting condensers, the latter can be discharged without actually connecting the opposed surfaces. When wires connected to them are brought within a short distance of one another the potential of the charge is sufficient to bridge the air gap, thus discharging the condenser. The energy represented by its charge manifests itself in the form of light, sound, and heat, as well as in invisible electromagnetic waves. The discharge of a bank of condensers, such as is used even in the ½-kw. sets, when allowed to take place through an open spark gap, affords, on a miniature scale, a very realistic imitation of lightning and thunder.

For many years it was considered that this discharge of a condenser was practically instantaneous and that it consisted of but a single spark or flash of current *in one direction*—that is, from the positively charged to the negatively charged surfaces—and that all the energy in the charge passed out of the condenser on discharge in one violent surge. It was discovered, however, that under certain conditions the discharge did not take place in this manner but was oscillating in character, that is, the condenser acted very much as a musical string that is stretched very taut and then suddenly plucked in the middle. Instead of returning at once to its normal position, the string is carried beyond in the opposite direction almost as far as it was originally held out of line and in returning it again passes this position. This is repeated a number of times, the travel of the string across its normal line of rest becoming shorter each time until it finally subsides; in other words, it continues to vibrate until the energy represented by the impulse given it has been dissipated. In the same manner, the condenser discharge falls to zero immediately upon its release, rises to almost the same value in the opposite direction, and again falls to zero, continuing this until the energy it contained is used up in overcoming the resistance of the discharge circuit, thus constituting an alternating current of high frequency. This is known as an *oscillatory discharge;* the frequency with which it occurs depends upon the capacity of the condenser, while the extent to which it continues depends upon the resistance of the circuit.

Dielectric Strength. As the capacity of a condenser depends upon its ability to hold a charge of electricity on opposing surfaces, it will be evident that this capacity must also be limited by the ability of the dielectric to withstand the electrostatic strain without permitting the passage of the current through it. If the potential of the charge reaches a point where it punctures the dielectric, the condenser is short-circuited; in other words, there is then a direct path for the current through it and it is no longer a condenser. It is now said to be *broken down.* The ability of the insulator to withstand the electrostatic strain is termed its dielectric

TABLE III*

Dielectric Strength of Different Materials

Material	Specific Inductive Capacity	Dielectric Strength (volts)
Air	1.00	4500
Hard rubber	2.29	40000
Soft rubber	2.10	30000
Mica	6.64	60000
Paraffin oil	2.71	7000
Glass	6.96 to 9.86	20000
Porcelain	4.38	16000

strength and it varies with different materials. Table III shows the specific inductive capacity and the dielectric strength of the materials commonly employed.

Voltage in the case of air is per millimeter up to distances of one millimeter; in the case of the other dielectrics, it is per millimeter of thickness and is only approximate in some instances.

Capacity varies inversely and dielectric strength directly as the thickness of the dielectric, but they do not vary in the same ratio. Air and oil require a greater distance between the plates of the condenser and consequently make necessary a condenser of greater size for the same capacity as compared with glass or hard rubber, but they have the great advantage of being self-mending, whereas when a solid dielectric, such as glass or hard rubber, has been punctured, the condenser is useless until it has been renewed. The dielectric strength of air increases with its pressure, but as this pressure decreases even in the most hermetically sealed tank it must be renewed from time to time with the aid of a compressor. Transformer oil is usually employed as the dielectric in the transmitting condensers, though copperplated Leyden jars have been very generally used for a number of years and many of this type are still in operation. The standard jar has a capacity of 0.002 microfarad and the battery of jars is mounted in a rack so that the outside connections are all made by the plate on which they rest, while the inside connections are effected by copper bars fastened to the terminals extending out of the jars at the top.

* See *Manual of Wireless Telegraphy for Naval Electricians.*

TRANSFORMERS

Need of Transformers. For the generation of electromagnetic waves capable of being radiated through long distances by the transmitting apparatus, a potential ranging from 15,000 to 50,000 volts is required, so that the next step is the transformation of the low-voltage current delivered by the alternator of the motor-generator set to one of high potential. This is accomplished by means of a transformer which operates on the principle of electromagnetic induction.

Principle of Transformer. It was shown under the head "Simple Induction Principle", page 30, that, when a coil of wire is placed parallel and in close proximity to a second coil through which a current is momentarily passing, a current will be induced in the first coil. This effect is greatly increased by inserting a soft-iron core in the coil which is excited by the current from a battery or generator. If the exciting current be direct, it is necessary to provide some means of making and breaking the circuit rapidly, in order to maintain an induced current in the second coil. This in brief is an induction coil, also known as an open-core transformer, since only part of the magnetic circuit is represented by the core, the remainder of the magnetic flux having to pass through the air from one pole to the other, as shown by the magnetic field of the solenoid, Fig. 11.

If the number of turns of wire is the same on each of the coils mentioned, a galvanometer connected to the terminals of the second one will show that the induced e.m.f. is of the same value as the applied e.m.f., or voltage, of the current exciting the first coil, less the losses due to the transformation process itself. If, however, the excited coil, termed the *primary*, consists of a comparatively small number of turns while the second coil, termed the *secondary*, has a great number, the induced e.m.f. as shown by the galvanometer will be increased over the applied e.m.f. in the proportion that the number of turns in the winding of the secondary bears to the number in the primary. The voltage will have been stepped-up to a higher potential so that this arrangement is known as a step-up transformer. By reversing the connections in the above experiment, so as to make the secondary the primary coil of the transformer, the applied voltage will be lowered in the same proportion and the transformer will be of the *step-down* type. Only the former type is employed in wireless work.

Induction Coil. *General Construction.* By winding the secondary coil directly over the primary on the same core and providing a magnetically operated make and break for the current entering the primary winding, we have what is known as an induction coil. The core consists of a bundle of soft-iron wires of fine gage inserted in a glass, hard-rubber, or other insulating tube on which the primary of one or two layers of comparatively heavy wire, such as No. 18, 16, or 14, is wound. In series with the primary coil is the interrupter, or make-and-break device, which

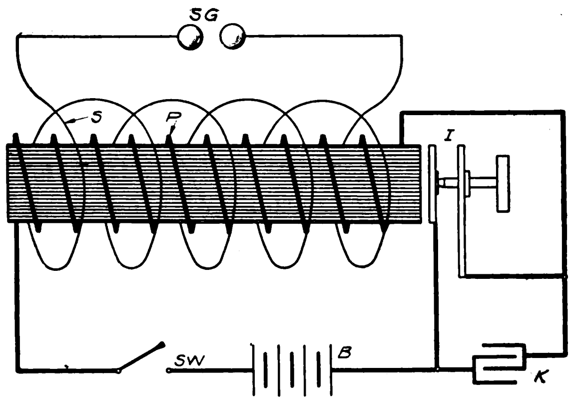


Fig. 83. Diagram Showing Circuits of Induction Coil—*C*, Core; *P*, Primary; *S*, Secondary; *B*, Battery; *SW*, Switch; *I*, Interrupter; *K*, Condenser; *SG*, Spark Gap

operates on the same principle as a buzzer or electric bell. An armature carried on a flat spring and having a platinum contact soldered to the spring is placed close to one end of the core. The spring is fastened to the base at its lower end so that it can vibrate at a rapid rate; its platinum contact bears against a similar stationary contact in the end of an adjusting screw. When the current passes, the armature is attracted by the magnetism of the core, thus breaking the circuit at these contacts; the core then immediately loses its magnetism and the spring recloses the circuit and repeats the operation, vibrating at a rapid rate.

Method of Winding Secondary. The diagram, Fig. 83, illustrates the relation that the windings and interrupter bear to one another. Owing to the immense difference of potential that would be set up between adjacent windings of the secondary, it is not wound directly over the primary in layers but in the form of pancakes, or sections, all of which are wound in the same direction and connected in series with one another. (If oppositely wound sections were connected together their inductive effect would be neutralized.) The high self-induction of the primary winding, due to its iron core, would cause a destructive arc at the contacts and burn them away unless prevented; a condenser is accordingly shunted across the terminals of the interrupter, as shown. This condenser absorbs the surge of current caused by self-induction on the breaking of the circuit and therefore becomes charged; it also increases the speed of the interrupter as the arc otherwise formed provides a path for the current, causing it to continue after the contacts have separated. When the circuit is remade by the contacts coming together again, the condenser discharges, adding its energy to the exciting current of the primary. At each interruption of the current in the primary, a spark will bridge the gap of the secondary, the length of this spark depending upon the size of the coil. Making this gap too long imposes an intense strain on the windings of the secondary and is liable to puncture them, unless an auxiliary or safety gap, the length of which represents the safe maximum distance, is provided.

Induction Coils Obsolete in Wireless Work. Induction coils were originally employed in wireless transmission and were later used for the emergency set in connection with a storage battery, but as the amount of current that can be handled in this manner is limited by the interrupter and the frequency of the high-tension current is restricted by the speed of the interrupter, they are now practically obsolete in commercial service and are confined to amateur use. To produce the best results, the contact screw must be adjusted to give the maximum speed of interruption, which is evidenced by a high-pitched note. Anyone who had experience in keeping the vibrators of a set of coils properly adjusted in the early days of the automobile will appreciate what a difficult condition this is to maintain. Numerous special types of interrupters, such as the mercury break, mercury turbine, and Wehnelt electrolytic interrupters were developed to increase the speed but none of them can approach, in this respect, an alternating current.

Closed-Core Transformer. In a closed-core transformer the magnetic circuit is increased in strength by making the core in the form of a rectangle so that the lines of force are not compelled to pass through the air to complete the circuit, Fig. 84.

The primary is wound on one leg of this core, while the secondary is placed on the opposite one, the core itself consisting of laminations of soft iron which are assembled after the coils are put in place. The primary is excited by the alternating current supplied by the a.c. generator, usually at 110 volts, and as this

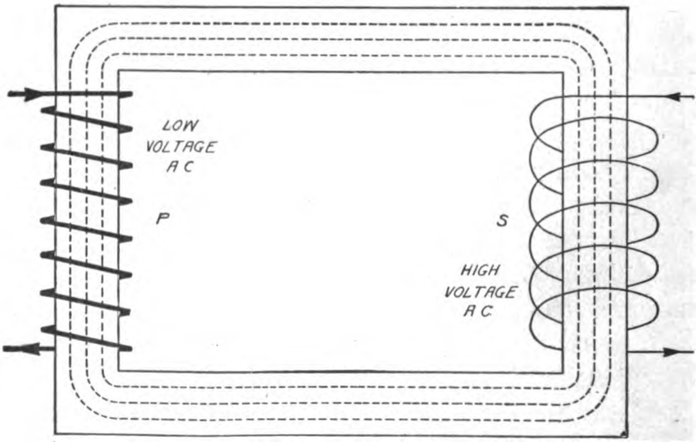


Fig. 84. Principle of Closed-Core Transformer—*P*, Primary; *S*, Secondary; Dotted Lines Show Magnetic Circuit

current is constantly rising and falling in strength and changing in direction, the core is being magnetized and demagnetized at the same frequency so that no interrupter is necessary. For example, in the transformer shown in the diagram, an alternating current at 110 volts is assumed to be flowing through the primary winding, the frequency being 60 cycles. This causes the magnetic flux to alternate through the core 120 times per second, inducing a similar number of alternations in the current which is set up in the secondary winding. But as this winding consists of a great many turns of wire, the voltage of the induced current is very much greater than that flowing in the primary, the ratio of the voltages being directly proportional to the ratio of the secondary turns to the primary turns; therefore, while the primary voltage is but 110. the secondary voltage may be 10,000 to 50,000 volts. The lowest potential now employed commercially is 10,000 volts.

Potential and Current in Transformers. While the voltage has thus been tremendously increased, the current has been decreased in the same proportion. For example, if 10 amperes are sent through the primary at 110 volts and the secondary voltage is 10,000, there will be only 0.11 ampere in the secondary circuit. The number of watts of energy is the same, barring transformer losses, but the voltage and current factors have been altered to suit the requirements. If the secondary voltage were 100,000, there would then be but 0.011 ampere of current, the product of the two in any case representing the amount of energy sent into the primary. A familiar mechanical analogy is that of the steam boiler in which 10 cubic feet of steam at 100 pounds pressure per square inch would be the equivalent of one cubic foot at 1000 pounds pressure per square inch; either would perform the same work.

Open-Core and Magnetic Leakage Transformers. While the induction coil is no longer employed in radio transmission, except for the emergency set, its counterpart, the open-core transformer supplied with current from the a.c. generator, is still used. As only part of the magnetic circuit is formed of iron in this type, there is little mutual induction between the primary and secondary windings and the self-induction of the primary therefore remains practically constant, so that this class of transformer will draw practically the same amount of current whether the secondary be on open or on short-circuit. This characteristic is sometimes given a transformer of the closed-core type by providing what is known as a magnetic leakage gap, Fig. 85, this gap often being made adjustable. The opening thus provided does not interfere with the magnetic flux from the primary to the secondary, but the magnetic reaction of the secondary, known as mutual induction, is dissipated through this gap so that variations in the secondary load, such as are caused by the operation of the wireless sending key, do not affect the self-induction of the primary.

The open-core type is not as efficient as the closed-core type owing to the fact that air forms such a large part of the magnetic circuit and the ratio of transformation is, therefore, not in direct proportion to the difference in the number of turns in the windings. To offset this, the secondary of this type of transformer is usually wound with a greater number of turns to make up for the magnetic leakage.

Auto-Transformer. By winding a single coil on a core with a small number of its turns connected to the source of exciting current and the balance of the turns connected to the secondary circuit, there is formed what is known as an auto-transformer. The secondary current from such a transformer is due only in part to electromagnetic induction, the remainder flowing directly from

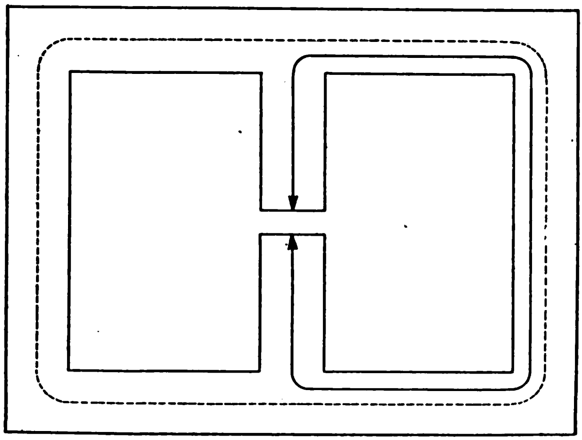


Fig. 85. Principle of Air Gap, or Magnetic Leakage, Transformer Dotted Lines Show Magnetic Flux between Primary and Secondary; Full Line and Arrows Show How Reaction of Secondary Is Dissipated at Air Gap

the primary, owing to its connection with the secondary. This type of transformer is not employed for high-potential currents but represents what is known as a tuning coil as originally employed for receiving wireless messages; it is still used to a greater or less extent in amateur installations. In this case, no iron core is provided and the transformer is known as an air-core type.

Oscillation Transformer. An auto-transformer is also employed in the transmitting set, in which case the primary consists of a few turns of heavy strip copper or tubing in order to conduct the high-frequency currents most effectively, while the secondary has a greater number of turns of smaller strip or tubing; the combination is known as an oscillation transformer. As originally used, this was of the auto-transformer type and was known as a helix, consisting of a spiral of copper strip or tubing of large diameter, two or three turns of which formed the primary while the balance constituted the secondary. As this arrangement did not permit the control of the mutual inductance between the two circuits of the transformer, it would not radiate what is termed a pure wave, that is, one capable of being sharply tuned, but furnished what is known as a broad wave, or one comprising a band of waves of varying wave lengths. As the helix does not comply with the government regulations, it is now obsolete.

With transformers handling high-frequency currents, however, the voltage of the secondary is not controlled by the ratio of the turns between it and the primary alone but is also dependent upon the capacity in either of these circuits and upon the resonance; therefore, a greater number of turns in the secondary of this type of transformer may act to step-down the voltage instead of the reverse.

Reactance. As has been made clear in the section "Induction", page 34, self-induction is a characteristic of a circuit supplied with a direct current only when this current is interrupted. Owing to the constantly fluctuating values and directions of an alternating current, it is a continuing factor in a.c. circuits and tends to oppose the e.m.f. of the current itself so that a higher potential is necessary to obtain a magnetic field of the same strength with alternating current than with direct current. This is a form of resistance which does not depend upon the size or the material of the conductor but is influenced solely by the rapidity of the change in the current. It is characteristic of all a.c. circuits but only assumes a high value in the case of a coil in which the turns react on one another to resist the change in the current. This factor is accordingly termed reactance.

Impedance. In addition to the counter-e.m.f. of self-induction known as the reactance of the circuit, the flow of the current is also hindered by the true resistance, that is, that due to the size, length, and material of which the conductor is composed. The total effect of the true resistance and the reactance of the coil, or circuit, is termed impedance. Both reactance and impedance are measured in ohms and the flow of alternating current in a circuit is usually controlled by reactance coils, or *choke coils,* instead of with the type of resistance employed with direct current.

ELECTROMAGNETIC WAVES

Formation of Waves. When the condenser of the oscillation circuit discharges there is set up about the point of discharge an electrostatic field and an electromagnetic field, the lines of strain of both being at right angles to each other and to the direction of propagation. But as each oscillation represents two alternations, or a complete cycle, it will be evident that at each reversal the falling of the current to zero creates a loop of these combined strains which leave the oscillator in this form, so that, as the oscillations succeed each other with great rapidity, corresponding loops of electrostatic strain pass off. These are termed electromagnetic waves and constitute the medium by which communication is effected in wireless telegraphy, as by breaking up these forces into groups representing dots and dashes of the Morse code intelligible signals are radiated.

Ether. It was long a question as to just how electromagnetic waves were propagated from one point to another. Sound we know travels through air, water, or other material conductors, a fact that can be shown by placing an electric buzzer on a felt pad under a glass dome and then exciting the buzzer by means of a battery current. The sound produced will be greatly reduced in volume with the glass cover over the buzzer, but, if the air be exhausted from the glass dome and the buzzer again operated, practically no sound will be heard (a small amount of sound will be conducted out through the felt); that is, there is no longer any medium through which the sound waves may be propagated. It is readily demonstrated, however, that electromagnetic waves do not require the presence of air for their transmission, for a wavemeter placed close to the glass dome will detect the electromagnetic waves created by the operation of the buzzer despite the fact that the space separating them is for the most part a vacuum, besides having one of the best known electric insulators—glass—also in the way. In the same manner, light will be transmitted whether it be in a body of air or in a vacuum as it is known that the light of the sun passes through millions of miles of space before reaching our atmosphere. It has accordingly been assumed that all space is filled with a medium known as the ether (this of course must not be confused with the anesthetic of the same name), sometimes termed the *luminiferous*, or *light-bearing*, ether since it serves to transmit light waves. In fact, the accepted hypothesis is that all forms of radiant energy, light waves, heat waves—which are merely light waves of a different length—and electric waves, are transmitted through this medium.

Wave Lengths of Ether Vibrations. The particular form in which these different ether vibrations make themselves felt depends upon the frequency of the vibrations producing them, which also controls the length of the wave thus created. Just as a body, like a rod, can vibrate in more than one way at the same time owing to the resultant of the forces setting it into vibration, so complex waves may be produced by superimposing vibrations upon one another, as in the transverse electromagnetic wave. A common analogy of this is the complicated wave frequently seen on the ocean, ripples, or small waves, appearing on the surface of larger waves; at times, short waves caused by local winds will be noted traveling on and in a direction opposite to that of long swells caused by distant storms.

Light and Heat Waves. Light is the result of ether vibrations varying in frequency from 430 to 740 trillions per second, while at higher frequencies is produced what is often termed *invisible light*, that is, the ultra-violet rays (above the violet end of the spectrum) and X-rays, which represent vibrations ranging from 870 to 1500 trillions per second. Below the lower, or red, end of the spectrum are the infra-red rays from 300 to 430 trillions per second, while still farther down the scale are the vibrations or waves, which manifest themselves as heat, ranging from 20 to 300 trillions per second. It will be evident that these are extremely short waves owing to their exceedingly high frequency.

Electromagnetic Waves. The electromagnetic waves produced by Hertz in his original experiments were but a few millimeters in length, while the spark gap used by Marconi at first only radiated a wave about 12 centimeters in length. This increase, however, was largely responsible for the much greater distances over which

Marconi was enabled to transmit his radiations as compared with other experimenters in the field. Since that time, electromagnetic waves have been produced which measured over 1,000,000 miles in length. The vibrations of the ether known as electromagnetic waves are twenty-five octaves lower on the scale of frequencies than those of light. Their identity with the latter, however, has been proved by the fact that they are subject to refraction, diffraction, reflection, absorption, and polarization, the same as light waves.

Production of Electromagnetic Waves. The propagation of electromagnetic waves through the so-called ether was known for

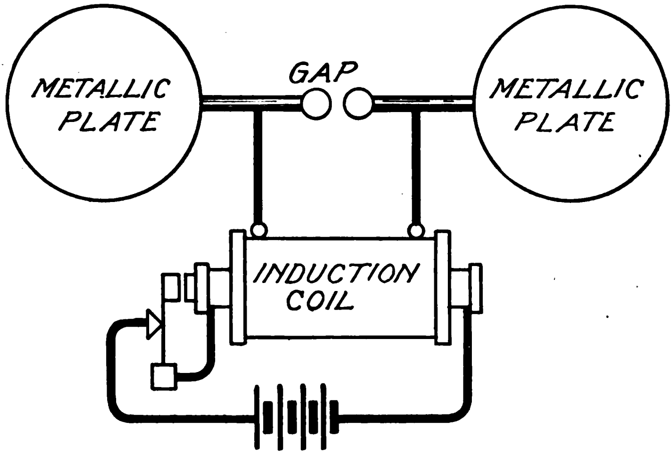


Fig. 86. Diagrammatic Representation of Oscillator

years prior to the discovery of Hertz (1888), but until that time no practical method of creating electromagnetic waves had been discovered. As already explained, a circuit, in order to be oscillatory in character, must possess certain values of inductance, capacity, and resistance and must be excited by a high-potential alternating current. Hertz reproduced these conditions by means of an induction coil, spark gap, and two metal plates (representing the capacity effect on the circuit) affixed to either end of the gap, Fig. 86. This is known as the Hertz oscillator. It will be apparent that the metal plates represent a condenser whose opposed surfaces are widely separated while the dielectric is the surrounding air. As the potential rises during the accumulation of the charge on these plates, a strong *electric displacement*—in other words, an electrostatic field—is set up about them. When the potential difference reaches the point where it overcomes the resistance of the spark gap, the discharge takes place between the balls of this spark gap and the potential difference between the plates is equalized by a series of rapidly damped surges of current in alternate directions, as explained under "Oscillatory Discharge", page 82. Each oscillation is attended by the radiation of an electromagnetic wave into space. The emission of these waves is intermittent, each complete discharge of the oscillator creating a group or train of waves which, from an oscillator of this character, are highly damped. The frequency with which the waves of these trains follow one another depends upon the frequency of the charging source; and as the frequency of the alternations produced by the induction coil are limited by the speed of its interrupter, it has long since become obsolete for this purpose. The frequency of the electromagnetic waves produced by a Hertz oscillator, however, was exceedingly high owing to the very short wave length employed, Table IV.

Radiation of Waves. The radiation of invisible energy through an equally invisible and intangible medium is naturally difficult to present in the form of an exact sequence. The commonly accepted theory of the formation and radiation of these closed loops of electric strain is shown graphically in Fig. 87. According to the electronic theory, every line of electric strain must be a closed line, or loop, or must terminate on an electron and a co-electron.*

In the successive illustrations, Fig. 87, *A* represents the electrostatic field about one plate of the condenser at the moment of the occurrence of the first oscillation while *B* and *C* indicate its theoretical development in extending through the dielectric—in this case, the air. At *D*, the oscillation has been completed and the direction reversed, thus closing this first loop of electric strain, which is shown passing off at *E*. The latter also shows the rise of the next oscillation, which is opposite in direction to the first. This succeeding oscillation develops into a loop of force

*For a detailed exposition of the electron theory, see Textbook of *Wireless Telegraphy* (Stanley).

as in the first instance and pushes its predecessor away, as illustrated by *F*.

Electric and Magnetic Loops. As the passage of an electric current, however, is always attended by the formation of both an electrostatic and an electromagnetic field, the oscillatory discharge also creates magnetic loops of strain, which are at right angles to the electric loops. Every electromagnetic wave is accordingly composed of two groups of forces acting in directions at right angles to each other. These magnetic loops of strain also alternate in direction with each oscillation, thus forming a series of closed loops of magnetic flux having the oscillator as their axis. But the value of the magnetic flux is increasing while that of the current or

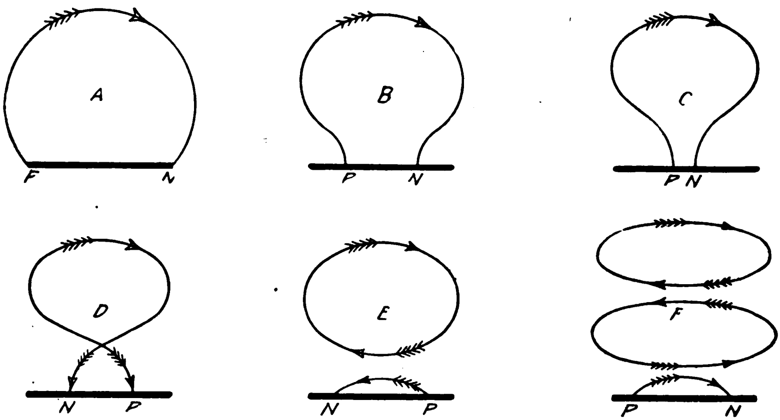


Fig. 87. Formation of Closed Loops of Electric Strain

electrostatic field is decreasing, so that, when discharging, the ether about the oscillator is being set into vibration by loops of electrostatic strain and concentric loops of electromagnetic strain both periodically reversing in direction, the electrostatic strain being at its minimum at the moment that the electromagnetic strain is at its maximum. The movement of the electrons in electromagnetic waves in the ether is at right angles to the direction of propagation of the wave, while the electric and the magnetic stresses are also at right angles to each other at any point in the wave front. To distinguish this vibration from the longitudinal vibrations which set up sound waves in air or water, it is termed transverse vibration.

This is presented more graphically, as occurring about a simple vertical aerial, or open oscillating circuit, Fig. 88, in which *A* is a vertical wire extending straight up into the air and grounded to earth at its lower end through the spark gap *S*, the horizontal line representing the ground. A source of high-potential alternating current is assumed but not indicated. The electrostatic field about this rudimentary open oscillation circuit, before discharge takes place across the gap, is indicated by the dotted lines. It will be noted that the aerial and the earth form the opposing surfaces of a condenser, and this is true of all wireless aerials, or antennae. In Fig. 87, *B* shows the lines of force of the magnetic field existing about this aerial at the moment that the electrostatic field drops to zero, owing to the reversal of the current, while the arrows of *C* indicate the combined forces of the electromagnetic wave as it leaves the aerial with the speed of light (186,000 miles per second).

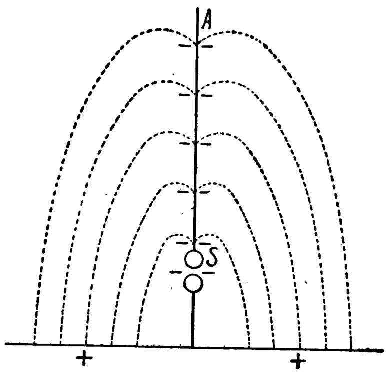


Fig. 88. Electrostatic Field Surrounding Simple Aerial before Discharge Takes Place

Characteristics of Electromagnetic Waves. Electromagnetic waves are distinguished by certain characteristics which are directly the opposite of those of light. For example, most insulators which are opaque to the short waves of light are transparent to the long waves used in wireless telegraphy. Thus a wireless aerial will render equally efficient service, all other conditions being the same, if erected inside a wooden building as it would if suspended on poles outside, the wooden roof of the building being just as transparent to the long electromagnetic waves as the air itself. Conductors, on the other hand, are opaque to electromagnetic waves. The latter travel along their surface, as mentioned under "High-Frequency Conductors", page 11, but in so doing more or less of the energy of the waves is *absorbed*. For this reason, an aerial erected inside a steel frame building or in one with a metal roof would not be as efficient as the same aerial in the air, since a large part of the energy would be absorbed. While insulators are transparent to electromagnetic waves, they also absorb some of their energy in transmission.

These characteristics of the electromagnetic wave account for the much greater distances of wireless transmission over water than over land, since salt water is an excellent conductor and is accordingly opaque to the wave, while the land, particularly in dry or mountainous regions, is an excellent insulator. According to the usually accepted theory, the upper atmosphere, or space above the atmosphere, is also a good conductor so that in wireless

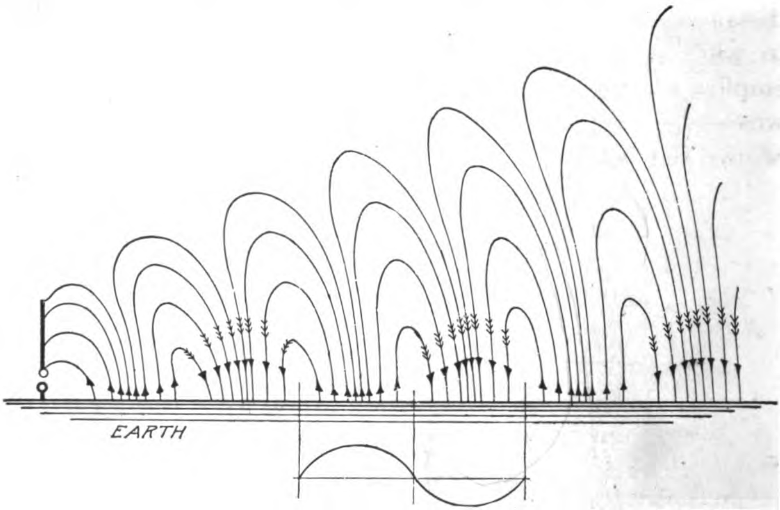


Fig. 89. Diagrammatic Representation of Sliding-Wave Theory of Propagation

transmission at sea, the wave travels forward with its foot on the surface of the ocean while the upper end of the loop is reflected downward and backward by the upper conducting strata in the manner illustrated in Fig. 89, which represents what is termed the *sliding-wave theory* of propagation. While only one series of waves is seen leaving the oscillator at the left, it is understood, of course, that the waves are radiated in all directions. The length of the wave is represented by the distance included between any two positions where the direction and intensity of the electric strain, as shown by the arrows and proximity of the lines, are identical. This is indicated by the horizontal line and the sine curve which shows the points of reversal of direction in the oscillation.

It will be noted that this differs from the theory of wave propagation outlined in connection with the Hertz oscillator and this is due to the fact that the latter was not *grounded,* or *earthed,* as is now the case with the open, or radiating, circuit in wireless transmission. The ground connection to the earth is a substitute for one of the capacity areas of the Hertz oscillator, while a vertical wire is an extension of the opposed area of the oscillator, which forms a capacity or condenser with the earth as one surface and the air as the dielectric. That the ground connection is not indispensable for effective radio transmission, particularly over short distances, is evidenced by the equipment employed on aeroplanes, in which a counter-capacity instead of a ground connection is employed. The aerial and the counter-capacity of an aeroplane wireless set are thus simply a reproduction on an enlarged scale of the Hertz oscillator.

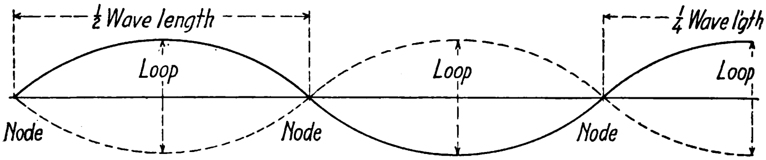


Fig. 90. Nodes and Loops of Stationary Waves

Stationary Waves. In the section on the "Fundamentals of Wireless Telegraphy", page 6, a familiar case of wave reflection is cited in the action of a rope hanging vertically which is given a a quick jerk and then held taut in the hand. A well-defined wave runs up the rope until it reaches the upper end, where it is reflected and runs back to the hand from which it again is reflected and once more starts upward, continuing this until the energy creating it has been damped out by the friction of the rope upon itself and the resistance of the air. When a number of equally timed jerks are given, a succession of waves at equal intervals travels up the rope and, when reflected at the top, the waves meet others coming up whose lengths equal those traveling downward. Consequently, there are points along the rope at which it tends to move a certain distance in one direction with the upward or direct wave and in the opposite direction for the same distance with the reflected wave. As the two opposing forces are equal they neutralize each other so that there is no movement of the rope at those points, Fig. 90, which are seen to be one-half the wave length apart. At all other points, the rope moves in the resultant direction of the direct and reflected wave impulse so that what are termed stationary waves are set up. Points at which there is no movement are termed *nodes*, while those at which the maximum movement occurs are *loops*.

By properly timing the impulses of energy, or oscillations, which create electromagnetic waves, it will be apparent that stationary waves may be set up in the aerial. By referring to the illustration, it will be clear that at its points of support the rope cannot move and these points must therefore be nodes. This is equally true of the aerial as no current can flow at the end of the conducting wires opposite to that at which the energy is received. Since, however, the greatest pressure, or tendency to move, occurs

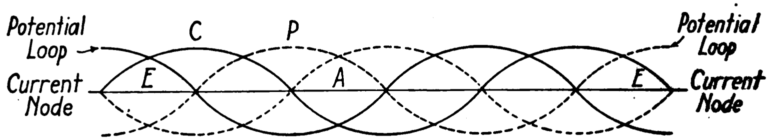


Fig. 91. Nodes and Loops of Current and Potential on Aerial—*A*, Aerial; *EE*, Ends of Aerial; *C*, Current; *P*, Potential

at that point, it must be a potential loop. As there is accordingly a phase displacement—the potential loop corresponding in time to the current node—the reverse of this condition, that is, a current loop and a potential node occur at every quarter-wave length. This is shown in Fig. 91, which represents the relative positions of current and potential nodes and loops in stationary electric waves and makes clear the reference to the alternations of the electrostatic and electromagnetic fields due to the oscillatory discharge of the condenser.*

Wave Lengths. It has already been explained that the distance traveled by the wave motion per second represents the velocity of the wave. Furthermore, the velocity divided by the number of waves per second will give the length of a single wave, since the velocity is the product of the distance traveled per second times the number of waves (frequency) radiated per second.

* See *Manual of Wireless Telegraphy for Naval Electricians.*

TABLE IV

Electromagnetic Frequencies and Wave Lengths

Frequency (cycles per second)	Wave Length (meters)	Frequency (cycles per second)	Wave Length (meters)
1,500,000	200	150,000	2000
1,000,000	300	100,000	3000
666,666	450	50,000	6000
500,000	600	37,500	8000
300,000	1000	30,000	10000

Very short waves, such as were employed by early experimenters, were absorbed too readily and could only be detected at comparatively short distances (most of the experiments by Hertz were carried out indoors); consequently, the wave lengths now employed in wireless telegraphy range from 200 meters (approximately 650 feet) up to 10,000 meters (over 6½ miles) in length. The shorter the wave the higher its frequency, and *vice versa*, as given in Table IV.

Commercial Wave Lengths. The 200-meter wave length is confined to the use of amateur stations, while the 300-, 450-, and 600-meter wave lengths are standard for ship stations and coast stations transmitting to and receiving from ships. In fact, these three wave lengths which correspond to 1000, 1500, and 2000 feet, respectively, are the ones most generally employed in commercial wireless telegraphy. It must be borne in mind, however, that while a station may be equipped to send on only certain wave lengths, such as the 300-, 450-, 600-meter standard employed on steamers, the same station is fitted to receive messages over a very wide range of wave lengths. The government station at Arlington (Radio), Virginia, sends out time signals and weather reports at noon and 10 P.M. on a 2500-meter wave length in order that this information may be picked up by steamers over a wide radius. Transmission from this station is also made at 600 and at 7500 meters. Generally speaking, the wave length employed depends on the distance to be covered, so that, when at sea, ship stations send on the 600-meter wave and, when approaching the coast, on the 300-meter wave. This is done to comply with the government regulation which restricts the amount of power employed in sending to that sufficient to establish satisfactory communication.

While some startling long-distance records have frequently been made with low power and the 600-meter wave under particularly favorable conditions, as during the night in midwinter, to maintain communication over a long distance necessitates the use of a great deal of power and a correspondingly longer wave. Ship stations range from $\frac{1}{2}$ to 2 kw., while the huge transatlantic stations have plants rated at several hundred kilowatts and operate on the longer wave lengths, that is, from 6000 to 10,000 meters. The latter stations transmit an undamped, or persistent, wave train which is much more efficient for long-distance signaling.

Measurement of Wave Length. The wave length depends upon the frequency of the oscillations and the frequency, in turn, is governed by the capacity and inductance of the circuit. Hence, if the frequency is known, the wave length may readily be determined by the simple equation

$$\lambda = \frac{V}{N}$$

in which λ (Greek lambda) is the wave length; V is the velocity, that is, the velocity of light, 186,000 miles, or 300,000,000 meters, per second; and N is the number of waves, or frequency. Assuming that the frequency is 300,000, the equation then is

$$\lambda = \frac{300000000}{300000} = 1000 \text{ meters}$$

It is necessary, however, that the wave length of both the closed and the open, or radiating, oscillatory circuits be known. That of the closed circuit may be calculated by the formula

$$\lambda = 59.6 \sqrt{LC}$$

in which L is the inductance in centimeters (microhenrys are converted into centimeters by dividing by 1000), and C is the capacity, the factor $\sqrt{LC}$ being the oscillation constant. These calculations are employed chiefly in designing wireless apparatus, however, practical wave-length measurements being made with the aid of a wavemeter, as explained on page 79.

Fundamental, or Natural, Wave Length. The wave length of the aerial forming part of the radiating oscillatory circuit may be determined approximately from its dimensions. This refers only to the wires comprising the aerial and does not include the tuning inductance or coil employed for adjusting this value. It is known as the natural wave length of the aerial. The length of the wave radiated from the aerial is found to be approximately four and one-half times that of the aerial itself, the length of the aerial including its ground connection and the lead-in, or wires connecting it to the instruments. This is based upon an aerial consisting of four wires, spaced from 2 to 3 feet apart. For example, a four-wire aerial 100 feet long of the inverted **L** type*, the ground connection and lead-in of which make the total length 150 feet, would emit a wave 150×4.5, or 675 feet, or 201 meters, since a meter is approximately 3.25 feet. Such an aerial would not comply with the law requiring amateur stations to send on a 200-meter wave length as this is simply its natural, or fundamental, wave length, and to this must be added that of the inductance (oscillation transformer) in circuit with it. The exact wave length of the open circuit is calculated by formulas which would not be of interest to the beginner, but it may be pointed out in this connection that the measurement of the capacity (distributed) of the aerial is influenced by its height, since the aerial itself is a condenser one side of which is the earth and since one of the factors determining the capacity of a condenser is the thickness of the dielectric between the surfaces. The height also affects the length of the lead-in.

Detection of Electromagnetic Waves. *Hertz Resonator.* The oscillatory nature of the discharge of a condenser as well as the fact that this discharge radiated electromagnetic waves was known for years prior to Hertz's time, but it was not until his discoveries were made that a practical method of producing these waves and, what is of even greater importance, of detecting their presence at a distance was possible. The Hertz resonator was the first wireless detector and, as shown by Fig. 92, it consisted of nothing more than a loop of wire with a small spark gap in it. This simple device is likewise the predecessor of the present-day aerial, to which Marconi gave practical dimensions as well as the ground, or earth, connection. By holding this resonator at certain distances from the oscillator, Fig. 86, Hertz found that minute sparks passed

* See "Aerials, or Antennae," page 151.

between the balls of the spark gap, which was made adjustable. Investigation showed that these represented high-potential currents of the same frequency as those produced by the oscillator, that is, that electromagnetic waves radiated into space by the oscillator could be detected by a device in resonant relation with it, which accounts for the term resonator.

At points directly in line with the oscillator, that is, at right angles to the capacity areas and at certain distances from it, the sparks at the gap of the resonator were of a maximum value, while at other distances they were much feebler and at still others no sparks appeared at all. From this Hertz calculated the character of the wave and its length and proved that it was distinguished by nodes and loops of potential and current, as already explained. At the points represented by current nodes, no sparks appeared, while at the points representing loops, the sparks were at the maximum. Owing to the difference in the value of the received current when the resonator was in a direct line with the oscillator, Hertz also employed a metal reflector back of the oscillator. This expedient was also experimented with on a larger scale by other scientists but it was not found to increase the efficiency to a sufficient extent to warrant its use, while it would be entirely impracticable with aerials of the size now employed. As stated under "Aerials, or Antennae", page 151, the L type aerial, as developed by Marconi, is found to be strongly directive, the maximum radiation being in a direction opposite to that in which the horizontal member of the L points.

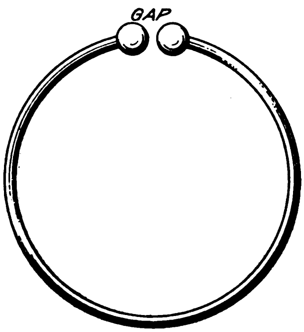


Fig. 92. Hertz Resonator

While the Hertz resonator was the prototype of the present-day wireless detector, it was naturally nothing more than a piece of experimental apparatus which served to indicate the presence of electromagnetic waves at a point close to their source, the maximum distance at which tests were carried out not exceeding a few hundred feet. The received currents had to be sufficiently strong to cause a visible spark, and a current value high enough to cause a visible spark even in a micrometer gap is thousands of times greater than that on which present-day detectors and receiving circuits operate efficiently.

Lodge Syntonic Jars. The amount of energy acting on the resonator, or receiving circuit, is proportional to the power radiated in the form of electromagnetic waves by the sending station and to the distance separating the two. This is readily demonstrated by a simple experiment with the so-called Lodge syntonic jars. As shown in Fig. 93, these consist of a pair of Leyden jars, one of which is fitted with a simple spark gap while the other has in circuit with it an adjustable inductance the value of which may be varied by sliding the link shown along the parallel wires. The spark gap of this second jar is formed of a strip of metal foil extending from the upright pillar, which is

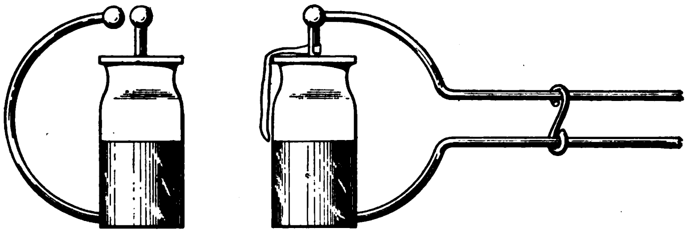


Fig. 93. Lodge Syntonic Jars

connected to the inside coating of the jar, down to a point close to the outside coating at its upper edge, as will be noted at the left side of the jar. When the jar at the left is charged to a potential which causes it to discharge across its spark gap, electromagnetic waves are radiated from it and impinge on the circuit represented by the second jar. The combined electrostatic and electromagnetic fields forming the waves are then converted into an oscillatory current, the frequency of which will be the same as that of the first jar, which corresponds to the sending station.

By radiating a continuous succession of waves from this station with the aid of an induction coil, meanwhile adjusting the sliding link to vary the value of inductance, a point will be found where sparks indicating a received current of the maximum value will occur at the spark gap of the second jar, or receiving circuit. The two circuits are then in tune, in syntony, or in resonance; in other words, the product of the inductance and the capacity in the two circuits is equal and they have the same oscillation constant, or natural period of oscillation. Any variation from this adjustment will decrease the size of the spark correspondingly, while if the two circuits are considerably out of tune with one another, no spark will occur. But if while adjusted to resonance so that the maximum current is being received, the receiving circuit with the adjustable inductance is moved away from the sending station, the spark will also decrease in strength as the distance increases until a point is reached where the amount of energy received is not sufficient to break down the air insulation of the spark gap. An oscillatory current is still being induced in the second circuit by electromagnetic waves from the sending station, but the value of the current received is too feeble to be detected by this crude detector. It is accordingly necessary to insert in the circuit highly sensitive receiving apparatus which will respond to these weak oscillations. But as their value is exceedingly small it has been found practical to convert them into audible, rather than visible, signals.*

TRANSMITTING APPARATUS AND CIRCUITS

Range of Discussion. In the foregoing part of this work the theory of wave, or radio, telegraphy and the electrical principles upon which it is based have been outlined. This exposition has been made as simple as possible and the mathematics of the subject has been omitted except where absolutely essential, but all the points necessary to enable the student to pass the government examination as well as to give him a good working knowledge of the theory of the subject have been fully covered.† In the following pages the working circuits are explained, together with descriptions of the apparatus in commercial use, reference being made to the elementary transmitting and receiving circuits to illustrate the development from early experimental forms to those now in practical use over long distances. No attempt is made in this connection to cover all the various types of apparatus that have been developed and reference to types that now have a historical value only has been omitted except where necessary to

* See "Current in Transmitting and Receiving Circuits," page 195.

† For more detailed works on electrical principles and the mathematics involved, see *Principles of Wireless Telegraphy* (Pierce) and *Practical Wireless Telegraphy* (Bucher).

explain subsequent developments. Interest is centered to a greater extent on the Marconi apparatus than on any other, since it is in most general use today.

Symbols Used. To simplify the illustration of the various circuits, certain arbitrary symbols have been adopted to designate the various pieces of apparatus and the student should familiarize himself thoroughly with these, as they are not only essential to quick reading of the diagrams but must be used in drawing diagrams in answering examination questions. In many instances these symbols so plainly suggest the apparatus they represent that they are readily recognizable as shown in Figs. 94 and 95.

Generators. A direct-current generator consists of an end view of the commutator, two brushes, and leads. When standing alone this indicates a d.c. generator, or source of direct current. When used in connection with a diagram of the field winding, it represents the d.c. armature alone. An alternating-current generator consists of two slip, or collector, rings with their corresponding brushes and is employed in the same manner as the d.c. symbol; that is, when alone it represents an a.c. generator; when with a field, the alternator armature alone.

Meters. An ammeter is indicated by a circle inclosing an A and having two connecting leads attached to its periphery. A voltmeter is signified if a V is substituted for the A without any other change being made. A wattmeter is indicated if two more connecting leads are added and a W is inserted in the circle, the chief distinguishing characteristic of this type of measuring instrument being the number of its connections to the circuit.

Rheostat. A rheostat, such as is employed in the field circuit of both the motor and the generator of the motor-generator, is indicated by a coiled resistance with taps and contact points and a movable switch arm.

Variable Reactance. A variable, or adjustable, reactance, such as is employed between the transformer and the a.c. generator to vary the value of the current entering the transformer, is represented by an iron core and winding from various parts of which taps are taken and with which contact is made by a movable switch arm.

Transmitting Key. A transmitting key to make and break a circuit in sending is self-explanatory.

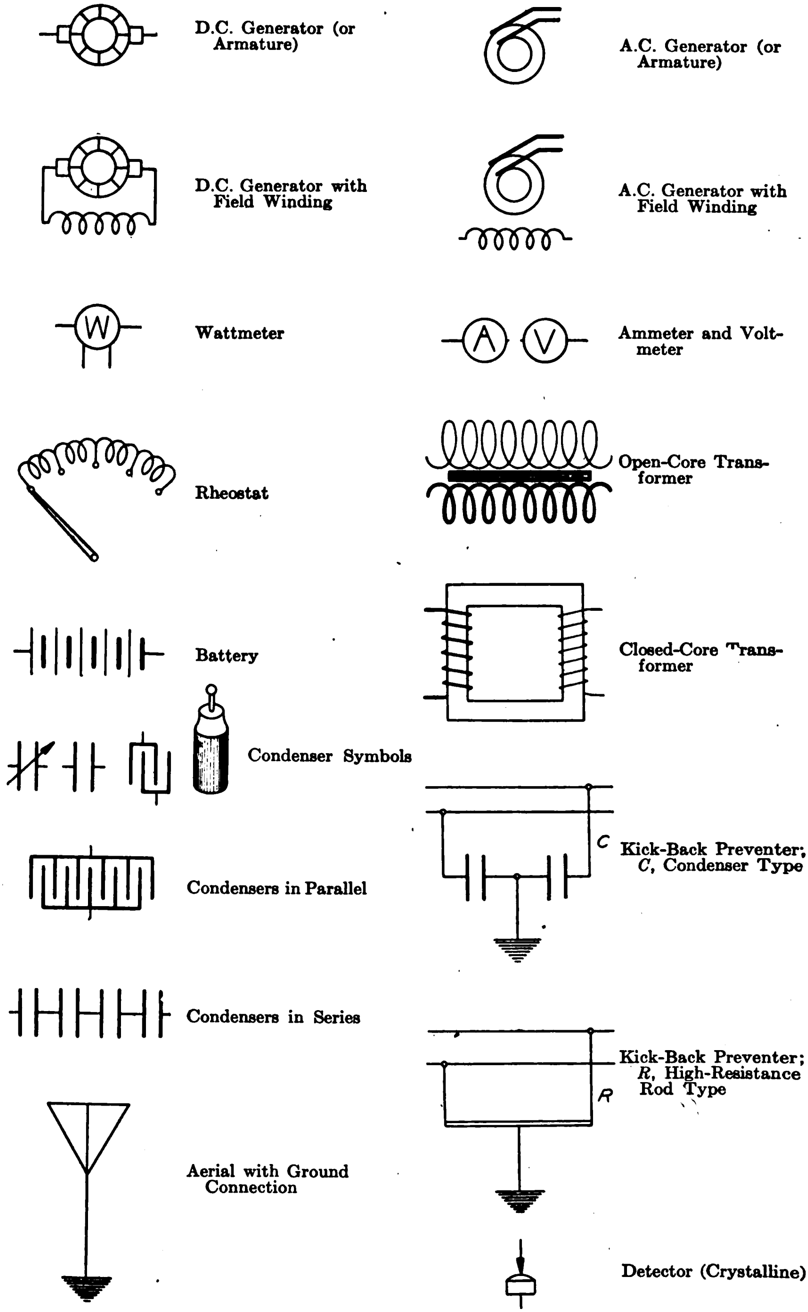


Fig. 94. Standard Symbols Used in Wireless Diagrams

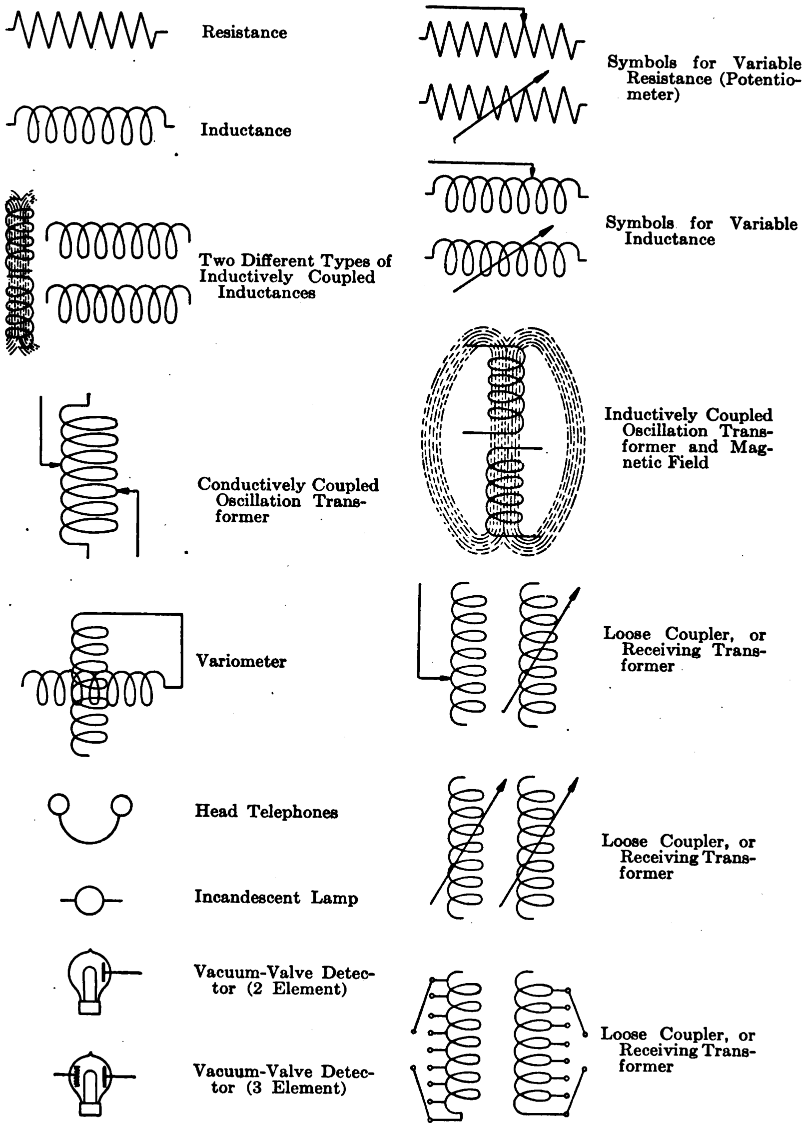


Fig. 95. Standard Diagrams Used in Wireless Diagrams

Transformers. In an open-core transformer the core and windings are apparent, the coarse winding being the primary and the fine the secondary. In actual practice the secondary is, of course, wound directly over the primary. A closed-core transformer is clear at a glance; the fine winding is the secondary, though when connected to other apparatus in a diagram the primary and secondary would naturally be distinguished by their connections. Thus the winding connected to the alternator and the reactance coil would always be the primary.

Induction Coil. An induction coil is indicated by a crude representation of the coil itself, but to avoid too much detail the interrupter of the coil is usually omitted.

Battery. A battery is indicated by alternate long and short lines equally spaced, each pair representing a cell of the battery, while their connections indicate whether they are in series, in multiple, or in series-multiple.

Condenser. A fixed condenser, one whose capacity cannot be altered, is usually shown by two parallel lines with a short space between them or by a simple outline of a Leyden jar. Banks of condensers in series or in multiple are shown by variations of the condenser symbol which indicate their method of connection in the circuit.

Incandescent Lamp. An incandescent lamp is represented by merely a small circle.

Resistance. A resistance coil is shown by a series of sharp peaks similar to saw teeth. A variable resistance is indicated by adding to the foregoing the representation either of a sliding contact or of an arrow crossing the sketch at an angle.

Inductance. An inductance is signified by an open coil and its connections, as indicated. A variable inductance is shown by either the sliding contact or the arrow, as in the case of the variable resistance. Coupled inductances are represented by two coils placed parallel or with one coil above the other. In the sending circuit this symbol is usually employed to represent the oscillation transformer, while the simple inductance shown above is the antennae tuning coil for varying the wave length of the aerial.

Oscillation Transformer. A conductive oscillation transformer is shown by drawing the inductance vertically and indicating two sliding contacts instead of one. This type of oscillation transformer is obsolete but is shown in connection with the elementary diagrams mentioned.

Aerial. An aerial is represented by a vertical wire with a triangle at the top and the usual ground connection symbol at the bottom. This merely indicates an aerial and not any particular type. Where it is desired to illustrate the type, a rough outline is given.

Ground. A ground connection is shown by a series of short parallel lines of unequal length tapering downward in the form of an inverted cone.

With the exception of the aerial and the ground connection, which are common to both circuits, the foregoing symbols refer to the transmitting circuit apparatus. The following are the chief symbols used to indicate the instruments of the receiving circuit.

Auto-Transformer. An auto-receiving transformer, or inductance, is represented similarly to a conductively coupled oscillation transformer, except that it may have three sliding contacts. It is now obsolete except in amateur apparatus.

Loose Coupler. A loose coupler, or inductively coupled receiving transformer, is shown by two coils, the one connected to the aerial being the primary while that connected to the receiving instruments is the secondary.

Variable Condenser. A variable condenser has the same symbol as the fixed condenser except that it has a slanting arrow across it.

Head Telephone. A head telephone explains itself.

Detectors. The crystalline and the electrolytic types of detectors are indicated by symbols that are rough outlines of the detectors themselves and as such are clear without explanation. The vacuum-valve detector is a miniature incandescent bulb with a grid or plate or both sealed in the glass in addition to the filament, depending upon whether it is a two- or three-element valve.

Variometer. The variometer symbol consists of two crossed coils. The inductive relation of the coils is varied by partly revolving one inside the other.

Potentiometer. The symbol for the potentiometer is the same as for a variable resistance. The instrument is a variable resistance designed to alter the value of current flowing from a battery through the receiving detector.

Kick-Back Preventer. This instrument is designed to prevent high-potential current from the transmitting set when in operation from reaching the motor-generator through electrostatic induction, which would be liable to destroy the insulation of the windings. The symbol takes the form of condensers or of a high-resistance graphite or carbon rod shunted across the power mains and grounded; the high-potential high-frequency current is prevented from reaching the motor-generator owing to the resistance and escapes through the ground connection.

Hot-Wire Ammeter. The hot-wire ammeter has the same symbol as the ammeter with the substitution for A of the letters **HWA.**

General Requirements. For the production and radiation of electromagnetic waves employed in wireless telegraphy, there is necessary: first, a source of alternating current; second, means for interrupting this current supply in order to break it up into the dots and dashes of the Morse system of signals; third, a method of converting this interrupted current into one of high frequency and high potential in order that it may be transformed into electromagnetic waves; and fourth, a means of radiating these waves efficiently so that they will travel the maximum distance for a given amount of power.

The first of these requirements is met by the use of a motor-generator for converting direct current at 110 volts into alternating current at 100 to 500 volts and a frequency of 60 to 500 cycles. The latter frequency is now standard for most of the Marconi apparatus employed on shipboard. To interrupt this current in order to form the necessary signals of the Morse code, a key similar in pattern (but without any circuit closer) to the ordinary telegraph key is employed. As it has to handle many times the current used with a telegraph key, it is very much larger in size and has correspondingly larger contacts. To prevent arcing at these contacts, a small condenser is usually shunted about the key, as mentioned under the head "Induction Coil", page 106. Where very heavy currents are employed, as in the huge transatlantic stations, a small key connected in shunt with a magnetically operated circuit closer is used, since it would be impracticable to make and break such a circuit in the ordinary way so close to the operator's hand.

To convert this interrupted current into one of high potential, it is passed through the primary of a transformer, which with the key and armature of the alternator completes the low-potential low-frequency circuit of the transmitting apparatus. The secondary of the transformer steps the current up to a high voltage, and to convert it into a high-frequency, or oscillating, current it is then passed through a bank of condensers. These condensers are charged by the transformer and their discharge through the spark gap creates the high-frequency oscillations or electromagnetic waves. The secondary of the transformer, the condensers, and the spark gap form what is known as the closed oscillatory circuit. As this is a good generator of oscillations but a very poor radiator, it is inductively coupled to the open oscillatory circuit, consisting of the oscillation transformer, tuning inductance, and aerial. The hot-wire ammeter is inserted in this circuit to indicate when it is radiating the maximum power or is in resonance with the closed oscillatory circuit.

MOTOR-GENERATORS

Types. The type of motor-generator in general commercial use in marine installations has already been described and illustrated. It will be apparent, however, that if a high-potential high-frequency alternating current could be generated directly by the dynamo, it would be unnecessary to use a motor-generator, while the condensers and spark gap could also be dispensed with, the operating key being connected directly in circuit with the high-frequency generator. Generators of this type have been developed for use in connection with wireless telephony but so far have not been employed commercially in wireless telegraphy, particularly in low-power installations.

TRANSFORMERS

Specifications. Transformers have also been illustrated and described previously, so far as their theory and principle of operation are concerned. In Fig. 96 is shown an open-core type of transformer as employed for wireless telegraphy, while a closed-core type is shown in Fig. 97. Owing to the tremendous difference of potential set up between the primary and secondary windings in operation, the critical part of the transformer construction is the insulation. A heavy layer of insulation, usually consisting of empire cloth, is accordingly placed between the core and the windings, while the secondary is wound in the form of *pies*, or

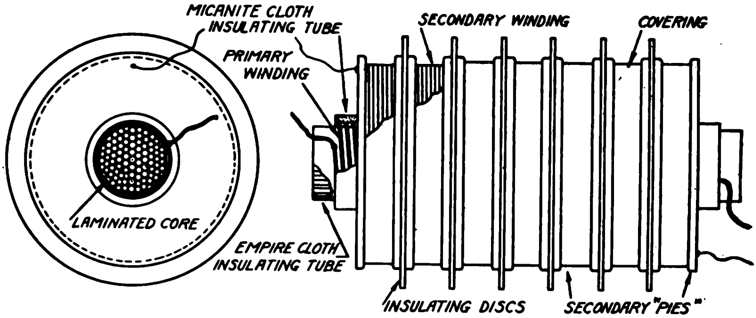


Fig. 96. End and Side Views of Open-Core Transformer Removed from Case; No Longer in Use

sections, to minimize the potential difference between adjacent turns. As the most frequent cause of the breakdown or puncturing of the insulation of the transformer is too wide an opening of the spark gap, the transformer is usually provided with a safety gap which represents the safe maximum distance that the transformer will bridge and across which the current passes when the spark gap points are open too far.

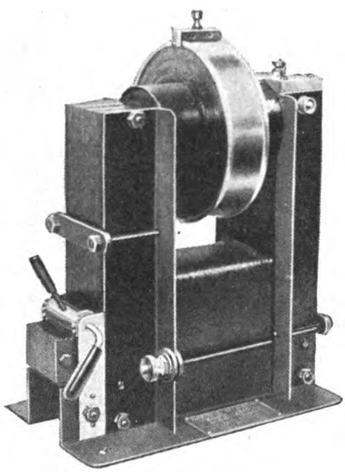


Fig. 97. Closed-Core Transformer Designed for Amateur Use

CONDENSERS

Leyden Jars. Leyden jars have been commonly employed as condensers in small installations and particularly on shipboard where the power used does not exceed 5 kw. They are made by electrolytically depositing copper on the inside and outside of the glass for about two-thirds the height of the jar. The transmitting condenser consists of a number of these units, the standard jar having a capacity of 0.002 microfarad. These jars are placed in racks designed to hold a number greater than that necessary for the desired output, the outside coatings being connected by resting on the metal bottom of the rack, while the inner coatings are connected by means of stranded bare cables soldered to them and to brass rods passing through the covers of the jars. These rods are, in turn, connected to the bus bars which form the charging connections of the entire unit. If it is desired to increase the capacity without unduly increasing the number of jars, they are sometimes inserted in a tank filled with insulating oil.

Metal-Plate Condensers. The functions of the condenser are to store the charge delivered to it by the secondary of the transformer until its potential reaches the desired value as determined by the spark gap and then to discharge through the spark gap. It fulfills its purpose by reason of its capacity to hold an electric charge, and the ideal condenser is one that is perfectly insulating, cannot be punctured, and shows no heat losses during charge or discharge. Where heating is concerned, this ideal has so far proved unattainable, but a high degree of insulation coupled with the property of *self-healing* is obtained by the use of oil or compressed air as the dielectric. Metal-plate condensers inserted in an oil tank are coming into more general use for ship installations as they have the great advantage of being much more compact than the Leyden jars. In the large shore stations, metal-plate condensers with compressed air as the dielectric are sometimes employed, though where space restrictions do not complicate the problem, the desired capacity is obtained by increasing the size of the plates, using air at atmospheric pressure as the dielectric. Glass, mica, micanite, and similar insulators are also used as dielectrics but they have the disadvantage of requiring replacement, if punctured. They also have the further disadvantage of permitting a *brush discharge*, or leakage, over the surface of the glass not covered by the metal plates and over the edges, this representing a loss of energy which becomes of moment when the potential reaches 25,000 volts or over. The dielectric strength of glass also decreases with the frequency while that of oil increases.

Condenser Connections. The number of condenser units employed depends upon the method of connecting them in the circuit. In Fig. 98 is shown a closed oscillation circuit operating at 20,000 volts. Three condenser units are connected in parallel, that is, in the case of Leyden jars, the three outside coatings are connected together as a single terminal while the three inside coatings form the other terminal, the three units thus being the equivalent of a single jar three times the size of one of the units, in other words, the total capacity is the sum of all the capacities in parallel, so that if these were standard Leyden jars of 0.002-microfarad capacity, the total capacity of the condenser would be 0.006 microfarad. If it became desirable to operate this circuit at so high a potential that it would cause these jars to break down, a larger number connected in series-parallel could be used, Fig. 99. Six jars would then be necessary, in two banks of three each in multiple, or in parallel, these combined units then being connected in series. If the total potential were then 30,000 volts, the voltage across each jar would be only 15,000 volts instead of 20,000, as before. Connecting two equal condensers in series gives a capacity equal to one-half that of one condenser; if three equal condensers are so connected, their capacity is reduced to one-third. Therefore, the condenser shown in Fig. 99 would have but one-half the capacity of that illustrated in Fig. 98. To make the total capacity the same, it would accordingly be necessary to double the number of units in each bank, as shown in Fig. 100.

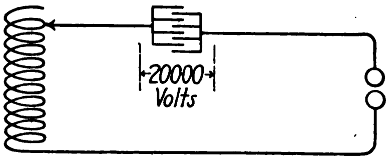


Fig. 98. Diagram Showing Potential across Condensers in Parallel

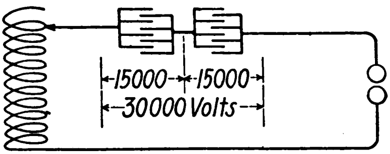


Fig. 99. Diagram Showing Potential across Condensers in Series-Parallel

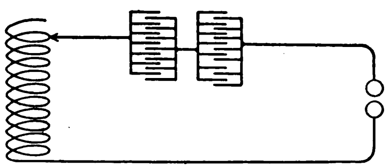


Fig. 100. Diagram Showing Number of Condensers in Series-Parallel Necessary to Give Same Capacity as in Fig. 98

Short=Wave Condenser. It has been pointed out under the head "Oscillation Constant", page 90, that the wave length of the radiating circuit may be varied by altering the value of either the inductance or the capacity in it. It will be evident that the wave length can readily be increased by adding inductance by means of an adjustable inductance with a movable contact, but, as the aerial is a fixed quantity, this wave length cannot be decreased below the value controlled by the inductance of the aerial itself and the minimum number of turns in the variable inductance. However, the radiating circuit is most efficient when its natural wave length approximates that on which the greater part of the transmission is effected, for example, 600 meters; therefore, it is necessary to adopt other means for reducing it to transmit a 300-meter wave. This is accomplished by taking advantage of the principle just outlined, that is, connecting condenser units in series halves the capacity. The aerial itself represents a capacity (distributed) so that by inserting a condenser of approximately equal capacity in series with it, the combined value is reduced to one-half that of either taken alone and the wave length is correspondingly shortened. This is known as the short-wave condenser and it is usually connected in series with the ground connection of the aerial by means of a switch which permits the cutting in or out of the aerial circuit as desired, Fig. 101. Two types of short-wave condensers are employed in the Marconi ship sets, one consisting of four glass plates 15 by 15 inches, covered with sheets of tinfoil 12 by 12 inches, each plate having a capacity of 0.002 microfarad, while the total capacity of the four connected in series is 0.0005 microfarad. The other consists of four jars, two of large and two of small diameter, and the smaller jars are set in the larger, thus making the series connection from the outside coating of one to the inside of the other; the total capacity of this condenser is the same as that of the glass-plate type.

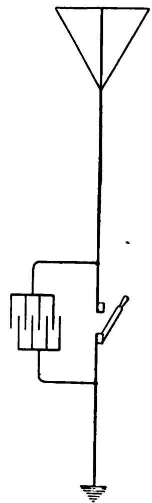


Fig. 101. Short-Wave Condenser and Switch Attached to Aerial

KEYS

Relay Key. For the smaller transmitting sets, an ordinary Morse key of large size, Fig. 102, with substantial silver contacts, operates without sticking or arcing even with rapid sending, but in the larger sizes, means of minimizing the arc upon breaking the circuit are necessary. This is usually accomplished by shunting the key by a resistance, a reactance, or a condenser, Fig. 103; in the first two instances, the key does not break the circuit completely, as the shunted resistance or reactance carries some of the current. Where it is necessary to handle currents in excess of 35 amperes, as in the largest stations, what is termed a relay key is employed. This is the magnetically operated key to which reference has been made previously. An ordinary Western Union key is connected with a 110-volt d.c. supply operating to close the circuit to an electromagnet. The armature of this magnet forms part of the transformer circuit, Fig. 104, and is fitted with a heavy contact which is brought up against a similar stationary contact when the magnet coils are excited by the closing of the key. The armature is drawn down to the pole pieces of the magnet against the pull of a spring which immediately breaks the circuit the moment the key is opened. This spring can naturally be made much stronger than that of a hand-operated key and the gap is also larger, so that the rapid break caused by the strong spring and the wider gap employed effectively prevent arcing, even at high-speed sending.

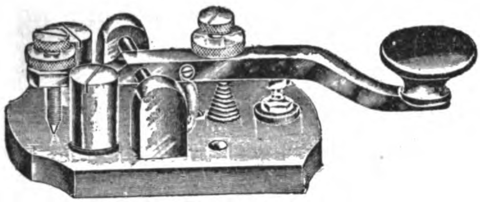


Fig. 102. Morse Telegraphic Key for Wireless Work

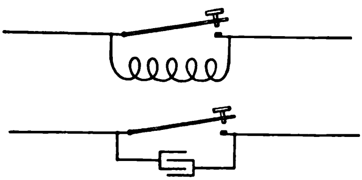


Fig. 103. Shunted Keys; Top Shunted by Reactance; Bottom Shunted by Condenser

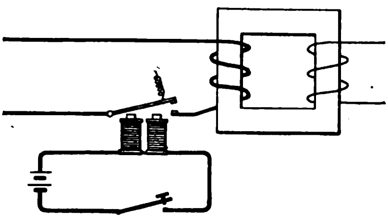


Fig. 104. Diagram of Circuit for Relay, or Electromagnetically Operated Key

Break Key. In wireless telegraphy, it is not ordinarily possible for the receiving operator to *break* the sending operator in case he fails to understand part of the message, as is the case on land lines. This is because it is necessary to throw the aerial switch from receiving to sending in order to connect the transmitting circuits for sending, and *vice versa* when receiving. Besides this function, the aerial switch also usually short-circuits the detector when thrown to the sending position, as the detector would otherwise be thrown out of adjustment by the powerful electromagnetic waves generated in such close proximity to it. To make it possible to have part of a message repeated without waiting until it has been completed, what is termed a break key has been devised. This is fitted with two sets of contacts, one of which serves for sending. Just after the current has been broken, as in sending a dash or dot, and the key is returning to its normal position, the extra set of contacts makes connection with the receiving circuit without the necessity of throwing a switch. The operator using a break key wears the head telephones when sending, so that whenever the receiving operator misses a word or letter, he simply holds his key down or sends the signal BK. The sending operator, having the telephones on and his receiving circuit tuned to the station to which he is transmitting, will accordingly hear this break call between the dots and dashes of his own message and will repeat the missed words. The use of a break key allows the sending operator to *listen-in* while transmitting.

Time signals are transmitted automatically from the standard clock at the Naval Observatory at Washington by means of a Western Union relay which closes the circuit of a local battery connected with a solenoid. The armature of this solenoid carries a lever which presses and releases a sending key so that the dot signals sent out by the government wireless station at Radio, Virginia are synchronized with the ticking of the clock and thus give the correct time.

SPARK GAP

Function. The function of the spark gap is to permit the condenser to discharge when the potential of the latter reaches a value sufficient to break down the resistance of the gap. This resistance varies with the size of the opening of the gap, but the latter is not set so that the maximum voltage of the charging circuit is required to overcome it. For example, in a circuit where the maximum potential reached in the condenser is 30,000 volts, the gap may be assumed to be adjusted to break down at 10,000 volts, as cited in the experiments of Professor Pierce.* As the resistance of the gap is very high, no current passes until

*See *Principles of Wireless Telegraphy.*

the potential reaches 10,000 volts, when the resistance is broken down. The resistance of the gap, due to the ionization of the air between its poles, then drops instantly to a very low value (less than 1 ohm), and during the first half of the oscillation the condenser discharges to zero potential.

It is easily shown that, while the discharge is apparently in but one direction, the sparks pass first in one direction and then in the opposite, and during the last half of the oscillation the condenser is again charged but with opposite polarity. The sparks pass with such great rapidity during the discharge that the gap does not regain its original resistance or any substantial fraction of it until the losses due to the radiation of the electromagnetic waves and the expenditure of energy in the form of heat and light at the gap cause a sufficient drop in the potential. The spark acts as a trigger, suddenly releasing the stored energy in the condenser and again resetting itself automatically as soon as the charge has been radiated, this release taking place as often as the condenser potential reaches the proper value. As the maximum charging potential in the circuit mentioned is 30,000 volts, the condenser may be charged and discharged several times during one half-cycle of the charging current, since the spark gap is adjusted to release its energy when the potential reaches 10,000 volts. One half-cycle of the charging current would be represented by one-half the curve, Fig. 18, showing the rise from zero to maximum potential and its fall in one direction. The complete curve shows one alternation, the current reversing in direction as it passes through the point of zero potential. Assuming this to be a 60-cycle current there would thus be 120 alternations per second so that the half-cycle, during which these several discharges take place, would occur in $\frac{1}{120}$ second. This is not a desirable condition for efficient radiation as explained under "Synchronous Rotary Spark Gap," page 142.

Length of Gap. The opening of the gap is made shorter than the maximum permissible in order to increase the number of discharges per alternation, since if it were such that the maximum potential of 30,000 volts were required to break down its resistance, but one discharge of the condenser would take place and only a single train of waves would be radiated. When the points of the gap are brought too close together an arc is formed and no oscillations are set up other than those due to the frequency of the charging current, which is very low as compared with that of the oscillatory discharge of the condenser. This is due to the fact that the discharge through the arc is continuous. The number of discharges through a given length of spark gap depends upon the frequency of the charging current and the time required to charge the condenser to the potential necessary to break down the resistance of the gap. Since the energy radiated varies as the square of the voltage, less energy is released per discharge through a short gap than through a longer one, but as a greater number of discharges take place in the same period through a short gap, practically the same amount of energy may be radiated by both in the same time. The ideal spark gap is one in which the resistance is very high while the condenser is charging, is greatly reduced in value during the occurrence of the discharge, and is again increased to its original value at the moment the discharge is dropping to zero potential during its last alternation, so that the open oscillatory circuit is free to radiate the energy induced in it without the interference otherwise caused by the oscillations of the closed circuit; in other words, the closed oscillatory circuit must have its oscillations shut off suddenly and completely as soon as the oscillations in the open circuit reach their maximum value, as shown in Fig. 105. These requirements are met by the rotary spark gap, or discharger, and the quenched spark gap, as explained in the discussion of those types.

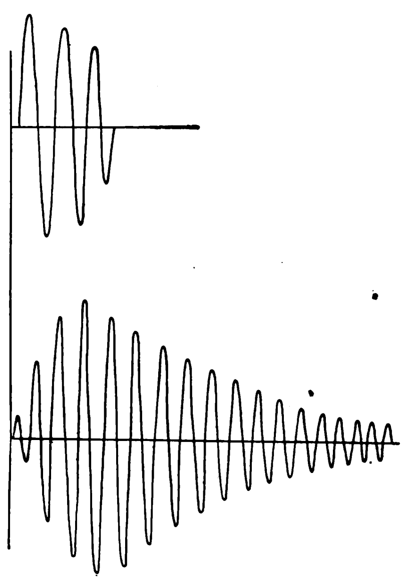


Fig. 105. Proper Relation of Oscillations in Closed and Open Oscillatory Circuits; Upper Curve Closed, Lower Curve Open Circuit

Types of Spark Gap. *Simple Form.* The spark gap originally used in wireless telegraphy consists of two ball or plane electrodes from ¼- to ½-inch diameter, mounted so that the distance separating them can be adjusted by hand, Fig. 106. The rods and terminals are zinc or copper and the adjusting handles hard rubber. One of the disadvantages of this type is that it becomes overheated in continuous operation and, to avoid this, radiating fins are sometimes placed on the electrodes. Other and greater disadvantages, however, are the tendency to arc when the electrodes are close together and the fact that the air in the gap remains conducting to a certain extent after the gap has been in operation for a short time, so that the condenser discharges at a lower potential than desired and the oscillations of the closed circuit are not quickly *quenched* but continue after the open circuit has started radiating at its maximum. These faults have been overcome to a certain extent by the use of a number of gaps in series and by applying an air blast either at right angles to the gap or through the electrodes themselves, which are made hollow for this purpose. This type of gap is still employed in small sets using either a 60-cycle alternating current or an induction coil, chiefly in amateur installations, but is not as efficient as the rotary type and does not give as clear a spark note.

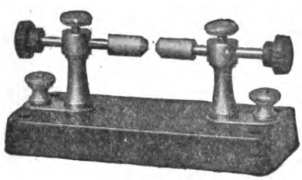


Fig. 106. Simple Form of Spark Gap

Rotary Spark Gap. To fulfill as far as possible the requirements given for an ideal spark gap, the discharge is caused to occur between the movable and stationary electrodes. In this way the resistance is greatest while the condenser is charging, as the electrodes are then farthest apart; it is at its minimum when the discharge is taking place, as the points are then opposite one another; and it is immediately increased by the continued rotation of the movable electrode so that the discharge is quenched long before the drop in potential would bring this about in the stationary type previously described.

The rotary gap consists of a small high-speed electric motor carrying on its shaft a metal disc or ring on which are mounted eight or ten short electrodes, usually of zinc. These electrodes pass between stationary electrodes directly connected in the closed oscillation circuit. As often as the revolving disc brings one of its electrodes close enough to the stationary electrodes, the discharge begins and it lasts until the continued rotation carries the moving electrode far enough to increase the resistance of the gap to a point where the potential of the discharge can no longer overcome it. As the motor runs at 1800 to 2500 r.p.m. this gap produces a musical note, the pitch of which varies with the speed of the motor. In Fig. 107 is illustrated a rotary spark gap such as is used with amateur sets. The relation between the speed of the motor and the number of gaps is usually designed to produce 250 to 300 discharges per second and the chief advantage of the rotary spark gap is that it produces a musical note from a low-frequency alternating current. It is accordingly used to a great extent on 60-cycle alternating current, for amateur and experimental purposes, but it has been largely displaced in commercial service by the synchronous type of rotary gap in connection with the 500-cycle alternator (Marconi).

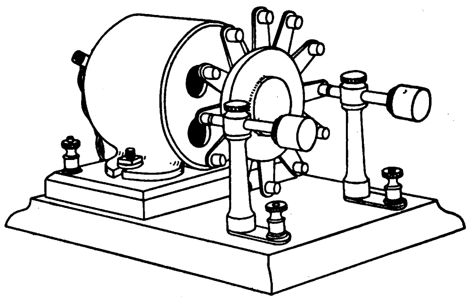


Fig. 107. Nonsynchronous Rotary Spark Gap

Synchronous Rotary Spark Gap. The type of rotary spark gap just described is known as a nonsynchronous discharger, since the speed of the motor bears no relation to the frequency of the charging current. While the discharges of the condenser are at a uniform rate, as shown by Fig. 108, which illustrates how the spark discharge is superimposed on the charging current, it will be apparent that the spark frequency is much greater than that of the charging current and the discharges are not of equal power. For example, the third spark on the first cycle occurs when the potential is close to zero while the second spark on the second cycle takes place close to the maximum amplitude of the wave, which

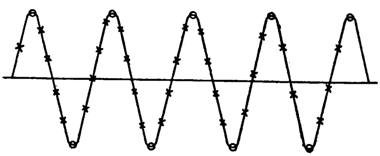


Fig. 108. Occurrence of Discharge with Relation to Amplitude of Wave with Nonsynchronous Rotary Gap; Sparks Should Occur as Shown by Circles
"Practical Wireless Telegraphy" by Bucher

is necessary for obtaining the most efficient radiation. But since the discharges are uniformly timed, a semimusical note composed of fundamental tones coupled with a number of overtones is produced and the pitch of this note is much more easily read than that produced by the simple spark gap, particularly when it is necessary to read it through interference. A discharge of the condenser at points of equal amplitude in successive alternations of the charging current may be obtained by adjustment of the speed

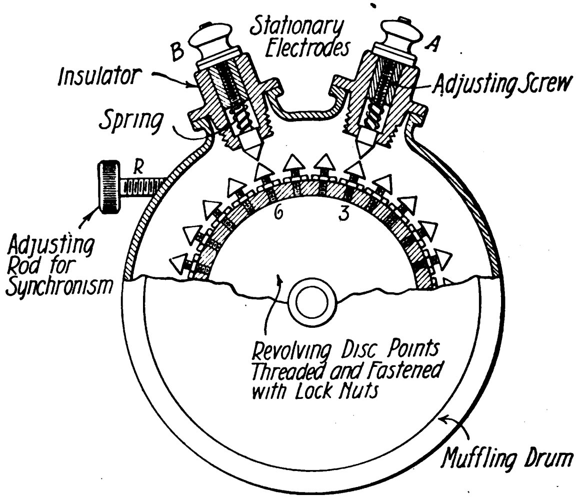


Fig. 109. Part Section of Marconi Synchronous Rotary Spark Gap

of the motor in a gap of this type and will produce a much more uniform note.

To render the rotary gap synchronous with the alternations of the charging current, it is mounted directly on the shaft of the alternator. The rotating disc is then equipped with the same number of electrodes as there are poles in the alternator in order that the gap may be so adjusted that the discharge will always occur at the maximum amplitude of each alternation. All the discharges are then of equal power. In addition to being adjustable for the length of the gap, the stationary electrodes are mounted so that they can be rotated through a small arc to give this result. With the 500-cycle alternator used in the Marconi sets, there are 1000 discharges of the condenser per second and the resulting spark note has a musical pitch corresponding to that frequency of vibration.

In Fig. 109 is illustrated the synchronous rotary spark gap employed on the 2-kw. 500-cycle Marconi ship set. A heavy steel disc carrying 30 copper electrodes is mounted directly on the shaft of the alternator itself. To silence the discharge, the noise of which is very loud and would annoy the operator, particularly when using a break key, this disc is inclosed in a muffling drum. The latter also carries the stationary electrodes *A* and *B*, which are insulated from it. To provide the necessary adjustment to obtain a synchronous discharge that will give a clear musical note, the drum is mounted so that it is rotated through an arc of 25 degrees by means of the rod *R*. The gaps themselves are adjusted so as to give the shortest possible distance between the moving and stationary electrodes without actually touching. A fine pitch thread on the stationary electrodes and a nut permit locking these electrodes in place and they are designed so that they may be adjusted 0.003 inch at a time. Similar locking nuts are provided on the movable electrodes mounted on the disc, as shown. The circuit through the discharger is from the stationary electrode *A* to electrode *3* on the disc, through the disc itself and the gap between the disc electrode *6* and the stationary electrode *B*. The minimum distance for favorable working is 0.005 inch between the stationary and rotating electrodes, but the effective length of the discharge gap is actually much greater than this as the discharge begins long before the electrodes are actually opposite one another. The rapid quenching of the discharge prevents the oscillations of the open, or radiating, circuit from being superimposed on those of the closed circuit and gives correspondingly more efficient radiation. Synchronous rotary dischargers of this type are also used on ½-kw. Marconi sets and have been used effectively on powers up to 500 kilowatts.

Quenched Spark Gap. It was discovered by Wien that a plurality of very short gaps between electrodes of large surface will also produce one discharge per alternation of the charging current; that this discharge may be made synchronous with the amplitude of the alternations; and also that this type of gap quickly stops the oscillations of the closed circuit, leaving the open circuit free to oscillate at its own frequency, so that waves of but one length are radiated. It also has the further great advantage of operating effectively on comparatively low voltages, giving rapid quenching of the oscillations of the closed circuit with close coupling of the oscillation transformer, and being practically noiseless in operation. The rapid quenching with close coupling enables the maximum amount of energy to be radiated from the open, or aerial, circuit for a given input at the transformer, so that much greater distances can be covered with the same amount of power when using this type of gap. The relation of the oscillations taking place in

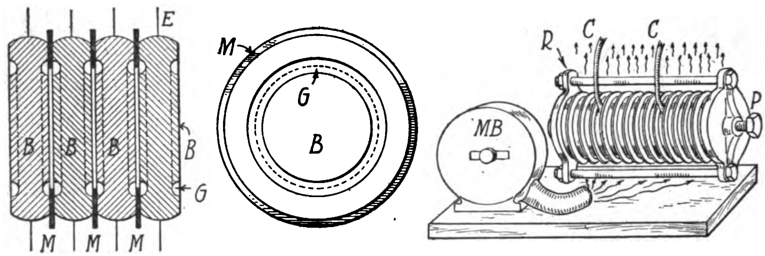


Fig. 110. Section and Details of Quenched Spark Gap—*B*, Brass Disc; *C*, Connecting Leads; *E*, Extension for Attaching Connections; *G*, Groove in Brass Disc; *M*, Mica Washers between Discs; *MB*, Motor Blower; *P*, Pressure Bolt; *R*, Rack. Arrows Indicate Passage of Air Over Discs; Containing Case not Shown

the closed and the open oscillation circuits with an effectively quenched spark is shown in Fig. 105.

The quenched spark gap consists of a number of heavy copper discs with grooves turned in their faces close to the outer edge of the disc. These discs are assembled in a rack, Fig. 110, with insulating washers between them, the inside edge of the washers covering the grooves. These washers are specially treated so that the discharge surface is air-tight and their purpose is to prevent the spark discharging at their edges, as this would soon cause a short-circuit. Pressure is applied, by means of the bolt shown, to hold the discs and washers tightly together and prevent the entrance of air, the space between the sparking surfaces of a set of plates not exceeding 0.01 inch (Marconi). The number of sets employed depends upon the voltage of the charging current, approximately 1200 volts being required for each gap. This type of gap is employed on voltages as low as 6000 and seldom above 15,000, so it has the great advantage of not imposing any undue strain on the condenser. The quenched gap, however, cannot be operated continuously, except with low power, unless some method of cooling is employed. In the Marconi type, Fig. 110, a small motor will be noted at the left-hand end of the gap; this discharges a blast of air through the gap when it is in operation. The quenched spark gap was introduced in connection with the Telefunken system, in which it is employed to the exclusion of other types. In the Marconi system, it is only employed for low-power sets, the synchronous rotary type being used for high-power installations. The clips and cables shown permit including a larger or smaller number of the gaps in the circuit to give the proper adjustment of the spark note.

OSCILLATION TRANSFORMER

Function. The function of the closed oscillation circuit is to create a series, or train, of high-potential high-frequency oscillations, in other words, electromagnetic waves. But as the closed circuit cannot be a good oscillator and a good radiator at the same time, it has been developed to produce the maximum efficiency as an oscillator while the function of radiating the wave is carried out by the open, or aerial, circuit. The oscillation transformer is the medium by means of which the oscillations are transferred from the closed to the open circuit. But as it also represents an inductance of variable value in each circuit, it has other offices to perform as well. Chief among these are varying the wave length emitted by adjusting the value of inductance of either coil of the transformer and limiting the damping of the emitted wave by a variation of what is known as the coupling of its coils, that is, varying either the distance separating them or their inductive relation. This reduces their mutual induction and makes possible the radiation of a pure wave.

Helix. As originally employed, the oscillation transformer consisted of a single coil of heavy copper wire or tubing, eight to twelve turns of which were spaced about one inch apart on an insulating framework 12 to 20 inches in diameter, these dimensions representing the requirements of a small sending set of not over one kilowatt. Part of this coil, or inductance, usually two to four turns, was included in the closed oscillatory circuit and represented the primary. The remaining turns or as many of them as might be necessary to give the proper value of inductance were included in the aerial circuit. This arrangement is termed a helix and the transfer of the oscillations in it is due partly to induction and partly to conduction. But as the mutual inductance of the two parts of the coil is very large and there is no way of reducing it, waves of two distinct lengths are produced by it, one due to the induction and the other to the mutual induction and both highly damped. It is not possible to produce a sharply tuned, or pure, wave with this type of oscillation transformer and as a result it has been obsolete for some time in commercial practice; in fact, its use is not permitted by government regulations, as it does not emit a wave that complies with the latter. One form of helix and its connections to the two circuits are illustrated in Fig. 111.

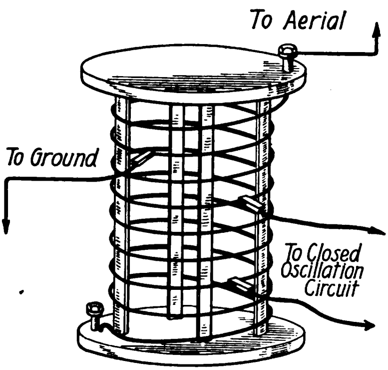


Fig. 111. Helix (now Obsolete)

Modern Types. To reduce the mutual induction, it was found necessary to make the two coils independent of each other, the primary being connected in the closed circuit and the secondary in the aerial circuit. By so doing the coupling of the two coils may be varied to adjust their mutual inductance and reduce the damping as is explained under the head "Explanation of Coupling", page 226. The method of effecting this depends upon the type of oscillation transformer employed. If the primary and secondary are in the form of flat, or pancake,

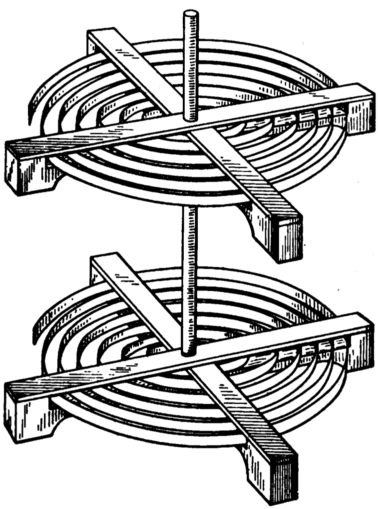


Fig. 112. One Type of Pancake Oscillation Transformer

coils, they are either moved apart directly in the same plane or are hinged so that the secondary may be swung out of line with the primary. Oscillation transformers of these two types are illustrated by Figs. 112 and 113. The inductance of both coils is made adjustable by means of a sliding contact or clips similar to those employed on the helix, and this also affects the coupling.

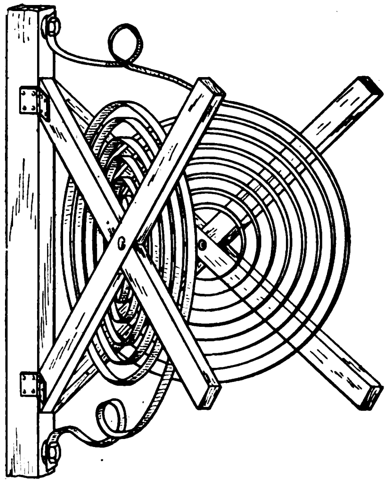


Fig. 113. Hinged Type of Oscillation Transformer

Under the head "Induction", page 31, it was explained that the induced current only attains its maximum value when the secondary coil is cut by the maximum number of the lines of force set up by the magnetic field of the primary. To accomplish this, the secondary coil must either be parallel or directly in line with the primary. If it is set at an angle with the primary, the number of lines of force cutting its windings diminishes until, at right angles, it is at a minimum. This principle is employed in the Marconi oscillation transformer, Fig. 114, and is termed a variometer. Copper tubing $\frac{3}{8}$ inch in diameter is wound on porcelain supports, giving the coil a diameter of 15 inches. This is the primary coil and its inductance is varied by the clips shown. The secondary consists of heavy stranded insulated copper cable wound on a hard-rubber spool which is mounted in trunnions directly above the primary so that it may be set directly in line with

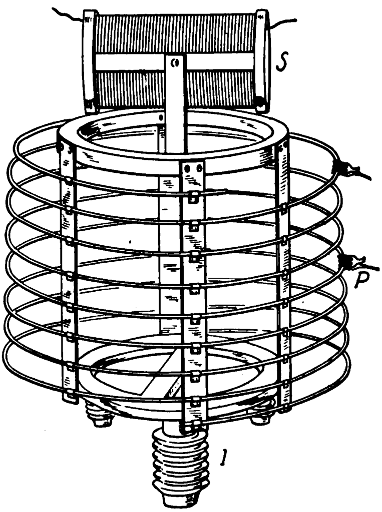


Fig. 114. Variometer Type of Oscillation Transformer—*P*, Primary; *S*, Secondary in Zero Position

it or at any angle up to 90 degrees. In Fig. 115 is illustrated the difference in the strength of the magnetic field set up in the secondary in the two positions representing the maximum and minimum effects obtainable. In this type of oscillation transformer, the inductance of the secondary is fixed, so a tuning inductance is employed to vary the wave length emitted.

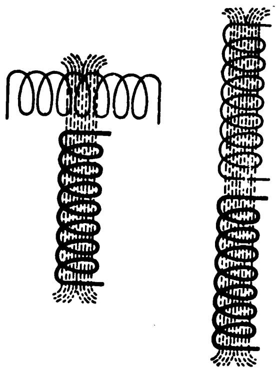


Fig. 115. Difference in Strength of Magnetic Field in Secondary of Oscillation Transformer of Variometer Type—Left, Minimum; Right, Maximum

Tuning Inductance, or Loading Coil. A tuning inductance is a variable inductance connected in series with the aerial circuit and is designed to increase the length of the wave that may be radiated from the circuit. When it is necessary to decrease the wave length below that obtained with the minimum number of turns of this inductance in circuit, the short-wave condenser is placed in circuit with the aerial. Loading coils, as they are most frequently termed, may take several forms, one of the earliest being that of a simple helix with a sliding contact or a movable clip to vary the number of turns in circuit,

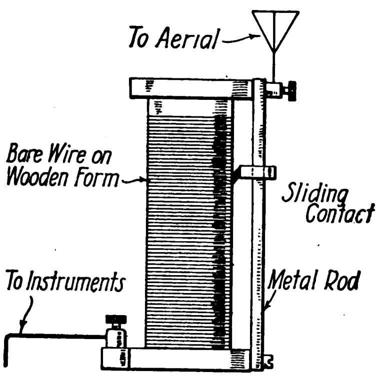


Fig. 116. Loading Coil or Aerial Tuning Inductance (obsolete)

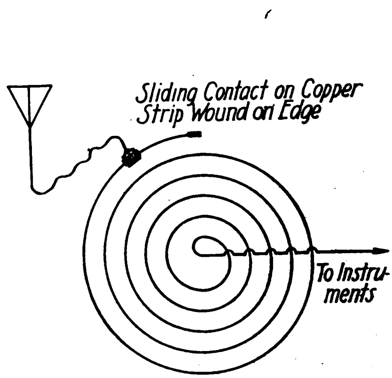


Fig. 117. Marconi Type of Continuously Variable Aerial Tuning Inductance

Fig. 116. They are also made in the form of a spiral consisting of a flat copper strip wound on edge and fitted with a sliding contact arranged so that it may be moved to any part of the spiral

winding. This type of loading coil, Fig. 117, is used on the Marconi ½-kw. 120-cycle set.

AERIALS, OR ANTENNAE

Relation of Form of Aerial to Its Wave Length. The electromagnetic waves transferred from the closed to the open oscillation circuit by means of the oscillation transformer are radiated into the ether through an aerial, sometimes termed an antenna. It has been mentioned that to be in resonance the products of the capacity and the inductance in the two circuits must be equal. In the closed circuit there is both concentrated capacity—the condenser—and concentrated inductance—the primary of the oscillation transformer. But as concentrated inductance, in excess of

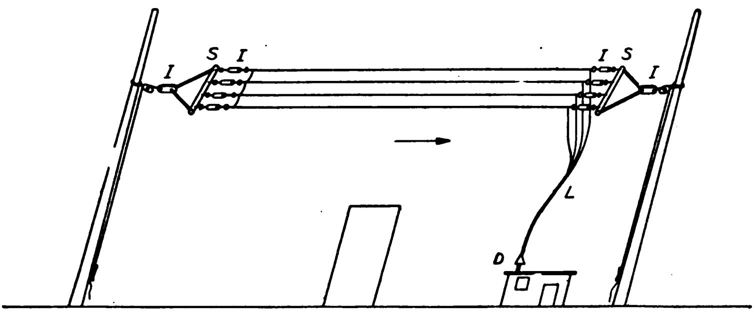


Fig. 118. Typical Ship Aerial—*I*, Insulators; *S*, Spreaders; *L*, Lead-In; *D*, Deck Insulator; Inverted L Aerial Strongly Directive as Shown by Arrow

that required to receive the energy from the closed circuit through the oscillation transformer, is detrimental to the radiating abilities of the open circuit, the difference must be made up by adding to the capacity of the aerial. This capacity, which is distributed, is increased by adding to the number of wires composing the aerial or by increasing its height. As structural difficulties usually restrict the height, the increase is effected by adding to the number of wires in parallel. Both height and width are limited on shipboard, however, and hence both the wave length and the power that can be employed in marine installations are limited.

The standard wave length for a ship station is 300 to 600 meters and the aerial itself consists of two, three, or four bronze or aluminum wires supported on wooden spreaders and guyed to the masts. The inverted **L** type is most commonly employed and

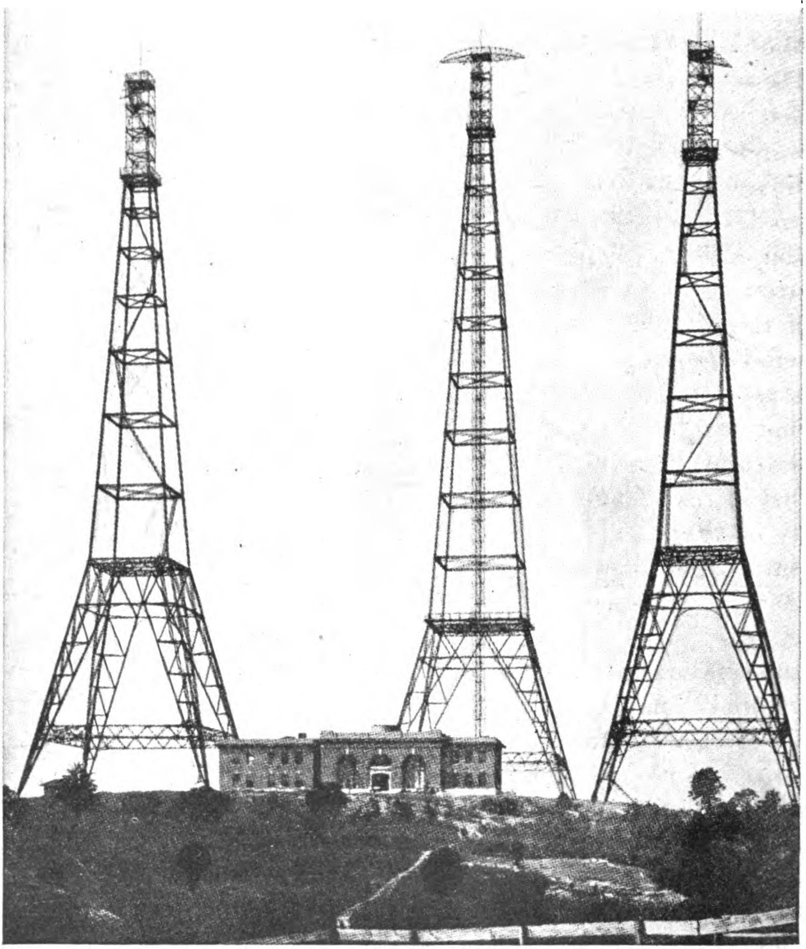


Fig. 119. United States Wireless Station at Radio, Virginia, Having Direct Communication within Radius of Over 3000 Miles—Tallest Tower Is 600 Feet High and the Other Two, 450 Feet Each.

Photographed by G. V. Buck, Underwood & Underwood, New York City the average natural wave length of the aerial is 400 to 450 meters, which is increased to 600 meters by the tuning inductance or decreased to 300 by means of the short-wave condenser. In Fig. 118 is shown a typical ship aerial.

As there is no limit to the horizontal length of the aerial of a shore station, except initial cost and maintenance, some of the Marconi transatlantic stations have aerials over one mile long. These are also of the inverted **L** type, since it has been found that this form of aerial is strongly directive, that is, the energy is radiated more strongly in line with the aerial than in any other direction. For example, the **L** aerial, Fig. 118, radiates most strongly in the direction indicated by the arrow, or the opposite of that in which the aerial itself points. It is also found to interrupt a greater part of the oncoming wave so that its receiving ability is correspondingly better; consequently, Marconi shore stations are equipped with aerials facing in opposite directions.

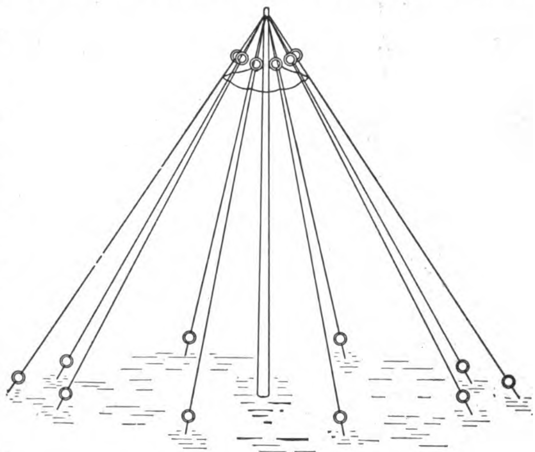


Fig. 120. Umbrella Type Aerial; Circles Indicate Insulators

Types of Aerials. *Inverted L Type.* As the dimensions of the aerial are governed by the length of the wave to be radiated and space is not always available for the long horizontal stretch required by a large inverted **L**, the same electrical length and capacity are obtained by other forms. Two parallel wires do not have double the capacity of a single wire unless spaced quite a distance apart so that, where space is limited, large aerials are frequently built in the form of a square, supported by four towers, like the aerial of the Telefunken transatlantic station at Sayville, Long Island, or in the form of a triangle, as at Arlington.

Umbrella Type. Where space is still further limited, the umbrella type of aerial, Fig. 120, which is supported by a single mast, is employed. This is the type used at the station at Nauen, Germany, from which messages were received at Sayville, Long Island, and Tuckerton, New Jersey. In the case of the large transatlantic stations, two aerials are employed, messages being sent from one station and received by another, 30 to 40 miles distant from the sending station. This is to prevent the great amount of energy radiated from the sending station from affecting the instruments at the receiving station. An umbrella type aerial is also employed at the Guantanamo (Cuba), U. S. Naval Station. Any conductor having sufficient inductance and capacity, plus the necessary elevation, will, however, act as an aerial, as messages over distances not exceeding 50 miles have been satisfactorily received by employing the electric light wiring or the water piping of a house.

T Type. The only other type of aerial in general use is the **T** aerial, which is simply a modification of the inverted **L** made by attaching the lead-in at the center of the horizontal leg instead of at one end. This is not as frequently used as the **L** type, since its natural wave length is shorter owing to the fact that the two halves of the horizontal top are thus converted into two inductances in parallel and their combined value is then less than that of either taken separately. As the wave length is a measure of the inductance and the capacity, the wave length is decreased correspondingly by reducing the inductance. The **T** aerial is often found necessary on steamers, since the distance between the masts is frequently so great that an **L** aerial would give a wave length in excess of 600 meters. It would then be necessary to use a short-wave condenser to decrease the wave length and this is objectionable because the condenser decreases the efficiency of radiation. Moreover, a condenser in series with the aerial cannot reduce the wave length of the latter below one-half its natural wave length, so that a 300-meter wave would be unobtainable under such circumstances. In case an extra long lead-in would be necessary to reach the operator's cabin with a **T** form aerial, which would also increase the wave length, the **L** type is used even on large steamers, but insulators are inserted in the aerial at a point which will give it the proper wave length, the remainder being utilized simply for support.

TABLE V

Aerial Data for Steamers Equipped with Marconi Apparatus*

Type	Horizontal Length (ft.)	Height (ft.)	Number of Wires	Natural Wave Length (meters)	Capacity (mfds.)
L	208	96	6	374	0.00128
T	200	125	6	368	0.00145
L	150	87	4	355	0.00115
T-Imp.	250	95	4	412	0.0015
L	200	90	6	360	0.0015
L	120	100	6	325	0.00132
T	130	92	4	285	0.00075
T	250	150	4	426	0.00096
L	200	90	6	360	0.0023
L	125	55	6	230	0.00085
T	151	110	6	290	0.0009
L	200	98	6	425	0.0024
L	170	85	4	380	0.00082

Data on Ship Aerials. On very small vessels the inductance has to be increased by adding to the number of wires in parallel, as many as six to eight being employed, and by providing an extra large tuning inductance in circuit with the aerial. The capacity of aerials on steamers is also affected by the proximity of steel masts, smokestacks, and other masses of metal and this is taken into consideration in designing them.

It will be noted from Table V, that with one or two exceptions the aerials in general use on steamers equipped with Marconi apparatus require the use of a condenser in series to give a 300-meter wave.

The form of the radiated wave, Fig. 89, is assumed to account for the fact that the receiving properties of the flat-top type of aerial are better than those of the vertical aerial, which has been shown to be a better transmitter. In the illustration, it will be noted that the wave travels with its foot on the earth or ocean and that the upper end travels faster than the lower, this being the case particularly where its propagation is retarded by passing over dry earth or other good insulators. The wave accordingly tends to become bent in the direction opposite to that of its movement with the result that the flat top of the aerial is then approximately parallel to the lines of force of the static field and

* See *Practical Wireless Telegraphy* (E. Bucher).

at right angles to those of the magnetic field, the conditions necessary for intercepting the maximum amount of energy from the passing waves.

Bellini "Wireless Compass." The Bellini "wireless compass" is simply a strongly directional aerial in the form of a triangle suspended vertically and with its horizontal limb passing through the operator's cabin. At the center of this horizontal stretch is placed an inductance. An aerial of this type will radiate the maximum amount of energy in the direction of its own plane and the minimum in the direction perpendicular to the triangle; conversely, it will give the strongest signals in the receiving instruments when the received wave is in the direction of its plane, so that by making the position of the aerial adjustable, as on a pivot, the bearing of the sending station to the receiving station is easily determined. This is, of course, only applicable to two ships at sea and serves to indicate the course that one is steering with relation to the other, which accounts for the term wireless compass. By erecting two similar triangular aerials at right angles to each other, each of which is fitted with an inductance coil at the center of the horizontal limb, a difference in the strength of the signals received on each aerial is noted. Both of these inductances are closed and a third coil, capable of being swiveled, is placed in inductive relation to them. For sending, this third coil would represent the primary of an oscillation transformer, and for receiving, a variable inductance in circuit with a detector and telephones. The two stationary inductances are mounted so that they are at the same angle to each other as their aerials and their angular position relative to the head of the ship is indicated on a scale. The plane of the movable coil, relative to that of the stationary coils when the received signals are of the maximum strength, is

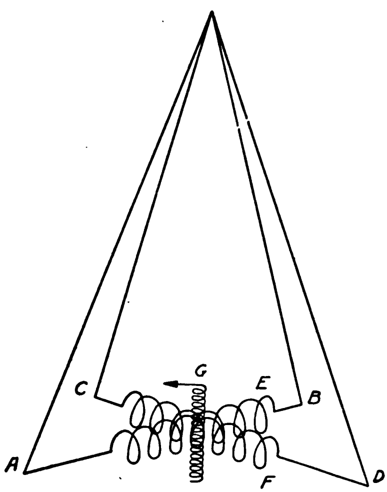


Fig. 121. Bellini-Tosi Wireless Compass

then approximately that of the intercepted waves and is shown by the scale in degrees with relation to the course of the ship. This arrangement is shown diagrammatically by Fig. 121, in which *A B* and *C D* are the two triangular aerials, *E* and *F* are their stationary. inductances, and *G* is the movable inductance in circuit with the receiving instruments. This is known as the Bellini-Tosi aerial and experiments have shown that it is so strongly directional that the emitted wave is not received at all by stations at right angles to its plane when sending, while in receiving it serves to eliminate interference to a marked degree. The receiving set used with it is termed a *radiogoniometer*, or wireless direction finder.

Aerial Construction. In Fig. 122 is illustrated the construction of a standard ship aerial as employed by the American

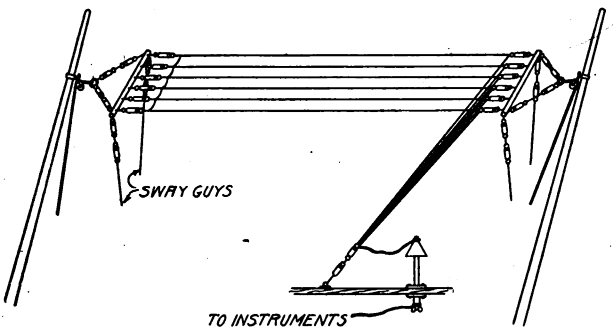


Fig. 122. Ship Aerial of Marconi Type

Marconi Company.* It consists of six silicon bronze wires made up of seven strands each of No. 18 B. & S. gage, the wires being equally spaced and all connected in parallel by a cross wire at one end while at the other they are extended downward to form the lead-in or vertical portion of the aerial. They are held apart by wooden spreaders 14 to 18 feet long and are insulated from the spreaders by long hard-rubber insulators, Fig. 123, while the spreaders are insulated, in turn, from the hoisting halyards of galvanized steel rope by strop insulators consisting of hard-rubber tubes fitting loosely over the bridle of boat rope, the space between the tubes and the rope being filled by pouring molten sulphur in it. When hardened by cooling this serves to keep out moisture.

*See *Practical Wireless Telegraphy.*

At the point where it enters the operating cabin, the lead-in is insulated by what is known as the *deck insulator*, which is capable of withstanding 30,000 volts. Two types of deck insulators are shown in Fig. 124. In the left-hand one, which is known as the Bradfield insulator, a brass rod is passed through a hard-rubber tube fitted with a metal hood to prevent rain dripping directly on the deckhouse joint and provided with a lock nut to which the end of the lead-in is connected. Wood blocks are threaded on the hard-rubber tube where it passes through the roof of the deckhouse and, when these have been drawn up tight on fabric washers

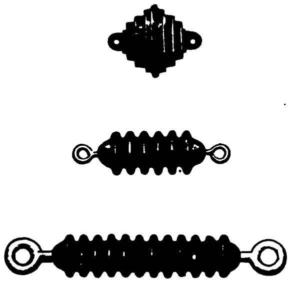


Fig. 123. Typical Insulators for Wireless Aerials

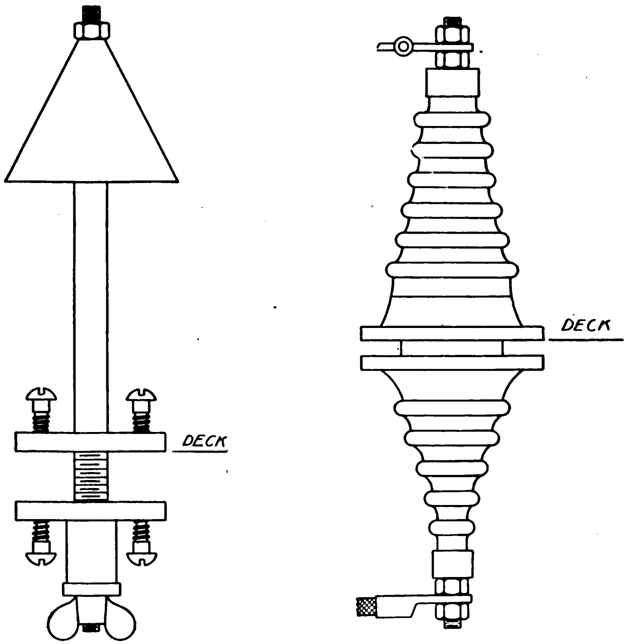


Fig. 124. Typical Examples of Deck Insulators

covered with white lead, wood screws are inserted. The type at the right consists of a brass rod on which an insulating compound, known as electrose, is molded in the form of tapering fins, threaded.

collars being employed to draw the two halves of the insulation together on rubber washers. The lead-in from the aerial is soldered to the upper lug shown, and the connection to the instruments, to the lower one.

Ground Connection. To be most efficient the ground connection of an aerial must be as short as possible and of heavy stranded cable. As the operator's cabin on a steamer is built of steel plates riveted directly to the steel beams and deck below it, it is only necessary to drill and tap a hole in the bulkhead or side of the house nearest to the instruments and screw a copper bolt in it, the connecting wire being clamped under the head of this bolt. The entire hull of the steamer then serves as the ground and transmission is much more efficient than on a wooden vessel, on which it is necessary to increase the length of the ground connection considerably to reach some metal part that is in contact with the water.

For the ground connections of small stations in houses, such as amateur installations, it is customary to use the water or gas piping, the fire underwriters' rules stating that this connection must be made with a No. 4 or larger gage insulated wire and that the connection itself must be made outside of the house. The grounding of a large station, however, is not so simple. Where the nature of the earth permits, large copper or zinc plates to which the ground leads are soldered are buried at a depth at which they will be kept constantly moist. If located on rocky or very dry soil, a *counter-capacity* is employed. This is practically a duplicate of the aerial itself but is laid on the ground directly under the flat portion of the aerial. All the wires of this counter-capacity are joined together at a common terminal in the same manner as a lead-in.

At the large transatlantic stations a combination ground consisting of zinc plates and copper cables is buried in the form of a circle, several hundred copper cables being employed to connect the plates to the station, while additional copper cables are extended radially from the zinc plates, the total area comprising a circle 200 feet or more in diameter. The size of the ground is, of course, determined by the size of the aerial and the nature of the soil, as, for instance, where low marshy ground is available, an effective ground connection can be obtained by sinking a few plates attached to copper cables directly in the water of the marsh.

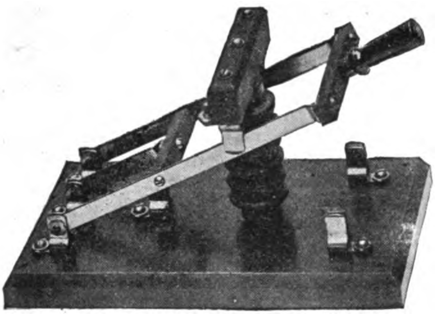


Fig. 125. Aerial Change-Over Switch

Aerial Change-Over Switch. In all wireless stations, except a few of the very large transatlantic stations in which the sending and receiving stations are separated by a distance of 30 to 50 miles, the same aerial is used both for sending and for receiving. Unless equipped with a break key, it is accordingly necessary that provision be made for disconnecting the sending circuits from the aerial when receiving, and *vice versa*. As shown in Fig. 125, this provision takes the form of a switch which, in a

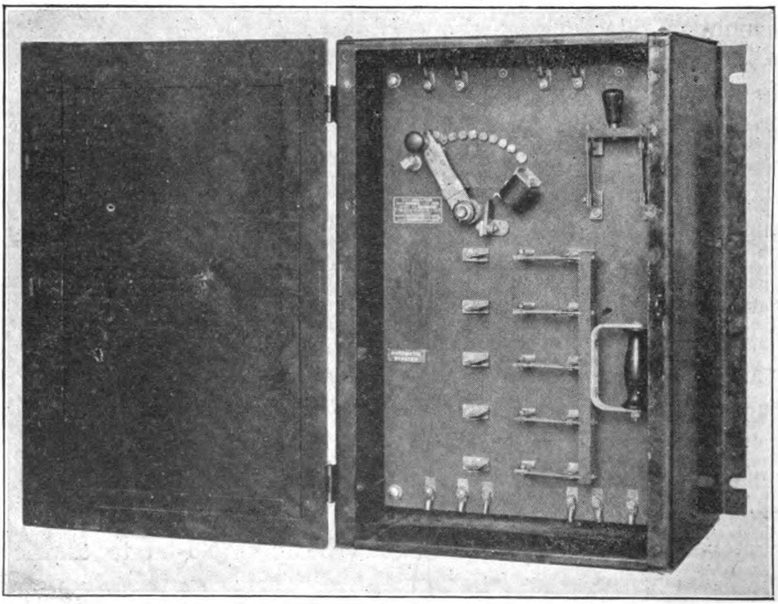


Fig. 126. Cutler-Hammer Combination Hand and Automatic Starter Switch in Metal Case

station using more than ½ kw., must have an effective opening of at least 6 inches to prevent the high-tension current from sparking across it. The number of contacts on the aerial switch depends upon the number of circuits it is designed to control. In its simplest form it consists of a single blade of the double-throw type and two contacts, one to connect the sending instruments and the other the receiving instruments in the circuit. Such a switch is mounted vertically and when thrown upward puts the transmitter in circuit, while in its lower position the receiving instruments are in circuit. With a detector of the type affected by the spark discharge, extra contacts are sometimes provided to short-circuit the detector when in the sending position. With such a switch it is necessary to employ separate switches for controlling the motor-generator and other apparatus. In Fig. 126 is shown a combination hand and automatic starter.

Commercial Type. In commercial usage where quick and efficient operation is essential, a type of switch is employed that will control all the necessary circuits with a single movement. In Fig. 127 is illustrated the circuits of an automatic Marconi switch. When thrown to the left, the motor-generator is started automatically, the aerial connection shifted from receiving to sending, and the transformer put in circuit through the different contacts as follows: *1* and *2* place the field winding of the alternator in circuit in order to excite it from the direct-current supply; *3* and *4* close the circuit of the automatic starter which sets the motor-generator in operation; *5* and *6* close the circuit of the primary winding of the high-potential transformer; and spring contacts *7* connect the aerial to the transmitting circuit. When the switch is lifted from the receiving side, the circuit of the receiving transformer is opened between *8* and *9*, the detector is short-circuited by contacts *10* and *11*, and contacts *12* and *13* serve to short-circuit the telephone receivers.

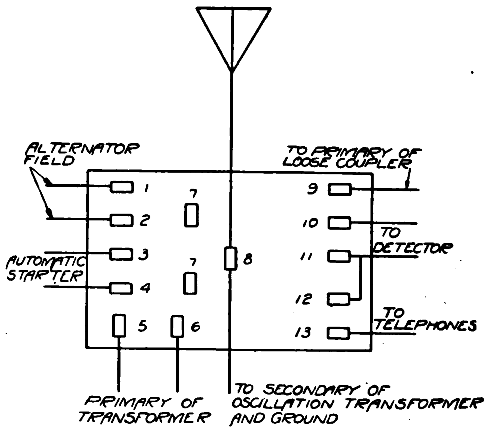


Fig. 127. Connections of Typical Marconi Change-Over' Switch

Lightning Switch. To provide protection for buildings in which wireless stations are installed, the underwriters' regulations require that a lightning switch be inserted in the aerial circuit. This is simply a single-pole double-throw switch and must be heavy enough to carry 100 amperes at 250 volts. It is mounted vertically on the outside of the building and when thrown upward connects the aerial in circuit with the antenna, or change-over, switch so that either the sending or receiving circuits may be used. When in the downward position it connects the aerial directly to the ground so that any atmospheric discharges will pass to the ground without entering the building. A lightning switch is also provided in connection with all ship installations for the protection of the instruments and the vessel itself.

TRANSMITTING CIRCUITS

Development of Transmitter. In its simplest form a complete transmitter would consist of a source of direct current, such as a

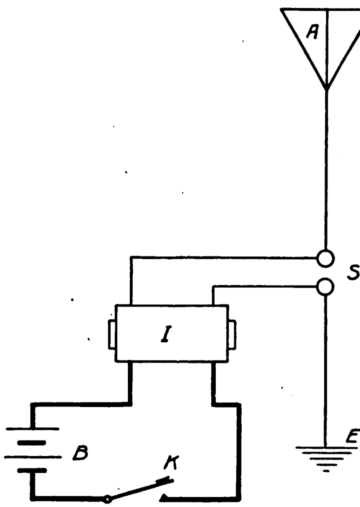


Fig. 128. Elementary Transmitter

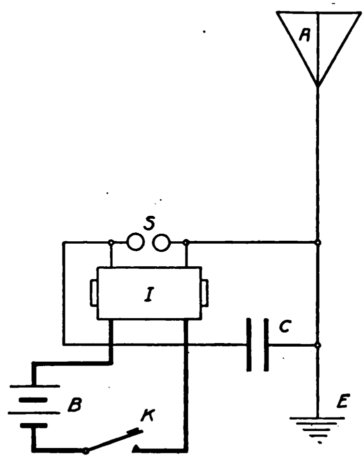


Fig. 129. Elementary Transmitting Circuit with Condenser

battery, an induction coil to produce the high-tension alternating current, and a spark gap, the last-named being inserted directly in the aerial circuit itself, Fig. 128. *A* is the aerial, *S* the spark gap, *E* the ground connection, *I* the induction coil, *K* the key, and *B* the battery. A key inserted in the battery circuit serves to break up the current into the desired signals. This represents the original sending circuit as employed by Marconi. Such a transmitter, however, produces a highly damped wave of low power, is only effective over a short range, and is incapable of being tuned. Its range is increased by inserting a condenser of appropriate capacity in the circuit and shunting the spark gap across the secondary of the induction coil instead of placing it directly in the aerial itself. This arrangement is shown in Fig. 129 and represents the first step in advance over Fig. 128. The

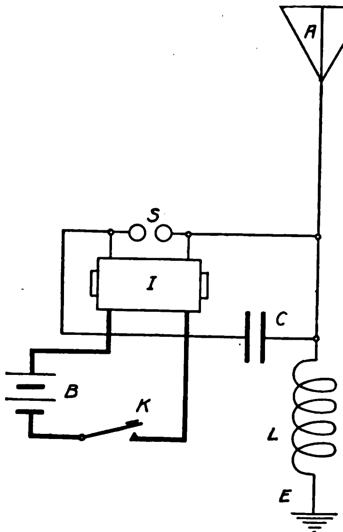


Fig. 130. Elementary Transmitter with Capacity and Inductance

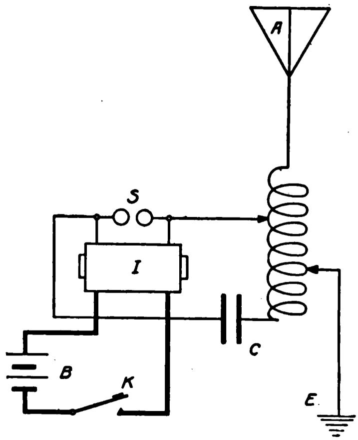


Fig. 131. Simple Direct-Coupled Type of Tunable Transmitter

capacity of this closed circuit, however, is greatly in excess of the value of its inductance, so that it is not an efficient oscillator nor is it any more capable of being tuned than the first type. Its sending range is greatly increased by inserting an inductance at the foot of the aerial, Fig. 130, and it is rendered capable of tuning by making this inductance variable, as illustrated by Fig. 131. This then represents a directly coupled transmitter and the inductance is known as a helix, which is described and illustrated under "Oscillation Transformer", page 148. Up to about 1912, this type of transmitter was in general use in the United wireless stations, the current supply being from a motor-generator. But as the closed and open oscillatory circuits are directly coupled in this type, the aerial is prevented from radiating freely at its own period while the high value of mutual induction produces a broad and highly damped wave, so that it is not capable of sharp tuning. This is explained in detail in a subsequent section, "Tuning the Transmitter," page 229.

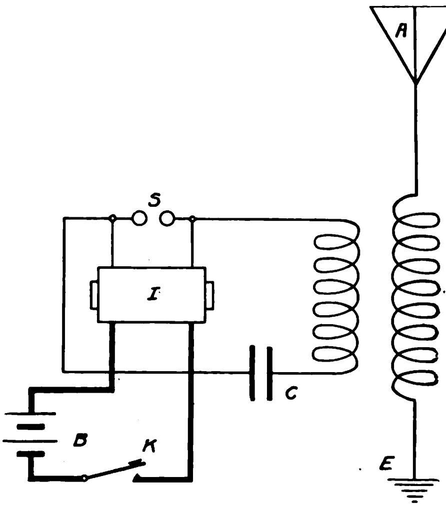


Fig. 132. Inductively Coupled Transmitter

Modern Transmitter. By separating the closed and open oscillation circuits through the medium of an oscillation transformer, the circuit becomes like the one shown in Fig. 132. The aerial circuit is now free to radiate at its own period, while the closed circuit is devoted solely to the generation of the high-frequency oscillations and does not play any part in the radiation of these oscillations except to the secondary of the oscillation transformer. By altering the value of the inductance in the primary and secondary of the oscillation transformer, the two circuits may be placed in resonance with each other, while by varying the coupling of the transformer, the decrement of the damping of the radiated waves may be decreased. It will be apparent that this circuit only requires the insertion of means of tuning to make it capable of

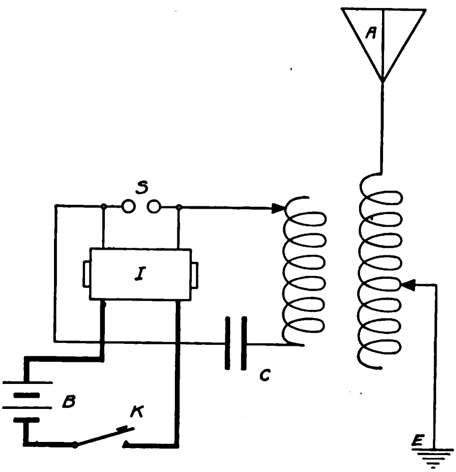


Fig. 133. Tunable Inductively Coupled Transmitter

radiating a sharply tuned wave, making the complete transmitter as shown in Fig. 133.

Substituting a motor-generator as the source of current for the induction coil and a synchronous rotary spark gap for the simple open type shown in previous illustrations, there results a modern

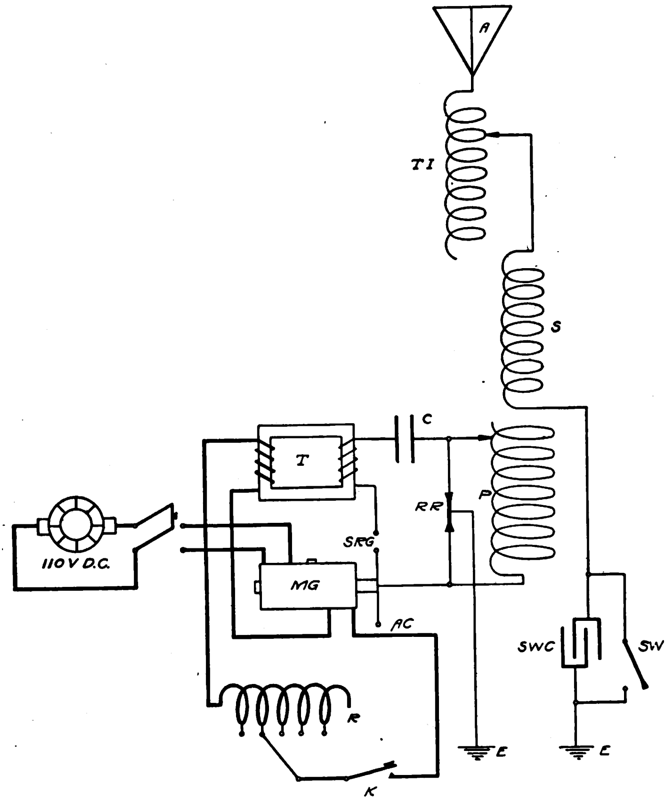


Fig. 134. Marconi Type of Transmitter—*A*, Aerial; *TI*, Tuning Inductance; *S*, Secondary of Oscillation Transformer; *SWC*, Short-Wave Condenser; *SW*, Switch for Cutting Short-Wave Condenser in or out of Aerial Circuit; *P*, Primary of Oscillation Transformer; *C*, Condenser; *T*, Transformer; *SRG*, Synchronous Rotary Gap; *MG*, Motor-Generator; *R*, Variable Reactance; *K*, Key; *RR*, Resistance Rod (Kick-Back Preventer) Grounded

type of transmitter, Fig. 134. This is the transmitting circuit of a standard Marconi set.

Relation of Wave Length to Frequency. Frequency is defined as the number of electrical oscillations per second, while the *period,* which is the reciprocal of the frequency, is expressed in fractions of a second. The velocity, that is, the velocity of light and electricity—300,000,000 meters per second—is naturally a constant, consequently, one second after the electromagnetic wave has begun to radiate from the aerial it has traveled 300,000,000 meters. But during this period the magnetic and the static lines of force have exchanged direction as many times as there are oscillations in the aerial circuit. The greater the number of times per second the fields have been reversed, the shorter will be the distance between points where the fields are in the same direction, Fig. 135; on the other hand, the fewer the reversals the greater will be the distance between these points. The

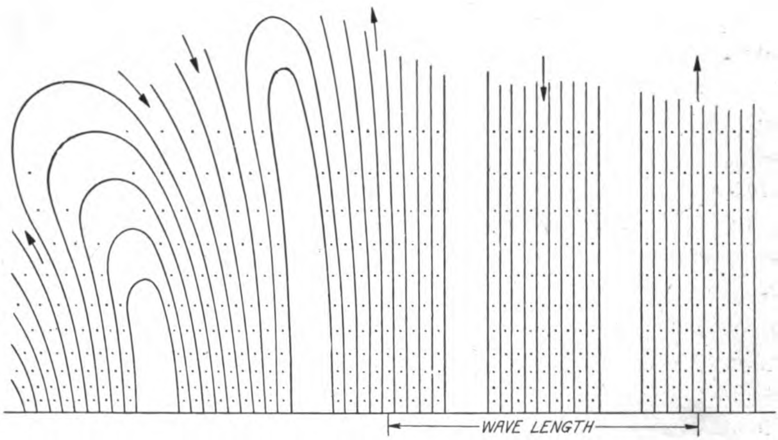


Fig. 135. Relation of Wave Length to Frequency—Dots Represent Electromagnetic Field; Lines Represent Electrostatic Field

relation between the frequency N and the velocity V is accordingly expressed in terms of the wave length λ as

$$N \times \lambda = V$$

this being one of the fundamental equations of wireless telegraphy. When the wave length is given, the frequency is accordingly determined, the relation between the two for the standard wave lengths being as given in Table VI.

Continuous-Wave Wireless Systems. All the apparatus thus far described as well as the circuits illustrated refer to what is known as the spark system of wireless telegraphy, that is, the one in which the high-frequency oscillations are generated by means of the discharge of a condenser and the electromagnetic waves thus produced are characterized by radiation in groups or trains of

TABLE VI

Wave Lengths and Corresponding Frequencies of Wireless Waves

Wave Length (meters)	Frequency (oscillations per sec.)	Wave Length (meters)	Frequency (oscillations per sec.)
100	3000000	2000	150000
200	1500000	3000	100000
300	1000000	4000	75000
400	750000	5000	60000
500	600000	6000	50000
600	500000	10000	30000
1000	300000		

waves which start at a maximum amplitude and are damped out by the increase of resistance at the spark gap. In a continuous-wave system, in which the waves are referred to as *undamped,* or *sustained,* the high-frequency oscillations are produced either by a high-power direct-current arc of the Poulsen or Duddel type, by the Pliotron system (vacuum oscillation waves) developed by the General Electric Company, or directly by a high-frequency alternator of the Goldschmidt or Alexanderson type. Marconi has also developed a method of producing continuous waves by means of a series of rotary gaps, or disc dischargers, and condensers, the charging current for which is generated by two 5000-volt generators in series, thus producing current at a potential of 10,000 volts without the aid of a transformer.

Up to the present, continuous-wave systems have been employed only for high-power long-distance transmission for which the undamped oscillations are very efficient. Even a brief description of these various systems and their method of working is beyond the scope of the present work, particularly as they have no bearing on the preliminary education in the subject required of the student to fit him as an operator.

STORAGE BATTERY

Storage Battery for Emergencies. All wireless stations on shipboard are supplied with current from the ship's dynamo located in the engine room. The supply is direct current and, for ordinary use, is transformed to alternating current by means of a motor-generator. The wireless operator's cabin is located on the superstructure so that it is as high above the water level as the navigating bridge and sometimes higher. But as any accident to the hull which puts the boilers out of commission cuts off the current supply, an emergency supply is carried in the form of a storage battery capable, when fully charged, of operating the set for several hours. It is accordingly necessary for the operator to be familiar with the storage battery and its care. In the earlier forms of equipment an independent emergency set was carried, consisting of a low-voltage storage battery and induction coil, the remainder of the transmitting apparatus being common to the regular and the emergency sets. The later Marconi sets, however, are provided with a storage battery capable of operating the motor-generator at its normal voltage.

THEORY OF STORAGE BATTERY

Principles of Action. The storage battery, also commonly known as an accumulator, differs from a primary cell in that chemical reaction is utilized to reproduce a current that has previously been sent through the battery, which accounts for the use of the term *storage* in this connection. For all practical purposes, the cell actually stores up current to be used when needed, though the process by which it absorbs and redelivers electricity is one of chemical conversion and reconversion upon a reversal of the conditions.

There are many makes of storage batteries but only two distinct types, the so-called lead-plate cell and the Edison cell, the former being in more general use. The original Planté storage cell consisted of two lead plates in a dilute solution of sulphuric acid and water. On passing a direct current through such a cell, the acid attacks the lead, converting the surface of the positive plate to peroxide of lead and that of the negative plate to pure lead in a spongy form. Alternating current naturally cannot be employed, as with its constant reversals of polarity no effect would be produced on the plates. After a cell has been charged, that is, after a direct current has been passed through it, for a length of time proportioned to the size of the plates, a certain percentage of the current thus absorbed may be drawn from the cell, which is then said to be *discharging*. If the cell is charged and discharged a number of times, the film of peroxide of lead on the positive plate and that of spongy lead on the negative become considerably thicker. This is known as forming the plates, and storage batteries were originally manufactured in this manner but the process is lengthy and produces cells in which what is known as the active matter is only loosely attached to the plates.

Elements of Cell. While the terms battery and cell are commonly used to mean the same thing, for the sake of clearness, it should be understood that a *cell* is but one of the units of which a battery is composed, a *battery* consisting of a number of cells proportioned to the voltage at which it is desired to use the current produced. All cells in a battery are alike, since, if some differed in capacity or characteristics from the remainder, the battery could not be charged or discharged uniformly, which is indispensable to its proper maintenance.

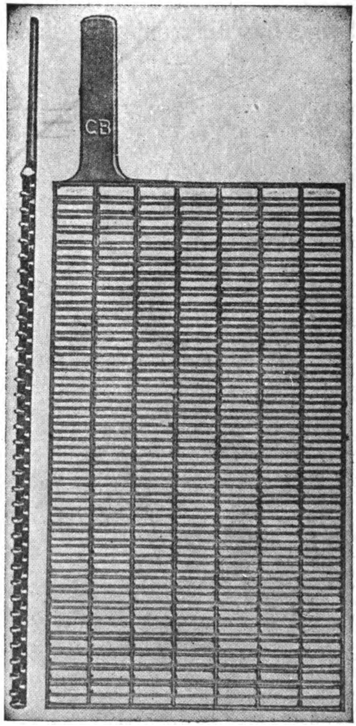


Fig. 136. Empty Battery Grid

The elements of the cell are the positive and negative plates and correspond to the positive and negative electrodes of a primary battery. Instead of being solid plates of lead, however, they consist of a casting of metallic lead in the form of a grid, the outer edges and the connecting lug of which are of solid lead while the remainder is in the form of lattice work made in two sections so that the openings do not correspond. There are as many patterns of these grids as there are makers of batteries, the one illustrated in Fig. 136 being typical. This shows the grid ready for the active material, and the object of making it in this form is to insure the retention of the active material between the bars of the grid and at the same time to make it as accessible as possible to the electrolyte, or solution of the cell.

This active material consists of peroxide of lead, or red lead, on the positive plate and litharge, or spongy metallic lead, on the negative plate. The plates are said to be *pasted* to distinguish them from the old-style plates which were formed by a number of charges and discharges. The active material is forced into the openings of the grid under very heavy pressure, so that when completed the plate is as hard and smooth as a piece of planed oak plank. In Fig. 137 is shown a completed plate, which, however, is a different type of grid than that shown in Fig. 136. The positive plate may be distinguished by its reddish color, while the negative plate is a dark gray.

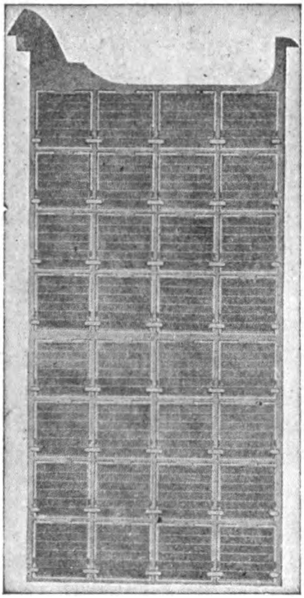


Fig. 137. Complete Battery Plate

Assembly of Cell. Each positive plate faces a negative plate in the cell, and as the capacity of a cell is determined by the active area of the positive plates, the number of plates in a cell is always odd, with the negative plates one in excess. The lead connector of each plate is burned to its neighbor of the same kind, thus forming the positive and negative groups which constitute the elements of the cell. As these elements must not be allowed to come in contact with one another, the plates are placed very close together with wood and perforated hard-rubber separators between them. Storage batteries for marine use are made in practically the same manner as those designed for electric vehicle use, as both types must be guarded against the effects of rough usage in service. Should the elements come in contact with one another, an internal short-circuit would result, ruining the cell. Reference to this is made under the head "Internal Damage," page 187. The reason for placing the plates so close together is to obtain the maximum capacity in the minimum space and to form a compact unit which cannot readily become loosened by shaking. The wood and rubber separators are illustrated in Fig. 138, while the complete group of elements with separators is illustrated in Fig. 139; the figure also shows what a snug fit the complete unit is in the hard-rubber container.

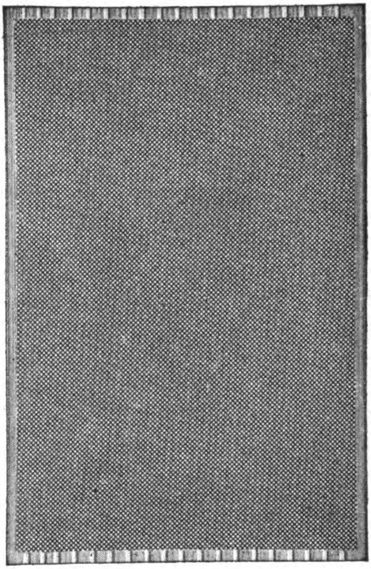


Fig. 138. Wood and Rubber Separator

Electrolyte. To complete the cell, the grouped elements with their separators are immersed in a hard-rubber jar holding the electrolyte. This is a dilute solution of water and sulphuric acid, both the water and acid being chemically pure to a certain standard. The water should be either distilled water, cleanly caught rain water or melted artificial ice, while the sulphuric acid should be of the grade usually sold by manufacturers as battery acid or in drug stores as C.P. (chemically pure). Commercial sulphuric acid or water suspected of containing impurities, especially iron, should never be used in storage batteries as either will impair their efficiency. As it is rarely necessary to add anything to a storage cell but distilled water, an operator seldom has occasion to handle acid, but in mixing electrolyte, a glass, porcelain, or earthenware vessel must be used and *the acid must always be poured into the water.* Never attempt to pour the water into the acid, but always add the acid, a little at a time, to the water. The addition of the acid to the water is not merely a mechanical mixture of the two but is a solution in the formation of which a considerable amount of heat is

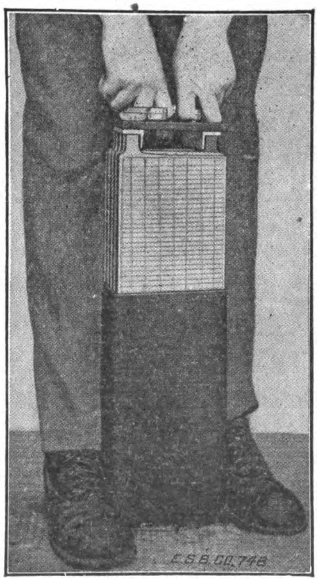


Fig. 139. Plate Assembly Ready for Hard-Rubber Jar

liberated. Consequently, if the acid be poured into the water too quickly, the containing vessel may be broken by the heat. For the same reason, if the water be poured into the acid, the chemical reaction will be very violent and the acid itself will be spattered about. Sulphuric acid is highly corrosive, will cause painful and dangerous burns, and will attack and destroy any fabric, metal, or wood, so that only glass, porcelain, hard rubber, or earthenware vessels should be used as containers.

Specific Gravity. The weight of a liquid as compared with distilled water is known as its specific gravity. Distilled water at 60° F. is 1, or unity. Concentrated sulphuric acid (battery acid as supplied by the manufacturer) is a heavy oily liquid having a specific gravity of about 1.835. A battery will not operate on full strength acid so that it is diluted to reduce its specific gravity to 1.275. This, however, is the specific gravity of the electrolyte only when the battery is fully charged. The specific gravity of the electrolyte affords the most certain indication of the condition of the battery at any time, and its importance in this connection is outlined at greater length under the head "Specific Gravity Tests," page 179.

Action of Cell on Charge. When the elements described are immersed in a jar of electrolyte of the proper specific gravity and terminals are provided for connection to the outside circuit, the cell is complete. However, as the lead-plate cell produces current at a potential of but 2 volts per cell, a battery is composed of a number of cells. The normal voltage of a fully charged lead-plate cell on open circuit, that is with no load connected, is 2.1 volts; when discharged it is 1.8. It should never be allowed to drop below 1.7 or the cell will become badly sulphated, as explained later. New cells may reach 2.5 volts or slightly over if tested on open circuit immediately after fully charging. In the latest type of Marconi ship sets a lead-plate battery of 60 cells is employed, and the potential is sufficient to run the motor-generator direct from the battery when the current from the dynamo in the engine room fails.

The different cells of the battery are permanently connected together by means of heavy lead straps, while detachable terminals are provided for connecting the battery to the charging circuit. These terminals are plainly marked + and − to indicate the polarity of the battery and the positive terminal is sometimes further distinguished by being painted red. This is to insure the replacement of the connections in the proper manner in case there is any necessity of removing them, as the battery must always be charged in the same direction. When the charging current is sent through a cell, the action is as follows: The acid which has combined with the active material is forced out of the plates into the electrolyte, thus raising the specific gravity of the latter and affording a direct indication of the state of charge. When practically all this acid has been transferred from the active material to the electrolyte, the cell is said to be fully charged and should then show a specific gravity reading of 1.275 to 1.300. The foregoing refers, of course, to the initial charge. After the cell has once been discharged, the active material of both groups of plates has been converted into lead sulphate. The action on charge, then, consists of driving the acid out of the plates and at the same time reconverting the lead sulphate into peroxide of lead on the positive plates and spongy metallic lead on the negative plates.

Action of Cell on Discharge. The action of a cell on discharge consists of a reversal of the process just described. The acid which has been forced out of the plates into the electrolyte by the charging current again combines with the active material of the plates when the cell is connected on discharge to produce a current. When the sulphuric acid in the electrolyte combines with the lead of the active material, a new compound, lead sulphate, is formed at both plates. This lead sulphate is formed in the same way that copper sulphate and iron sulphate are formed when sulphuric acid is dropped on copper terminals and on iron parts, respectively. In cases of this kind it will be noted that the amount of sulphate is always all out of proportion to the amount of metal eaten away. In the same manner, when the sulphuric acid of the electrolyte combines with the lead in the plates to form lead sulphate, the volume is such as to fill the pores of the active material completely when the cell is completely discharged. This makes it difficult for the charging current to reach all parts of the active material and accounts for the manufacturer's instructions never to discharge the battery below a certain point and likewise for the rule not to allow the battery to stand without charging for more than a certain period, usually two weeks at the most.

As the discharge progresses, the electrolyte becomes weaker by the amount of acid that is absorbed by the active material of the plates in the formation of lead sulphate, which is a compound of acid and lead. This lead sulphate continues to increase in bulk, filling the pores of the plates, and as these pores are stopped up by the sulphate, the free circulation of the acid is retarded. Since the acid cannot reach the active material of the plates fast enough to maintain the normal action, the battery becomes less active, which is indicated by a rapid falling off in the voltage. Starting at slightly over 2 volts when fully charged, this voltage is maintained at normal discharge rates with but a slight drop until the lead sulphate begins to fill the plates. As this occurs, the voltage gradually drops to 1.8 volts per cell and from that point on will drop very rapidly. A voltage of 1.7 volts per cell indicates practically complete discharge or that the plates are so filled with lead sulphate that the battery should be placed on charge immediately.

During the normal discharge, the amount of acid used from the electrolyte will cause the specific gravity of the solution to drop 100 to 150 points, so that, if the hydrometer showed a reading of 1.280 when fully charged, it will indicate but 1.130 to 1.180 when fully discharged. The electrolyte is then very weak, in fact, it is little more than pure water. Practically all the available acid has been combined with the active material of the plates. While the acid and the lead combine with each other in definite proportions in producing the current on discharge, it is naturally not possible to provide them in such quantities that both are wholly exhausted when the cell is completely discharged. Toward the end of the discharge the electrolyte becomes so weak that it is no longer capable of producing current at a rate sufficient for any practical purpose. For this reason, an amount of acid in excess of that actually used in the plates during discharge is provided. This is likewise true of the active material.

Capacity of Battery. The amount of current that a cell produces on discharge is known as its capacity and is measured in ampere-hours. It is impossible to discharge from the cell as much current as is required to charge it, the efficiency of the average cell of modern type when in good condition being 80 to 85 per cent or possibly a little better when in perfect condition, that is, after the first five or six discharges; in other words, if 100 ampere-hours are required to charge a battery, only 80 to 85 ampere-hours can be discharged from it. This ampere-hour capacity of the cell depends upon the type of plate used, the area of the plate, and the number of plates in each cell, the last two factors giving the total positive-plate area opposed to the total negative-plate area. To make this area a maximum, both outside plates in a cell must be negatives. In the case of a battery in which all the cells are connected up as a single series, which is the usual practice, the ampere-hour capacity is the same as that of any single cell in the series, the voltage increasing 2 volts per cell.

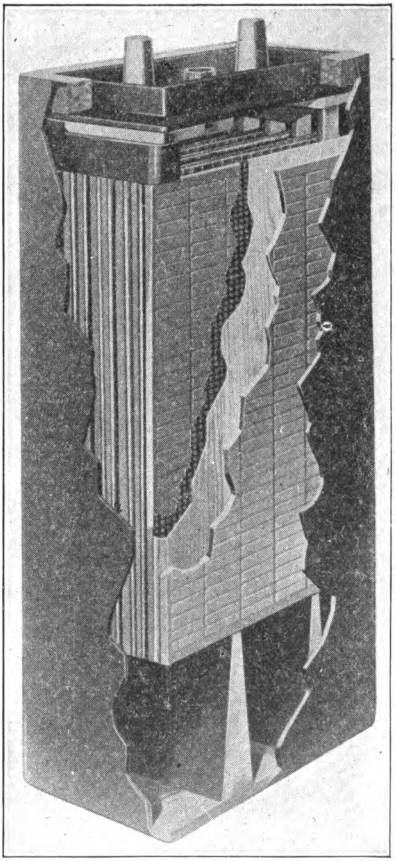


Fig. 140. Storage Cell Showing Mud Space

Normal Discharge Rate. The capacity of the cell as thus expressed in ampere-hours is based on its normal discharge rate or a lower rate. For example, take a 100-ampere hour battery. Such a battery will produce current at the rate of 1 ampere for practically 100 hours, 2 amperes for 50 hours, or 5 amperes for 20 hours, but as the discharge rate is increased beyond a certain point, the capacity of the battery falls off. The battery in question would not produce 50 amperes for 2 hours. This is because of the fact that the heavy discharge produces lead sulphate so rapidly and in such large quantities that it quickly fills the pores of the active material and prevents further access of the acid to it. Thus, while it will not produce 50 amperes for 2 hours on continuous discharge, it will be capable of a discharge even greater than this for short periods if allowed to rest between demands for current. When on open circuit, the storage cell recuperates very quickly.

Battery Construction Details. The elements of the cells are placed on insulating supports in the bottom of the hard-rubber

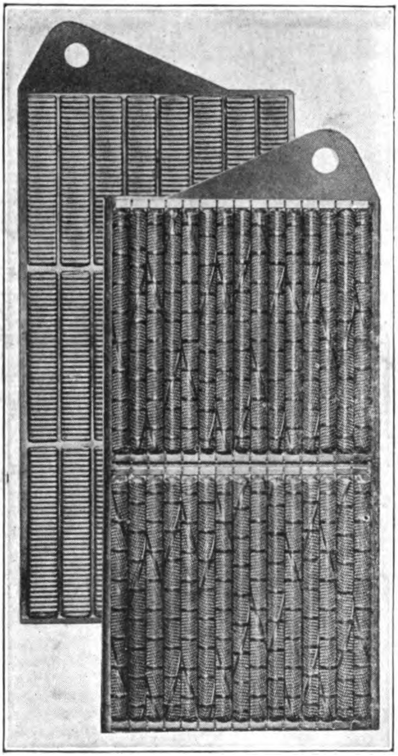


Fig. 141. Assembled Positive and Negative Edison Plates

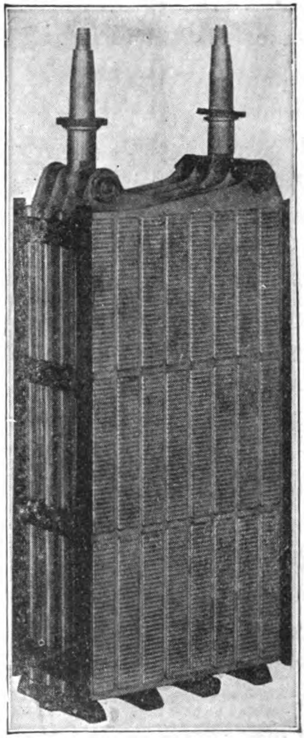


Fig. 142. Completely Assembled Edison Cell

jars. These supports are molded of hard rubber as an integral part of the jar itself and serve to hold the elements several inches from the bottom in the latest types of cells, as will be noted in Fig. 140. The space thus provided is known as the mud space and is designed to receive the accumulation of sediment composed of the active material shaken off the plates in service. This active material is naturally a good electrical conductor, and if it were allowed to come into contact with the bottoms of the groups of plates, it would short-circuit the cell and ruin it. It is now considered good practice to allow sufficient space under the plates to accommodate practically all the active material that can be shed by the plates during the active life of the battery.

In sealing the elements into the hard-rubber jar, a small opening is left through which to add distilled water and also to permit the hydrogen gas developed by the battery when on charge to escape. Except when being used for refilling the jars, this opening is closed by a soft-rubber stopper which has a small hole through which the hydrogen passes out of the cell when the latter is gassing, as explained under "Gassing," page 185.

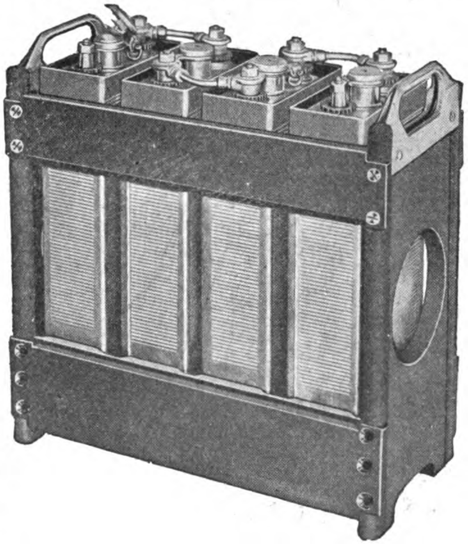


Fig. 143. Tray of Four Edison Cells

Edison Cell. The elements of the Edison cell consist of nickel and iron in an alkaline solution of caustic potash and distilled water. The positive plate is formed of vertical rows of thin perforated steel tubes filled with nickel hydrate, these tubes being supported in a frame somewhat similar in appearance to a pencil-form lead grid, as will be noted in Fig. 141, which shows a positive and a negative plate complete. Rows of flat perforated steel jackets filled with iron oxide, likewise held in a thin steel frame, compose the negative plate. The elements are, accordingly, nickel, iron, and steel in a 21 per cent solution of potash in distilled water, and these elements constitute a storage cell which differs radically in every respect from the lead-plate type. The elements are not attacked by the electrolyte when left standing in a partly or even a wholly discharged condition.

Iron oxide will be recognized as one of man's most persistent and ubiquitous enemies, rust. Nickel hydrate is the product of a special electrolytic process originated by Mr. Edison. When on charge, the iron oxide of the negative plate is converted into metallic iron, while the oxygen generated passes over to the positive plate and converts its nickel-hydrate content into a new form of nickel oxide previously unknown to science. The oxidizing of the nickel hydrate causes it to expand just as the peroxide of lead of the positive plate of a lead cell expands, but there is no danger of it escaping as it is held in a rigid steel tube. The latter has numerous fine perforations to permit the access of the electrolyte but these are so small and numerous that the steel tube approximates wire netting or gauze. The complete assembly of the elements ready for insertion into the light steel container is shown in Fig. 142, while a group of four cells is illustrated in Fig. 143. The voltage of the Edison type, however, is but 1.25 volts per cell, as compared with 2 volts per cell for the lead-plate type, so that a greater number of cells of the former must be provided to produce current at the same voltage. The Edison cell needs no other attention than periodical refilling with distilled water.

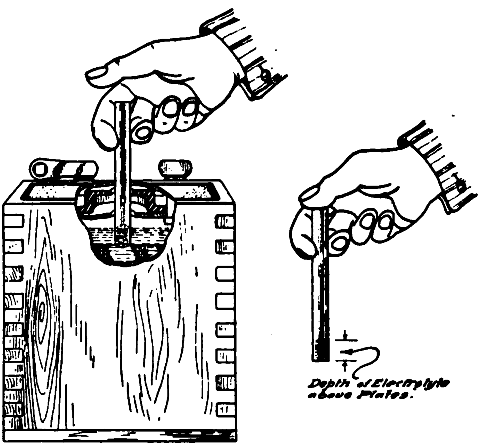


Fig. 144. Diagram Showing Method of Measuring Height of Electrolyte over Plates
Courtesy of United States Light and Heat Corporation, Niagara Falls, New York

Care of Lead-Plate Battery

Height of Electrolyte in Cell. In order to function properly, the plates in lead-plate cells must be covered by the electrolyte at least ½ inch at all times. In Fig. 144 is shown a handy and convenient method of determining definitely the depth of the electrolyte. A small piece of glass tube, open at both ends, is inserted in the vent hole of the cell until it rests on the tops of the plates. A finger is then pressed tightly on top of the tube and the tube itself is withdrawn from the cell. It will bring with it at its lower end an amount of acid indicating the depth of the electrolyte over the plates. This should always be returned to the same cell from which it was taken. The electrolyte consists of sulphuric acid and water; the acid does not evaporate but the water does and the rapidity with which this takes place will depend on the conditions of charging. If kept on charge too long or at too high a rate (the proper rate is usually stamped on the cell itself) the electrolyte will become very warm and considerable water will be evaporated. Even though not used, the battery should not be allowed to stand more than two weeks without testing the height of the electrolyte over the plates. While it is necessary to maintain the electrolyte ½ inch over the tops of the plates, care must be taken not to exceed this, for if filled above this level the cells will flood when charged owing to the expansion of the solution with the increasing temperature.

No Addition of Acid. When the level of the electrolyte in a cell becomes low, the cause is, under normal conditions, the evaporation of the water and this loss should be replaced with water only. *There being no loss of acid, it should never be necessary to add acid to the electrolyte during the entire life of the battery.* When some of the electrolyte has accidentally been lost from the jar of the cell, the loss should be replaced with electrolyte of the same specific gravity as that remaining in the cell and not with full strength acid nor with water alone. The former would make the solution too heavy while the latter would make it too weak. Consequently, unless acid is actually known to have escaped from the cell, none should ever be added to it. In the following section further reasons are given why no acid or electrolyte should be added to the cell under normal conditions and the conditions which would seem to make the addition of acid necessary are explained.

Specific Gravity Tests. *Hydrometer.* One of the most important tests in connection with the care of the storage battery is taking the specific gravity, which is done with the aid of an instrument termed a hydrometer. It consists of a small bulb weighted with fine shot and having an extension on which is engraved a calibrated scale. In distilled water at 60° F. the instrument sinks until the scale comes to rest at the surface of the liquid at the division 1.000. The lighter the liquid, the further the hydrometer will sink into it; the heavier the liquid, the higher it will float. For constant use in the care of a storage battery, the hydrometer shown in Fig. 145 is the most convenient. This is a hydrometer inclosed in a syringe. The rubber tube is inserted through the vent hole of a cell with the rubber bulb squeezed flat; upon releasing the bulb, enough of the electrolyte is drawn into the syringe to float the hydrometer. Care must be taken to hold the syringe vertically so that the hydrometer does not stick to its side. Whenever possible the reading should be made without withdrawing the syringe from the cell in order that the electrolyte taken into the syringe may always be *returned to the same cell.* When the battery is located in a position difficult of access, as under a table, the syringe may be drawn full of electrolyte and then lifted out, since the soft-rubber plug in the bottom of the glass barrel is made in the form of a trap so that when the instrument is held vertically the solution will not run out.

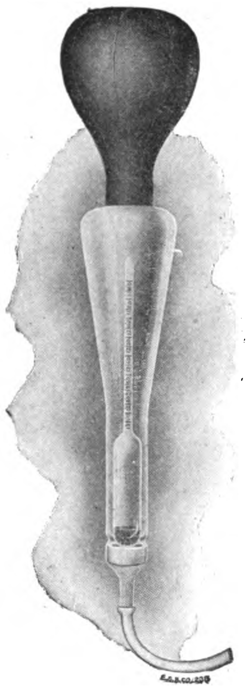


Fig. 145. Syringe Hydrometer Set

Failure to replace the electrolyte in the same cell from which it was drawn will result in destroying the uniformity of the cells. For example, if electrolyte has been drawn from cell *1* and, after taking the reading, is replaced in cell *2*, the amount taken from *1* must later be made up by adding water and the solution will be that much weaker, while that of *2* will be correspondingly stronger.

In taking a hydrometer reading first see that the instrument is not held by the sides of the glass syringe barrel; then note the level of the instrument by looking at it from below; that is, holding it up above the level of the eye. Reading the hydrometer in this way is found to give more accurate results than looking down on it.

Value of Hydrometer Tests. While the hydrometer affords the best single indication of the condition of the battery—the cells should test 1.275 to 1.300 when fully charged and 1.150 when fully discharged, below which point they should never be allowed to go—there are conditions under which the instrument may be misleading. For example, when fresh distilled water is added to a cell to bring up the level of the electrolyte, the additional water does not actually combine with the electrolyte until the cell has been on charge for some time. Consequently, if a hydrometer reading were taken of that particular cell just after the water had been added, the test, owing to the low specific gravity reading obtained, would show the cell to be nearer the fully discharged state than it actually was. If, on the other hand, fresh electrolyte or pure acid had been added to the cell just prior to taking readings, the reading would show the cell to be fully charged, whereas the reverse might actually be the case. In this instance the specific gravity would be much higher than it should be. To determine accurately the condition of the cells under such circumstances, the hydrometer readings would have to be checked by making tests with the voltmeter, as described later. Under average conditions, however, the hydrometer alone will closely indicate the state of charge and its use should always be resorted to whenever there is any question as to the condition of a battery.

Variations in Hydrometer Readings. Specific gravity readings between 1.275 and 1.300 indicate that the battery is fully charged; between 1.200 and 1.225, that the battery is more than half discharged; between 1.150 and 1.200, that the battery is quickly nearing a fully discharged condition and must be recharged very soon or injury will result. Below 1.150 the battery is entirely exhausted and must be recharged immediately to prevent the plates from becoming sulphated, as explained under the head "Sulphating," page 187. As is made clear in the sections "Action of Cell on Charge," page 172, and "Action of Cell on Discharge," page 173, the acid of the electrolyte combines with the active material of the plates to produce the current on discharge. The further the cell is discharged, the more acid there will be in the plates and the less in the solution. Consequently, low gravity readings practically always mean a lack of acid in the solution and that implies a lack of charge. Unless there is something wrong with the cell, charging will restore the acid to the electrolyte and bring the specific gravity readings up to normal. In case a jar is leaking or has been overturned and lost some of its electrolyte, no amount of charging will bring its specific gravity up to the proper point.

The gravity readings of the cells vary somewhat in summer and winter and they also decrease with the age of the plates, but the battery will continue to give good service as long as its specific gravity rises to between 1.275 and 1.300 when fully charged. A rise in specific gravity above 1.300 is an indication that excess acid has been added to the electrolyte and this must be corrected by drawing off some of the electrolyte with the syringe and replacing it with distilled water. A gradually decreasing specific gravity in all the cells is an indication that sediment is accumulating in the bottom of the jars and that the battery, if of the older type with low mud space, requires washing; if of the later type with high mud space, that its elements require renewal. Before coming to this conclusion make certain that the low reading is not due to insufficient charging.

If the specific gravity in any cell tests more than 25 points lower than the average of the other cells in the battery, it is usually an indication that this cell is out of order and it should be placed on charge separately. (Dependence should not be placed on a single reading, however, where there is any question regarding the specific gravity, but several readings should be taken and averaged.) If the rheostat on the switchboard does not permit charging the cell separately, an emergency resistance may be made of 16- or 32-c.p. carbon-filament lamps, using one of the latter or two of the former size lamps for each ampere of current required. The lamps are connected in multiple and the group then connected in series with the battery. After the low cell has been on charge for one or two hours, note, by taking a hydrometer reading, whether its specific gravity is rising. If, after several hours of charging, its specific gravity has not risen to that of the other cells, it is an indication that there is something wrong with the cell. Variations in cell readings may be caused by internal short-circuits in the cell, by putting too much water in the cell and causing a loss of electrolyte through flooding or overflowing on charge, or by loss of electrolyte through a cracked or otherwise leaky jar. Internal short-circuits may result from a broken separator or from an accumulation of sediment in the mud space of the jars reaching the bottoms of the plates.

Quite a substantial percentage of all the troubles experienced with the battery is caused by permitting the electrolyte to fall too low in the jars. The effect of this is to weaken the battery, causing it to discharge more readily and frequently resulting in harmful sulphating of the plates and injury to the separators. When such an injury occurs, it permits the plates to come into contact with one another and an internal short-circuit results. The importance of always maintaining the level of the solution ½ inch above the plates by the periodical addition of distilled water will be apparent from this. One of the most frequent causes of low electrolyte in a single cell of the battery is a cracked or leaky jar. If a particular cell requires more frequent addition of water than the others to maintain the proper height of the electrolyte, it is an indication that it is leaking. Where all the cells of the battery require the addition of water at unusually short intervals, it is an indication that the battery is being overcharged. Unless a leaky jar is replaced immediately, the cell itself will be ruined and it may cause serious damage to the rest of the battery. Apart from accidental injury the only cause for a leaky jar is freezing. The presence of a frozen cell in the battery shows that it has been allowed to stand in an undercharged condition in cold weather, as a fully charged cell will not freeze, except at an unusually low temperature.

Adjusting Specific Gravity. Where the hydrometer shows a low reading for all the cells, no attempt should ever be made to raise the specific gravity of the electrolyte by adding acid until the battery has been subjected to a long slow charge. The maximum specific gravity of the electrolyte is reached when all the acid combined in the active material of the plates has been driven out by the charging current. Adding acid will increase the specific gravity but will not increase the condition of charge; it will simply give a false indication of a charged condition. For instance if the electrolyte of a cell tested 1.225 and, without giving it a long charge, acid were added to bring the specific gravity up to 1.275 and it then rose to 1.325 when put on charge, it would show that 50 points of acid had remained combined in the plates when the low readings were taken.

The necessity for adjusting the specific gravity of the electrolyte in a cell can only be determined by first bringing it to its true maximum. To do this it should be given a prolonged charge at a low rate and kept on charge continuously until tests show that the specific gravity of the electrolyte has ceased to rise. Should the cell begin to gas violently, while tests show that the specific gravity is still rising, the charging current should be reduced to stop the gassing or, if necessary, stopped altogether for a short time and then renewed.

If, after this prolonged charge, tne specific gravity is still low but not more than 25 points below normal, some of the solution may be drawn off with the syringe and replaced with small quantities of 1.300 electrolyte, which should be added very gradually to prevent bringing about an excess. Should the specific gravity be too high at the end of the charge, draw off some of the electrolyte and replace it with distilled water to the usual level of ½ inch over the plates.

Conditioning Charge. A charge such as has just been described is termed a conditioning charge also an equalizing charge and is usually carried out once a month. With the ampere-hour meter now mounted on the panel board of the latest type Marconi sets it may be done very conveniently. An ampere-hour meter is an instrument that gives a direct reading of the state of charge of the battery. For example, with a 60 ampere-hour battery, the reading of the instrument will show 60 ampere-hours when the battery is fully charged, the hand moving backward as current is drawn from the battery until the zero point is reached. Upon charging the cells, the movement of the pointer is reversed while its action is compensated so that, when it again reads 60 ampere-hours, 70 or more have actually been sent through the cells to allow for losses, as the efficiency of the battery is between 80 and 90 per cent.

The batteries supplied for emergency purposes range from 60 to 224 ampere-hours capacity, the larger ones being employed where it is desired to light auxiliary lamps from them as well as to run the motor-generator. To give a battery of this capacity the usual monthly overcharge, the charging current is sent through it until the ampere-hour meter records the maximum charge and its pointer is then set back by hand 50 points and the charge continued until the maximum is again reached.

Temperature Corrections. All specific gravity readings are based upon a temperature of the electrolyte of 70 degrees and as the electrolyte expands with the heat and contracts with the cold, its specific gravity varies accordingly. These changes in temperature do not affect the total amount of acid present but do affect the strength of the electrolyte per unit volume. Therefore, the effect of temperature must be taken into consideration when making the tests. The temperature is that of the electrolyte itself and not that of the surrounding atmosphere, and as the plates and solution of a battery become warmer as the charge proceeds, their temperature may be very much higher than that of the surrounding air. Consequently, the only method of checking this factor accurately is to insert a battery thermometer in the vent hole of a cell.

The temperature correction is one point (0.001) for each three degrees above or below 70 degrees, positive for readings above and negative for readings below. Therefore, if the temperature of the battery itself was 100 degrees, due to the charging current, an allowance of +10 points would have to be made in the observed reading, so that 1.265 would actually mean 1.275 for this difference in temperature. Hydrometer scales, with a temperature scale showing the corresponding correction necessary, simplify the task of correcting the readings, but to make these accurate a battery thermometer must be employed as the temperature of the electrolyte itself is the only factor to be considered. In actual service, reliance is usually placed chiefly on the reading of the ampere-hour meter to check the condition of charge. This, however, only indicates the charge and discharge of the battery as a whole. If the discharge were disproportionately rapid to the actual amount of current drawn from the battery, the cells would have to be tested individually with the hydrometer to ascertain the defective ones.

Gassing. When the current is sent through the cell on charge, it immediately attacks the lead sulphate, into which the active material of both the positive and negative plates has been converted during discharge, and begins to reconvert it into peroxide of lead at the positive plate and spongy metallic lead at the negative plate. As long as there is an ample supply of lead sulphate on which the charging current may act, as in a fully discharged battery, the entire amperage being sent through the battery is restricted to carrying on this process, in other words, the current will always do the easiest thing first—follow the path of least resistance. When the cell is in a discharged state, the easiest thing to do is to decompose the lead sulphate. As there is a comparatively large amount of this lead sulphate in a fully discharged battery, a correspondingly large amount of current can be used at the start. But as the amount of sulphate progressively decreases with the charge, a point is reached at which there is no longer sufficient sulphate remaining to utilize all the current.

The excess current will then begin to do the next easiest thing, which is to decompose the water of the electrolyte and liberate hydrogen gas. This gassing is not due to any defect of the battery, as is more or less commonly supposed, but is simply the result of charging at so high a rate that the battery cannot absorb the current. Another common error is thinking that one of the functions of the circuit-breaker, or automatic battery cut-out, is to prevent the battery being overcharged. Gassing is simply an indication that too much current is being sent into the battery, that is, the charging rate is too high. Every storage battery has a *starting rate* and a *finishing rate* and the current must be tapered from the former to the latter as the charge proceeds. This information is usually stamped on the battery or is given on the panel board or on the sheet of charging instructions. It is always safe to employ a charging rate that does not cause gassing.

Overheating. Another indication of charging at too high a rate is the temperature of the cells themselves. It is good practice never to allow this to exceed 100 degrees, and if it reaches 105 degrees, the charge should be stopped immediately and the battery given a chance to cool before resuming the charge. Nothing shortens the life of a battery so rapidly as allowing it to become overheated, as this tends to expand the active material and force it out of the grids. Where a battery thermometer is not employed to check the temperature of the cells during the charge, the necessity for refilling them with distilled water at unusually short intervals is a certain indication that the charging is done at too high a rate, causing rapid losses by evaporation.

Sulphating. At the end of a discharge, both plates are covered with lead sulphate. The conversion of the active material of the plates into lead sulphate which takes place during the discharge is the normal reaction and, as such, occasions no damage. But if the cells are allowed to stand for any length of time in a discharged condition, the sulphate not only continues to increase in bulk but becomes hard. It is also likely to turn white and, therefore, white spots found on the plates of a cell when it is dismantled are an indication that it has been neglected. When the plates are in this condition, they have lost their porosity to a certain extent and it is correspondingly more difficult for the charging current to penetrate the active material. When a battery has stood in a discharged condition for any length of time it becomes *sulphated.* The less current it has in it at the time and the longer it stands in this condition, the more likely it is to be seriously damaged. The only method of preventing sulphating is the monthly conditioning, or equalizing, charge already mentioned. Where sulphating has occurred, it may be remedied by long continued charging at a low rate, frequently extending over two or three days. With a badly sulphated battery the charge should be continued until there has been no rise in the specific gravity of the electrolyte for a period of twelve hours.

An individual cell may become sulphated by adding excess acid to the electrolyte (thus giving a false specific gravity reading showing that the cell is fully charged when, in fact, it is only partly charged); by an internal short-circuit; or by drying out caused by failure to maintain the electrolyte at the proper height or by a leaky jar.

Internal Damage. Internal damage is usually caused by an internal short-circuit due either to an accumulation of sediment reaching the plates or to the breaking of a separator, which may be caused by the active material being forced out of the grid, a process usually termed buckling. Overheating on charge or a dead short-circuit on discharge will bring about the latter. It is important to be able to determine whether or not the low efficiency of a certain cell is caused by internal trouble without having to dismantle the cell itself. For this purpose a good portable voltmeter is necessary.

Voltage Tests. *Precautions.* Under some conditions, the voltmeter will also indicate whether the battery is practically discharged or not, but, like the hydrometer, it should not be relied upon alone. To insure accuracy it must be used in conjunction with the hydrometer. Since a variation as low as 0.1 volt makes considerable difference in what the reading indicates regarding the condition of the battery, the necessity for making careful tests will be apparent. Care must also be taken to use the instrument as outlined on the sheet of instructions accompanying it. There are low and high reading scales put in circuit by using different binding posts. The total voltage of the number of cells to be tested must never exceed the reading of the particular scale being used at the time. For example, on the 3-volt scale but one cell should be tested, otherwise, the coil of the scale in question is liable to be burned out.

Where the voltage to be tested is very low, as in the case of a single cell, a very slight increase in the resistance will affect it considerably and destroy the accuracy of the reading. Clean contacts are accordingly very necessary in making such tests. A fine file should be used on the lead connector of the cell and the test points from the voltmeter should be sharp and bright. Even a thin film of dirt or a weak contact will increase the resistance to a point where the test is bound to be misleading. The positive terminal of the voltmeter must be brought into contact with the positive terminal of the cell. If the markings of the cell terminals are indistinct, contact may be made at random. In case the pointer butts up against the stop at the left, the connections are wrong and should be reversed; if the instrument shows a reading, they are correct. This test can be made with a voltmeter without any risk of short-circuiting the cell as the instrument is wound to a high resistance and will pass very little current. Connecting an ammeter across a cell, however, would put it on dead short-circuit and ruin the instrument as well as the cell itself.

How to Take Readings. It is one of the peculiarities of the storage cell that when on open circuit, that is, not doing any work, it will always show approximately 2 volts, regardless of whether it is almost fully charged or the reverse. Consequently, voltage readings taken when the battery is on open circuit, in other words, neither charging nor discharging, are valueless, except when a cell is out of order. Therefore, a load should be put on the battery before making these tests. This can be done by the use of a portable bank of lamps where it is not convenient to run the apparatus to which the battery is usually connected, for instance, the induction coil or the motor-generator.

With the load on, connect the voltmeter as already directed and test the individual cells. If the battery is in good condition, the voltage readings, after the load has been on for about ten minutes, will be but slightly lower than if the battery were on open circuit. The difference should amount to about 0.1 volt. Should one or more of the cells be completely discharged, the voltage of these cells will drop rapidly when the lamps are first switched on and, when a cell is out of order, will sometimes show a reverse reading. Where the battery is nearly discharged, after the load has been on for five minutes, the voltage of each cell will be considerably lower than if the battery were on open circuit.

Detection of Deranged Cells. To distinguish the difference between cells that are merely discharged and those that are out of order, put the battery on charge and then test again with the voltmeter. If the voltage of each cell does not rise to approximately 2 volts after the battery has been on charge for ten minutes or more, it is an indication of internal trouble which can be remedied only by dismantling the cell. When making voltage tests, it must be borne in mind that the voltage of a cold battery rises slightly above normal on charge and falls below normal on discharge. The reverse is true of a warm battery, that is, the voltage will be slightly less than normal on charge and higher than normal on discharge. For the purpose of simple tests for condition, voltage readings on discharge are preferable, as variations in readings on charge mean little except to a battery expert.

Joint Hydrometer and Voltmeter Tests. As already explained, neither the hydrometer nor the voltmeter reading alone can always be taken as conclusive evidence of the condition of the battery. There are conditions under which one must be supplemented by the other to obtain an accurate indication of the state of the battery. In making any of the joint tests described later, it is important to take into consideration the four following points:

(1) The effect of temperature on both voltage and hydrometer readings;

(2) The voltage readings should be taken only with the battery discharging, as voltage readings of an idle battery in good condition indicate nothing;

(3) That in making tests a load should never be employed that calls for an excessively high discharge rate, as the effect of such a discharge is to cause the voltage to drop rapidly; and

(4) That the voltage of the charging current will cause the voltage of a battery in good condition to rise to normal, or above, the moment it is placed on charge, so that readings taken under such circumstances are not a good indication of the condition of the battery.

In any battery which is in good condition, the voltage of each cell at a normally low discharge rate will remain between 2.1 and 1.9 volts per cell until it begins to approach the discharged condition. A voltage of less than 1.9 volts per cell indicates that the battery either is very nearly discharged or else is in a bad condition. The same state is also indicated when the voltage drops rapidly after the load has been on a few minutes.

The following joint hydrometer and voltage tests will be found to cover the majority of cases met with in actual practice.

(1) A voltage of 2 to 2.2 volts with a hydrometer reading of 1.275 to 1.300 indicates that the battery is fully charged and in good condition.

(2) A voltage reading of less than 1.9 volts per cell with a hydrometer reading of 1.200 or less indicates that the battery is almost completely discharged.

(3) A voltage reading of 1.9 volts or less per cell with a hydrometer reading of 1.220 or more indicates that excess acid has been added to the cell. A 2-volt battery lamp connected to the terminals of the cell will burn dimly although the hydrometer reading alone would appear to indicate the battery to be more than half charged.

(4) Regardless of voltage—high, low, or normal—a hydrometer reading over 1.300 indicates that an excessive amount of acid has been added to the electrolyte.

(5) Where a low-voltage reading is found, as mentioned in cases (2) and (3), to determine whether the battery is in bad condition or merely discharged, stop the discharge by switching off the load and put the battery on charge. Then note whether the voltage of each cell rises promptly to 2 volts or more. If not, the suspected cells are probably short-circuted or otherwise in bad condition.

EMERGENCY TRANSMITTING APPARATUS

U.S. Statutes Require Wireless. To comply with the so-called wireless law (U.S. Statutes, Act of August 13, 1912), all sea-going steamers carrying passengers and steamers carrying more than fifty persons, whether passengers or crew, must be equipped with wireless apparatus. War conditions have since made wireless almost universal on steamers from a sea-going tug

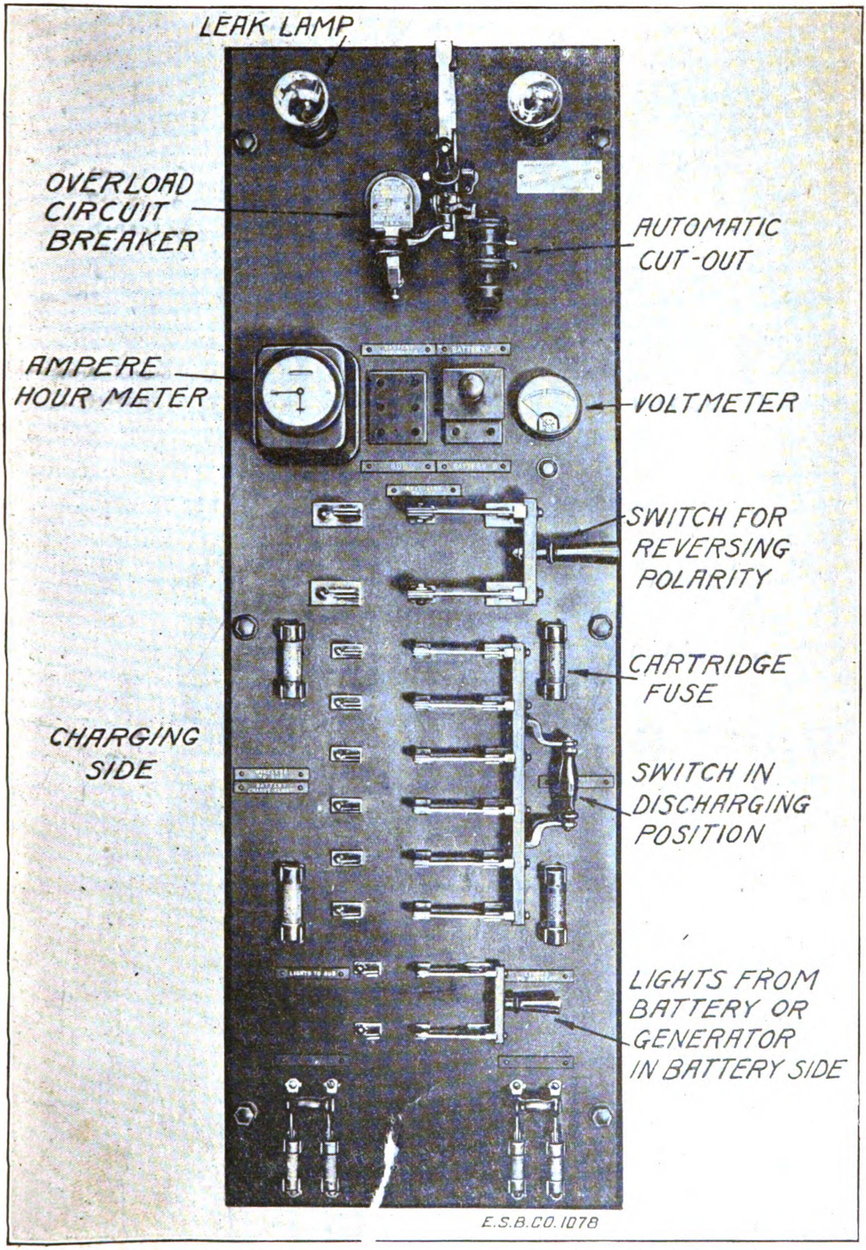


Fig. 146. Typical Marine Storage Battery Switchboard
Courtesy of Electric Storage Battery Company, Philadelphia, Pennsylvania

up, and even large sailing ships and oil barges have been so equipped. Further provisions of the statute require either that an auxiliary source of power, *independent of the ship's generator,* be provided to operate the regular transmitting apparatus or that a completely dependent emergency transmitting set be installed. In either case, the auxiliary source of power must be capable of operating the regular or the emergency set continuously for a period of four hours, while if an independent emergency set is provided, it must have a minimum daylight range of 100 miles.

Standard Battery Powers. To provide an auxiliary source of power which is not affected by the failure of the ship's dynamo to operate, a storage battery is supplied. The voltage and capacity of this battery depend upon the purpose for which it is designed—whether it is intended to operate the regular transmitter by running the motor-generator or simply to operate the emergency transmitter. In the former instance, it consists of 60 cells of 60 to 224 ampere-hours, while in the latter case there are only 12 cells. The great difference between the two battery capacities, in the first instance, is due to the fact that the battery is sometimes designed for operating the motor-generator alone and sometimes may also be utilized to light a number of emergency lamps in different parts of the ship. In such cases the battery is usually the property of the steamship company and is looked after by the engineer's department. The 12-cell battery of the emergency set is part of the wireless company's apparatus and must be taken care of by the operator. In any case the wireless operator must be familiar with the care of the battery; instructions on this point are given elsewhere in this text. A typical marine storage battery switchboard is shown in Fig. 146.

Types of Emergency Transmitters. *Plain Type.* Emergency transmitters are either of the plain aerial type, Fig. 147, in which a 10-inch induction coil energized by the 12-volt storage battery is directly connected to the aerial, or are of the type where the induction coil and battery are substituted for the motor-generator and transformer as the source of power, Fig. 148. As government regulations do not permit the use of the plain aerial set except in case of collision, wreck, or fire at sea, the latter type is generally employed on steamers not carrying a storage battery capable of operating the motor-generator. This restriction is due to the fact that the plain aerial type is an untuned set which emits a broad and highly damped wave that seriously interferes with the operation of all other stations within its range.

Marconi Tuned Coil Set. In Fig. 148 is illustrated the complete wiring diagram for the sending circuits of the standard power set and the emergency set in which the induction coil and storage battery take the place of the generator and trans-

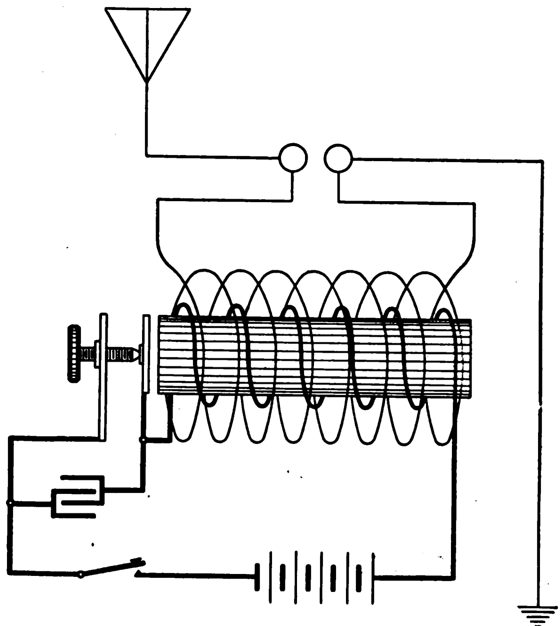
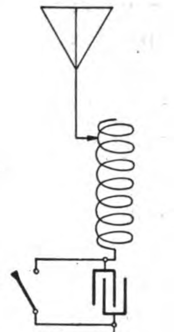


Fig. 147. Plain Aerial Type of Emergency Transmitter, Using Small Storage Battery, Induction Coil, and Spark Directly in Aerial (now Obsolete)

former. The connections of the standard power set will already be familiar as they have been detailed in other diagrams. It will be noted that instead of being connected directly in the primary circuit of the transformer, the operating key is controlled by the change-over switch *S;* when thrown upward, this switch connects the key with the alternator as the source of power; when thrown downward, it puts the induction coil and battery in circuit with the condenser and oscillation transformer. *P* is the primary winding of the induction coil, *S* the secondary, *I* the interrupter, *C* the condenser shunted around the interrupter, and *V* a voltmeter in shunt with the battery. *ACO* is the automatic cut-out, or underload circuit-breaker, used to prevent the battery from discharging when the generator voltage falls below that of the battery, and *BR* is a rheostat to control the amount of current passing into the battery when on charge. These elements are included in the circuit of the auxiliary source of power when the generator fails, as will be noted by tracing the connections. The main-line switch is thrown, as illustrated, and the contacts of the circuit-breaker are moved together by hand, thus putting the battery in circuit with the coil. To prevent the voltmeter from being burned out by elec-



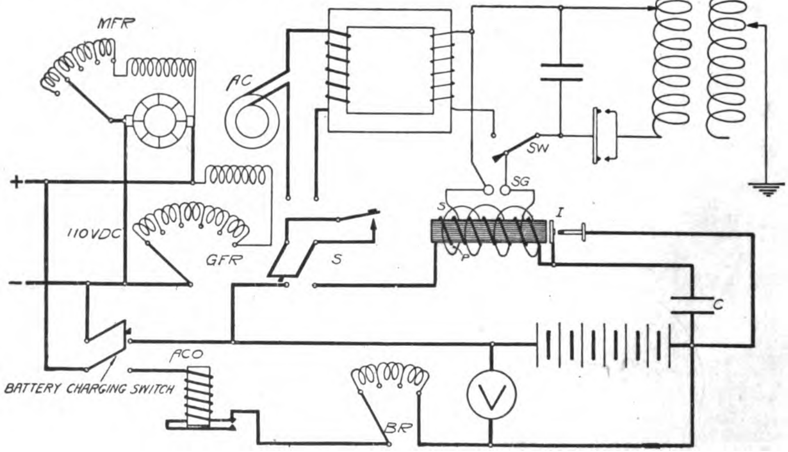


Fig. 148. Connections for Operating Auxiliary Set—*SW*, Switch Connecting Induction Coil to Closed Oscillation Circuit; *S*, Switch for Cutting Out Transformer and Connecting Key with Storage Battery and Primary of Induction Coil; *I*, Interrupter; *B*, Storage Battery (30 Volts); *GFR*, Generator Field Rheostat; *MFR*, Motor Field Rheostat; *SG*, Spark Gap of Induction Coil; *ACO*, Automatic Cut-Out for Battery; *BR*, Battery-Charging Rheostat; *V*, Voltmeter

trostatic induction from the induction coil when in operation, it is not permanently connected in the circuit but is provided with a small strap key by means of which readings may be taken. The range of the set with the battery as a source of power is from 125 to 225 miles in daylight and it will cover a much greater distance at night. This set is naturally not designed merely for sending out distress signals but is intended for use in case of accident to any part of the standard power set, such as the motor-generator or transformer, or for failure of the ship's dynamo.

RECEIVING APPARATUS AND CIRCUITS

Comparison of Transmitting and Receiving Circuits. It will be apparent that to receive the electromagnetic waves radiated from the sending station, it is necessary to have a circuit which is a counterpart of the sending circuit. In the transmitting circuit itself there is practically a sending and a receiving circuit, the sending being the closed oscillation circuit and the receiving, the open, or radiating, circuit. When the product of the capacity and inductance in each is the same, the circuits are in resonance and of the energy released by the closed circuit the maximum amount is induced in the open circuit through the cutting of the coil in this circuit by the lines of electrostatic and electromagnetic force.

Process of Receiving Radiations. Essentially the same thing occurs when the radiated waves are intercepted by the receiving aerial, the only difference between a sending and a receiving aerial in this connection and the closed and open circuits of the sending station being that of distance. The oncoming wave consists of a train, or group, of electrostatic lines of force in a vertical plane and a similar train of electromagnetic lines of force in a horizontal plane so that the wires of an inverted L type aerial, part of which are vertical and part horizontal, are cut by these lines of force. Hence, alternating currents of the same frequency are induced in these wires, and if the capacity and inductance of the aerial circuit are of such values that it is in resonant relation with the sending aerial, the induced potential and current will be the maximum receivable at the distance in question.

Current in Transmitting and Receiving Circuits. The factor of distance is responsible, however, for a very important difference between the two stations, that is, the strength of the current. The secondary of the oscillation transformer responds to a high-power wave emitted from a primary in the most efficient inductive relation with it, whereas, if the sending aerial be considered as the primary of a long-distance transformer and the receiving aerial as the secondary, it will be apparent that the secondary must respond to very feeble waves, since the strength of the radiated current is said to decrease approximately as the square of the distance.* A current of 10 amperes radiated from the sending station will accordingly have decreased to a value of a few milliamperes when the electromagnetic waves reach the receiving station several hundred miles away. Thus, while the receiving circuit must be a counterpart of the sending circuit, there are necessary in addition delicate instruments to detect the presence of the passing waves and still others to convert the currents induced in the receiving circuit into audible signals. These instruments are the detector and the head telephones.

DETECTORS

Coherers. The first practical detector used in wireless telegraphy was the coherer, so-called because it was discovered that the passage of the high-frequency oscillations through granules of conducting material whose resistance in their normal state of inactivity was very high caused these particles to cohere, thus reducing their resistance practically to zero and permitting the passage of the current through them. Once in this state, they remained cohered until mechanically shaken apart again. The coherer was invented by Branly, improved by Lodge, and rendered much more efficient by the form given it by Marconi, as shown in Fig. 149. It consisted of a glass tube 4 centimeters long by 2.5 millimeters in diameter and with silver plugs so inserted in it that their faces were 1 millimeter apart. The space was filled with a powdered mixture of nickel and silver with a trace of mercury to increase its conducting ability, and the glass tube was exhausted of its air. An electro-mechanical tapper, consisting of an electric bell mechanism, was arranged so that the hammer struck the glass tube opposite the space between the electrodes. The impulses received by the coherer were imposed on the current

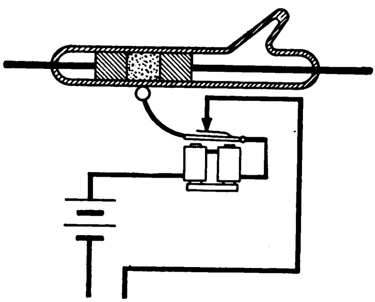


Fig. 149. Coherer and Tapper

* This is not known definitely as the strength of the received current is influenced by many factors besides distance.

from a local battery which set a relay in operation, cutting a second local battery into the circuit. The function of this second battery was to actuate a Morse inking register which recorded the message on a tape and in turn to excite the magnets of the tapping device. Thus, as soon as the signal had been recorded by the register, the coherer was tapped and decohered, ready to receive the next impulse. The coherer, however, was slow in action, not sufficiently sensitive for long-distance receiving, and had the great disadvantage of responding quite as readily to atmospheric electrical disturbances as it did to the waves radiated from a sending station. Therefore, it has been obsolete for a number of years.

Difficulties with Telephone Detectors. When wound with a large number of ampere-turns on its magnet and fitted with a very light diaphragm, the telephone receiver is so extremely sensitive that it will respond to current impulses too low in value to actuate any other electrical instrument except a precision galvanometer such as is used in laboratory work. But the oscillations of high-frequency current are not only alternating in nature but also far exceed in rapidity the vibrational period of the lightest of diaphragms. Even if the telephone were capable of responding to these high-frequency alternations, their rapidity is so great (for example, 500,000 per second for a 600-meter wave length) that no audible sound would be produced, since the human ear does not respond to vibrations in excess of 20,000 per second. It is consequently necessary to convert the high-frequency alternating current into one that will actuate the telephone receiver at a period of vibration within the range of audibility.

Rectified Current Impulses. For converting small amounts of power in the form of high-frequency alternating currents into direct-current impulses which will operate the telephone receiver, what is known as a rectifier has been found most practical. There are a number of different types in use, but all operate on the same principle, viz, *unilateral conductivity;* in other words, such detectors will pass the current in one direction but not in the other, so that while current impulses in alternate directions enter the rectifier, only those in one direction are permitted to pass out. Half of the aletrntiang waves are thus suppressed, surelting in impulses of current flowing in one direction and termed a direct current.. This may be made more clear from a consideration of the diagram, Fig. 150. The upper line represents the wave trains of damped high-frequency oscillations, or rather the alternating current which these oscillations induce in the aerial circuit; in the second line, which represents the rectified current, it will be noted that the reverse current waves have been suppressed, but the direct-current impulses are still of the same frequency and consequently far beyond the range of audibility. If the oscillations shown in the first line were of constant amplitude, the rectified impulses would also possess this characteristic and it would not be possible to produce an audible sound in the receiver without some means of breaking them up into groups. The method of effecting this breaking-up is explained in the section "Receivers of Undamped Oscillations," page 216.

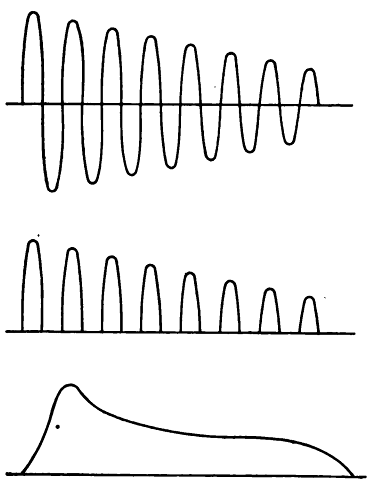


Fig. 150. Conversion of High-Frequency Oscillations to Pulsation of Direct Current—Upper Curve, Incoming Oscillations; Middle Curve, Rectified Current Showing One-Half of Wave Suppressed; Lower Curve Showing Direct-Current Impulse through Telephone, One for Each Wave Train

But as each wave train begins with an alternation of the maximum amplitude and is quickly damped out after a number of oscillations occur, the current dies away with the completion of each train so that the telephone diaphragm is only attracted once for each group of waves and is released as the latter are damped out, producing one sound. Hence, there is but one current impulse through the telephone receiver for each complete wave train, as indicated by the third line of the diagram. If it were not for the damping characteristic of the wave, the amplitude of the latter would be constant and the diaphragm of the receiver would be attracted and held down as long as this undamped wave continued, so that no sound would result. Above 10,000 alternations per second the reversals are so rapid that the diaphragm does not move, hence, it is incapable of responding directly to the frequency of the longest waves employed, namely, 10,000 meters, which have a frequency of 30,000 cycles per second.

Crystal Detectors. It has been found that certain crystals and minerals possess this property of rectifying high-frequency oscillations; in fact, it is a peculiarity of a large number of such substances, but those in more or less general use are carborundum, galena, silicon, molybdenite, and zincite-bornite (perikon). This characteristic is most strongly marked when the connections to the crystal are through greatly disproportionate areas of contact, as shown by Fig. 151, which illustrates a silicon detector. It will be noted that one contact consists of metal touching the entire lower face of the crystal (Wood's metal, a soft alloy, melting at a very low temperature is employed for the purpose, as heat destroys the sensitiveness of the crystal), while the other contact is in the form of a fine point. The point is mounted so that it may be moved in any direction over the face of the crystal, as all parts of the surface of the crystal are not equally sensitive. It is also arranged that greater or less pressure may be brought to bear on this contact, some crystals such as galena, rectifying most efficiently with a very light contact, while others, such as perikon, require a heavier pressure for their operation.

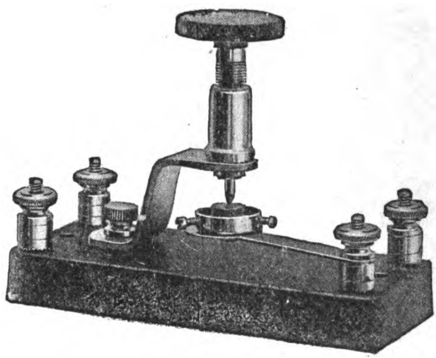


Fig. 151. Crystal Detector
Courtesy of W. J. Murdock Company, Chelsea, Massachusetts

Methods of Use. Carborundum is a product of the electric furnaces at Niagara and is the abrasive next in hardness to the diamond. Silicon is produced in the same way, while galena is a mineral crystal of lead, a bluish-gray substance separating into layers or cubical forms when broken. The perikon detector employs two crystals, the smaller being of copper pyrites (bornite) while the larger is of zincite. One holder supports several crystals of zincite, while another carries a small cup in which is clamped a small pointed crystal of bornite so arranged that it may be brought into contact with any part of the zincite crystals.

Characteristics of Carborundum. All parts of a crystal are not equally sensitive and all crystals of the same material are not equally good rectifiers. Thus, out of a hundred crystals of carborundum, for instance, only a half-dozen may be effective, and even these selected crystals may have but a limited number of sensitive spots on their surfaces. To employ such a crystal for receiving, it is necessary to locate the most sensitive spot with the aid of the test buzzer and then adjust the pressure to give the maximum sound in the telephone receiver. Silicon, galena, and most of the other crystals tried have the great disadvantage of being thrown out of adjustment by the sending current, which makes it necessary to readjust them for receiving every time the transmitting apparatus has been used. Carborundum is one of the few crystals that are free from this disadvantage, while it has the further peculiarity of a decreasing resistance with an increasing current and is therefore rendered much more sensitive by putting it in circuit with a local battery and potentiometer. The potentiometer, Fig. 152, is a variable resistance, consisting either of a rod of carbon or a winding of bare high-resistance wire on an insulating core and provided with a sliding contact so that the number of turns and, in consequence, the resistance may be varied.

Fig. 152. Carbon Rod Type of Potentiometer

This peculiarity of carborundum is illustrated by the current-voltage curve, Fig. 153, which shows that up to 0.8 volt there is only a slightly perceptible increase in the current, or from zero to approximately 3 microamperes. Thus, if this particular crystal were employed without a local battery, a received voltage of 0.6 (due to the electromagnetic waves intercepted by the aerial) would produce a current of only 1 microampere across the terminals of the telephone receiver and the resulting sound would be very faint. But if there already exists a potential of 0.8 volt across the crystal, due to the local battery in circuit, the slight increase resulting from the received waves makes a very marked difference in the current. Doubling the voltage in this instance increases the current from 3 to 35 microamperes and the sound produced in the telephone receiver is correspondingly louder. By comparing this curve with that of a perikon detector shown in Fig. 154, it will be noted that the current is proportional to the voltage in the case of the latter, so that there is no advantage in using a local battery with the perikon type.

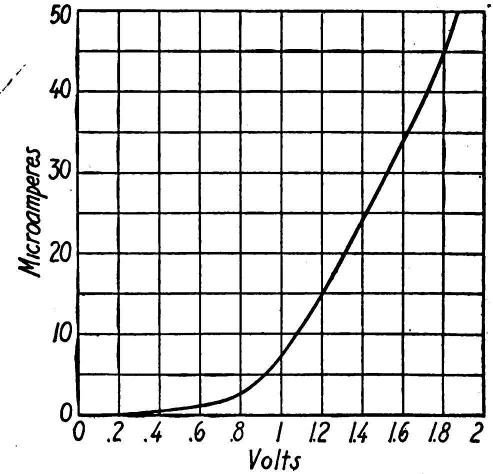


Fig. 153. Current-Voltage Curve of Carborundum Detector

With the carborundum crystal, instead of starting from the zero point of the curve, the received potential is applied at the most sensitive point. In case the potentiometer is adjusted to permit a higher voltage to flow through the crystal from the local battery, then the steady current resulting is well up on the curve and the additional alternating potential set up by the electromagnetic waves will be less effective in operating the diaphragm of the telephone receiver. Under such circumstances the crystal becomes conductive in both directions and accordingly does not rectify the incoming oscillations, while the current may reach a value that causes excessive heating at the contact point. The proper adjustment of the potentiometer is obtained with the aid of the test buzzer, described on page 213. In the operation of a crystal detector of this type, the oscillating potentials set up by the

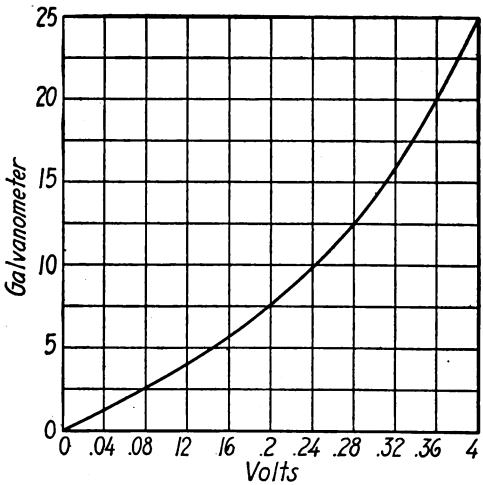


Fig. 154. Current-Voltage Curve of Perikon Detector

incoming waves are, during one-half the cycle, added to the local battery voltage to increase the current, while during the other half they oppose one another, thus reducing the effective current to a practically negligible amount; therefore, the detector rectifies the oscillating currents, and the current impulses through the telephone receiver are always in the same direction. It is a further peculiarity of carborundum, however, that the same crystal is not equally efficient as a rectifier when the current is passed through it in either direction. It must be subjected to tests to ascertain the direction in which it is most efficient and then connected in the local battery and potentiometer circuit so that the current passes through it in that direction.

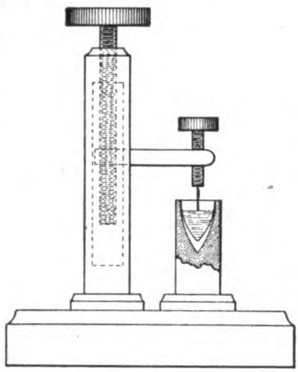


Fig. 155. Liquid Barreter

Electrolytic Detector. A similar rectifying effect is obtainable with what is practically a miniature primary battery cell consisting of a carbon cup containing a dilute solution of nitric or sulphuric acid on the surface of which a very fine platinum wire makes contact. This wire measures only 0.0001 inch in diameter. It is termed a Wollaston wire and is formed by casting an ingot of silver with a platinum core and then drawing the ingot down to a fine wire. Before using, a comparatively heavy current from a local battery is sent through the cell, Fig. 155, thus stripping the silver away from the point. The local battery current is then reduced to the point at which the incoming signals are most audible. This type of detector has the disadvantage of producing a constant frying or hissing noise in the telephones, while the acid solution is subject to rapid evaporation and on shipboard would slop out of the carbon cup. It has never been employed to any extent in commercial usage.

Magnetic Detector. The magnetic detector was invented by Marconi and was successfully used in his early transatlantic work (1902) and in many of the smaller stations for a number of years thereafter, but it has since been displaced almost entirely by the carborundum detector, already described, and the vacuum-valve detectors, discussed in the next section. It is shown diagrammatically in Fig. 156 and consists of a continuous band of fine iron wires passing over the pulleys *P* and *P′* and revolved slowly by means of clockwork. This causes the iron wire band to pass through the glass tube *T* and at the same time through the field of the permanent magnets *N S* and *S N*. On this glass tube are wound the primary and secondary of a receiving transformer, the primary being connected in series with the aerial and ground while the secondary terminals are connected to the telephone receiver. As the iron band passes through the field of the permanent magnets, it becomes magnetic by induction and, owing to the hysteresis of the iron, tends to retain this magnetism for a short time after it passes out of the influence of the field. The passing of the

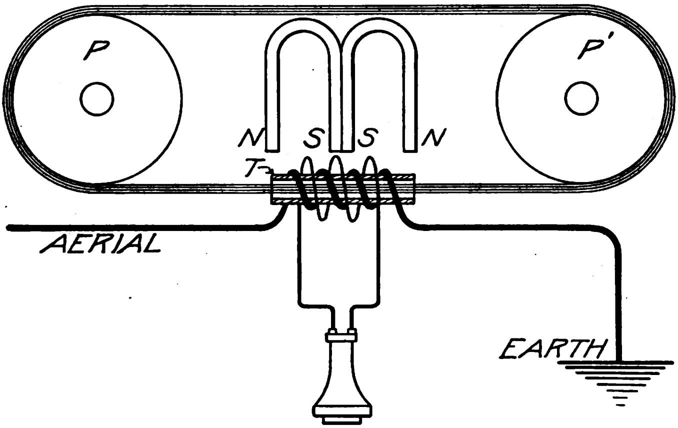


Fig. 156. Diagram of Marconi Magnetic Detector

oscillatory current through the primary winding, however, sets up a cyclic change in the induced magnetic field in the iron wire band and this variation of the magnetic flux induces a corresponding current in the secondary winding which produces a sound in the telephone receiver. This is but one of the theories of the action of this type of detector, all of which are not in accord. While very sensitive for longer waves, it is not the equal of the carborundum detector for the standard commercial wave lengths, namely, 300 and 600 meters. As the resistance of the magnetic detector is low in comparison with that of the crystal type, the secondary of the coil being wound with wire such as No. 20 or No. 18, a low-resistance telephone receiver must be employed with it, the resistance of the secondary and that of the telephones being approximately equal.

Vacuum-Valve Detectors. When the filament of an electric light bulb is made incandescent by the passage of the current through it, electrons pass off from the filament and fill the space between it and the glass bulb, thus rendering this space (a vacuum) conductive. By inserting in the bulb another conductor, which in Fleming's original type of vacuum detector took the form of a cylinder of copper gauze, Fig. 157, these negative electrons passing off from the filament establish a current between it and the copper cylinder. If the cylinder itself be connected in a local battery circuit so as to give it a positive potential, the electrons will be strongly attracted and an increased current will flow; but if the cylinder have a negative potential, the electrons will be repelled and very little, if any, current will then flow from the filament to the cylinder; in other words, the combination acts practically as a check valve plus an accelerator in not only permitting but even encouraging the current to flow in one direc-

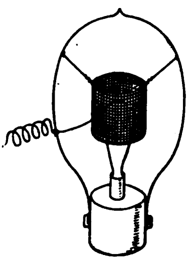


Fig. 157. Fleming Vacuum-Valve Detector

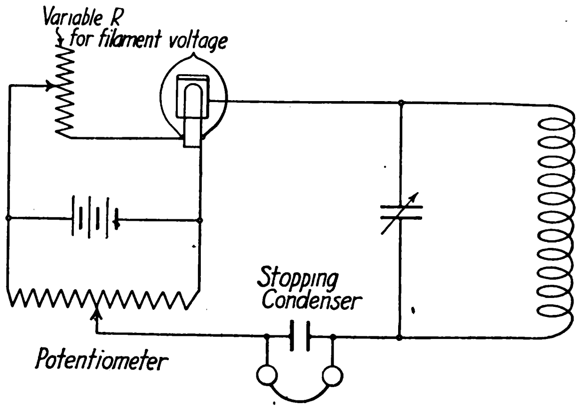


Fig. 158. Circuit for Vacuum-Valve Detector

tion and preventing it from flowing in the opposite direction. This type of detector is commonly referred to as a vacuum-valve detector though special types are given trade names.

As shown in the diagram, Fig. 158, a local battery is employed to bring the filament of the bulb to incandescence. The oscillating currents set up by the passing electromagnetic waves in the aerial circuit, in which the cylinder is included, cause the gauze to alternate from positive to negative at the same frequency. When its potential is positive, the electrons from the filament are strongly attracted and a current flows across the space from the filament to the gauze; when its potential is negative, practically no current flows, owing to the opposing force of the negative potential on the electrons. In this way half the wave is suppressed, with the result that the current flowing to the cylinder and through the telephones in circuit with it is in one direction and, therefore, the combination possesses the same characteristic of unilateral conductivity that renders certain crystals such good detectors. In the original Fleming valve a galvanometer was employed to indicate the direct current by its deflections.

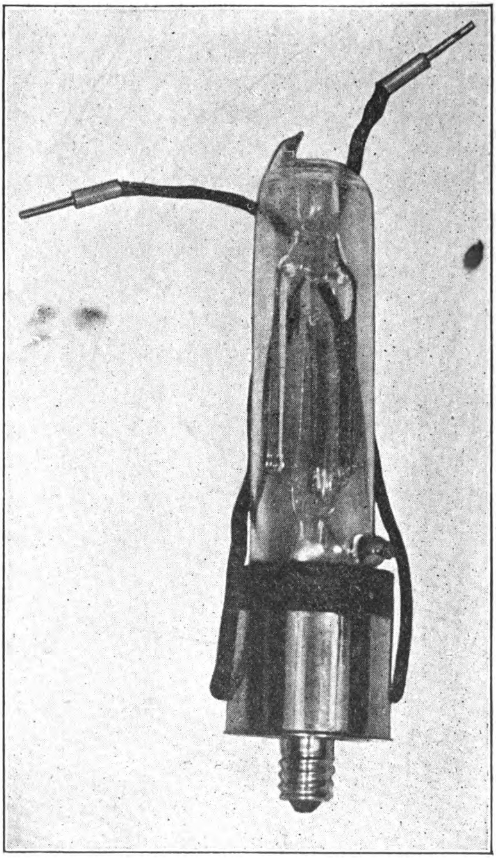


Fig. 159. Improved Type of De Forest Audion

Audion. Dr. De Forest improved on this instrument by the addition of a second battery to create a positive potential at the second element and employed a plate for this purpose instead of a cylinder, terming the combination an audion; one of the latest types is shown in Fig. 159. A multi-point switch is employed in both battery circuits so as to permit varying the degree of incandescence to which the filament is raised as well as

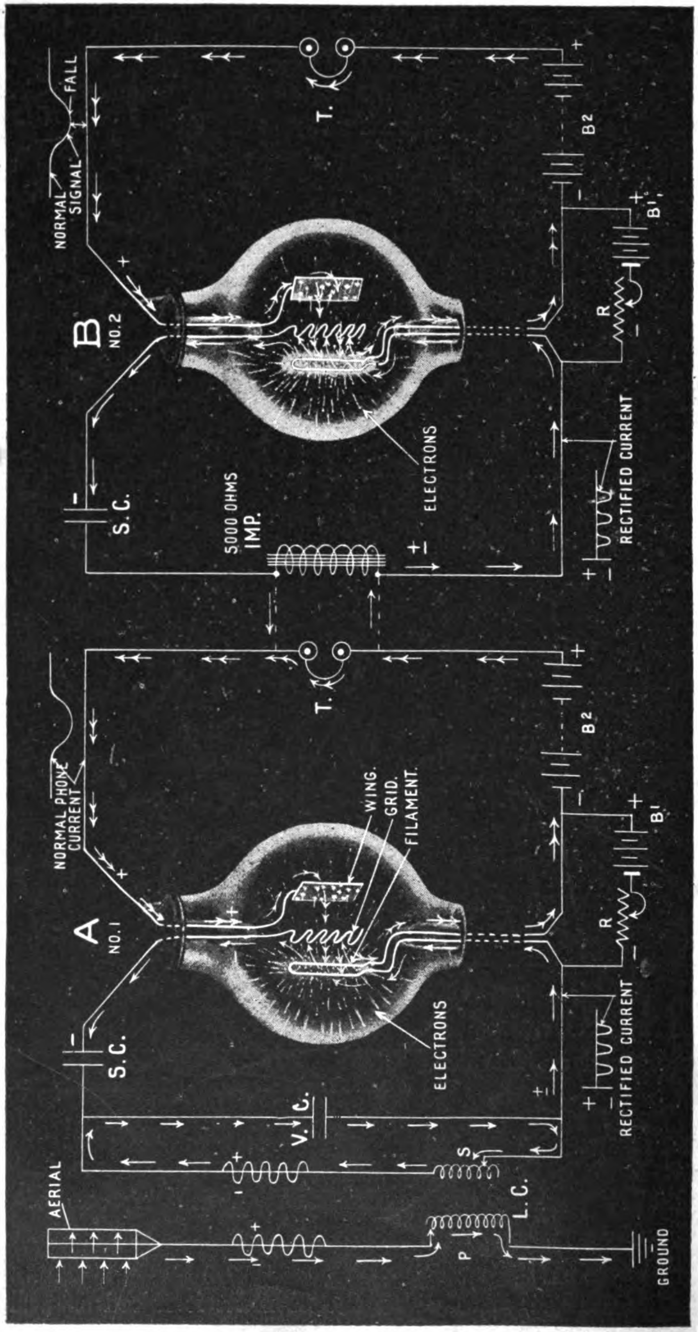


Fig. 160. Typical Audion Amplifier Wiring Diagram
Courtesy of Electrical Experimenter, New York City

the strength of the potential imposed on the plate. This is an extremely sensitive detector the adjustment of which is not disturbed either by mechanical vibration or the proximity of heavy electrical discharges, as is the case with several of the crystal detectors. It exhibits the same rise in the current-voltage curve as the carborundum detector; hence, the potential applied to the plate may be adjusted to a certain critical value which, when increased by the slight additional voltage of the currents induced in the aerial by the passing electromagnetic waves, causes a large increase in the current flowing from the local battery through the telephone receivers and makes possible a distinctly audible signal with an extremely weak current in the aerial circuit.

To start with, suppose that an incoming signal in the form of an electromagnetic wave impinges upon the aerial, Fig. 160; this, in turn, sets up high-frequency oscillating (or alternating) currents in the antenna circuit, which includes the primary *P* of a loose coupler, or transformer, *L C.* By magnetic induction this current is transferred (and usually changed in potential) to the secondary circuit *S* of the loose coupler. In circuit *1*, which is a standard one, an oscillating current will flow around the circuit *S–V C*. Also this circuit may be tuned to resonance with respect to the incoming wave length. This current, when led off to the filament and grid of the vacuum valve, becomes rectified; that is, the negative pulses are permitted to pass from the hot filament to the cold grid. The grid, too, by virtue of its position in the electron stream, gathers up an appreciable negative charge; in other words, a negative charge is accumulated on it. This charge naturally passes along the wire connected to the right-hand plate of the stopping condenser *S C*. When this occurs there is a scattering effect in the electron field between the filament and wing, which weakens it in so far as conductivity is concerned. Hence the current, passing from the positively charged wing to the filament, is reduced, as shown by the graphic curve in the upper right corner of circuit *1*. The time period of this depression in the wing current corresponds to that of a group of sparks, or, in other words, the group frequency of the transmitting station. In consequence the telephone receivers *T* will sound or their diaphragms will be partially released while this effect occurs. On the cessation of the incoming signal, the negative charge on the grid and in the condenser gradually dissipates and the circuits regain their normal state.

Considering circuit *2* in conjunction with *1*, we have a common form of audion amplifier of the two-stage type. This circuit yields remarkable amplifying effects. With such a circuit the pulsating current in the phone circuit of valve *1* passes through a high-resistance iron-core impedance *IMP*. When this pulsating current passes through the impedance coil, there is a tendency for it to be converted into an alternating current, owing to the lagging effect of the iron core. However, the current flowing in the filament grid circuit of audion *2* is amplified in the same manner as described for audion *1*, and amplified charges pass from the filament of audion *2* to the grid. Thus the grid becomes alternately negatively and positively charged, and likewise the condenser plate to which it is connected. This audion then works in the same manner as audion *1*, so as to greatly increase the fluctuations in the telephone receiver current from battery B_2; in other words, it will readily be seen that a very strong amplifying effect takes place in the two detectors, as the current passing through the impedance coil in the secondary circuit of the first bulb is very strong. This comparatively strong current is then used as a trigger or control current for audion *2*. Since this current in question is many times stronger than the trigger current, as in the case of audion *1*, it is evident that an extraordinary current change will occur in the telephone circuit of audion *2*.

Three-Element Oscillation Valve. De Forest also developed what is termed the three-element oscillation valve. In this, a perforated plate, or grid, is interposed between the filament and the plate. This grid is connected directly in the secondary of the receiving circuit but has no electrical connection with the plate, so that the electrons are compelled to pass through this grid to reach the plate. A condenser is shunted across the head telephones and each complete train of waves, or oscillations, as rectified by the vacuum valve, serves to charge this condenser, which then discharges through the telephones. The variable condenser employed in the receiving circuit must have a very small capacity since the vacuum valve gives the strongest rectified current when its secondary circuit has a maximum inductance and minimum shunt capacity for a given frequency or wave length. In the English Marconi Company sets, using a vacuum-valve detector, what is known as a Billi condenser is employed. This consists of two small brass tubes arranged to slide on two hard-rubber rods in which are embedded two brass rods, the hard rubber thus serving as the dielectric. The capacity is varied by sliding the brass tubes on or off the hard-rubber rods.

Amplifier. The audion detector is also employed as a relay to magnify the received current and is then known as an amplifier. Two or more audions are connected in cascade with small step-up transformers between them; that is, the plate of the first bulb is connected to the primary of one of these transformers and the secondary of the transformer is connected to the grid of the second bulb. This constitutes a single-step amplifier. If a third bulb be employed the connections are the same as just given, the current from the second passing through the primary of a second transformer which steps it up once more, the current from the secondary winding of this transformer passing to the grid of the third bulb and the plate of the latter being connected to the head telephones. This is a three-step amplifier. An audion detector and single-step amplifier is shown in Fig. 161.

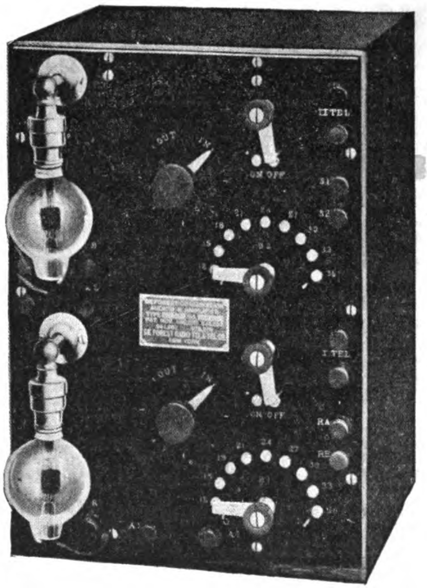


Fig. 161. De Forest Combination Audion Detector and Single-Step Audion Amplifier

TUNING DEVICES

Capacity and Inductance in Receiving Circuits. In order that the receiving circuit may be placed in resonance with the frequency of the sending circuit to intercept the maximum amount of energy from the passing waves, it is necessary that the product of the capacity and inductance be the same in both cases. As the currents handled are so small, however, the condensers and inductances employed in the receiving circuit are different from those already described for the transmitting circuit. The standard type of variable condenser employed consists of semicircular plates in two groups, one stationary and one movable, as shown in Fig. 80.

The inductances used are of several forms although the multi-point switch type is practically standard for commercial use. This is a step-by-step type in which the number of turns of the coil in circuit is varied by means of a switch which is moved over a series of contact points or by a sliding contact bearing on an uninsulated part of the coil and varying the inductance by increments of one turn at a time. These inductances are of the single-coil type in which part of the coil is connected in the aerial circuit to serve as the primary and part of the remainder is connected in the receiving circuit to act as the secondary of an oscillation transformer, but as this does not permit any variation in the mutual induction of the two parts of the transformer sharp tuning is not possible. Such coils are now only employed as loading inductances to change the total inductance value of the receiving circuit in order that it may respond efficiently to different wave lengths. In this case, however, only a single set of connections is necessary, the coil being in series with the aerial, and a multi-point switch is employed to vary the number of turns included in the circuit.

Loose Coupler. The term commonly employed to designate the oscillation transformer used in the receiving circuit is loose coupler. However, owing to the fact that resonance between the sending and receiving circuits is obtained by using a comparatively high value of capacity and a correspondingly low value of inductance in the sending circuit and reversing these conditions in the receiving circuit, the loose coupler bears no resemblance to the transmitting oscillation condenser. In the transmitting circuit it is essential that the resistance be kept down to the minimum so that the decrement of damping will be correspondingly low. Consequently, comparatively few turns of heavy strip copper or tubing are employed in the transmitting oscillation transformer and its small value of inductance is offset by the use of larger condensers. The heavy currents used in the closed oscillation circuit to charge the condensers make it possible to employ effectively a transformer having so few turns.

But in the receiving circuit the conditions are directly the opposite. Exceedingly feeble currents must be made to produce distinctly audible sounds in the telephone receivers and to accomplish this it is necessary that the transformer have a comparatively large number of ampere-turns, otherwise, the passage of the very weak current through its primary would not create a sufficiently strong magnetic field to induce a current of the desired value in the secondary. Consequently, the receiving transformer takes the shape shown in Fig. 162. Its dimensions vary in accordance with the range of wave lengths it is designed to receive, but for standard commercial wave lengths, ranging from 300 to 2500 meters, it consists of a primary winding of No. 24 or 26 B. & S. gage insulated wire wound on a 4½-inch tube about 6 inches in length and a secondary of No. 30 B. & S. gage insulated wire on a 4-inch tube of the same length. Taps are taken from each of these windings to the contacts of the multi-point switches so, by turning the switches, a greater or less number of turns of either the primary or secondary coil may be placed in circuit. A larger number of contacts is provided in the primary circuit than in the secondary so that it may be varied by smaller increments in order to give sharp tuning of the received waves.

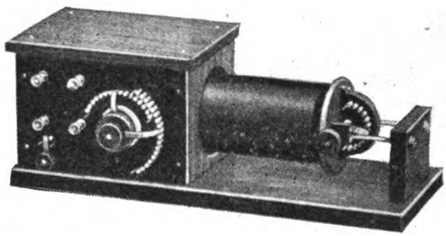


Fig. 162. Early Type of Loose Coupler now Used by Experimenters

These two coils are mounted so that the secondary may be slid in or out of the primary in order to vary what is known as the coupling, the meaning of which is given in the section, "Explanation of Coupling," page 226. The primary coil is accordingly fixed while the secondary is arranged to slide on guide rods, as shown by Fig. 162, which illustrates an early type of commercial loose coupler now largely used by experimenters. By examining the illustration, the difference between the number of taps provided for the primary and the secondary windings of the loose coupler will be noted. For example, in one of the standard Marconi tuners (loose coupler) the unit primary switch gives an adjustment of one coil of the winding per contact, the remaining contacts representing increments of 10 turns each. In the secondary, the number of turns varies progressively, viz, 5, 10, 15, 25, 40, 65, 55, 45, and 40, there being 340 turns of wire on the secondary and 390 on the primary.

Variometer. Under the head "Induction," page 29, the variation of the magnetic field set up in one coil by another as influenced by their relative positions has been explained; when the two coils are parallel their inductance is at a maximum, whereas at right angles it is almost zero. This principle is the basis of a receiving tuner known as a variometer. As usually constructed, this takes the form of two windings in series, one of which is placed on a spherical form resembling a hollow ball with its ends cut off. This winding is fixed, while the second winding is placed on a similar but slightly smaller form mounted on a rod so that it may be revolved inside the first, Fig. 163.

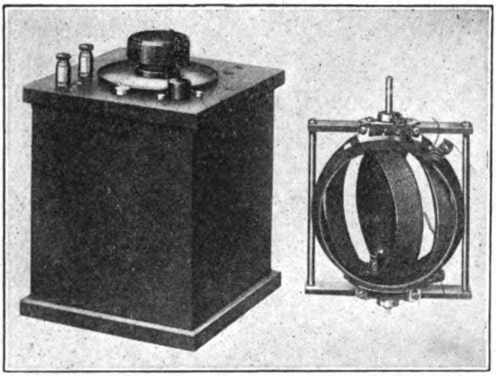


Fig. 163. Variometer Mounted in Case; Windings Shown Separately at Right
Courtesy of General Radio Company, Cambridge, Massachusetts

As shown at the left in the illustration, both windings are inclosed in a wooden case on the upper face of which is mounted a scale, the knob attached to the rod carrying the movable winding having a pointer to indicate the relative positions of the windings. By this means the inductance of the receiving tuner may be varied without the use of multi-point switches. The variometer permits very close variation of the value of inductance but has the disadvantage, owing to the series connection of its coils, of presenting considerable resistance to the passage of the high-frequency currents when the value of the inductance used is very low.

Simple Tuning Coil. Both the loose coupler and the variometer are sometimes referred to as tuning coils, but the latter term is used more frequently to designate a simple form of inductance long since obsolete in commercial practice but still employed to a large extent in small amateur stations. A tuning coil consists of a single winding (all tuning inductances have but a single layer of wire), usually of bare wire, along which two sliding contacts pass when the number of turns in the circuit is varied, one being connected directly to the aerial and the other to the receiving instruments. Finer adjustment is obtained by the use of a third sliding contact, which gives a three-slide tuning coil. As no variation of the mutual inductance of the two parts of the coil is possible, such a tuner is not capable of tuning as sharply as either the loose coupler or the variometer, while the mechanical construction is faulty since the contact either loosens the winding, causing the adjacent turns to short-circuit, or wears through the wire. The different types of tuning coils mentioned are illustrated in connection with the diagrams of receiving circuits.

MISCELLANEOUS TYPES OF RECEIVERS

Test Buzzer. All parts of the crystal of a detector are not equally sensitive, and with different crystals a slight variation in the pressure of the adjustable contact makes all the difference between an easily read signal and one that it is next to impossible to distinguish in the telephone receivers. The vacuum-valve detectors also require adjustment of the potential to both the filament and the plate, so that with all detectors some means of determining when they are in the most sensitive condition for receiving is necessary. It is obvious that this must be ascertained from time to time as none of the crystal detectors are stable over long periods and, to save the batteries, the valve detectors are only put in circuit when ready to receive.

To make such determinations the test buzzer is employed. This consists of a small buzzer similar to that used in offices and residences as a call but of more sensitive construction. It is connected in circuit with two cells of battery, a small inductance, and a push button or key. When this inductance is placed in inductive relation to either the open or closed circuit of a receiving set and the buzzer is set in operation by pressing the button, the fluctuations of the battery current caused by the rapid make and break of the circuit at the interrupter induce feeble currents in the receiving circuit. If the detector is properly adjusted, these currents are rectified in the same manner as the oscillatory currents received by the aerial and produce audible signals in the telephones. The buzzer is usually kept in operation continuously, while the contact is moved over the face of the crystal and its pressure varied or, in the case of a vacuum valve, the number of cells of battery in circuit with the filament and the plate are varied

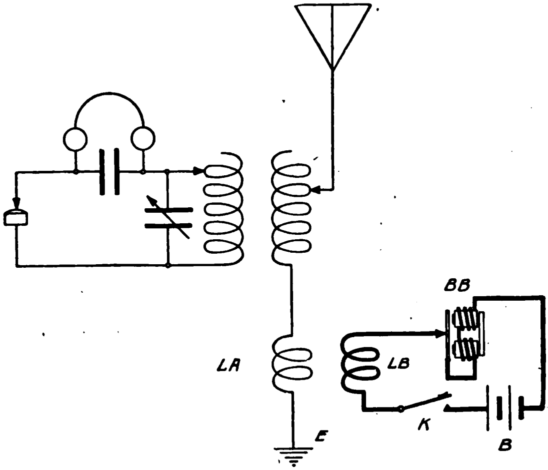


Fig. 164. Diagram Showing Test Buzzer and Its Inductive Relation to Aerial for Adjusting Detector—When *K* Is Depressed, Buzzer *BB* Operated by Battery *B* Excites Buzzer Inductance *LB* Which Acts as Primary of Oscillation Transformer, Inducing Current in Secondary *LA*

until the detector produces the desired high-pitched note in the telephone receivers. In Fig. 164 are illustrated the circuit of the test buzzer and the method of placing it in inductive relation with the receiving circuits. This test buzzer set is a wave meter as well. A few turns are made in the ground connection of the aerial and several turns of the winding comprising the buzzer inductance are wound around it but insulated from it, thus constituting a miniature oscillation transformer of the sending type, the buzzer and battery representing a closed oscillatory circuit. This charges the aerial circuit, causing it to oscillate at the particular frequency for which it happens to be adjusted. By adjusting the secondary of the receiving circuit to resonance with the aerial and varying the adjustment of the detector to place it in the most sensitive condition, the maximum sound will be produced in the telephone receivers.

Telephone Receivers. The telephone receivers used are of the same type as those ordinarily employed on telephone lines (that is, of the watchcase pattern), but as they must respond to extremely feeble currents, they are made with extra light diaphragms and are wound with a great many turns of fine wire, since the strength of the field produced by an electromagnet is the product of the strength of the current times the number of turns in the exciting coils, in other words, the number of ampere-turns. As has been previously stated, a current of 1 ampere passing through ten turns of wire will have the same magnetizing effect on the core as a current of 10 amperes flowing through a single turn of wire. Wireless telephone receivers are usually rated in terms of their total resistance, though it is the number of ampere-turns of wire on the core rather than its resistance that determines the degree of sensitiveness obtained. As these turns must be as close as possible to the core to be effective, exceedingly fine wire is employed (No. 40 B. & S. gage is finer than a human hair), and this naturally has a high resistance. The number of turns that may be used is limited by the distance of the outer layers from the core, since their effectiveness in creating the magnetic field decreases with their distance and after a certain depth extra layers add to the resistance only without appreciably increasing the strength of the magnetic field.

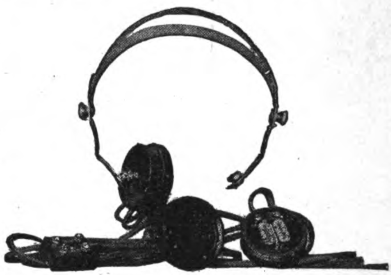


Fig. 165. High Resistance Head Telephones, Cap and Diaphragm Removed
Courtesy of W. J. Murdock Company, Chelsea, Massachusetts

Certain types of detectors, such as the Marconi magnetic detector, the three-element vacuum valve, and the tikker used in connection with the reception of undamped oscillations, are efficient with telephone receivers having as low a resistance as 75 to 150 ohms, but the crystal detectors require receivers with windings of 2000 to 3000 ohms, divided between the two receivers in series. A typical set of high-resistance receivers is shown in Fig. 165.

Receivers of Undamped Oscillations. As the wave train emitted by an undamped oscillation transmitter consists of a series of alternations of constant amplitude, it will be apparent that if the diaphragm of the telephone receiver were influenced by such a wave train, it would simply be moved once each time the key was depressed, since the frequency of the oscillations is entirely too high for it to respond by vibrating in unison with them. It would accordingly be held down while the key was depressed and released again when the circuit was open and could

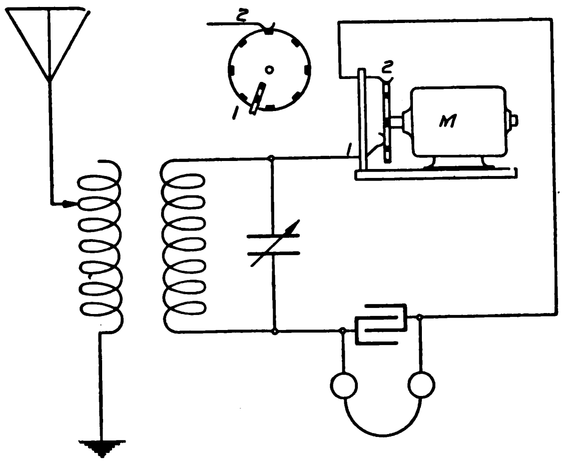


Fig. 166. Poulsen Tikker Circuit—*M*, Motor; *1*, Contact Bearing against Side of Toothed Wheel; *2*, Brush Bearing on Periphery of Toothed Wheel. Wheel and Contacts Are Shown Separately at Left

not produce an audible sound. To cause it to vibrate, the oscillations must be broken up into groups, or short trains of waves.

Poulsen Tikker. There are several methods of doing this, the simplest of which is the Poulsen tikker, shown diagrammatically in Fig. 166. It consists of a toothed wheel, the openings of which are filled level with the periphery with an insulating compound in order that the brush bearing on it may run smoothly. This wheel is mounted directly on the shaft of a small high-speed motor, and one brush bears directly against the side of the wheel while the second brush bears on the periphery so that the wheel forms part of the secondary circuit of the receiving tuner. The current in the latter is thus interrupted at a rate which is the product of the speed of the motor and the number of insulating segments in the wheel, usually 300 to 600 times per second. An even simpler form of tikker consists of an ordinary buzzer energized by a local battery and carrying on its vibrating armature a second set of contacts which open and close the tuner circuit in the same manner and at a speed determined by the rate of vibration of the buzzer.

Slipping Contact Detector. A variation of the tikker is termed the slipping contact detector. Instead of the toothed wheel with its insulating segments, a plain grooved pulley of copper is mounted

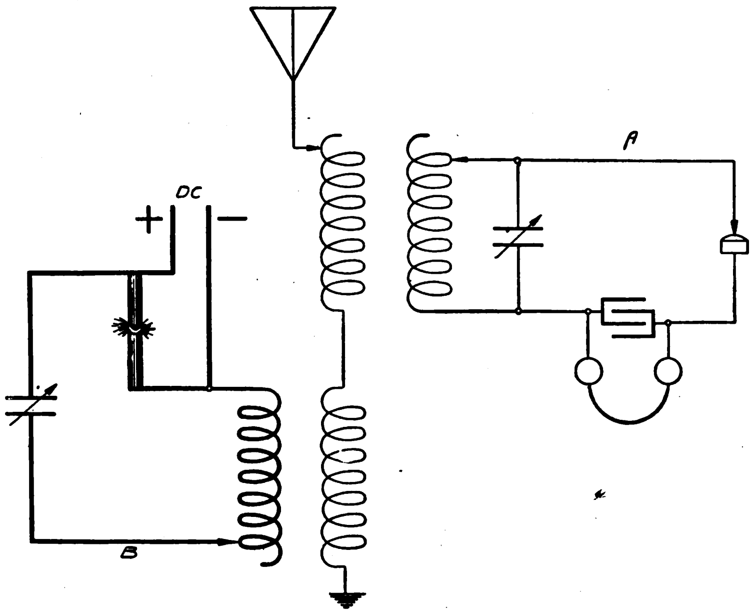


Fig. 167. Heterodyne Receiving Circuit Using Direct-Current Arc to Generate Undamped Oscillations—*A*, Receiving Circuit; *B*, Generator of Undamped Oscillations

on the motor shaft and an adjustable spring copper or stiff brass brush bears in the groove, a second brush bearing against the side of the wheel itself, completing the circuit as previously described. At high speed the grooved pulley tends to pull the spring brush along with it, thus causing a contact of variable resistance which breaks up the incoming current into pulsations that permit the telephone condenser to charge and discharge at the same speed.

Heterodyne Receiver. The heterodyne receiver, so termed from the Greek *heteros,* meaning *combining forms,* and "dyne", which is the unit of force in the C. G. S. (centimeter-gram-second) system, is based upon the principle that when two vibrational periods are combined, that is, one superimposed on another, the resultant vibration, or note, will be the difference between their respective frequencies. In practice, a generator of undamped oscillations having a frequency which differs from the frequency of the received oscillations by a certain small period forms part of the receiving set. An example of this is shown in Fig. 167, in which a direct-current arc is employed as the means of generating the undamped oscillations at the receiver. Then if the received oscillations have a frequency of 100,000 per second and the receiving oscillation generator superimposes on this a current having a frequency of 99,000 oscillations per second, the resulting current will have a frequency represented by their difference, or 1000 cycles per second. This is termed a beat current, in that the two frequencies have been combined to produce beats of a frequency equal to their difference. The same effect is obtained whether the received oscillations be higher or lower in frequency than those of the receiving oscillation generator. The latter differs from the closed oscillation circuit of a spark system only in the substitution of a direct-current arc for the transformer and spark gap of the latter.

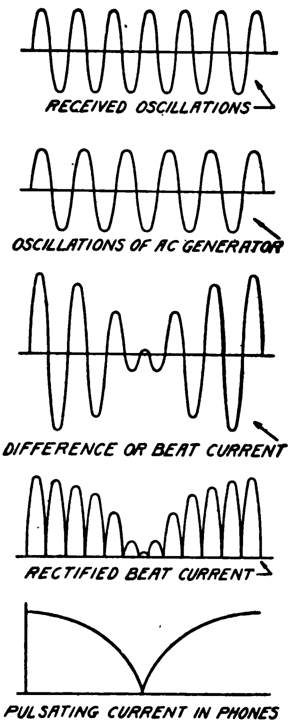


Fig. 168. Curves Showing Operations of Heterodyne Receiver

The curves in Fig. 168 serve to make clear the operation of this type of receiver. In this diagram, the topmost curve represents the received oscillations; the curve just below it, the oscillations, of a slightly different frequency, generated by the arc in circuit with a variable condenser and adjustable inductance; while the third curve is the beat current. The remaining curves illustrate this beat current after it has been rectified by the crystal detector and converted into pulsations of direct current in the telephone receivers. The rise and fall of the beat current, as indicated by its curve, is accounted for by the periodic variation of phase of the two sets of oscillations. When they are in phase with each other, their force is combined and the beat current is at a maximum; when out of phase, they oppose each other and the beat current drops approximately to zero. A buzzer, a vacuum valve, or a high-frequency alternator may be employed as the source of the undamped oscillations at the receiver. The heterodyne receiver not only renders undamped oscillations audible in the telephones but also acts as an amplifier, increasing the strength of the received signal considerably. It is also employed in connection with damped, or spark, systems, but in this case produces a note of much lower pitch.

RECEIVING CIRCUITS

Necessity for Accurate Means of Detecting Radiations. Mention has already been made under the head "Resonance of Piano Strings," page 89, of the fact that when a tuning fork is given a smart blow and then held near an open piano all the strings of the piano will respond to some extent, but the particular string that has the same period of vibration as the fork itself will respond most strongly by producing a distinctly audible note. The fork and that particular string are in resonance. The response of other strings having approximately the same period may also be audible to a lesser degree, but that of the remaining strings cannot be detected by the unaided ear. With the number of wireless stations now in operation, the ether is in a constant state of vibration; an endless number of electromagnetic waves of different frequencies is constantly being radiated. Like piano strings, the numerous receiving stations respond to these waves to a greater or less extent, depending upon whether or not the period of vibration, or frequency, to which they are adjusted approximates that of certain of the sending stations. It will be evident that to respond most strongly to any particular sending station, the receiving station must have the same frequency, or wave length, as that station. As the oscillations received at a distance of 1000 miles or more are very feeble, the currents induced in the aerial circuit by them are correspondingly low in value, sometimes not exceeding more than a few millionths of an ampere. It is accordingly essential that the aerial circuit be sharply tuned to resonance with the transmitting circuit besides being provided with highly sensitive detecting devices.

Directly Coupled Circuits. In the common parlance of the wireless operator both transmitting and receiving circuits are denominated *hook-ups.* The number of types of circuits, particularly for receiving, is almost infinite although the majority are simple modifications of standard types and present no particular advantage. In commercial apparatus, of course, the circuits are

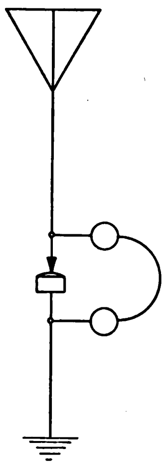


Fig. 169. Elementary Receiving Circuit

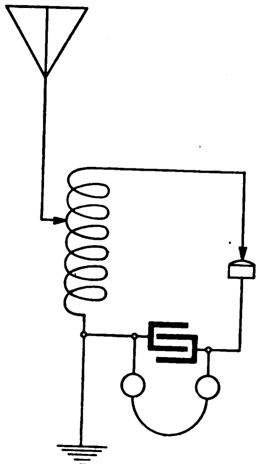


Fig. 170. Elementary Tuned Receiving Circuit with Telephone Shunted by Stopping Condenser; One-Slide Inductance

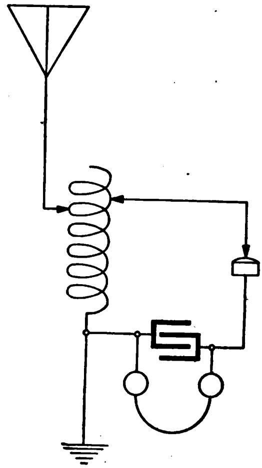


Fig. 171. Same Circuit as Fig. 170 with Two-Slide Inductance

determined by the manufacturer's engineering staff and cannot be altered by the operator, except by adjustments specially provided for the purpose, but the great army of experimenters are constantly devising new hook-ups. To prevent confusing the student, only a limited number of approved circuits are illustrated and described, with a preliminary reference to the elementary forms from which they have been developed.

Simple Circuit. In Fig. 169 is shown the rudimentary form of receiving circuit. It consists of nothing more than a detector inserted in the ground connection of an aerial. It will be apparent that such a receiving circuit could respond only to waves of practically the same length as the natural wave length of the aerial itself, while, as the values of inductance and capacity (distributed) are both very low, this wave length would necessarily be a short one unless the aerial were very large and well elevated. Moreover, the strength of the received signals would depend entirely upon the sensitiveness of the detector, unaided by any other devices. As neither its inductance nor its capacity can be varied, such a circuit is said to be *untunable*. It can respond only to wave lengths of the same or approximately the same frequency as it itself.

Tuned Circuit. By inserting a variable inductance between the aerial and the detector, Fig. 170, there results an elementary form of tuned circuit. The inductance in question is termed a single-slide tuning coil. By varying the number of turns in circuit with the aerial, the wave length of the latter can be adjusted within the range of the additional inductance thus provided. Placing another sliding contact on the inductance, Fig. 171, converts it into a two-slide tuning coil and makes possible somewhat finer adjustments, and a further refinement is obtained by the addition of a third slider, making it a three-slide tuning coil. It will be evident, however, that in these circuits inductance preponderates, the only capacity being the distributed capacity of the aerial and the variable inductance. While it is an advantage to have an excess of inductance over capacity in the receiving circuit, it must be borne in mind that the wave length is determined by the product of the two and that the value of the latter must be greater than that afforded by the distributed capacity of the aerial circuit and must also be variable.

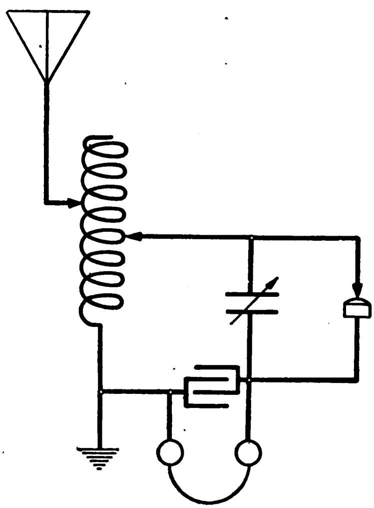


Fig. 172. Direct-Coupled Receiving Circuit with Variable Inductance and Capacity

Unless the capacity as well as the inductance be variable, sharp tuning is not possible. Hence, the next step is the addition of a variable condenser, Fig. 172, shunted across the detector circuit. A stopping condenser is also connected in series with the detector and in shunt across the telephones to prevent the high resistance of the latter choking back the oscillations. With the two-slide tuning coil shown in this circuit, an auto-transformer effect is obtained, the part of the coil connected to the aerial acting as the primary and the part connected to the detector, as the secondary. The portion of the inductance not in use is termed the dead end and is a disadvantage in that it absorbs part of the received energy to no purpose. In the design of modern receiving circuits, these dead ends are eliminated as far as possible or their effect is minimized by cutting them out of the circuit.

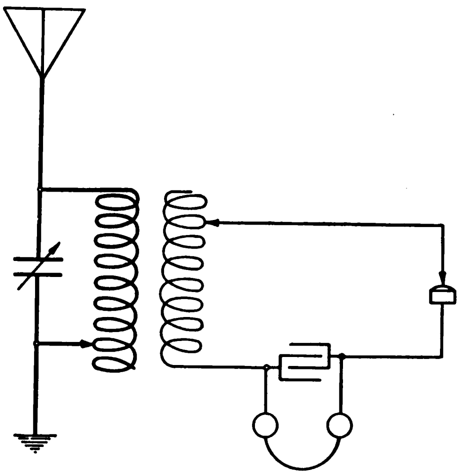


Fig. 173. Inductively Coupled Receiving Circuit with Variable Inductance and Capacity in Primary of Receiving Transformer Circuit

All the foregoing are termed *directly coupled* circuits for, while an inductive, or transformer, effect is obtained with the two- and three-slide tuning coils, a metallic connection exists between the aerial and the detector circuits. It is accordingly impossible to control the mutual induction of the primary and secondary of the receiving inductance; one reacts on the other so that sharp tuning of the incoming wave is not possible. Consequently, this type of receiving circuit suffers from the same disadvantages as the directly coupled transmitting circuit. Directly coupled circuits for either sending or receiving have long since been obsolete.

Inductively Coupled Circuits. *Variable Inductance and Capacity in Primary and Secondary.* It has already been pointed out that variations of the wave length are made by adjustments of both the capacity and the inductance, and in the simplest form of an inductively coupled circuit, Fig. 173, both the inductance and the capacity in the aerial circuit are made adjustable. This represents the primary, or open, circuit, while a second inductance is introduced in the closed circuit, which forms the secondary of a receiving oscillation transformer. In this simple circuit only the inductance of the secondary can be varied, so a better balance is secured by the addition of a variable condenser to the secondary circuit, Fig. 174. Resonance is then obtainable by adjusting the values of inductance and capacity in both the primary and secondary circuits.

Effect of Inductive Coupling. Coupling in the receiving circuit has the same effect as in the transmitting circuit. In the case of the transmitting circuit the open and closed oscillation circuits

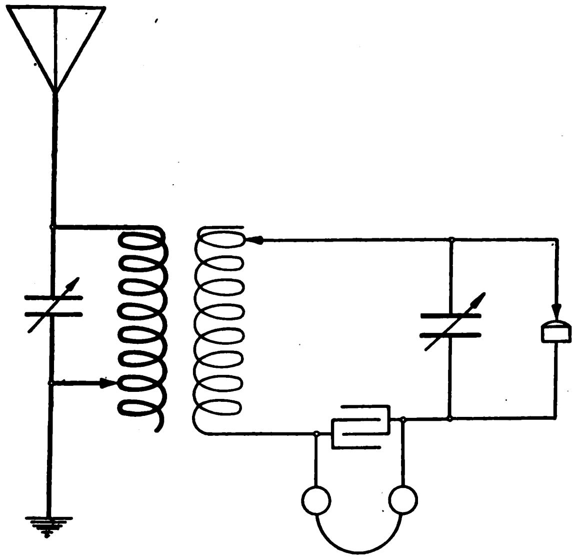


Fig. 174. Inductively Coupled Receiving Circuit with Variable Inductance and Capacity in Primary and Secondary

may be tuned to the same wave length, but waves of two distinct lengths will be radiated if the circuits are closely coupled. In the same manner, the primary and secondary of the receiving circuit may be tuned to resonance at two different points, if closely coupled, showing that there are two distinct wave lengths in each circuit, even though only a single wave length is being radiated by the transmitting station. The wave length is accordingly affected quite as much by coupling as by the adjustment of the values of capacity and inductance in the two circuits, so that when the receiver has been tuned to an incoming wave and it is then necessary to loosen the coupling to eliminate interference, it is necessary to readjust the values of capacity and inductance.

Typical Commercial Circuits. In Fig. 175 is shown what may be termed a fundamental circuit of the inductively coupled type, that is, it comprises all the essentials necessary to a circuit of this class, such as a receiving oscillation transformer of which both the primary and secondary are variable, adjustable capacities in both

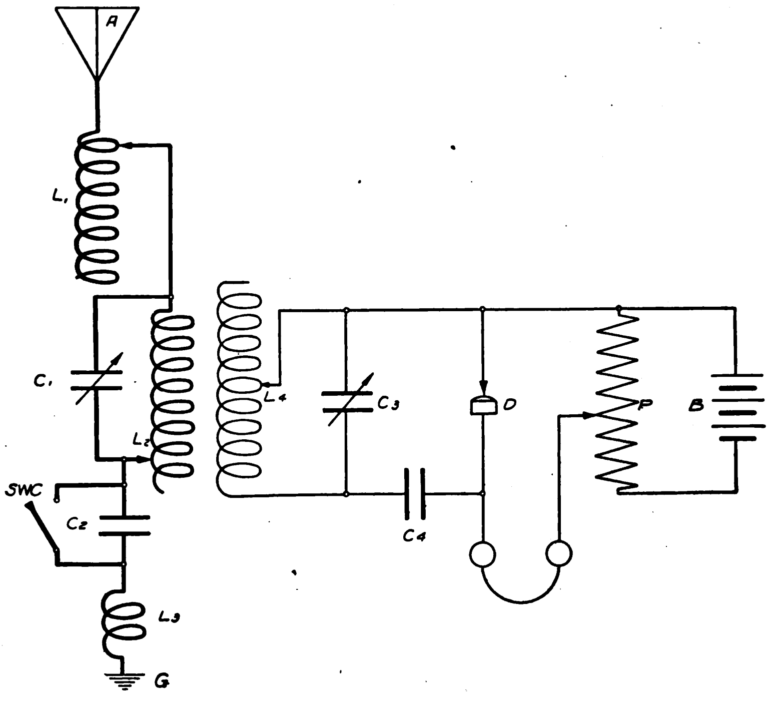


Fig. 175. Complete Receiving Circuits of Inductively Coupled Type with Crystal Detector—L_1, Aerial Tuning Inductance; L_2 and L_4, Primary and Secondary of Receiving Transformer; L_3, Test Inductance Coil; C_1, Variable Capacity in Shunt with Primary; C_2, Short-Wave Condenser; C_3, Variable Capacity in Shunt with Secondary; *P*, Potentiometer; *B*, Battery; *S WC*, Short Wave Condenser Switch

primary and secondary circuits, detector, stopping condenser, and telephones. With this as a basis, auxiliary apparatus is added to increase the strength of the received signals so that audible sounds may be produced in the telephones by the weakest currents; to suppress interference; and to add to the selectivity of the receiving circuits. For example, a local battery and potentiometer, Fig. 152, are employed in connection with the crystal detector; two local batteries are employed with a vacuum-valve detector, as illustrated in Fig. 160; or an intermediate closed oscillation circuit

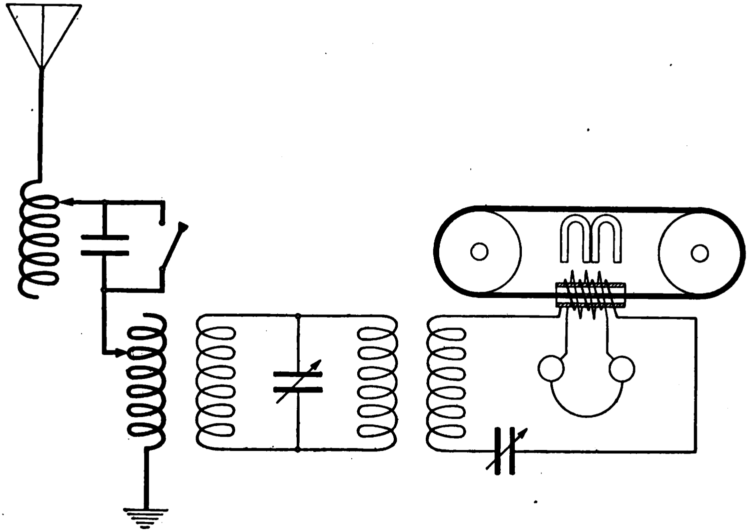


Fig. 176. Circuits of Marconi Multiple Tuner with Magnetic Detector—In Actual Practice Additional Condensers Are Employed in Series and in Parallel in Intermediate and Detector Circuits to Vary Wave Length While Magnetic Detector Is Connected so That It May Be Switched Directly into Aerial Circuit for Stand-By Position. Only Primary of Receiving Transformer is Variable

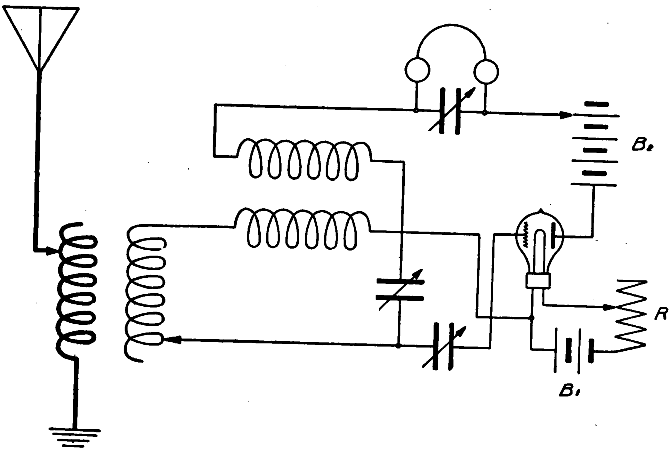


Fig. 177. Regenerative Vacuum-Valve (Three-Element) Circuit—B_1, Battery for Lighting Filament; B_2, Battery for Imposed Potential on Plate of Valve; R, Resistance for Varying Potential across Filament

may be interposed between the aerial and the detector circuits, as shown by Fig. 176, which represents the fundamental circuit of the

Marconi multiple tuner. In this the received oscillations are transferred from the aerial to the intermediate circuit and from the latter to the detector circuit. This type of tuner is employed by the English Marconi Company in connection with the magnetic detector. A *repeater*, or *regenerative circuit*, for increasing the strength of the incoming signals is shown in Fig. 177. This consists of a three-element vacuum valve, four variable condensers, and an additional inductively coupled inductance, as illustrated by the wiring diagram. By means of this apparatus the oscillations flowing in the telephone circuit are repeated back to the grid of the vacuum valve, and thus their amplitude is increased and, in consequence, the sound produced in the receivers, without interfering with the functioning of the valve as a detector. In the Armstrong regenerative circuit the currents flowing in both the oscillation and the telephone circuits are simultaneously repeated back to the grid of the valve with a marked increase in the amplitude of the signals.

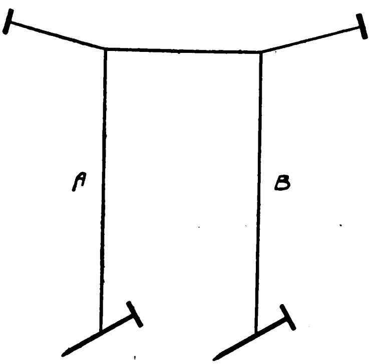


Fig. 178. Pierce Sympathetic Pendulums for Illustrating Coupling

Explanation of Coupling. It is very necessary that the student should have a clear idea of the meaning of the term coupling in order to understand the effect of inductively coupling two circuits and the important bearing that it has on the sharpness to which both the sending and receiving circuits may be tuned. Hence, the mechanical analogue of the *sympathetic pendulums* devised by Professor Pierce* as a means of illustrating this is cited. The device consists of two pendulums suspended from a transverse cord, as shown in Fig. 178, this supporting cord being about 3 feet long. The experiment may be carried out by tying this cord to the backs of two chairs, while the pendulum bobs may be any convenient objects of approximately the same weight, such as nails. The threads supporting the bobs must be of the same length.

By allowing one pendulum *B* to remain stationary and then

*See *Principles of Wireless Telegraphy* by G. W. Pierce.

drawing the other *A* out at right angles to the supporting cord and releasing it, *B* will begin to swing in sympathy with *A* and as the amplitude of the oscillations of *A* decrease, those of *B* will increase; when the latter have reached their maximum, the action will be reversed. This shows that when two vibrations of different periods coexist in the same system, the slower of these vibrations will fall more and more behind the other in phase until they neutralize each other; then the slower vibration will again fall more and more behind until it is a whole vibration behind the faster, when the two vibrations will be added together and will thus intensify each other. This action has been recorded by

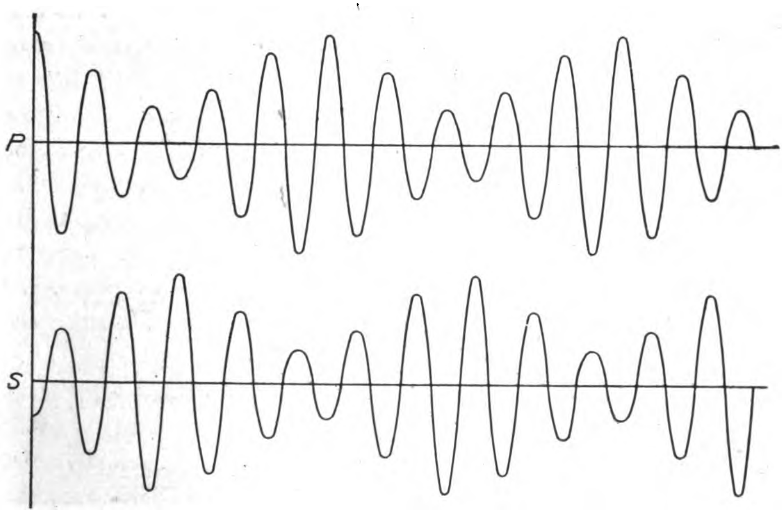


Fig. 179. Curves Traced by Sympathetic Pendulums

Professor Pierce with the aid of an oscillograph, giving the curves in Fig. 179, in which *P* corresponds to the primary circuit of the coupled condenser circuit. The curve *P* was obtained by leaving *B* at rest and setting *A* in motion and corresponds to the primary current of the coupled condenser circuit; the curve *S* was made by leaving *A* at rest and setting *B* in motion and corresponds to the secondary current of the coupled condenser circuit. The same action as is shown by the pendulums takes place with the electrical vibrations of condenser circuits that are coupled together.

When two circuits are coupled together, either directly or inductively, the primary circuit will have two periods of oscillation and the secondary circuit will have the same two periods of oscillation, this being true even when both the circuits have been tuned to the same frequency before being coupled. This gives rise to two distinct wave lengths and it will be apparent that if the energy in each represents a substantial fraction of the total, it will be difficult to receive either without interference from the other. Coupling permits of varying the mutual inductance so that the greater part of the energy radiated can be concentrated in one wave length. When the energy in the shorter wave is but 10 per cent or less of that in the longer wave, the result is said to be a *pure* wave which complies with government regulations. The receiving circuit can then be tuned sharply to that particular wave length, thus minimizing the interference from waves of other lengths.

"Tight" and "Loose" Coupling. When the primary and the secondary are placed close together, the coupling is said to be *tight;* when they are moved apart, it is *loose.* This applies to both the transmitting and the receiving oscillation transformers but is used more particularly with reference to the former as it is the coupling of the sending oscillation transformer that determines the nature of the wave radiated. By reducing the coupling, the oscillations of the two different frequencies approach closer and closer to the same period so that they almost merge into a single frequency, but as a certain amount of mutual induction is necessary for the transfer of the energy from the primary to the secondary, they can never exactly coincide. The tighter the coupling, the higher the damping of the wave, so when the two are very close together what is termed a *broad wave* results, while with loose coupling a sharp wave is produced, though this is naturally at the expense of the amount of energy transferred.

As an example of the percentage of coupling, assume that both open and closed circuits have been tuned to 600 meters. The lengths of the two waves being emitted are then found to be 650 for the longer and 475 for the shorter. Then $\frac{650-475}{600}$, or 29+ per cent shows that the coupling is too tight. By separating the primary and secondary, curves showing 625 meters for the longer and 565 meters for the shorter wave are then obtained, giving a percentage of coupling of 10, so that by loosening the coupling slightly more the two waves might be made almost to coincide, but any substantial reduction beyond the point given would result in too great a decrease in the efficiency of the transfer of the energy.

Stopping Condenser. In the various diagrams of receiving instruments it will be noted that a condenser is usually shunted across the head telephones. This is done in order to provide a complete circuit for the high-frequency oscillations without their having to pass through the telephone receivers, the high inductance of which would cause them to act as choke coils, thus holding back the oscillations and preventing the vibration of the diaphragms. In some types of receiving circuits this condenser also serves to prevent the short-circuiting of the local battery and this accounts for the term stopping, or blocking, condenser often applied to it. With the high-resistance telephones employed in connection with crystal detectors, the capacity of this condenser is usually about 0.003 to 0.0035 microfarad, the value of this capacity, however, varying with the frequency. For a 500-cycle transmitter, it would be lower, say, from 0.002 to 0.003 microfarad. A large capacity cannot be used for this purpose since it would act as such a low-impedance shunt for the pulsating currents from the detector that no current would pass through the telephone receivers. Nor can a very small capacity be used to advantage as it would prevent the passage of the oscillations through it. A variable condenser is sometimes used for this purpose but the fixed type is usually employed. The use of a variable condenser here in connection with an adjustable telephone receiver (one in which the period of vibration of the diaphragm may be made to correspond to the frequency of the circuit by altering its distance from the pole pieces of the magnet) serves to increase the strength of the signals and the selectivity of the circuits without any variation of the tuner.

TUNING CIRCUITS

TUNING TRANSMITTER

Importance of Resonance. In the foregoing sections the nature of electromagnetic waves and the method of their production and propagation through the ether have been outlined. A study of those sections should have firmly impressed upon the student the importance of resonance in all wireless circuits. From the inception of the wave at the sending station to its reception at the distant receiving station, resonance plays the most essential rôle. Unless the alternator be in resonance with the primary of the transformer, the efficiency of the latter will not be at the maximum; likewise, the primary and secondary circuits of the transformer itself must be in resonance. Consequently, unless these circuits vibrate in unison there will be a power loss in addition to that ordinarily attendant upon the stepping-up of the potential through the transformer. The greatest amount of energy can be transferred from the closed oscillation circuit to the open, or radiating, circuit, only if they are also in resonance. As the distance covered by the signals for a given amount of power is measured by the efficiency of the transmitting station, the operator must vary the adjustments in order that the maximum percentage of the current input at the transformer be converted into radiated energy in the aerial circuit in the form of a sharply tuned wave.

Process of Tuning. The term tuning is used in analogy with the tightening or loosening of the string of a musical instrument to cause it to produce the same note as that given out by a tuning fork. Wireless circuits may be said to be tightened or loosened to put them in tune with each other, as by varying their values of inductance and capacity they are caused to produce or to respond to notes of lower or higher pitch, since the frequency of the vibrations directly determines the wave length. From the preceding paragraph, it will be evident that tuning is almost wholly a matter of resonance, for when once adjusted to emit a given wave length, the efficiency of the transmitter is governed by the resonant relation of its circuits. This relation of the alternator and the primary of the transformer is usually inherent in their design, though in some cases it is secured by means of reactance regulators provided for that purpose. The capacity of the transmitter is usually a fixed value, except that provision is sometimes made for changing the connections of the bank of condensers from parallel to series to reduce their capacity, so the chief adjustments of the transmitter are those of the spark gap, or discharger, value of inductance (number of turns or parts of turns in the primary and secondary of the oscillation transformer in circuit), and the coupling of the two elements of the transformer in order that a sharply tuned pure wave may be emitted.

Approximating Resonance. *Detection with Hot-Wire Ammeter.* To provide a constant indication of the operation of the transmitter, a hot-wire ammeter is included in the aerial circuit. When the oscillation circuits are adjusted to give the maximum reading of the ammeter, they are in resonance and the set is operating at the maximum efficiency for that particular wave length.

Detection with Incandescent Lamp. Another equally simple, though not quite so effective, method is the use of a resonator, or resonance indicator. This is simply a low-voltage incandescent bulb of the carbon-filament type placed in inductive relation to a part of the aerial circuit. When the latter is energized, the filament will glow and it will reach the highest degree of incandescence when the greatest amount of energy is being radiated.

Commercial Adjustments. In some commercial sets the bulb is provided as an emergency substitute for the hot-wire ammeter in case of the failure of the latter in operation. In all commercial apparatus, of course, definite and quickly made adjustments are provided for changing from one wave length to another. For example, in the Marconi ship sets, a simple throw of a switch shifts all the necessary connections to change from 300 to 450 meters or from the latter to 600 meters. After throwing this switch, any slight variations necessary in the inductance are made to give a maximum reading of the hot-wire ammeter. Definite locations are also marked on the oscillation transformer to indicate the coupling necessary to emit a sharply tuned pure wave for ordinary communication or a broad wave to send out a distress call.

While the operation of the transmitter is thus rendered easy, it is essential that the student should be thoroughly familiar with the nature of the adjustments necessary and the method of making them. To tune a transmitter when the wave-length adjustments are not marked on the instruments, it is necessary to determine the wave length of the open and the closed circuits and, in addition, to measure the length of the radiated wave, since, as has already been pointed out, the coupling also affects the latter and waves of two distinct lengths may be radiated even though the closed and open circuits are sharply tuned to the same wave length.

Uses of Wavemeter. As has already been explained under the head "Wavemeter," page 79, the wavemeter is a miniature oscillation circuit which has been calibrated by comparison with a standard so that it is quickly adjustable to a given range of known wave lengths. It will be apparent that by providing the wavemeter with some form of indicating instrument the wave length of a circuit under measurement will be known when this instrument indicates resonance between it and the wavemeter.

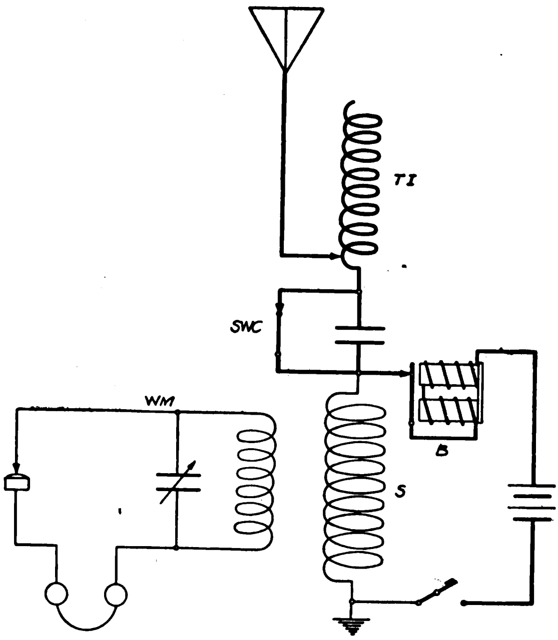


Fig. 180. Measuring Natural Wave Length of Aerial Circuit with Wavemeter—Aerial Being Excited by Buzzer *B* while Wavemeter *WM* Is Placed in Inductive Relation with Secondary of Oscillation Transformer *S*; Tuning Inductance *TI* Adjusted to Zero and Short-Wave Condenser Shunted by Switch

This indicator may take the form of a detector and the usual receiving telephones, a hot-wire ammeter, an incandescent bulb, or a vacuum tube; in the first instance, resonance is indicated by the maximum sound in the telephones, whereas in the others the indication is visible.

Measuring Open Circuit. To measure the wave length of the open, or radiating, circuit, the primary of the oscillation transformer is entirely disconnected from the closed oscillation circuit.

The aerial, or open, circuit is then energized by exciting it with a buzzer and battery, as shown in Fig. 180, and the wavemeter is placed in inductive relation with the secondary of the oscillation transformer. In case it is desired to measure the natural wave length of the aerial circuit, the sliding connection on the loading inductance must be set at zero in order that no turns of the latter be included. The variable condenser of the wavemeter is then adjusted until the loudest sound is produced in the telephone receivers, at which point the two circuits will be in resonance and the wave length of the wavemeter will be that of the aerial circuit, since their frequency is the same. This wave length can then be read either directly from a scale on the wavemeter or with the aid of the wavemeter scale and a calibrated chart.

Measuring Closed Circuit. Closed-circuit measurements are carried out by first isolating the aerial circuit, including the ground

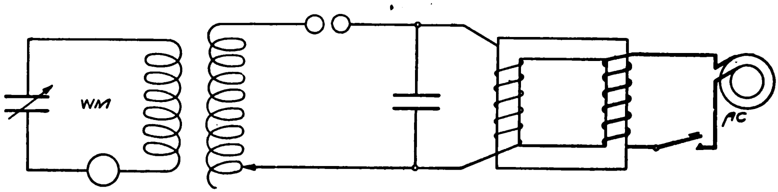


Fig. 181. Measuring Wave Length of Closed Oscillation Circuit with Wavemeter *WM*

connection, from the closed circuit, as illustrated by the diagram, Fig. 181. The closed circuit is then energized in the usual manner by the alternator, transformer, condensers, and spark gap, in other words, it is operated as usual, but the place of the open circuit is taken by the wavemeter. When measuring the open circuit with the aid of a buzzer, the wavemeter may be placed within a few inches of the circuit as the current in it is merely nominal, but in making the measurement of the closed circuit, the wavemeter must not be placed closer to the instruments than 6 to 8 feet, as the powerful current induced in the wavemeter coils would be liable to burn them out. In this case resonance may be indicated with the aid of the small incandescent bulb instead of with the telephones.

Measuring Radiated Wave. While tuning the open and closed oscillation circuits adjusts them to the same wave length, the length of the radiated wave is also influenced by the degree of coupling between the primary and secondary of the oscillation transformer, so that it is also necessary to measure the length of the radiated wave when the percentage of coupling is varied. The connections of the set are restored to normal and the wavemeter is then placed in inductive relation with the ground con-

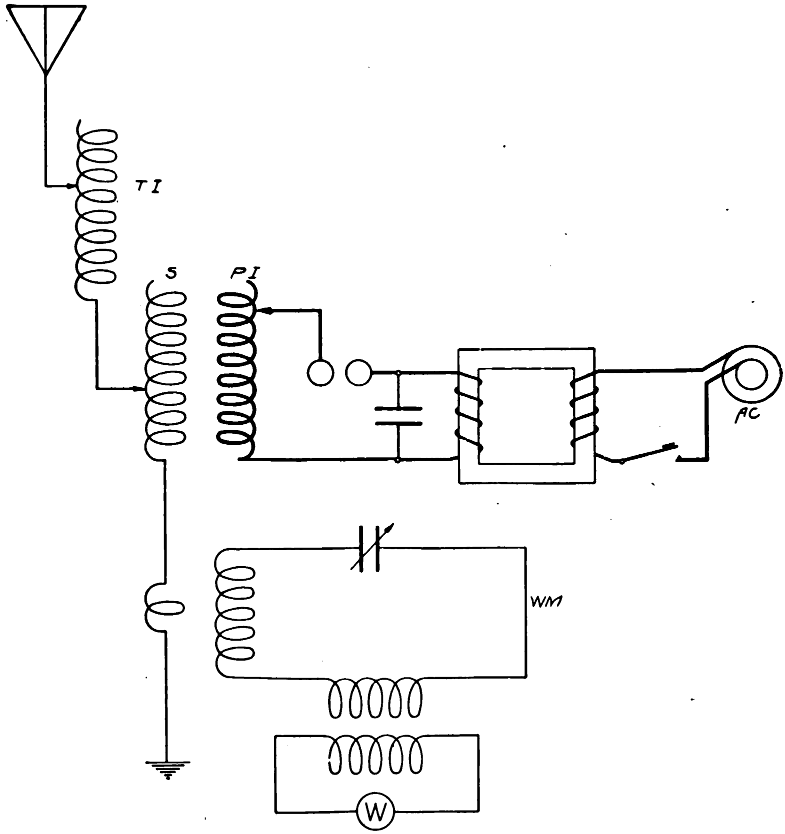


Fig. 182. Measurement of Radiated Wave—*TI*, Tuning Inductance; *WM*, Wavemeter; *W*, Wattmeter Operated through Wavemeter by Small Transformer. By Varying Percentage of Coupling between *P* and *S*, Resonance Curve May Be Plotted

nection of the open circuit, a loop or coil usually being taken in this to increase its inductive effect, Fig. 182. If the windings of the oscillation transformer are close together, that is, tightly coupled, the wavemeter will indicate that two waves of widely separated lengths are being radiated, the set being put into operation in the usual manner. The coupling must then be loosened by drawing the primary and secondary apart or varying their inductive relation, if of the variometer type, until either the wave-meter indicates that but a single wave length is being emitted or, if two wave lengths are still plainly read, the energy of the smaller does not exceed 10 per cent that of the latter. From this, it will be apparent that the approximate method previously described, that is, with the hot-wire ammeter, while indicating resonance between the closed and open circuits does not give the length of the radiated wave nor its character as influenced by the degree of coupling. With the quenched gap in efficient operating condition the coupling may be closer than with any of the other types.

Adjustment of Spark Gap. The pitch of the spark note emitted as well as the degree of damping of the wave is determined to a large extent by the adjustment of the spark gap. It is essential that the resistance of the gap be practically infinite just before the discharge starts and that it be reduced to almost zero during the discharge and again quickly increased to a high value. As the air is rendered conducting by the passage of the spark, it will be evident that this condition cannot be met by the plain spark gap, since the heated air and gases in the latter will remain conducting long after the closed circuit should have ceased oscillating. An air blast is accordingly employed to keep this type of gap cool; its use is chiefly restricted to emergencies in which a broad wave is an advantage, as in sending out a distress signal. The rotating gap, whether of the synchronous or nonsynchronous type, is adjusted as previously explained, the object being to have the electrodes come as close together as possible, short of the point where an arc will be formed between them. If the gap be too wide, an excessive strain is placed on the condensers while the secondary winding of the transformer is also subjected to undue strain and the spark itself becomes rough and irregular.

Use of Decremeter. It has been pointed out that in coupled circuits energy is radiated at two different wave lengths, which differ according to the degree of coupling, the shorter wave train being the most highly damped. But each circuit has its own decrement of damping and the decrement of the radiated wave differs from that of either. The symbol employed to represent the factor of damping is δ (Greek letter delta), and the damping of any circuit is found by the equation

$$\delta = \frac{R}{2nL}$$

in which R is the resistance, n is the frequency, and L is the inductance of the circuit, δ being the Naperian logarithm of the ratio of two successive oscillations in the same direction. The damping

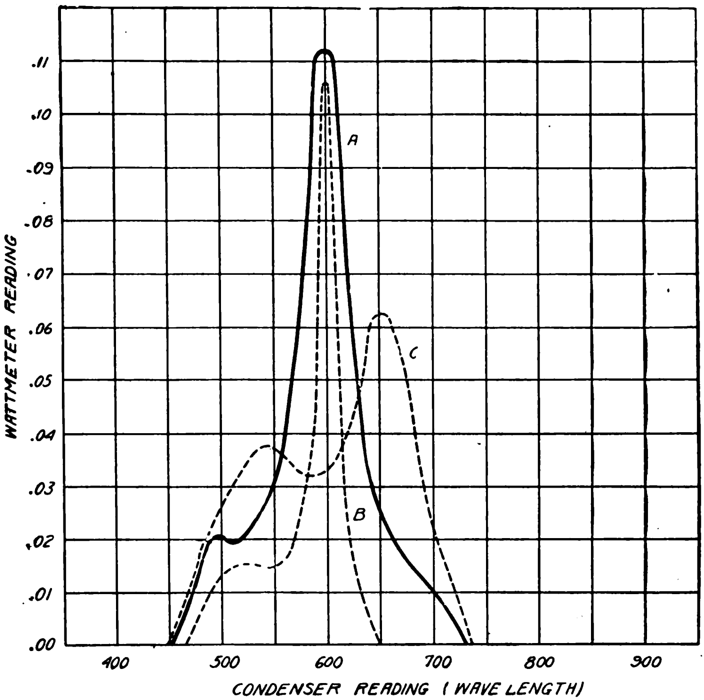


Fig. 183. Resonance Curves as Plotted—*A*, Sharp Wave but Does Not Comply with U.S. Regulations Since More than 10% of Energy is Being Radiated in Short Wave; *B*, Pure Wave Approximately Fulfilling Requirements; *C*, Broad Wave Having Two Distinct Lengths at 550 and 650 Meters, the Shorter Having Approximately 40% of Total Energy

of the radiated wave is determined with the aid of the decremeter, which is simply a wavemeter combined with a current-measuring device, such as a hot-wire ammeter or a wattmeter. Using the decremeter, the strengths of the currents received at various wave lengths are employed to plot a resonance curve of the circuit. The contour of this curve will be proportional to the amount of energy radiated at the various wave lengths, and when the two circuits are properly tuned and the oscillation transformer is loosely coupled, the curve will represent a sharp peak, as in Fig. 183. Curve *B* represents a pure wave, that is, the energy of the lower hump of the curve, at approximately 520 meters, is less than 10 per cent of that of the larger. Curves *A* and *C* do not comply with government regulations since, in both cases, more than 10 per cent of the energy is being radiated by the shorter wave. By further loosening the coupling necessary to produce curve *B*, the two wave lengths may be made to practically coincide. Except as it may be controlled by a variation of the coupling, the damping factor is a function of the design of the circuits and is accordingly not under the control of the operator. The decremeter is chiefly employed by government inspectors in testing an installation before approving it for commercial use and by the manufacturers of the apparatus.

TUNING RECEIVER

Sending Circuit Sharply Tuned Except When in Distress. The tuning of the receiving circuit is affected by three factors: (1) the variations of inductance and capacity necessary to place the receiving circuit in resonance with the sending circuit; (2) variations of the degree of coupling in the receiving oscillation transformer; and (3) adjustments designed to render the detector most sensitive. Except when necessary to send out a distress call, the sending circuit is never operated on anything but a sharply tuned wave, in order to minimize interference with other stations. For transmitting a distress signal, however, tight coupling is employed to radiate a broad wave, that is, a band of waves of various lengths, so that the signal may be heard by the greatest number of stations within reach. This end is also attained in emergencies by placing the spark gap directly in circuit with the aerial so that a very broad and highly damped set of wave trains is emitted, thus intentionally producing the maximum interference.

Method of Setting Receiving Circuit. *Broad Wave at First.* Until the receiving operator has established communication with some particular station, he has no means of knowing on what particular wave length messages intended for him will be sent. The tuner is accordingly adjusted to receive a broad wave while the operator is *listening-in,* that is, listening for his own call.

This is known as the stand-by position, by analogy with the naval command given in the same words and calling for readiness to receive further orders or perform a certain duty when the moment arrives.

"Stand-By" and "Tune" Adjustments. On some commercial sets there is accordingly provided a switch that, when thrown to the stand-by position, gives a broad adjustment. When the operator hears his own call, he throws this switch to the tune position and then proceeds to make the necessary adjustments of the loose coupler; that is, he varies the inductance of the primary

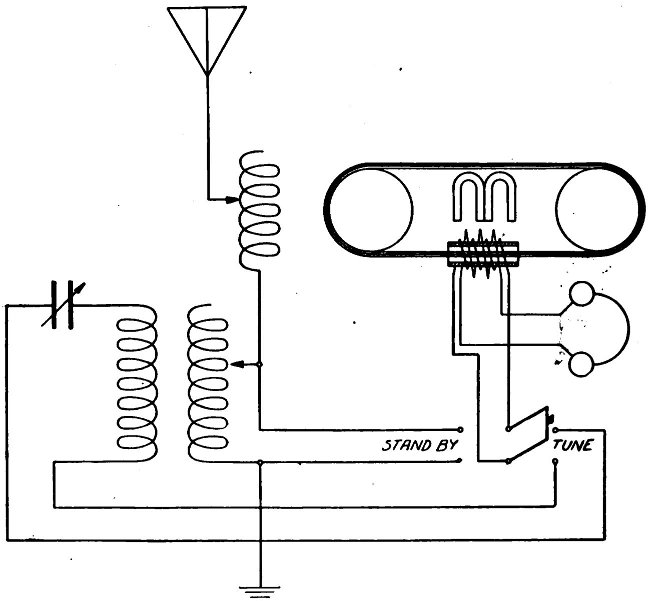


Fig. 184. Wiring Diagram for "Stand-By" and Tune Positions of Marconi Tuner (Intermediate Circuit Omitted)—When Thrown to Left, Switch Connects Detector and Phones Directly in Aerial Circuit for "Stand-By" Position

and secondary as well as their coupling and adjusts the variable condensers in order to bring in the signals clearly. An illustration of this provision is given in Fig. 184, which represents the Marconi multiple tuner with a magnetic detector. In the stand-by position the magnetic detector is directly connected in the aerial circuit through this switch and a separate ground connection, as shown. In the tune position this ground is cut out and the magnetic detector thrown into circuit with the secondary of the multiple tuner.

Adjusting Detector. Before beginning his watch at the stand-by position, however, the operator first makes certain that the detector is in a sensitive condition for receiving. This is accomplished by the use of the buzzer test set which, as previously explained, acts as a miniature sending set. In the case of a crystal detector, the contact is moved over the face of the crystal and the pressure increased or decreased until the most sensitive spot is located; then the potentiometer is adjusted until the current from the local battery, superimposed on the oscillations produced by the buzzer, creates the loudest sound in the telephone receivers. The detector is then ready for receiving, but as in this condition it is subject to derangement to a greater or less extent by mechanical vibration or by the operation of the transmitter, it is necessary to check it from time to time with the buzzer test. In the case of the vacuum valve, the battery switch is closed to bring the filament to incandescence and then the multi-point switch of the high-voltage battery is adjusted until the potential across the grid is located at which the buzzer oscillations produce the loudest sound. This type of detector is not affected by outside influence and, as the proper voltage for efficient receiving is readily determined after a little experiment, the position of this switch is known, so it is only necessary to place the two battery switches on points which are known to give easily read signals in the telephones.

Variations of Inductance. When a broad wave is being radiated by the sending station, the receiving operator may select either of the wave lengths on which he can receive the message, it often being the case that equally efficient receiving can be done on either of two waves of considerable difference in length. But when a sharply tuned wave is being transmitted, the receiving tuner must be adjusted to equally close limits in order to receive it effectively. When there is little perceptible difference in the audibility of the signals over a wide range of adjustment, the operator knows at once that a broad wave is being received. If a sharply tuned wave is being received, only a very slight change in the adjustment will result in making it unreadable or in losing it altogether. The primary inductance is therefore tuned by the *tens* switch until the signal is as loud as can be obtained with that adjustment, and then the *units* switch is employed to vary the inductance a single turn at a time to place the primary in resonance with the sending station. The secondary is similarly tuned but its adjustment need not be so fine. A further approach to resonance between the primary and the sending station is obtained by varying the adjustment of the primary condenser, and the secondary circuit is then placed in resonance with the primary by similar adjustments of its condenser.

Elimination of Interference by Coupling. *Damping Out Secondary Waves.* After both the inductance and the capacity have been adjusted to the proper values to bring the signals in clearly by using the multi-point switches of the coils to vary the number of turns in circuit and then using the handles of the variable condensers to find points on their scales where the circuits are in resonance, the usual result is that not alone the desired message but a number of others on approximately the same wave lengths will be heard in the telephones. When a circuit is tuned for the reception of a certain wave length, it is understood that waves of that length cause signals of the maximum strength to be heard in the telephones. But waves of slightly different lengths, either longer or shorter, will also produce audible signals in the receivers, and while these signals will be weaker than those of the desired wave, they are often of sufficient strength to interfere with its reading. This is on the assumption that the foregoing adjustments have been made with the loose coupler more or less tightly coupled. The coupling is then loosened in order to render the receiver responsive through a narrower range of wave lengths, thus eliminating the undesired signals.

Reading Messages in Spite of Interference. While it is stated above that the undesired signals are weaker, this is not always the case, as the relative strength of the signals depends on the relative distances of the different sending stations. For example, if the desired station is at a great distance and several other stations are operating at short distances from the receiver, their waves are apt to come in very much stronger than those of the station it is desired to read. The coupling would then have to be made very loose in order to minimize the effect of these nearby stations, but as this is accomplished at the expense of the amount of energy received, the signals of the distant station are correspondingly weakened, so a point has to be found where the message from the latter can be read through the interference. In a case of this kind, it is practically impossible to *tune out* the undesired stations entirely, since a much greater proportion of energy is reaching the receiver from them than from the distant station. But where a number of stations, all of which are distant from the receiver, though their distances may differ considerably, are heard, it is usually possible to tune them out entirely—or at least to the point where they do not interfere in any way with the reception of the desired message. The further away the sending station, the closer the coupling must be for effective receiving, since with very loose coupling a large proportion of the energy is sacrificed and the exceedingly feeble currents received at great distances do not permit the loss of any more of their energy than is absolutely necessary to eliminate interference.

Use of Condensers. In the foregoing section, the order in which the various adjustments are made in tuning is not arbitrary by any means. As an operator is apt to leave both inductances and capacities adjusted approximately at the values at which he is accustomed to receive most frequently, a slight variation of the coupling may be all that is necessary to tune the set sharply. It must also be borne in mind that a variation of the coupling influences the self-induction of the primary and secondary of the loose coupler and that altering the coupling involves changing either their adjustment or that of the variable condensers to place the circuits in resonance again. A variation of the inductance value should preferably be used in tuning the primary, or aerial, circuit, as the use of the shunt condenser in this circuit to increase the wave length by increasing the capacity is usually at the expense of the energy received, with the result that the signals are weaker. Some types of receivers are not fitted with a condenser in the primary, though its use gives increased selectivity.

Short-Wave Condenser. In the majority of ship stations the natural wave length of the aerial circuit so closely approximates the standard commercial wave, that is, 600 meters, that but slight changes in the value of inductance in the aerial circuit are necessary to tune it. This also refers to the intermediate wave length of 450 meters, but to receive on the 300-meter wave, as is necessary to comply with government regulations when approaching the coast, the short-wave condenser must be included in the aerial circuit to reduce the natural wave length of the latter.

Shunted Condenser. The condenser shunted across the secondary of the receiving oscillation transformer is of small value and is normally kept adjusted close to the zero point on the scale. Its chief function is to aid in eliminating interference so, when further loosening of the coupling does not effectively tune out an interfering station and weakens the desired call too much, the capacity of this condenser in the circuit is increased and the value of the secondary inductance decreased to compensate for it. This permits tuning out wave lengths which vary but slightly from the one being received. When the use of a larger value of capacity reduces the inductance in circuit to a low value and the signals being received are very few and weak, the *end turn switch* is operated to cut out those sections of the inductance that are not being employed. While a transmitting station, such as a marine installation, is only designed to transmit on the 300-, 450-, and 600-meter wave lengths, the receiver used with it must be capable of receiving a wide range of wave lengths in order to enable the operator to pick up shore stations as well. For example, weather reports and time signals are sent out by Arlington on a 2500-meter wave. Most ship sets are accordingly capable of receiving wave lengths of from 200 to 3000 meters. For this reason the inductances must be made considerably larger than is necessary for use on the shorter wave lengths and, therefore, when receiving on a 600-meter adjustment, a large part of the coil is not in use. As this unused part may be of such length as to have approximately the same frequency as the aerial circuit, it will be in resonance with the latter and some of the energy of the oscillations will be absorbed.

Stopping Condenser. The functions of the stopping condenser, which is shunted across the telephone receivers, are to provide a complete circuit for the oscillations without their having to pass through the windings of the telephone receivers, which have a very high inductance; and also to discharge through the telephones the energy thus received from the oscillations, in this way increasing the audibility of the signals. Where low-resistance telephone receivers can be employed, as in connection with the magnetic detector, no condenser is necessary. In some instances, as in the English Marconi receiver, the stopping condenser is made adjustable by means of a switch plug giving two or three changes of value, but ordinarily this condenser is of the fixed type and calls for no attention.

General Requirements as to Care of Receiving Apparatus. As the currents received are very feeble, the most important part of the care of the receiving apparatus is to see that its contacts are kept bright and clean and that none of the adjustments of the switches becomes loosened so as to make poor or loose contact, since dirty surfaces and poor contacts introduce substantial increases in the resistance, thus dissipating in the form of heat a valuable proportion of the already very limited amount of available energy. All adjustments, whether of inductance, capacity, or coupling, must be made in small increments, since the reception of sharply tuned waves involves placing the receiver accurately in resonance with the sending station and increasing or decreasing the inductance or capacity by comparatively large amounts causes the desired adjustment to be passed over too quickly to note the difference in the signals received.

The local battery employed in connection with a crystal detector should be placed in circuit only when receiving, and adjustments of the impressed voltage across the detector should also be made by very gradual movement of the potentiometer slider.

OPERATING PROBLEMS

INTERFERENCE

QRM—Are you being interfered with?*

In explaining by means of a mechanical analogue the propagation of electromagnetic waves through the ether, reference has been made to the familiar comparison of the waves set up by throwing a stone into a pond, also to the wave traveling along a taut string. If the stone at one end and the hinged paddle at the other are considered as representing, respectively, a crude sending and a receiving station, it will be apparent that waves other than

*See Table IX for official list of abbreviations, page 255.

those originating at the sending station will actuate the paddle, or receiving instrument, and that other waves may prevent those sent out from the sending station from reaching the receiving station as definite clear-cut impulses; in other words, while the ether will transmit a number of waves of different lengths at the same time, just as the surface of the pond will, the presence of a number in action at the same time is apt to cause confusion at the receiving station.

This confusion is termed interference and it may be made clear by slightly amplifying the action of the stone and paddle. Station *A* begins sending by plunging a 1-pound stone in the water three times. A triple series of waves start out in all directions but before they reach station *B* at the receiving end, station *C* begins sending but uses a 5-pound stone. More powerful waves are thus sent out and, as they travel at the same speed, they overlap those sent from *A* before the latter reach *B*. Instead of responding definitely to the three impulses sent from *A*, the paddle at *B* is actuated by the double set of waves and a confused and irregular movement results. If, instead of a 5-pound weight, one of 10 pounds is employed at station *C*, the waves from the latter will be so much more powerful that those from *A* are drowned out altogether before reaching *B* and the receiver at the latter responds only to the waves from *C*.

The example just cited is an instance of interference between a low-powered and a high-powered station in the same vicinity and is responsible for the regulation that "All stations are bound to carry on the service with the minimum of energy necessary to insure safe communication"; and also for the requirement that a warning be sent out in advance of transmission by high power. To expand the above simile a bit further, assume that station *C* is not sending with any greater power than station *A*, but that, instead of transmitting a sharply defined impulse which produces a clean-cut wave of definite characteristics, it makes a splash that results in sending out a number of waves of different lengths. When these waves meet those sent out from *A*, the latter are not drowned out as in the case of the more powerful interference, but instead of responding only to the signals from *A*, *B* now receives waves from both *A* and *C*, some of which are of the same length and others of indeterminate lengths, so that the resulting usion is even greater.

This type of interference results from the sending of highly amped waves as well as from sending out broad waves, that is, waves of two or more distinct wave lengths, such as are produced by an untuned sending station. This is the class of interference for which the amateur has been largely responsible and it has resulted in restricting amateur stations to a very short or long wave length, well below or above those of the commercial stations and with a well-defined decrement. As the amount of power necessary to transmit on the long wave length is beyond the reach of the amateur, he is restricted to the 200-meter length and must transmit only a pure wave. The only instance in which it is allowable for a broad wave to be used is that of a ship station sending out a distress call, which must be heard by as many other stations as possible.

Interference also results from natural causes, all of which are usually grouped under the head *static* and are explained in the following section.

STATIC

QRN—Have you much static?*

Lightning being an oscillatory discharge of practically the same nature as that produced by the oscillating circuit of a sending station, thunderstorms produce electric waves of great power and wide variation of lengths. These waves are highly damped and, owing to their power, often affect stations at great distances. In addition to the powerful electrical disturbances thus set up, there is always a difference of potential between the earth and different strata of the air, usually termed local electrification. This differs with the season, the time of day, and the location of the station, usually being most marked in summer, the upper air generally being positively electrified and the earth negatively. Consequently, the aerial becomes charged and in turn discharges to earth through the ground connection. These discharges are irregular in both power and time of occurrence, and their passage sets up noises of varying character in the receiving telephones ranging from inter-

*See Table IX for official list of abbreviations, page 255.

mittent sharp clicks through a faint and continuous humming to a constant roar that renders receiving all but impossible. These discharges, together with the electric waves for the origin of which it is difficult to account, constitute a natural form of interference known as static.

As thunderstorms are most numerous and frequent in summer, interference of this nature is worst during the warm months and is, of course, encountered the year round in the tropics. The atmospheric difference of potential is also greater in summer than during the cold seasons of the year, so that interference from static is greatest in the warm months. This is one of the reasons why long-distance receiving can be carried on so much more efficiently during the winter and especially at night.

Static, also termed atmospherics in this country and *X's* and *strays* by British investigators,* is one of the problems of wireless telegraphy. While it is customary here to group all natural disturbances affecting the receiving instruments under the head of static, the terms *X's* and *strays* are generally employed with reference to those natural electric wave trains which, in general, are heavier and more frequent, the longer the wave to which the receiving circuit is adjusted.* A distinction is made between these vagrant waves and the discharges from the aerial due to local electrification. Among the commoner forms in which these disturbances manifest themselves in the receiving telephones are a sizzling, or frying, sound similar to that produced by an electrolytic detector but much more audible; sharp isolated clicks at irregular intervals and sometimes very loud; a rattling or grinding noise which is more or less constant; and a continuous roar, which may be likened to the sound heard when a large conch shell is held to the ear. Briefly, these are known to operators as the *hum,* or *sizzle, clicks, grinders,* and *roaring.* The hum, or sizzle, is usually due to a distant thunder squall, and for years advantage has been taken of this phenomenon in the central electric light and power stations in New York City to indicate the approach of a storm, as the latter always causes an unusually heavy demand for current in the lighting circuits in the business section. For this purpose, a filings coherer (the original type of detector now obsolete in

* See *Year Book of Wireless Telegraphy.*

wireless practice), tapper, relay, and local battery are employed to ring an ordinary electric bell. The effect of such storms on the receiving apparatus of a station may be appreciated from the fact that they frequently made their approach known four to six hours in advance of their occurrence.

The aerial of an inductively coupled receiving set thus forms an excellent lightning rod and serves as a protection to the station, rather than the reverse, as is commonly supposed. In fact, it is acting in this capacity more or less constantly all the year round and even when there are no storms, as is evident from the static discharges heard in the telephones. While danger from lightning is minimized by the aerial so far as the buildings are concerned, as the ground switch required by the fire underwriters can always be thrown to conduct any discharges directly to earth, the operation of a wireless station during a local thunderstorm is dangerous and should not be attempted.

LEARNING THE CODE

Continental Morse Code. Since the London Convention went into effect (July 1, 1913), all wireless communication, regardless of the system employed, is carried out by means of the Continental Morse Code. This is a slight variation of the original Morse system of dots and dashes, usually referred to as the American Morse. The chief distinction between the two is the elimination of spaced letters in the Continental. In the latter, there is a maximum of four elements to any one letter and only one length of dash is employed, that is, one equivalent to three dots, whereas in the American Morse, **P** is five dots and **L** is a double-length dash. The dash is used less in the American Morse so that it is faster than the Continental, but the Continental is better adapted to wireless. Operators holding commercial extra first grade licenses must be equally proficient in both codes, as when stationed on shore they must receive radio messages and transmit them over land lines. Continental is now known as the International Code and the differences between it and the American Morse will be noted in Table VII.

Practice Equipment. Wireless signals may be readily simulated with the aid of a simple buzzer set, as shown in Fig. 185.

TABLE VII

Telegraph Codes

SYMBOL	AMERICAN MORSE	CONTINENTAL
A	· —	· —
B	— · · ·	— · · ·
C	· · ·	— · — ·
D	— · ·	— · ·
E	·	·
F	· — ·	· · — ·
G	— — ·	— — ·
H	· · · ·	· · · ·
I	· ·	· ·
J	— · — ·	· — — —
K	— · —	— · —
L	———	· — · ·
M	— —	— —
N	— ·	— ·
O	· ·	— — —
P	· · · · ·	· — — ·
Q	· · — ·	— — · —
R	· · ·	· — ·
S	· · ·	· · ·
T	—	—
U	· · —	· · —
V	· · · —	· · · —
W	· — —	· — —
X	· — · ·	— · · —
Y	· · · ·	— · — —
Z	· · · ·	— — · ·
1	· — — ·	· — — — —
2	· · — · ·	· · — — —
3	· · · — ·	· · · — —
4	· · · · —	· · · · —
5	— — —	· · · · ·
6	· · · · · ·	— · · · ·
7	— — · ·	— — · · ·
8	— · · · ·	— — — · ·
9	— · · —	— — — — ·
0	————	— — — — —
.	· · — — · ·	· · · · · ·
?	— · · — ·	· · — — · ·

A dash is equal to three dots.

The interval between the signals which form the same letter is equal to one dot.

The interval between two letters is equal to three dots.

The interval between two words is equal to five dots.

This consists of an ordinary call buzzer, two cells of dry battery, a telegraph key, a simple condenser, and a telephone receiver, and the entire outfit can be assembled at an expense of a few dollars. In its usual form, however, the buzzer will only produce a low and harsh note which does not give an easily read signal. This is due to its low speed of vibration and is caused by the spring contact employed. To raise the frequency, the platinum contact should be removed from the spring, which should be taken off the armature and discarded, and the contact should then be soldered directly on the armature at a point where it will touch the stationary screw contact. By adjusting the screw, a high-pitched note will be obtained, very closely approximating that of a 500-cycle transmitting set; or, the entire armature and its operating spring may be discarded, substituting in its place a piece of piano wire held taut across the pole pieces of the electromagnet by means of a piece of clock spring at one end, Fig. 186. The platinum contact is then soldered to this wire directly underneath the screw contact.

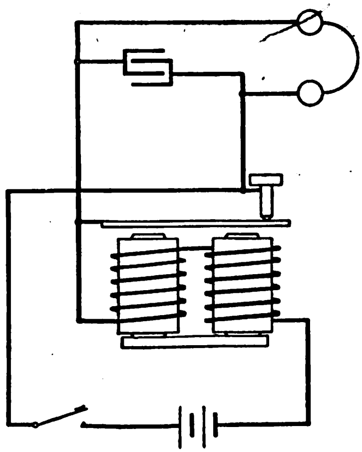


Fig. 185. Buzzer Set for Simulating Wireless Signals

A description of a condenser suitable for this purpose has already been given in the section on "Condensers," page 97. One of these may be made in a few minutes or a more ambitious effort undertaken with the use of tinfoil and paraffin paper purchased for the purpose, mounting the finished condenser in a wooden case. This will improve the appearance of the set although not its operating qualities, as the emergency condenser described will serve the purpose equally well. The telephone may be a single receiver of the watchcase type and of 75 ohms resistance, such as is employed in connection with low-priced telephones for house service, or it may be of the regulation wireless pattern with two receivers on a headband; there will be no noticeable difference in the operation of the two except that the double

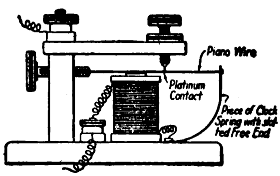


Fig. 186. High-Pitch Note Buzzer

receivers shut out other noises. Dry cells that have already seen more or less service are preferable to new ones, as the volume of sound produced is apt to be too great rather than otherwise. Where this is the case to a degree that tires the ear, a variable resistance may be introduced to cut down the noise. This rheostat may easily be constructed by the student with a few feet of small German silver wire or with a discarded arc light carbon and a sliding contact of copper or a battery rheostat may be purchased. It is preferable to make both the condenser and the rheostat at home, as a better understanding of their principles will thus be obtained.

Practicing Code Signals at Two Stations. While it is possible to become adept in the formation of the various letters and other

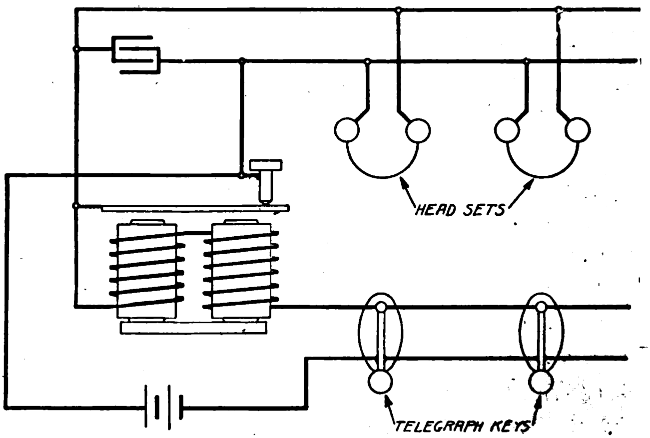


Fig. 187. Circuits of Buzzer Outfit for Learners at Two or More Stations

signals with the aid of a simple outfit such as that described, practice in sending alone will not enable the student to receive. Where two or more students can co-operate, this difficulty is readily overcome by duplicating the telephone and key units of the learner's set for the number of stations desired, using the same battery, buzzer, condenser, and resistance. In Fig. 187 only two stations are shown, but as additional outfits are simply connected in multiple, the keys with the buzzer and battery circuit and the telephones with the condenser and resistance circuit, it will be an easy matter to add any number desired. If the occasion assistance of an experienced telegrapher can be had, progress in both sending and receiving will be much more rapid, as the student can then be certain that his efforts are along the right line.

Care must be taken in the formation of the letters and numbers to see that the intervals mentioned are properly observed, that is, one dot between parts of the same letter; three dots between separate letters; and five dots between words; otherwise, parts of different letters or different words will run together to form combinations totally foreign to those the student is under the impression he is sending. For example, if too much space be allowed in the center of the letter • • ▬ • (F) it becomes • • ▬ • (in); an undue interval between the first dot and the remaining parts of • ▬ • • (L) converts it into **ed**, or a similar break in the middle results in **ai**; on the other hand, failure to allow the proper interval between A and I in a word converts them into L. Omitting the necessary interval at the end of a word runs it on to the following word, and if an unintentionally long interval has been allowed in some part of the first word, the result will be three senseless words resembling code. All the four-element letters are easily divisible by poor spacing into signals representing two or three other letters as, for example, ▬ • • ▬ (X) may be ▬ • • ▬ (**tu**); ▬ • • ▬ (**na**); ▬ • • ▬ (**tea**); and so on. Poor sending makes for difficult receiving, so that the first object of practice is to attain control of the key in order to be able to send each signal sharply and clearly. The first and second fingers should be placed on top of the key button and the thumb below it so as to control its upward as well as its downward movement; the arm should rest on the table from the elbow down in order to allow unrestricted movement of the wrist, as otherwise cramping will result.

Where the services of a fellow student cannot be obtained, there are a number of simple automatic devices on the market which will serve as an effective substitute. Probably the best known of these is the *omnigraph.* In this a notched disc is revolved by clockwork against a spring contact in circuit with the battery and buzzer. This disc has cut in its periphery a series of notches corresponding to the letters and spaces of a message which is sent automatically by the revolution of the disc at any speed desired. The instrument should be connected in the circuit in place of the second key shown in the diagram, Fig. 187, so that when in action it takes the place of another operator. A great variety of discs is obtainable.

COMMERCIAL TRAFFIC REGULATIONS*

Power Allowed. All stations must communicate with the minimum power to effect reliable communication. Commercial ships are forbidden to use more than one kw. of power at the generator terminals under normal circumstances and when within 200 miles of the nearest coastal station.

Every station which has occasion to transmit with high power shall first send out three times, with the minimum of power necessary to reach neighboring stations, the signal of warning — • • — given with other signals in Table VIII. The station shall not begin to transmit with high power until five seconds after sending the warning signal. The International Code shall be used exclusively.

Wave Lengths. Two wave lengths, 600 and 300 meters, are authorized for general public service. All naval stations, ship and coastal, shall use these wave lengths when communicating with commercial ships. Commercial coastal stations are required to use a different wave length when communicating with each other, such wave lengths to be below 600 or above 1600 meters. In general, the standard wave lengths used are 600 and 300 meters for ship and ship, and ship and shore work, and all stations open to commercial service are prepared to use these wave lengths. Such stations may listen-in on these wave lengths for at least five minutes every quarter-hour, except when engaged in communication on other wave lengths, in which case they must cease every fifteen minutes and listen-in for three minutes on 600 meters.

Call. As a general rule, it is the ship that calls the shore station and ships coming within range of a shore station should call the latter for **TR** (position) report, in order that the ship may report to the shore station its position and probable hour of arrival. The call is composed of the attention signal — • — • — (call) followed by the call letters of the station called, repeated three times, then **de** (from), followed by the call letters of the

* U.S. Naval Radio Service.

TABLE VIII

International Conventional Signals

Period	• • • • • •
Semicolon	— • — • — •
Comma	• — • — • —
Colon	— — — • • •
Interrogation	• • — — • •
Exclamation point	— — • • — —
Apostrophe	• — — — — •
Hyphen	— • • • • —
Bar indicating fraction	— • • — •
Parenthesis	— • — — • —
Inverted commas	• — • • — •
Underline	• • — — • —
Double dash	— • • • —
Distress call	• • • — — — • • •
Attention call to precede every transmission	— • — • —
General inquiry call	— • — • — — • —
From (de)	— • • •
Invitation to transmit (go ahead)	— • —
Warning—high power	— — • • — —
Question (please repeat after....)—interrupting long messages	• • — — • •
Wait	• — • • •
Break (Bk.) (double dash)	— • • • —
Understand	• • • — •
Error	• • • • • • • •
Received (O.K.)	• — •
Position report (to precede all position messages)	— • — •
End of each message (cross)	• — • — •
Transmission finished (end of work) (conclusion of correspondence)	• • • — • —

calling station, repeated three times. To call a ship or station within range whose call is not known or to ascertain if any station is within range, the general call — • — •   — — • — (CQ) is used in place of the call letters of a station being called; for example ship *KSA* calls *NAN*. — • — — •   — •   • —   — • (*NAN*) repeated three times; — • •   • (de), — • —   • • •   • — (*KSA*) repeated three times.

If a station does not answer the call transmitted three times at intervals of two minutes, the call shall not be resumed until after an interval of fifteen minutes, the station issuing the call having first made sure that no radio correspondence is in progress.

Distress Call. The distress call is • • • ▬ ▬ ▬ • • • (SOS), which is substituted for the call letters of the station called. It shall be answered by any ship or station that hears it, unless there is added the call of any particular station, when that station alone shall reply. Any ship or station hearing a distress call shall cease all other radio work until the call is answered and the correspondence relating thereto is finished.

Reply. A station replies by making the attention signal ▬ • ▬ • ▬ followed by the call letters of the calling station repeated three times, ▬ • • • (de), its own call letters made once, and at the end the go ahead signal ▬ • ▬ (K), if ready to receive, otherwise the wait signal • ▬ • • • or one of the conventional abbreviations which fits the case; for example, *NAN* having been called by *KSA* replies: ▬ • ▬ • • • • ▬ (*KSA*) repeated three times ▬ • • • (de), ▬ • • ▬ ▬ • (*NAN*), ▬ • ▬ (K, or go ahead), or ▬ • ▬ • ▬ (attention), ▬ • ▬ • • • • ▬ (*KSA*) repeated three times, ▬ • • • (de), ▬ • • ▬ ▬ • (*NAN*), ▬ ▬ • ▬ • ▬ • ▬ • • ▬ (QRX, or **Shall I stand by?**). This last is merely a typical example of the use of the conventional abbreviations, which are given in Tables VIII and IX.

Special care shall be taken not to interrupt the business of the station, which at the time may be receiving signals that cannot be received on board ship on account of the lower aerial; the ship shall, therefore, cease calling promptly on demand.

Position Reports. When a ship is calling a coast station, as soon as the coast station has answered, the ship station shall furnish it with the following data in case it has messages to transmit, or shall furnish it upon request from the coast station, the report being preceded by the letters TR; approximate distance in nautical miles of the vessel from the coast station; position of vessel indicated in a concise form; next port of call; number of radiograms, if total number of words does not exceed fifty, otherwise, total number of words; and also speed of ship, if specifically requested, for example, ▬ • ▬ • ▬ TR 50 Off Cape Canaveral Vera Cruz

TABLE IX

List of Abbreviations to Be Used in Radio Communications*

Abbreviation	Question	Answer or Notice
— · — · — — · —	(C Q)......................	Signal of inquiry made by a station desiring to communicate.
— · — ·	(T R)......................	Signal announcing the sending of particulars concerning a station on shipboard.
— — · · — —	(!)........................	Signal indicating that a station is about to send at high power.
PRB	Do you wish to communicate by means of the International Signal Code?	I wish to communicate by means of the International Signal Code.
QRA	What ship or coast station is that?	This is ....
QRB	What is your distance?......	My distance is ....
QRC	What is your true bearing?..	My true bearing is .... degrees.
QRD	Where are you bound for?....	I am bound for ....
QRF	Where are you bound from?	I am bound from ....
QRG	What line do you belong to?	I belong to the .... line.
QRH	What is your wave length in meters?	My wave length is .... meters.
QRJ	How many words have you to send?	I have .... words to send.
QRK	How do you receive me?....	I am receiving well.
QRL	Are you receiving badly? Shall I send 20 · · · — · for adjustment?	I am receiving badly. Please send 20 · · · — · for adjustment.
QRM	Are you being interfered with?	I am being interfered with.
QRN	Are the atmospherics strong?	Atmospherics are very strong.
QRO	Shall I increase power?.......	Increase power.
QRP	Shall I decrease power?.......	Decrease power.
QRQ	Shall I send faster?..........	Send faster.
QRS	Shall I send slower?..........	Send slower.
QRT	Shall I stop sending?.........	Stop sending.
QRU	Have you anything for me?..	I have nothing for you.
QRV	Are you ready?...............	I am ready. All right now.
QRW	Are you busy?................	I am busy (or, I am busy with ....). Please do not interfere.
QRX	Shall I stand by?............	Stand by. I will call you when required.
QRY	When will be my turn?......	Your turn will be No...........
QRZ	Are my signals weak?.......	Your signals are weak.
QSA	Are my signals strong?......	Your signals are strong.
QSB	Is my tone bad?.............	The tone is bad.
QSB	Is my spark bad?............	The spark is bad.
QSC	Is my spacing bad?.........	Your spacing is bad.
QSD	What is your time?.........	My time is ....
QSF	Is transmission to be in alternate order or in series?	Transmission will be in alternate order.

*When an abbrevation is followed by a mark of interrogation, it refers to the question indicated for that abbreviation.

TABLE IX (Continued)

List of Abbreviations to Be Used in Radio Communications

Abbreviation	Question	Answer or Notice
QSG	....	Transmission will be in series of 5 messages.
QSH	....	Transmission will be in series of 10 messages.
QSJ	What rate shall I collect for?	Collect ....
QSK	Is the last radiogram canceled?	The last radiogram is canceled.
QSL	Did you get my receipt?......	Please acknowledge.
QSM	What is your true course?....	My true course is .... degrees.
QSN	Are you in communication with land?	I am not in communication with land.
QSO	Are you in communication with any ship or station (or, with ....)?	I am in communication with .... (through ....).
QSP	Shall I inform .... that you are calling him?	Inform .... that I am calling him.
QSQ	Is .... calling me?	You are being called by ....
QSR	Will you forward the radiogram?	I will forward the radiogram.
QST	Have you received the general call?	General call to all stations.
QSU	Please call me when you have finished (or at .... o'clock).	Will call when I have finished.
QSV*	Is public correspondence being handled?	Public correspondence is being handled. Please do not interfere.
QSW	Shall I increase my spark frequency?	Increase your spark frequency.
QSY	Shall I send on a wave length of .... meters?	Let us change to the wave length of .... meters.
QSX	Shall I decrease my spark frequency?	Decrease your spark frequency.

*Public correspondence is any radio work, official or private, handled on commercial wave lengths.

3 • ▬ • ▬ • (finish signal) *KSA*. Translated this reads: "Position 50 knots off Cape Canaveral, bound for Vera Cruz, have three radio messages." The items of distance and destination may also be designated by the abbreviations as, for example, QRB 50 Cape Canaveral QRD Vera Cruz. These signals are interrogative, when sent out by a calling station, as QRB, "What is your distance?" but when used by the answering station they are in the affirmative as QRB 50, "My distance is 50 knots."

In acknowledging the TR report, the coast station states the number of radiograms for transmission to the ship or the number of words, if over fifty, and the order of transmission, and, if the latter cannot take place at once, the length of time the ship's operator is to wait. In case the latter cannot receive at once he informs the shore station how long it will be necessary to wait. In the exchange of messages between two ships the station called may fix the order of transmission, and a coast station receiving calls from several ships fixes the order in which it shall receive their messages. The following is an example of an acknowledgment of a TR report by a coast station: *NAR* is acknowledging position report of ship *KSA*; *KSA* • ▬ • TR 50 series 3 • ▬ • ▬ • This indicates that *NAR* has fifty words to send to *KSA* and that transmission is to be made in series of three messages. The signal • ▬ • ▬ • (**finish**) means that *NAR* has closed off from sending simply to receive *KSA*'s acknowledgment, after which *NAR* will resume sending. This is another example: *KSA* • ▬ • TR 50 QSF • ▬ • ▬ •, which reads "Have fifty words to send to you. Transmission to be alternately. I shall begin after you acknowledge." The message *KSA* • ▬ • TR 50 QSF ▬ • ▬ is the same as that in the example just preceding except that *KSA* is told to go ahead (▬ • ▬) with the transmission of its first message. A further typical example would be: *KSA* • ▬ • TR 50 • ▬ • • • (**wait**) • • ▬ ▬ • ▬ • ▬ •, meaning, "I have fifty words to transmit to you. Stand by for twenty minutes." The numeral twenty here is abbreviated as permitted abroad, though not allowed by the U.S. Radio Service, in which it would have to be sent in full • • ▬ ▬ ▬ ▬ ▬ ▬ ▬ ▬. The ship would then acknowledge this last message *NAR* • ▬ • *KSA*.

Rules for Transmission. The transmission of every message shall be preceded by the attention signal ▬ • ▬ • ▬. When a message contains more than forty words, the sending station shall interrupt the transmission after each series of about twenty words with an interrogation • • ▬ ▬ • • and shall not continue until the receiving station repeats the last word received and ▬ • ▬, or, if the transmission is very good, simply the go ahead signal ▬ • ▬.

In the case of transmission by series, acknowledgment of receipt shall be made after each radiogram.

Coast stations engaged in the transmission of long radiograms shall suspend the transmission at the end of each period of fifteen minutes and remain silent for a period of three minutes before resuming transmission, listening-in on the 600-meter wave length for distress calls during the three-minute period.

Every message comprises the following: attention signal — • — • —; preamble; supplementary instructions, if any; address and route, if any; text; signature; and sending station call (only at end of last message if a series is being sent).

The preamble consists of all the items sent before the address. It follows the attention signal — • — • — and is followed by the break signal — • • • —, which separates it from the supplementary instructions or the address, as the case may be. The form consists of: prefix; office of origin; number of message; operator sending-receiving check (not transmitted but put on message for record); special prefix; date and hour of filing; via (if relayed) address; text; and signature.

The prefix for any commercial radiogram is the word **radio**. For a paid service message it is **radio ST**; for regular service messages between telegraph offices, ships, and stations **SVC** is used. In case the message is in the International Code, as when operators on two ships do not speak the same language, the letters **PRB** follow the word **radio**.

GOVERNMENT EXAMINATION QUESTIONS

General Instructions. In order to be eligible for a position as a wireless operator, either on shipboard or at a shore station, the applicant must pass an examination, upon which he will be granted a license of the grade to which his standing entitles him. To obtain a first-grade commercial license, a mark of 75 must be obtained, while for a second-grade commercial license 65 is sufficient. Applicants for first-grade commercial licenses who fail to attain a speed of 20 words per minute in the code test but who demonstrate their ability to receive at the rate of 12 words per minute and obtain between 65 and 75 per cent in the written examination may be granted second-grade licenses. Examinations are held at all navy yards and at many customhouses. The student can learn the location of the nearest point to him by writing the Bureau of Navigation, Washington, D. C.

Contrary to the more or less general impression, speed in the handling of the key and in receiving are not the most important factors in enabling the student to pass the examination successfully. A good knowledge of the theory and practice of wireless telegraphy plus ability to send and receive at a moderate rate will qualify the student for one of the lower grades. With the experience gained in the latter, he may present himself for examination for a higher grade license within a comparatively short period. The values given the various branches are as follows:

Experience (ability in sending and receiving)	20 per cent
Diagram of transmitting and receiving apparatus	10 per cent
Knowledge of transmitting apparatus	20 per cent
Knowledge of receiving apparatus	20 per cent
Care and operation of storage batteries	10 per cent
Care and operation of motors and generators	10 per cent
International regulations and U.S. radio laws	10 per cent

The examination is chiefly designed to test the applicant's fundamental knowledge of the working of all the apparatus to insure that he will not be at a loss in case of emergency, since by far the greater number of operators are on shipboard where they must rely upon their own resources to a great extent to keep the station in working order. Practically without exception, the naval officers and radio inspectors in charge of the examinations will be found very considerate and helpful, so the student need not fear having to undergo a severe ordeal. It must not be assumed that either the following questions or answers are in exactly the form in which they will be given. Naturally this is frequently changed for obvious reasons and the student should depend upon his knowledge of practice and principles rather than attempt to learn any of the answers by rote. The questions do, however, cover all the subjects included in the examination and will prove of considerable assistance in that they make clear the knowledge that the student must have to enable him to operate a station successfully.

TRANSMITTING APPARATUS

Q. What is the source of current supply for the transmitter and what is the nature of the current employed?

A. Direct current from the dynamo of the ship at 110 volts is supplied to a motor-generator. The motor is a direct-current type while the generator is an alternator and supplies alternating current to a step-up transformer.

Q. What is the nature of the current in the fields of the generator and in the armature and why?

A. Direct current from the mains of the ship is supplied to the fields of the alternator in order to excite them, that is, render them magnetic, while alternating current is delivered by the armature of the alternator.

Q. Why is alternating current necessary and what are the advantages of an alternating-current supply rather than an interrupted direct current such as that supplied by an induction coil?

A. It is not absolutely necessary to have an alternating-current supply as an induction coil operated by storage batteries will also serve the purpose, but with an alternating current a much higher frequency is obtainable and heavy currents may be handled without troublesome contacts or interrupters, such as are needed with an induction coil. Both the speed and current-carrying capacity of the induction coil are limited by its interrupter.

Q. How is the alternating-current supply employed to produce the high-frequency oscillations necessary to generate electromagnetic waves?

A. It is sent through the primary of a step-up transformer to raise it to a high potential. In circuit with the secondary of this transformer are a condenser, spark gap, and inductance.

Q. What functions do the spark gap and condenser perform?

A. The spark gap, owing to its high resistance, acts similarly to a spring-loaded valve and permits the condenser to charge from the secondary of the transformer until this charge reaches a certain pressure (potential), when the condenser immediately discharges its energy across the gap. The condenser serves as a storage capacity for the energy from the secondary of the transformer and also to convert this accumulated energy (the charge) into high-frequency oscillations by its discharge across the spark gap.

Q. How may the amount of energy supplied to the transformer by the alternator be increased; decreased?

A. It may be increased by inserting additional resistance in the fields of the motor, causing its speed and that of the alternator to increase; also by decreasing the amount of resistance in circuit with the alternator fields, thus increasing the strength of the magnetic field of the latter as the amount of exciting current is increased. It may be decreased by reducing either the speed of the generator or the strength of its magnetic field.

Q. By what other method may the amount of energy supplied to the transformer be varied?

A. By the use of a reactance regulator which acts as a choke coil, or alternating-current resistance. This consists of a coil having high self-induction and provided with a multi-point switch so that the induction may be varied by placing more or less of the coil in circuit; the coil is wound on a heavy soft-iron core.

Q. What is the function of the inductance in circuit with the secondary of the transformer, condenser, and spark gap, and what is this inductance termed?

A. The inductance, in connection with the capacity of the condenser, serves to impress upon the oscillations produced by the latter through the spark gap a certain definite frequency of oscillation, and as this frequency is a direct measure of the wave length, it helps to determine the latter. It is known as the primary of the oscillation transformer.

Transformer

Q. What is the transformer and what is its purpose? How many types are used?

A. It consists of two windings, one of comparatively coarse wire and of few turns, called the primary winding, and the other of a great number of turns of fine wire, called the secondary winding, wound on a laminated iron core. Its action depends upon the mutual induction in the two coils, the alternating current in the primary inducing an alternating current in the secondary in the same manner as an induction coil described on page 105. The use of alternating current in the primary makes it unnecessary to provide a make-and-break mechanism as used in the induction coil. The reversals occur twice as many times per second as there are cycles in the alternating-current supply, that is, with 60-cycle current, 120 times; with 500-cycle current, 1000 times. But due to the much greater number of turns in the secondary winding, the resulting induced current is at a very much higher potential. Two types are in general use, the open-core transformer, in which the secondary is wound directly over the primary, and the closed-core type, in which the core is in the form of a rectangle and the primary is wound on one leg while the secondary is on the other.

Q. What voltages are used in wireless telegraphy?

A. The direct-current supply is usually 110 volts; that of the alternating-current generator is 320 volts on open circuit, and the transformer steps this up to 15,000 to 30,000 volts through its secondary winding.

Q. With such a high potential in the transformer what prevents the current from breaking down the insulation?

A. The secondary is wound in the form of pies, or sections, so that there is a minimum difference of potential between adjacent turns and all parts of the transformer are very thoroughly insulated from each other and from the core.

Q. What places an excessive strain on the transformer and how is it protected against this?

A. Opening the spark gap unduly places a tremendous strain on the insulation of the transformer. It is usually protected by placing a safety spark gap on the transformer itself. The opening of this gap is below the safe maximum that the transformer can bridge, and if the spark gap, or discharger, is opened too wide, the current will find a path of lesser resistance at the safety gap.

Condensers

Q. What types of condensers are employed in the transmitting apparatus and how are they connected in circuit?

A. The Leyden jar, consisting of a glass jar copperplated inside and out to a certain height, is most commonly employed. Metal plates in a tank of insulating oil or in a receiver in which the air is raised to a high pressure are also used. They are connected in series, in parallel, or in series-parallel, according to the capacity desired.

Q. What effect has the opening of the spark gap on the dielectric of the condenser?

A. If opened too wide it will submit the condenser to an excessive strain and may puncture the dielectric.

Q. What is the result of puncturing the dielectric in the case of a Leyden jar; in the oil plate; and in the compressed-air condensers?

A. In a Leyden jar a hole is made in the glass so that the condenser is short-circuited and becomes useless. In the other two types, the dielectric is said to be self-healing, that is, an excessive strain may cause an arc to form between the plates but as soon as the condenser discharges the resistance of the dielectric is re-established so that no damage results.

Q. How can the condensers be protected from excessive strain?

A. By careful adjustment of the spark discharger; by providing on the condensers a safety gap similar to that used on the transformer; or by connecting the condensers in series-parallel so that the maximum voltage to which any unit is subjected is reduced.

Q. What should be done when a condenser unit breaks down?

A. Examine the jar to note whether the breakdown was caused by an inherent defect or by some outside cause; inspect spark gap to note if it is opened too wide. The latter is the commonest cause of failure of the condensers. Correct the cause, if possible, and replace the broken-down unit with a spare.

Q. In case the complete condenser broke down and all spares had been used, what connections should be made for transmitting?

A. Cut out the condenser and the oscillation transformer, connecting the spark gap directly in the aerial.

Q. Would such an arrangement be an efficient transmitter?

A. No. It would radiate a highly damped wave of small power causing a great deal of interference and good only for short distances. Even by reducing the power input at the transformer, trouble would be experienced with the spark gap arcing if used for more than a few minutes.

Q. With a modern commercial set would such an expedient be necessary?

A. Not when the auxiliary set is provided with an independent condenser of its own, but when the emergency set is designed to operate through the same condenser as the main set, some such expedient would be unavoidable in case of the total breakdown of the condensers.

Q. In case one or two units of the condenser break down and there are no spares to replace them, how would you operate the set?

A. Transmit on a shorter wave length, as the reduction in the total capacity of the transmitting condenser reduces the wave length. The aerial circuit could then be tuned to resonance with the closed oscillation circuit by reducing the number of turns of its inductance in circuit. If this could not be done by reducing the number of turns of the oscillation transformer secondary in circuit or by cutting out the loading or tuning inductance altogether, the short-wave condenser would have to be put in circuit. The coupling would also have to be made tighter, that is, the primary and secondary of the oscillation transformer brought closer together so as not to reduce the amount of energy being radiated.

Q. What is the short-wave condenser and what is its purpose? Explain how this is effected.

A. The short-wave condenser is connected in series with the aerial and the ground and is provided with a switch so that it may be included in the circuit or omitted, as desired. Its purpose is to reduce the wave length of the aerial below its natural or fundamental wave length. This can be accomplished because the total value of two capacities connected in series is less than that of either taken singly and, therefore, connecting the short-wave condenser in series reduces the distributed capacity of the aerial itself and, consequently, its wave length.

Spark Gap

Q. How many types of spark gaps are there?

A. Four; the plain, or open, type, consisting of stationary electrodes the distance between which is adjustable; the rotary type, in which a pair of electrodes is rotated at high speed by a small motor close to a series of stationary electrodes; the synchronous rotary type, similar to the one just described but having the revolving electrodes mounted on the shaft of the alternator so that it is in phase with the latter; and the quenched-gap type, consisting of a series of grooved plates separated by mica insulating discs, the whole being clamped together under pressure. The adjustment of the synchronous rotary type is also variable, but once set it is not changed except to compensate for wear; the quenched-gap type is adjusted by putting more or less pressure on the discs.

Q. Which of these types are in general commercial use, and why?

A. The quenched-gap type is favored for low powers, up to 2 kw., while the synchronous rotary type is used for both small and large sets up to 500 kw., these two types being used practically to the exclusion of any others. This is because both these types quench the oscillations in the closed circuit very rapidly, thus permitting the aerial circuit to vibrate at its own period without interference from the closed circuit. In this way the maximum distance may be covered with a given input at the transformer, the damping factor is not too high, and the coupling need not be made so loose as to waste a high percentage of the energy as a single wave length is radiated.

Q. What are some of the disadvantages of the plain spark gap?

A. It becomes conducting and tends to arc after a short period of operation, if closely adjusted; if too open, it places an undue strain on the condensers and transformer. Unless equipped with an air blast or other means of removing the conducting gases from the gap, its quenching is very slow so that the closed and open circuits react on each other, generating waves of two distinct lengths which make necessary very loose coupling of the oscillation transformer, with its attendant loss of energy. High-potential transformers must be used with it, whereas the quenched type permits the use of a transformer with a low potential in the secondary. The frequency of the plain spark gap is very low and it produces an unpleasant low-pitched note that is difficult to read, particularly through interference.

Oscillation Transformer

Q. Describe the closed oscillatory circuit and its functions.

A. This consists of the secondary winding of the transformer, the condenser, spark gap, and variable inductance. The condenser charges from the secondary of the transformer until its potential reaches a value sufficient to break down the resistance of the gap of the discharger (spark gap); it then discharges across this gap, producing high-frequency oscillations, the frequency of which is determined by the capacity of the condenser and the amount of inductance in the circuit.

Q. Why are these oscillations not radiated directly from this circuit to the aerial?

A. Because this circuit is designed to be an efficient oscillator but is not a good radiator and it is not possible for it to have both characteristics in the same degree; if the circuit were efficient as a radiator, it would not be equally so as a generator of high-frequency oscillations.

Q. How are these high-frequency oscillations transferred to the open, or radiating, circuit?

A. By means of the oscillation transformer. This is practically an air-core step-up transformer, the primary of which forms the inductance value of the closed oscillatory circuit, while the secondary performs the same function for the aerial circuit. The oscillations in the primary are transferred to the secondary by electromagnetic induction.

Q. What is meant by coupling and why is a variation of coupling necessary?

A. The closed oscillatory circuit in its operation generates electromagnetic waves of two distinct lengths and it is desirable that as much as possible of the energy be radiated as a single wave length. By transferring these oscillations from one circuit to the other through an oscillation transformer and by adjusting the inductive relation of the secondary to the primary of this transformer, it is possible to practically eliminate one of these waves. This adjustment of the inductive relation of the primary and secondary is known as their coupling. Reducing the effect of the magnetic field on the secondary is *loosening* the coupling; increasing it is *tightening*, or increasing, the coupling.

Q. How many types of oscillation transformers are used?

A. Two general types, of which one is the pancake coil type, in which the primary and secondary are in the form of flat coils which may be moved together or apart in the same plane or swung on a radius, both being hinged at a common center. The type in which both primary and secondary are helices and the primary is arranged to move in or out of the secondary is a variation of construction only and not of principle. The second general type is the variometer, in which both primary and secondary are helices but the secondary is mounted so that it may be revolved to bring it in line with the primary, at right angles to it, or at any intermediate angle, thus altering their inductive relation from zero to maximum.

Q. What is mutual induction and what is its effect?

A. When the primary of the oscillation transformer creates a magnetic field about the secondary, a current is induced in the latter just at the moment that the current in the primary is dropping to zero. The magnetic field thus created in the secondary then reacts on the primary and induces a current in it. This action and reaction of the circuits on each other is termed mutual induction and it generates waves of two distinct lengths, one by the inductive effect of the primary on the secondary and the other by the reaction of the secondary on the primary.

Q. How can the undesirable effects of mutual induction be overcome?

A. By reducing the coupling of the oscillation transformer until the reaction of the secondary on the primary is such a small percentage of the energy transferred to it by the primary that the second wave is practically suppressed.

Q. What is the maximum coupling allowed by the regulations?

A. Twenty per cent.

Q. Why may the coupling be tighter with a quenched spark gap than with the rotary type?

A. Due to the extremely rapid quenching of the oscillations in the closed circuit with this type, the reaction between the closed and the open circuits is reduced to a minimum, so that a closer degree of coupling is possible, thus transferring the maximum amount of energy. There is a greater amount of reaction, or mutual induction, with the rotary type of gap and therefore the coupling must be looser.

Q. What other essentials are necessary to complete the open, or radiating, circuit?

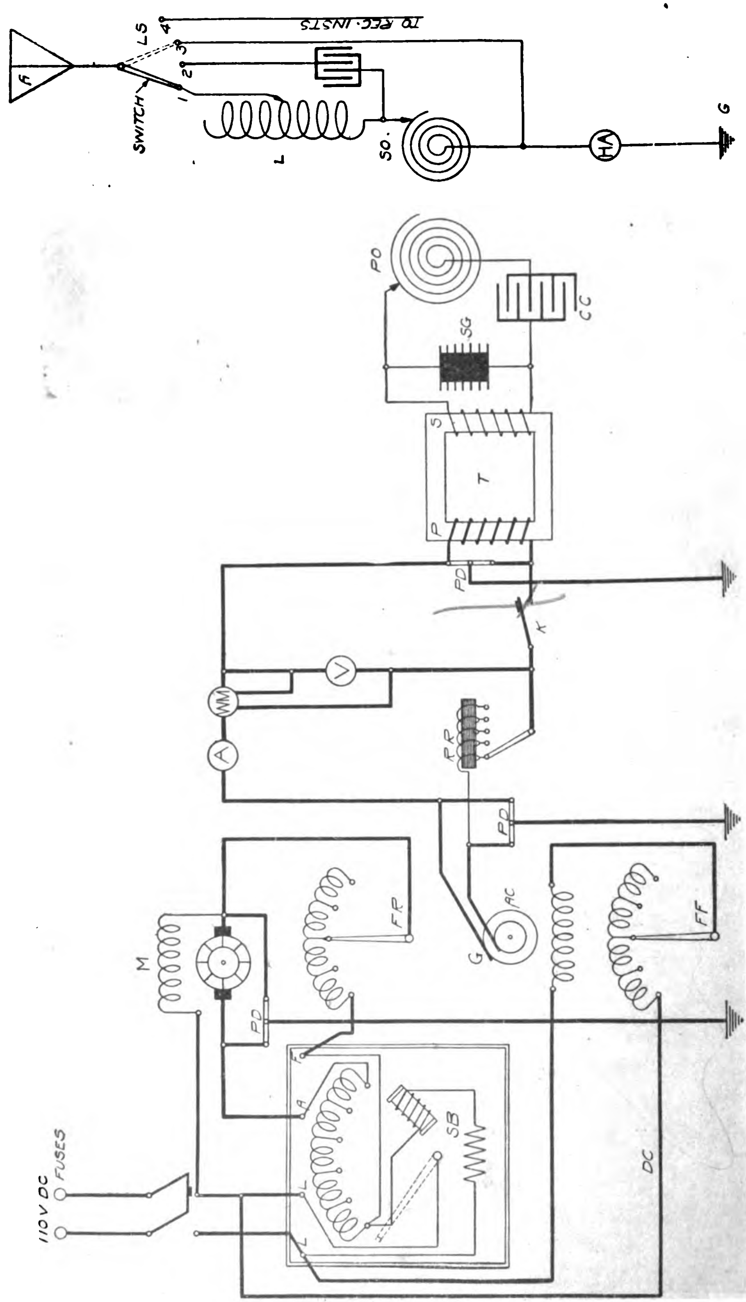


Fig. 188. Circuits of Transmitter with Hand-Starter Motor-Generator—*SB*, Hand-Starter Box; *LL*, Line Connections; *A*, Armature Connection; *F*, Field Connection; *FR*, Motor Field Rheostat; *FF*, Generator Field Rheostat; *PD*, Protective Devices; *A*, Ammeter; *WM*, Wattmeter; *V*, Voltmeter; *K*, Key; *T*, Transformer; *SG*, Quenched Spark Gap; *CC*, Condensers; *PO*, Primary; *SO*, Secondary of Oscillation Transformer; *L*, Tuning Inductance; *HA*, Hot-Wire Ammeter; Switch Points: *1*, Sending; *2*, Sending through Short-Wave Condenser; *3*, Lightning Protection; *4*, Receiving Instruments

A. The aerial, the tuning, or variable loading, inductance, the ground connection, the short-wave condenser, and a lightning switch.

Q. What is the purpose of the lightning switch?

A. To connect the aerial directly with the ground so that, in case the aerial is struck by lightning, the high-potential discharge will pass directly to the ground without going through the instruments.

Q. Draw a simple diagram, showing the complete connections of a transmitting set equipped with a hand-started motor-generator, a quenched type of spark gap, and a pancake type oscillation transformer. Include all instruments and protective devices.

A. See Fig. 188.

Q. Draw a simple diagram showing the details of a standard ship's aerial of the L-type showing the lead-in and identifying the various parts of the aerial.

A. See Figs. 118 and 122, pages 151 and 157, respectively.

Instruments and Protective Devices

Q. What instruments are necessary in the transmitting circuits?

A. A voltmeter in shunt across the alternator circuit; an ammeter in series with the alternator, also a wattmeter in series and shunt with the alternator; and a hot-wire ammeter in series with the aerial.

Q. What protective devices are necessary?

A. (1) A kick-back preventer to prevent a surge of high-potential current from the secondary of the transformer reaching the alternator, which takes the form either of a high-resistance rod provided with ground connection to its center and shunted across the alternator circuit or of a pair of condensers similarly connected to the alternator mains and the ground; (2) an overload circuit-breaker and fuses in the direct-current mains to the motor-generator; (3) a no-voltage release on the motor starter; and (4) an automatic cut-out in the storage battery charging circuit.

Q. What is the purpose of the circuit-breaker?

A. In case the load exceeds the safe maximum it automatically opens the circuit to protect the motor-generator. The fuses employed have a higher carrying capacity than the circuit-breaker so that the latter operates first; in case it fails, the fuses then blow out. The spring which operates the circuit-breaker contacts is adjustable so that it can be set to open the circuit whenever a certain number of amperes is exceeded.

Motor-Generator

Q. Why is it necessary to have a starting box in circuit with the motor-generator and how should this be handled?

A. The starting box is a variable resistance which cuts down the current on starting until the armature by virtue of its speed can exert sufficient counter-e.m.f. to increase its resistance to a point where it will not be damaged by the full current. The starting handle should be moved slowly, dwelling a few seconds on each contact of the rheostat; if moved too quickly the armature is liable to be burned out; if moved too slowly the resistance coils may overheat as they are only designed to carry the current for a short time.

Q. What is an automatic starter and how does it operate?

A. It is a rheostat the decrease in the resistance of which is effected automatically by electromagnetic switches instead of by hand.

Q. In case the handle of the starter box flies back instead of being held by its electromagnet, what is probably the cause of the trouble?

A. There may be a break in the field circuit of the motor or a short-circuit in the winding of the magnet.

Q. Should the trouble prove to be in the electromagnet of the starter and it is not possible to repair it at once, what should be done?

A. Fasten the handle in place with a rubber band or string.

Q. Draw a diagram showing the circuits of the starter box and motor.

A. See Fig. 41.

Q. Should the circuit-breaker open when the motor is being started, what would you do to locate the trouble?

A. Close the circuit-breaker and try starting more slowly. If the circuit-breaker jumps again, examine the motor and field rheostat for signs of a short-circuit. The circuit-breaker through long use may become very sensitive and trip with a very slight increase in current over the normal; adjust it so that it will require a slightly higher amperage to operate it.

Q. How would you determine whether the tripping were caused by a short-circuit in the motor field, the armature, or the field rheostat.

A. Connect a pair of flexible leads with a 16-candle power carbon-filament lamp in circuit on the motor side of the fuses. Bare the points of these leads and test for a ground or short-circuit by touching the bare points of the leads to the field coils and frame, commutator and shaft, field rheostat coils and supports, or similar parts of any of these suspected sources of the trouble through which current should not flow. In case there is a short-circuit or ground, the lamp will light. This testing outfit should be connected on the motor side of the fuses so that, in case of a short-circuit through the lamp, these fuses will blow and protect the generator (ship's dynamo).

Q. In case the trouble is located in the field rheostat and the latter cannot be used, how would you run the motor?

A. It will not be at all likely that the whole rheostat is put out of commission. Locate the shorted coil and cut it out by bridging it with a *jumper*, that is, a short wire to carry the current around it to the next coil.

Q. How would you locate the burned-out coil?

A. A pair of head telephones connected in series with a battery of one or two dry cells and flexible leads with bared tips may be used as a testing set. When these tips are placed on the resistance contacts a click will be heard in the telephones; when the broken coil is reached no response will be heard.

Q. Should it not be possible to replace the rheostat in commission after locating the break, how would you provide the necessary resistance for the motor field?

A. Insert five 16-candle power carbon-filament lamps in multiple and connect this group in series with the rheostat leads. This will permit $2\frac{1}{2}$ amperes of current to pass; if all this is not needed, unscrew one or more bulbs. Should more be necessary, 32-candle power bulbs taking 1 ampere each may be used.

Q. What parts of the motor-generator will require attention most frequently?

A. The commutator and brushes of the motor. The commutator should be kept clean, the brushes should have a true bearing over their entire surface and be held against the commutator firmly by their springs.

Q. What are the commonest causes of sparking at the commutator?

A. An accumulation of carbon dust and oil on its surface;

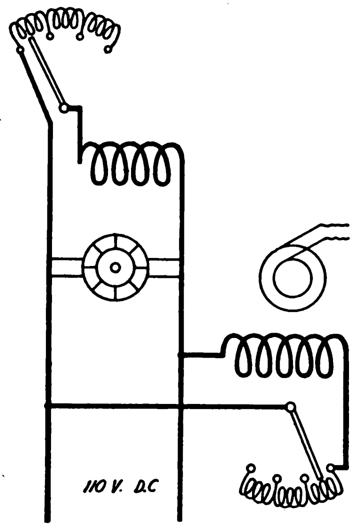


Fig. 189. Diagram of Shunt-Wound Motor-Generator

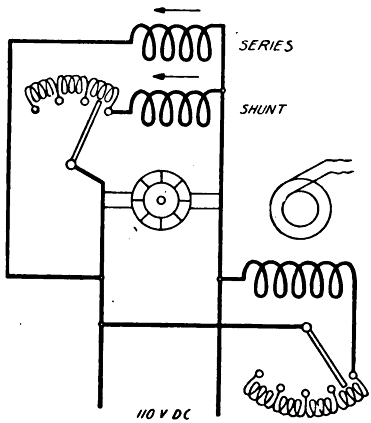


Fig. 190. Diagram of Compound-Wound Motor-Generator

badly worn brushes; brushes not adjusted to the neutral point; and a brush jammed fast in its holder. Fine sandpaper should be used to clean the commutator and, if necessary, to give the brushes a true bearing on it. Brushes should be adjusted to the neutral point by means of the rocker arm. If none of these measures remedies the trouble, it may be due to a short-circuited coil in the armature, in which case the sparking is liable to be severe.

Q. How can the output of the alternator be controlled?

A. By varying the speed of the motor and the amount of resistance in circuit with the field of the alternator.

Q. How is the speed of the motor varied?

A. Increasing the resistance in series with the field increases the speed, and *vice versa*.

Q. In case either the motor or the generator tend to overheat, what is the cause?

A. A dry bearing may be the cause in either case, though putting an excessive load on the generator may also cause it to run hot.

Q. What types of generators are used in motor-generators designed for commercial service? Draw diagrams showing their windings.

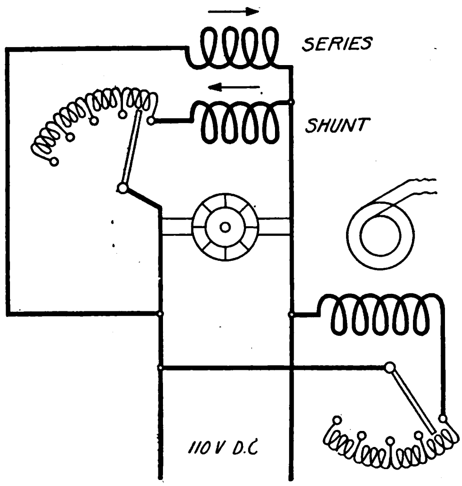


Fig. 191. Diagram of Differentially-Wound Motor-Generator

A. The simple shunt-wound type, Fig. 189; compound-wound, Fig. 190; and differential type, Fig. 191. In the first type, the field is a single winding and is placed in shunt with the armature; in the second, there are two windings in the field, one in shunt and the other in series with the armature. Both windings are in the same direction on the pole pieces, so their effect on the strength of the field is cumulative. With an increase of the load in a motor-generator of this type, there is an increase of current through the series winding, thus strengthening the field and keeping the speed fairly constant. In the differential type, the series winding is opposed to the shunt winding, so the effect of one is offset by the other to maintain the speed constant under variable load. In all three, a regulating rheostat is connected in series with the shunt field winding to control the amount of current and, in consequence, the strength of the field.

Operation of Transmitting Set

Q. Show by a diagram the complete circuits of a transmitting set, from the source of current supply to the aerial, naming the different parts and explaining their operation.

A. *DC* is the current supply from the ship's dynamo, *M* the motor, *G* the generator, *SB* the starting box of the motor, *FR* the field resistance of the motor, and *FF* the field resistance of the generator, Fig. 188. *RR* is the reactance regulator, and *K* the operating key in series with the primary *P* of the transformer *T*, of which *S* is the secondary in circuit with condensers *CC*, the quenched spark gap *SG*, and the primary *PO* of the oscillation transformer. This completes the current-supply circuit, the low-voltage low-frequency alternating-current circuit, and the closed oscillatory circuit. *A* is the aerial, *L* the tuning inductance, and *SO* the secondary of the oscillation transformer, while *SW* is the short-wave condenser, *HA* the hot-wire ammeter, *G* the ground, and *LS* the lightning switch.

With the motor running, depressing the key sends current from the armature of the alternator through the primary of the transformer. This current is stepped-up to a high potential in the secondary of the transformer and charges the condensers until their potential is sufficient to break down the air gap of the discharger, or spark gap. The discharge of the condensers across this gap generates a train of high-frequency oscillations which pass around the coils of the primary *PO* of the oscillation transformer and create a strong magnetic and electrostatic field in its vicinity. The lines of force of these two fields cut the coils of the secondary *SO* of the oscillation transformer and induce in them oscillations of the same frequency as in the primary. These oscillations are conducted through the tuning inductance to the aerial, from which they are radiated. In case of local electric storms, throwing the lightning switch *LS* cuts out the instruments and provides a direct path from the aerial to the ground.

Q. When sending, how do you know whether or not electromagnetic waves are being radiated from the aerial?

A. The reading of the hot-wire ammeter is the only visible indication, and when this reading cannot be brought up to what is known to be its normal amperage by previous experience, it is a sign that the closed oscillation circuit is not working at full efficiency or that there is something wrong with the aerial itself. A QRZ signal from the station communicated with will confirm the ammeter reading regarding the weakness of the signals sent out.

Q. How should the transmitter be adjusted to send out a distress signal, and why?

A. The circuits being in resonance, as indicated by the hot-wire ammeter, the coupling should be tightened to the maximum. This is done to produce a broad interfering wave that will be detected at once by all stations within range. Tightening the coupling increases the damping and results in producing broad waves, that is, waves of two or more distinct wave lengths.

Q. How do you determine whether a pure wave is being radiated? Describe the characteristics of such a wave.

A. With the aid of a decremeter and the formula for the measurement of the logarithmic decrement. The decremeter is a wavemeter fitted either with a hot-wire ammeter or a watt-meter. Its inductance coil is placed in inductive relation with a loop in the ground connection of the transmitter and, with the latter in operation, the coupling is varied until a point is found at which a further decrease in coupling does not decrease the damping. With the meter adjusted to resonance with the aerial circuit, a reading of the current-indicating instrument is taken, also a reading of the capacity of the condenser as shown by its scale. The variable condenser is then adjusted to place the wavemeter below the point of resonance until the current reading is one-half that of the former reading, and then the capacity of the condenser is again noted. A second adjustment is made above the point of resonance until the current is once more half of the first reading, and again the capacity of the condenser is noted. The values thus obtained are then worked by the formula

$$\delta_1+\delta_2=\frac{C_1-C_2}{C}\times 1.57$$

in which δ_1* is the decrement of the aerial circuit; δ_2 is the decrement of the wavemeter; C_1 is the capacity of the condenser about resonance; C_2 is the capacity of condenser below resonance; and C is the capacity of the condenser at resonance, the object of taking readings above and below resonance being to determine a mean value of the damping. The decrement of the wavemeter is usually stamped on it so that subtracting this from the result

* The Greek letter delta (δ) is the symbol of the logarithmic decrement.

given by working out the equation gives the decrement of the circuit.

A pure wave is a sharply tuned wave and sharp tuning is not possible when the wave train consists of less than fifteen oscillations, corresponding to a decrement of 0.2. The percentage of coupling also affects the sharpness of the wave. The wave is said to be pure when the coupling is reduced to a point where the second wave set up by mutual induction, or the reaction of the secondary on the primary circuit, has 10 per cent or less of the energy of the longer wave. For a diagram of a pure wave see the curve, Fig. 183.

Q. What is the decrement of damping permissible under U.S. regulations and how is it measured?

A. The maximum decrement must not exceed 0.2. See preceding answer for method of determining it.

Q. What wave lengths may ship stations operate on?

A. For calling, either 600 or 300 meters may be used, but for operating, after communication has been established, these wave lengths or any between them may be used. Modern ship sets are equipped to send on wave lengths of 300, 450, and 600 meters.

Q. How can the transmitter be adjusted to these wave lengths definitely?

A. With the aid of a wavemeter, the closed circuit first being adjusted to the wave length desired and then the aerial circuit adjusted to resonance with it. The wave length being radiated is then measured and the coupling varied to insure that the maximum amount of energy, as shown by the hot-wire ammeter in the aerial circuit, is being radiated as practically a single wave. The number of turns necessary in the various inductances as well as the proper point of coupling is directly marked, so that the change from one wave length to another may be made quickly with a few adjustments. In the later Marconi sets, this may be effected by throwing a single switch which makes all the necessary connections.

Q. What is the natural wave length of the aerial?

A. This is its wave length as determined by its dimensions, that is, length and number of wires in parallel without a tuning inductance or short-wave condenser in circuit.

Q. When this natural wave length is in excess of 300 meters, how is the transmitter operated on that wave length?

A. By opening the switch shunting the short-wave condenser so that the latter is placed in series with the aerial; reducing the amount of inductance in the primary of the oscillation transformer and in the tuning inductance; and tightening the coupling. Where

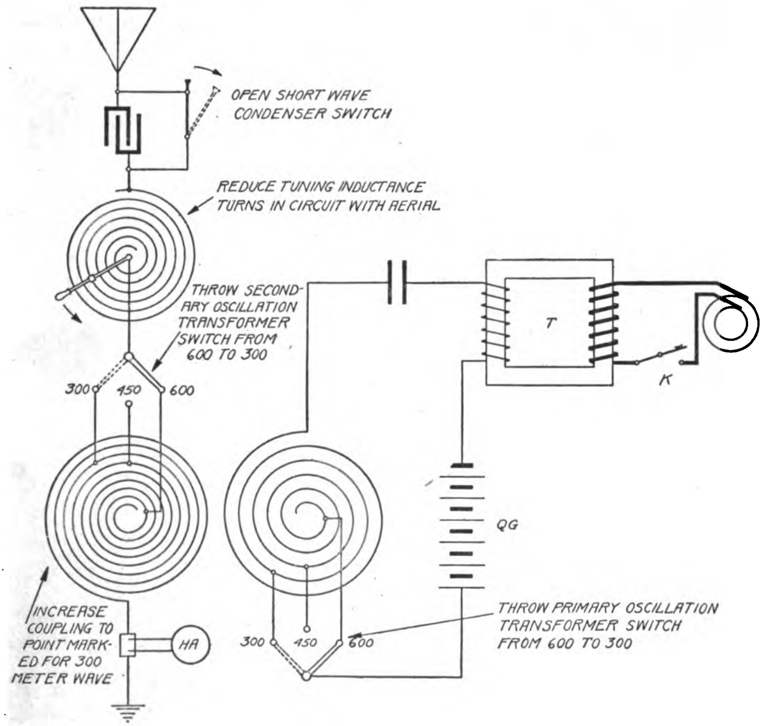


Fig. 192. Diagram Showing Method of Changing from 600- to 300-Meter Wave

a switch is not provided to make all these adjustments directly, they are either marked on the apparatus itself or posted in the operating room.

Q. Upon what does the wave length of an oscillatory circuit depend?

A. Upon the values of inductance and capacity, it being assumed that in any well-designed wireless set the resistance is too low to be a factor.

Q. If you increased the inductance value of the closed oscillation circuit only, would the transmitting set still be in tune?

A. The closed circuit would no longer be in resonance with the open circuit, so the set would not be in tune.

Q. Explain with the aid of a diagram the method of changing from 600- to 300-meter wave length.

A. Referring to Fig. 192, decrease the number of turns of the tuning inductance (aerial circuit) and the number of turns of the primary of the oscillation transformer in circuit to points marked on them or as shown on a chart in the operating room. Increase the coupling correspondingly. Open condenser switch.

Q. What variations of coupling are employed, how are they designated, and how used?

A. Generally speaking, either a tight or loose coupling is employed, the former when it is desired to radiate a broad wave for emergency calls and the latter to radiate a sharply tuned wave. The division between the two falls at a point where the difference in the length of the two waves emitted is 20 per cent of the natural wave length of the circuit. For example, in an aerial circuit having a natural wave length of 600 meters, two waves, one of 660 and the other of 540 meters are emitted, the percentage of coupling is $\frac{660-540}{600}$, or 0.20. A greater percentage than this, representing a greater difference in the length of the waves is tight coupling; less than 20 per cent is loose coupling. As some mutual inductance is necessary for the transference of the energy, however, the two wave lengths can never coincide exactly.

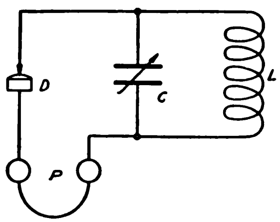


Fig. 193. Diagram of Wavemeter

Q. Draw a diagram of a wavemeter and describe its uses.

A. A wavemeter, Fig. 193, consists of a fixed inductance *L*, variable condenser *C*, detector *D*, and telephones *P*. Flexible connections between the inductance and condenser permit the former being placed in any position desired while the condenser is at some distance from the circuit to be measured. The telephones and the carborundum detector are in series and both are in parallel with the condenser. The lamp is in series with the inductance and may be cut out of the circuit by means of the key or switch. The pointer of the variable condenser moves over a scale which may be calibrated directly in wave lengths or have an empirical scale the degrees of which are converted into wave lengths by reference to a curve provided with the instrument. In using the wavemeter, the inductance must be so placed that it is cut by the lines of magnetic force of the circuit under measurement. In the case of the transmitting circuit, it must be at some distance from the latter to protect the coil, the proper distance being found by starting with the wavemeter several yards at least from

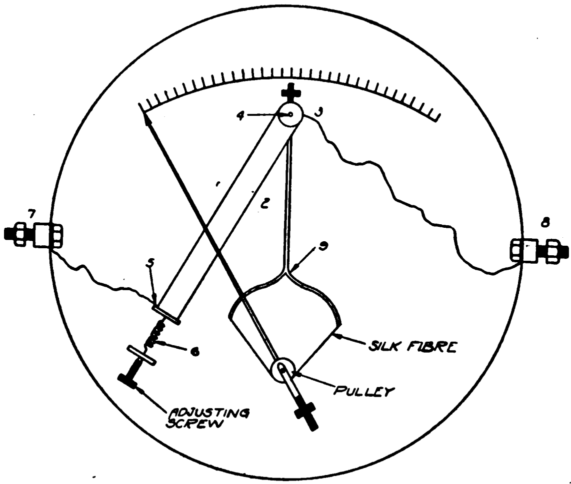


Fig. 194. Circuit of Roller-Smith Type of Hot-Wire Ammeter

the circuit and gradually approaching closer until a point is found where measurements may be made without risk of burning out the coil. When measuring a receiving circuit, the inductance may be placed in close proximity to it.

Q. Draw a diagram of a hot-wire ammeter and describe its uses.

A. A loop of high-resistance wire of fine diameter *1–2*, Fig. 194, passes over a pulley *3* mounted on the shaft *4*. At one end this loop is connected mechanically and electrically with the plate *5*, while its other end is also connected to the opposite end of the plate *5* but is insulated from it. A spring *6* keeps this loop under constant tension. The current enters at the left-hand binding post *7* and passes through the side *1* of the loop and out at the binding post *8*. The passage of the current through this fine high-resistance wire heats it and causes it to expand, so that the tension on the two sides of the loop is then unequal and the pulley *3* rotates sufficiently to equalize it. In so doing, it carries with it the yoke *9*, between the arms of which there is a fine silk fiber passing over a pulley on which is mounted the pointer of the instrument. The movement of the pointer over the scale is consequently directly proportional to the expansion of the wire *1*.

For ordinary service, the hot-wire ammeter is used to place the two circuits in resonance; also to indicate when the maximum amount of energy is being radiated and, in the case of a quenched spark gap which is silent in action, to indicate that the latter is operating. By the addition of a hot-wire ammeter to a wave-meter the latter becomes a decremeter.

Q. When approaching a coast station how would you reduce the amount of power being used in order to comply with the regulations?

A. Decrease the alternator voltage by inserting additional resistance in circuit with its field; reduce the speed of the motor-generator by decreasing the amount of resistance in circuit with the motor field; and loosen the coupling. This refers to a set having a rotary spark gap and any one of these adjustments may be sufficient without the others. With a quenched gap, the number of sections of the gap in circuit is reduced and the voltage of the alternator lowered. In the Marconi sets having a rotary gap and a variometer-type oscillation transformer, none of these adjustments is necessary as the desired reduction is obtained by simply varying the coupling. Placing the secondary at a right angle to the primary decreases the current in the aerial practically to zero and it may be varied from this point to the maximum by turning it through a quarter-revolution. It is also necessary to reduce the power for any short-distance transmission.

Q. In case the current failed while transmitting, where would you seek the trouble and how would you repair it?

A. If the motor-generator continues to run but the alternator fails to deliver any current, first investigate the fuses in the low-voltage alternating circuit to the transformer. Should these not have blown, ascertain if there is a break in the exciting circuit of the alternator fields; this may be determined in a moment by holding a knife or screwdriver on the field frame of the alternator, if it is strongly magnetic the exciting current has not failed. Examine the slip rings of the alternator and note whether one of the brushes has been loosened so as to vibrate out of contact with its ring. In case the motor-generator has stopped, examine its circuit-breaker and fuses. The remedy for any of these faults is apparent.

With the motor-generator operating, the primary or the secondary of the transformer may have become short-circuited or its insulation broken down. The spark gap may have become short-circuited or one of the condensers punctured or there may be considerable leakage in the spark gap muffler (rotary type). To locate the short-circuit, the battery and telephone testing the set should be used to test the generator field circuit and the primary and secondary windings of the transformer. If the short-circuit is in the generator field circuit, it will probably be in the field rheostat and the burnt-out coil may be bridged by a jumper. If in the primary of the transformer, it may be repaired by taking down the coil and unwinding it, using ample insulation at the damaged place when located. In case it is located in the secondary, the section at fault should be cut out and removed and the sections on either side of the damaged pie connected together, the transformer then being operated at a lower potential. A ruptured condenser may be replaced by a spare or, if none is available, the remaining units may be connected in parallel to give the same capacity, but the transformer must be operated at a lower voltage to prevent subjecting them to excessive strain. Cleaning out the spark gap muffler will often prevent any further leakage at that point. If it cannot be overcome in this way, the muffler should be removed and the gap operated without it.

Q. When using a quenched spark gap how can you determine whether it is producing a clear sharp note and whether the maximum amount of energy from it is being radiated by the aerial?

A. To ascertain the character of the note, place a simple receiving apparatus, that is, inductance, detector, and telephones, in inductive relation with the ground connection of the aerial and listen to the signals. To determine whether the maximum amount of energy is being radiated, the coupling and the values of inductance should be adjusted to give the maximum reading of the hot-wire ammeter at the same time regulating the voltage of the generator to give a clear musical note. The number of sections of the gap necessary can be found by trial, more being added or subtracted and the generator voltage increased or decreased until the proper result is obtained. This is on the assumption that the closed and aerial circuits are in resonance; if they are not the note will be irregular.

Aerials

Q. Why is it necessary to insulate the aerial carefully from its supports and solder all its connections?

A. Unless it is well insulated, leakage will occur and a large part of the energy will be lost instead of being radiated, while if its joints are not good electrically, they will increase its resistance and also cause losses of energy, this being particularly important in receiving, as the currents received are so feeble.

Q. What types of aerials are generally employed and why?

A. The inverted L type and the T type are used for practically all ship stations, the inverted L being used except where the distance between the masts is so great that the aerial would have too long a natural wave length to permit its being reduced to 300 meters with the aid of the short-wave condenser. In such cases the T type is employed. The latter is also used when the natural wave length would be so long that the short-wave condenser would be necessary to transmit on the 450-meter wave. The natural wave length of the average ship's aerial is close to 300 meters and its capacity approximately 0.001 microfarad.

Q. How could you tell whether there were leakage at the aerial or not, and how would you remedy it?

A. All other parts of the set being in efficient operating condition, inability to send the usual distance would be an indication of leakage. At night leakage across the insulators would usually be visible. Clean the insulators by scraping the carbonized surfaces and paint with the insulating compound usually supplied for the purpose. If the leakage is still in evidence, decrease the coupling. A test of the insulators may be made by inserting a spark gap (simple open type) in series with the aerial circuit and discharging the high-potential current from the secondary of the transformer across it. Excessive leakage would be indicated by a failure of the sparks to bridge the gap as the circuit would be completed through the defective insulators and the steel rigging. The strength and character of the spark discharge would afford a measure of any intermediate degree of leakage.

Q. What is the purpose of the aerial switch?

A. To change over from the transmitting to the receiving circuits so that the aerial may be placed in connection with either, as the aerial is alternately used for both sending and receiving. When sending, it connects the secondary of the oscillation transformer to the aerial; closes the primary circuit of the transformer; disconnects the aerial from the receiving transformer, or loose coupler, the ground, and the detector; and short-circuits the last named to protect it during transmission. When receiving, it disconnects the oscillation transformer secondary from the aerial circuit; puts the primary of the receiving transformer in circuit as well as in connection with the ground; opens the primary transformer circuit; and puts the detector in the receiving circuit.

Emergency Set

Q. What are the government requirements for an emergency set?

A. It must have a daylight radius of at least 100 miles and the source of current supply must be capable of operating it for at least four hours.

Q. Of what does the emergency set consist?

A. Either an entirely independent set, consisting of an induction coil, storage battery, and spark gap directly connected in the aerial circuit to give a broad interfering wave, or simply a large storage battery, capable of running the motor-generator for the required period.

Q. What is the international distress signal and how should the set be adjusted to send it to the best advantage?

A. The international distress signal is • • • ▬ ▬ ▬ • • • (SOS). In transmitting it, the coupling should be tightened and the maximum power employed in order that it may be read by as many stations as possible. As soon as communication is established, the ship's position (latitude and longitude) and its course and speed, if still steaming, are given. The call is sent on the 600-meter wave length.

Q. Draw a diagram of any emergency set with which you are familiar and explain its working.

A. Fig. 148 shows one of the types of emergency sets employed in Marconi installations. In this, the induction coil *I* is energized by a storage battery of fifteen cells delivering current at 30 volts. The condensers of the regular set are charged by the secondary of the induction coil and discharged through the rotary spark, but the latter is stopped for this purpose with its electrodes in such a position that they will provide a very short gap, the length of this gap being adjusted to produce a clear sharp note. Except for the motor-generator and the transformer, which are idle, the balance of the set is used in the same manner as ordinarily, the coupling being adjusted to produce the maximum reading of the hot-wire ammeter. As there is less power available, the coupling is tighter than with the motor-generator in operation. In case the condensers have also broken down and no spares are available, the spark gap will then be connected directly in the aerial circuit.

Storage Battery

Q. What types of storage batteries are employed for wireless emergency sets and how do they differ?

A. The lead-plate type and the Edison cell. In the former, the elements are lead plates, or grids, into which the active matter is forced under pressure, while the electrolyte, or solution in which the plates are immersed, consists of a dilute solution of sulphuric acid in distilled water. The Edison cell consists of a nickel-iron couple in an electrolyte of dilute caustic potash.

Q. What determines the capacity of a storage battery, in what terms is it stated, and how is it usually measured?

A. The number and area of the positive plates per cell of a lead battery determine its capacity, which is stated in ampere-hours and measured by an ampere-hour meter.

Q. How may the energy represented by the charge of the battery be employed?

A. The battery must be discharged at a certain rate, termed its normal discharge rate, in order not to injure the plates. An ampere-hour represents a current of 1 ampere passing in a circuit for 1 hour. If the cell has a capacity of 100 ampere-hours, it will produce 1 ampere for 100 hours, 2 amperes for 50 hours, 5 amperes for 20 hours, or 10 amperes for 10 hours. As its discharge rate increases, however, its efficiency falls off, so that the cell in question would not produce 50 amperes for 2 hours, though it would give a current considerably in excess of this for very short periods. The normal discharge rate is usually stamped on the cell itself and approximates its normal charging rate. Either may be exceeded within certain limits for short periods without injuring the cells, but a very high discharge rate would be liable to buckle the plates and short-circuit the cell, while a high charging rate will cause excessive gassing which loosens the active material and causes it to fall out of the grids.

Q. How is the condition of a lead-plate battery tested?

A. By the specific gravity of its electrolyte taken with the aid of a hydrometer.

Q. What is the specific gravity of a solution and what should it be for a fully charged lead-plate cell; a discharged cell?

A. The specific gravity of a solution is its density as compared with that of distilled water. For a fully charged lead-plate cell, this should be 1.275 to 1.300; a cell that is practically discharged should have a specific gravity of 1.190.

Q. What is the voltage of the lead-plate cell; of the Edison cell?

A. That of the former is 2 volts and that of the latter is 1.25 volts.

Q. What attention is necessary to keep a battery of lead-plate cells in good working condition?

A. They must be examined at short intervals and the height of the electrolyte above the tops of the plates noted. If this is not at least ½ inch, distilled water or clean rain water must be added to bring it up to this level. The battery should never be allowed to discharge at a point where its specific gravity is under 1.190 or the voltage per cell less than 1.9 volts. If allowed to get in such a condition, it should be recharged at once and the charge continued over a long period at a low rate until the specific gravity has ceased to show any increase for a number of hours. It should be recharged regularly, starting at the normal rate as marked on the cells and reducing this rate as soon as the cells begin to gas, the new rate of charge being continued until the cells begin to gas again, when the rate is once more reduced, this process being continued until the cells are fully charged. At least once a month, the battery should be given a long overcharge, or what is known as a conditioning charge, the rate being successively reduced at each recurrence of gassing. This is done to prevent an accumulation of lead sulphate on the plates and its hardening with age, which would reduce the efficiency of the cell. On discharge, the lead peroxide of the positive plate and the spongy metallic lead of the negative plate are both converted into lead sulphate; the charge reconverts this, but even a normal full charge does not dissolve all of it out of the plates, which accounts for the necessity of the conditioning charge at regular intervals.

Q. Is it ever necessary to add anything else to the cells?

A. Unless electrolyte has been lost by accident, it should never be necessary to add anything but distilled water to the cells during their effective life. In case acid has been spilled, electrolyte of 1.300 specific gravity may be added in small amounts to bring the specific gravity of the cell up to the proper point, this being added only after a charge has been continued until the specific gravity no longer shows any increase and it does not reach the normal of 1.275 to 1.300.

Q. What other precautions should be taken with a storage battery?

A. Open lights should be kept away from it as the hydrogen gas generated on charge is very inflammable of itself and highly explosive when mixed with the proper proportions of air (oxygen). All metal and tools should be kept away from the cells as any metal object, such as a screwdriver, falling on the terminals would short the battery and ruin the cells.

Q. Can the condition of the battery be tested in any other way than with the hydrometer?

A. A low-reading voltmeter may be used to take readings of the voltage of each cell, but the battery must be discharging at approximately its normal rate and not on open circuit, that is, without any load, when the test is made.

Q. The normal charging rate of your battery is 10 amperes; how would you charge it?

A. Close the switch of the direct-current mains leading to the battery and adjust the rheostat so that a current of 10 amperes is passing into it. As soon as the battery begins to gas, reduce this to 7 amperes by inserting further resistance and continue the charge until gassing again takes place; then reduce the current to 5 amperes, and so on until fully charged.

Q. What is the purpose of the automatic cut-out, or underload circuit-breaker, in the charging circuit of the battery and how does it act?

A. It serves to protect the battery by preventing it from discharging back through the line in case the current fails or the voltage of the battery becomes superior to that of the charging current, as in the case of a large battery such as is employed to run the motor-generator. The cut-out consists of an electromagnet having two windings, a voltage coil, a current coil, and a movable armature equipped with contacts. When the current first passes through it, the voltage coil draws the armature down, completing the circuit to the battery and at the same time through the current coil, thus greatly increasing the attraction of the magnet for the armature. In case the charging current fails, the current from the battery passes through the current coil in the opposite direction, magnetizing the core with an opposite polarity and releasing the armature, so that the circuit is opened automatically.

Q. What attention is necessary with the Edison cell?

A. It should be kept filled with distilled water and should be recharged when its voltage has dropped to 0.9 volt. No specific gravity or other test is necessary, and neither incomplete charging nor allowing it to stand discharged will injure it.

Q. What instrument is used to give a visual indication of

the state of charge of the battery and how does it automatically compensate for the loss between the charge and discharge?

A. An ampere-hour meter. This reads directly in ampere-hours and its pointer shows the extent of the charge in the battery at any time. For example, with a 100-ampere hour battery it will read 100 when fully charged and the pointer will gradually return to zero as the current is used. But as approximately 120 ampere-hours of current must be put into the battery in order that 100 may be drawn from it, its efficiency being about 80 per cent, the instrument is fitted with an automatic compensating device which causes the hand to move that much slower over the dial when charging than when discharging, so that the reading of the pointer always indicates the energy actually available. The instrument is operated by means of a small motor of unusual design and is sometimes fitted with an automatic circuit-breaker which cuts off the current when the battery is fully charged.

Q. If the ampere-hour meter became deranged, how would you determine the state of charge of the battery?

A. With the aid of the hydrometer and its specific gravity readings or a low-reading voltmeter.

Q. In case neither of these instruments was available, how would you determine when the battery had been on charge long enough?

A. By the number of times it had reached the gassing stage after a reduction of the charging current. For example, if the charge had been successively reduced from 10 to 7, 5, 3, and 2 amperes, it would be safe to assume that it was fully charged when it reached the gassing stage at the 2-ampere rate.

Q. Should you find that through neglect your battery had become discharged and it was necessary in the face of pending emergency to charge it as quickly as possible, how would you go about it?

A. Start the charge at the highest rate available that could be safely used with the wires and connections in the circuit. For example, if the wiring of the circuit were capable of carrying 50 amperes, it would be safe to use this, even though the normal charging rate were but 10 amperes. But the battery would have to be closely watched and as soon as signs of gassing were in evidence, the rate would have to be reduced, say, to 40 amperes; then to 30, and so on, the reduction being made as quickly as gassing appeared. It is safe to charge a lead-plate storage battery at as high a rate as it will absorb without gassing. In this way, the charge could be carried out in a fraction of the time ordinarily necessary, but the longer charge at the low rate is naturally preferable.

Q. In case your charging rheostat burned out, how could you regulate the charging rate of the battery?

A. Wire up a group of incandescent lamp sockets in multiple and connect this group in series with the battery and charging source; if 10 amperes are necessary, screw ten 32-candle power carbon-filament lamps into the sockets, reducing the number of lamps lighted to reduce the charging rate.

RECEIVING

Q. Show by diagrams the progress of development from the rudimentary receiving circuit, that is, the simplest apparatus with which signals can be received, up to the modern tuned receiver, giving a short description, the method of operation, and the advantages and disadvantages of each type.

A. Fig. 169 shows what may be termed a fundamental receiving circuit in that it contains the minimum number of instruments with which receiving can be effected. A detector is connected in series with an aerial and ground connection and a pair of head telephones shunted about the receiver. Signals can be received only at the natural wave length of the aerial circuit; the circuit is untunable and has no provision for offsetting the effects of atmospheric electrical disturbances.

In Fig. 170 is represented a rudimentary form of tunable receiving set, in that a variable inductance has been inserted in the aerial circuit, but it is subject to practically the same disadvantages as the preceding type.

Fig. 172 shows a further development in the form of additional provision for tuning by the use of extra sliding contacts on the tuning inductance and by the use of a variable condenser shunted across the detector, and a small stopping condenser is shunted across the telephones, thus increasing the audibility of the signal for a given strength of received current. While this represents a considerable advance over its predecessors, in that it may be tuned more sharply to resonance, it is still of the directly coupled type and no provision is made for controlling the mutual induction.

The receiving set represented by Fig. 173 is a much greater advance in that the tuning inductance has been converted into a transformer of which the primary is in circuit with the aerial and the secondary forms part of the closed receiving circuit. This is an inductively coupled type possessing all the good points of the preceding types with the further advantage that it permits a variation of the coupling, which gives much greater *selectivity* by making it possible to tune out undesired messages and reduce the effects of static to the minimum.

Q. What further apparatus may be added to this last type in order to make its selectivity still greater and to make it capable of converting the feeblest currents into audible signals?

A. Further selectivity is made possible by shunting a variable condenser across the primary of the receiving oscillation transformer. The strength of the received signals is increased in the telephones by the addition of a local battery in series with the detector and telephones, a potentiometer being shunted across this circuit to permit varying the strength of the current from the battery. A test buzzer set is also included to permit adjusting the crystal detector to the most sensitive condition.

Q. Draw a diagram of a receiving circuit showing the connections of all the apparatus just mentioned and describe the method of using such a set.

A. In the diagram, Fig. 175, A is the aerial, L_1 the aerial tuning inductance, L_2 the primary of the receiving oscillation transformer, C_1 a variable condenser shunted across the primary (this condenser is used in some sets and not in others), C_2 a variable condenser in series with the aerial, that is, a short-wave condenser, L_3 a small loop inductance in the ground connection of the aerial for use in connection with the buzzer test set, and G the ground connection. This completes the aerial circuit, also known as the open oscillation circuit, which serves to intercept the passing electromagnetic waves. L_4 is the secondary of the oscillation transformer for receiving, C_3 a variable condenser shunted across the receiving circuit, D the crystal detector, P the potentiometer, and B the local battery connected to the telephones. This completes the closed oscillation circuit, or local detector circuit, in which the high-frequency oscillations are rectified into pulsations of direct current so as to produce audible signals in the telephone receivers.

To receive with such a set, the test buzzer is set in operation and the carborundum detector adjusted to the maximum sensitivity by moving the adjustable contact over its surface and varying the potential from the local battery until the oudest sound is produced in the receivers. The direction in which the current from the battery passes through the detector must be determined by experiment, as the carborundum crystal responds much more strongly with the current in one direction than in the other; the potential impressed upon the detector by the local battery must also be gaged accurately by gradual adjustments of the potentiometer until the point is found where the loudest signals result.

The value of the aerial tuning inductance is then varied to place the aerial circuit in resonance with the sending station and similar adjustments of the primary of the oscillation transformer are also made. If a variable condenser is shunted across the primary, it is also adjusted. Should these adjustments to a minimum value not lower the wave length of the aerial circuit sufficiently, the short-wave condenser is placed in circuit.

A corresponding adjustment of the inductance value of the secondary of the receiving transformer is then made to place it in resonance with the primary, the coupling between the two is varied to eliminate interference, and the condenser C_3 is adjusted to strengthen the signals. Further strengthening of the signals may be found possible by adjustments of the potentiometer or of the detector itself. The fixed condenser C_4 is known as the stopping condenser and its object is to prevent the current from the battery passing through the secondary of the oscillation transformer instead of through the detector. The details of the connections of the detector, battery, and receivers vary with the different types of detectors employed. In the case of an electrolytic detector, the circuit would be the same as that illustrated.

Q. Draw diagrams showing how this circuit would be altered by the use of (1) a valve detector; (2) a three-element valve detector.

A. See Figs. 195 and 196.

Q. What is meant by a multiple tuner and how does it differ from an inductively coupled receiving circuit, such as that illustrated?

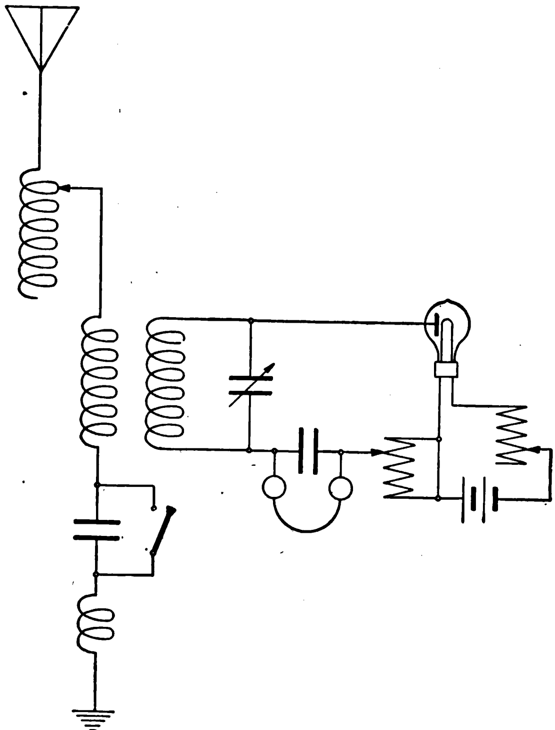


Fig. 195. Receiving Circuit with Valve Detector

A. In a multiple tuner an intermediate inductance, across which a variable condenser is shunted, is placed between the primary and secondary of the oscillation transformer.

Q. What is meant by the stand-by position and by the tune position of a modern receiver and what adjustment differentiates them?

A. In the stand-by position the receiver is adjusted to respond to a broad wave; that is, it will respond to a number of waves of different lengths almost equally well, so that a number of messages may be heard at the same time with little or no further adjustment. In the tune position, it is adjusted to respond most effectively to waves of a single length. The two are distinguished chiefly by the difference in the amount of coupling.

Q. How would you couple the receiving transformer to listen-in (that is, stand-by); to tune?

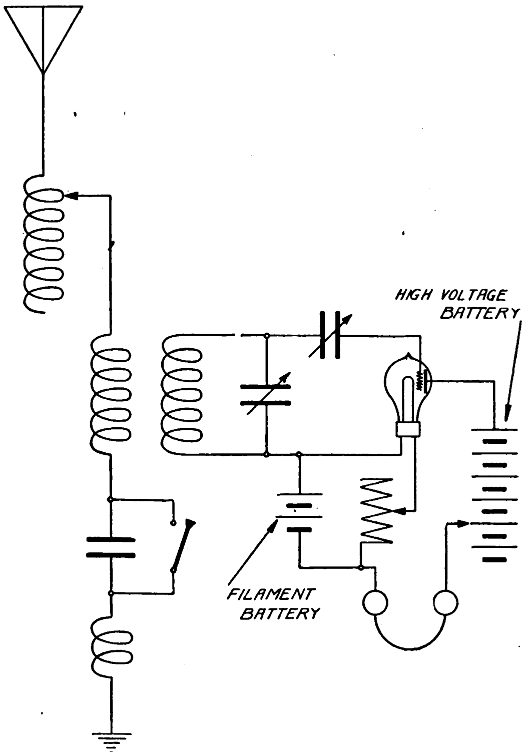


Fig. 196. Receiving Circuit with Three-Element Valve Detector

A. For the former, tight coupling would be necessary, for the latter, loose coupling.

Q. What further advantages are obtainable by a variation of the coupling?

A. By proper adjustment, signals of an incoming message may be made distinctly audible in spite of the noises caused in the telephone receivers by strong atmospheric electrical disturbances, or static. Stations sending at the same time as the desired station, even on the same wave length, may be tuned out owing to the difference in the damping of the waves, so that their signals are rendered weaker and those of the desired station stronger.

Q. Why are a local battery and potentiometer used with a carborundum detector?

A. To increase the audibility of the signals by impressing on the detector a certain potential above which any slight increase, such as is caused by the incoming oscillations, produces a marked increase in the strength of the current rectified by the detector.

Q. Why is it necessary to have a battery and buzzer set in connection with the receiving circuit?

A. To be able to determine whether the detector is in a sensitive condition for receiving.

Q. If, having just tested the detector and put it into good receiving condition, you were then unable to hear any signals of an expected call, what would you do?

A. Repeat the buzzer test and if the telephones failed to respond, investigate their connections both at the receiver ends and at the tips that are held by the screws of the binding posts. It is nothing uncommon for one of the latter to be pulled out inadvertently. If there is nothing wrong with the telephone or other connections and continued change of adjustment fails to locate a sensitive spot on the crystal, insert a new crystal.

Q. When receiving a message, how are you able to determine whether the station you are receiving from is sending a pure wave or not?

A. The fineness of the tuning necessary to receive a message is a certain indication of the character of the wave radiated by the sending station. If the signals may be heard equally well over a comparatively wide range of adjustment, the wave is a broad one, as it may be tuned in at several different lengths; if, on the other hand, a very slight adjustment one way or the other is sufficient to lose the signals, so that they can be heard only at a certain adjustment, the wave is sharply tuned.

Q. Does a wave that may be received with the receiving circuit out of resonance with the sending station, that is, one that

gives signals of almost equal audibility at two distinct wave lengths, comply with the regulations regarding the use of a pure wave?

A. No. Because this is an indication that the energy is being radiated at two distinct wave lengths, the energy of the shorter of which exceeds by a considerable percentage the allowable maximum of 10 per cent that of the longer.

Q. Can the buzzer test set be used for any purpose besides that of testing the sensitiveness of the detector?

A. When the buzzer test set consists of a wavemeter excited by a buzzer it may also be employed for adjusting the receiving circuit to a given wave length in anticipation of a call on that wave length. Receiving sets, however, are usually calibrated and the adjustments for various wave lengths marked on them either directly or by means of an empirical scale the wave length equivalents of which are given on a chart posted in the operating room.

Q. How is the detector, when of the crystal type, protected from the strong waves emitted by the sending circuit when in operation?

A. The detector is short-circuited or the coupling between the primary and secondary of the receiving transformer is reduced to its lowest point to minimize the amount of energy transferred.

TRAFFIC REGULATIONS AND LAWS

Q. By what signal must all calls be preceded?

A. The attention signal — • — • —

Q. Which determines the order in which messages shall be transmitted, the ship or the coast station?

A. The coast station.

Q. How do you answer a call when ready to receive?

A. By making the attention signal — • — • — followed by the call letters of the sending station repeated three times, **de**, one's own call letters given once, and the go-ahead signal — • — (K).

Q. How do you answer a call if not ready to receive?

A. The procedure is the same except that at the end of the signal • — • • • (wait) and the time necessary are given instead of the go-ahead signal.

Q. On what wave lengths do ship stations correspond?

A. Naval vessels between 600 and 1600 meters and merchantmen between 600 and 300 meters, though in some instances waves in excess of 1600 meters are permitted. These wave lengths have been fixed by international agreement.

Q. How can you learn the location, call letters, and range of various coast stations, also the call letters of various ships?

A. They are given in the U.S. List and the International Call Book, with both of which all ships are provided.

Q. When you wish to relay a message but do not know whether there are any ships within range of you at sea, how do you get in touch with the nearest vessel?

A. Use the International inquiry call — • — • — — • — (CQ), which will be answered by any vessel within range.

Q. Are you permitted to use your apparatus to correspond with other operators?

A. The International regulations prescribe that all licensed stations must be used for business purposes only and that no superfluous signals be sent. In the earlier days operators spent so much time sending their own private messages, that is, *talking* with one another, that considerable interference resulted and stations desired by others could not be communicated with because they were exchanging compliments or the like. An operator guilty of this practice nowadays would probably forfeit his license.

Q. How many of the International abbreviations do you know?

A. See complete list, page 255.

Q. When do you use the abbreviation PRB?

A. When the operator of the answering vessel does not speak the same language as you do, so that it is necessary to resort to the International Signal Code.

Q. What is the finish signal?

A. • — • — • This indicates the end of the radiogram. But in acknowledging each message of a series (U. S. Regulations) • — • is sent followed by the message number. On completing communication, the signal • • • — • — is made followed by the call letters; the sending station transmits the same signal followed by its own call letters. In other words, both sign off.

Q. If no answer is received to a call repeated three times at intervals of two minutes, how long must you wait before calling again?

A. Fifteen minutes.

Q. How many times may a message be repeated?

A. Three times.

Q. In what form may radiograms be transmitted?

A. In plain language, code, or cipher. For plain language, the maximum permissible length of a word is fifteen letters. Code may consist of words in English, Spanish, French, Italian, Dutch, Portuguese, Latin, or German, or of artificial groups of letters, no word of which shall exceed ten letters and all words of which must be pronounceable in some one of the languages mentioned. Alterations or reversals of words in plain language or combinations of two or more words contrary to accepted usage are not permitted. Cipher consists of groups of letters and figures or of combinations of letters, words, expressions, or names not classified as either code or plain language.

Q. How do you compute the charges for a radiogram?

A. By what is known as *cable count*, in which all words, including address and signature, are counted as part of the message. If a plain-language message contains one or more code words, it is charged for as a code message, so words having more than ten letters in such a message would be counted as two words. Cipher is charged at the rate of five figures or five letters, or fraction of five to the word, figures and letters in the same group being counted separately, that is, **B7X** would be three words. Where plain language, code, and cipher are combined in the same message, the first two are charged as code and the last as cipher in computing the total charge; when plain language has cipher with it, the latter is counted as such and added to the charge for the number of words in plain language.

Q. If while you are receiving from another ship, you hear a distress call, what should you do?

A. Immediately notify the ship from which the message is being received of the distress call, and then listen-in to note what answers are given to the distress signal. By comparing the position of the ship in distress with that of your own vessel together with the other answers heard to the call, you will know whether you are nearest to the ship in distress. If this proves to be the case, immediate acknowledgment of the distress signal should be made and full information should be requested. This should then be given to the commander of your ship. In case vessels much nearer to the vessel in distress answer its call, all sending should be stopped to avoid interfering with them.

Q. What penalties are prescribed by the U.S. Regulations for infractions.

A. Malicious interference is a misdemeanor which carries with it a fine of $500 or imprisonment for one year or both. General violations of the regulations are punished by a fine of $25 for the first offense and a suspension or revocation of the license for repeated offenses. Imprisonment for five years or a fine of $2500 or both are the penalties for sending out fraudulent distress signals.

Q. Why do the regulations prescribe that the logarithmic decrement must not exceed 0.2?

A. A logarithmic decrement of 0.2 represents fifteen oscillations per wave train, which is the minimum that will permit sharp tuning. A higher decrement than this would cause undue interference with other stations.

Q. How much power should be used in sending?

A. Only as much as is necessary to establish satisfactory communication.

Q. In case you find it necessary to operate at high power what should you do?

A. Send out the warning prescribed by the regulations before beginning to transmit.

Q. What limitation is there on the amount of power to be used when in the vicinity of a naval station?

A. The transformer input must not exceed 1 kw. when within 15 miles of a government station, or ½ kw. when within 5 miles of such a station, except when necessary to send a distress signal or correspondence relating thereto.

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