Wireless Telegraphy

AND

High Frequency Electricity

A

MANUAL CONTAINING DETAILED INFORMATION FOR THE CONSTRUCTION OF TRANSFORMERS WIRELESS TELEGRAPH AND HIGH FREQUENCY APPARATUS, WITH CHAPTERS ON THEIR THEORY AND OPERATION

BY

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PREFACE

Many books have been written on induction coils in which detailed instruction has been given for their construction and operation.

With the advent of wireless telegraphy, the X-ray and high frequency electricity for curative purposes, the induction coil became a commercial machine.

The induction coil is a very inefficient transformer of energy, but in spite of this it has proved very useful to the medical profession and to the scientific world.

In the case of wireless telegraphy, however, its limit was soon reached. As long as wireless communication was confined to comparatively short distances, the coil answered the purpose very well. Long distance work, however, required more energy, and the transformer, already developed commercially, was tried with great success.

The induction coil is a very troublesome instrument on account of the necessity for a vibrator or a make and break device. Its small efficiency also renders it a very expensive instrument, which places it beyond the reach of many amateurs.

On the other hand, transformers are very efficient, and they can be made at small expense. They are easy and convenient to use.

But few books have been written, furnishing the detailed information for their construction and operation. Those that have been written are large and expensive, and their contents are put in such form as to be of little use to the uninitiated.

This book aims to furnish the information in a clear and concise form, so that anyone can, by its use, design and manufacture high potential transformers for wireless or high frequency work.

The first chapters deal solely with the construction of the transformer and other wireless apparatus. This is followed by detailed instruction for its installation and operation.

In order to add to the interest and usefulness of the work, chapters on the design and manufacture of Tesla coils and Oudin resonators follow.

No person who takes up this fascinating study should neglect the theory of it, if he expects to derive the greatest benefit and pleasure from its pursuit. Chapters are added, dealing in as simple a way as possible, with this part of the subject.

Finally fourteen transformer designs are worked out and the data is collected in a table, making it very convenient for those who do not care to design the transformers, themselves.

The detailed method of design is given, however, for those who may desire to design larger machines.

A chapter on station calculation is added for those who may have mathematical tastes. In this chapter the method of practically calculating capacities and inductances is given, whereby the wave length and frequency of the station can be calculated. By this method instruments can also be calibrated.

The subject is not touched upon historically, and the presentation of a great variety of systems and their names is avoided. Only the fundamental principles are considered.

Selective tuning has not been attempted, since it is complicated, and as yet little understood, but it is the problem in wireless telegraphy and telephony today. Without it they have reached their limit and commercial success is impossible unless selective tuning is practicable.

I desire to acknowledge my indebtedness to the boys of Los Angeles, who have worked with me in this fascinating field. Many useful things have been developed at their suggestion.

The following boys deserve special mention: Roy Zoll, A. E. Abrams and Parke Hyde. Roy Zoll is one of the pioneers in this field in Los Angeles, and he has done some excellent long distance work. Parke Hdye has been especially active in the construction and operation of high frequency apparatus.

Dean Farran, Walter Cooper and George Roalfe put up the aerial on the Polytechnic High School, and Dean Farran has done some excellent long distance work with the station established there. The mechanical drawings are the product of the boys of the Polytechnic High School, the most of them being made by Sidney Twining, who also constructed some of the apparatus.

I wish also to express my appreciation for the help and suggestions of Mr. J. T. LaDu, and Mr. E. J. Ovington, in the field of high frequency electricity. Mr. Ovington suggested the dimensions of the Tesla coils and Oudin resonators that have proved so successful.

The following works have been freely consulted in the preparation of this book: The Principles of Electric Wave Telegraphy, by J. A. Flemming; An Elementary Manual of Radiotelegraphy and Radiotelephony, by J. A. Flemming; Wireless Telegraphy, by J. Erskine Murray; and A Manual of Wireless Telegraphy for the use of Naval Electricians, by Lieutenant Commander S. S. Robinson, of the U.S. Navy. While no claims are put forward for originality in any of the work presented in this book, yet everything here is the result of my own experience, or the experience of some of the boys with whom I have come in contact. I shall be pleased to have my attention called to any errors that have crept into the text, and I would consider it a favor to hear from those who construct transformers from the designs in this book.

H. LaV. TWINING.

Los Angeles, Cal., July 1, 1909.

WIRELESS TELEGRAPHY
and High Frequency Electricity

CHAPTER I.

THE TRANSFORMER

1. **Directions.**—All of the data necessary for the building of any transformer, from a 100 watt to a 5 kilowatt, is to be found in tables 1 and 2 in the back part of this book. The few pages preceding the table give the method of transformer calculation.

These calculations are based on the design of commercial power transformers, and they are then modified to fit the needs of wireless telegraphy. It is not necessary for the reader to do the calculating, as the data for fourteen transformers are given in the table, but the method is given for the sake of those who might wish to make use of it.

In this chapter the construction of a transformer, from the data given in the table, is described, and for this purpose the 200 watt transformer is selected.

The core of the induction coil is made of a straight bundle of iron wires, but the core of the transformer is made of laminations of iron arranged in the form of a rectangle, thus forming a closed magnetic circuit.

2. **The Iron Core.**—For reasons to be described later this iron core should be made of the best soft iron to be had. This is called transformer iron. It is difficult to obtain any iron of this kind, but the Palmer Electric Company of Los Angeles have obtained a large supply of this iron which they will sell to individuals in small lots. Transformer iron should be used by all means, but if it cannot be obtained, the next best thing is ordinary sheet iron, which can be obtained at the tinsmiths. It should be as thin as it is possible to get it, but a thirtieth of an inch thick will do. For the 200 watt transformer it should be cut into strips an inch wide. Consulting the table, we find that the iron core should be 10½ inches long and 6½ inches wide, outside measure.

Since the iron is to be an inch wide, half of the strips should be 9½ inches long for the sides of the rectangle, *C* and

D, *Fig. 1*, and the other half should be 5½ inches long, *A* and *B*, *Fig. 1*. Enough of these strips should be obtained to

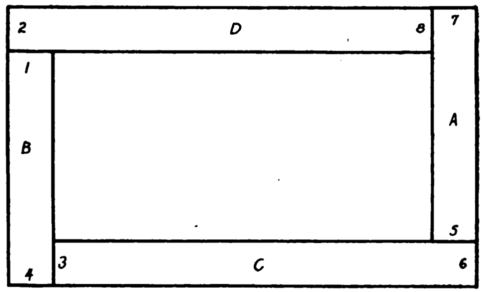


Fig. 1. First layer of iron core showing staggering.

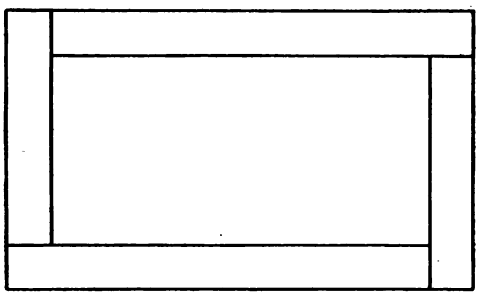


Fig. 2. Second layer of iron core showing staggering.

make the core when assembled and tightly pinched together, about one inch thick. The iron should be assembled according to the diagram given in *Fig. 1*.

The strips are laid down in the form of a rectangle. The end *1* of the short strip *B* is placed against the side of the end *2* of the long strip *D*. The end *3* of the long strip *C* is placed against the side of the end *4* of the short strip *B*. The end *5* of the short strip *A* is placed against the side of the end *6* of the long strip *C*, and the end *8* of the long strip *D* is placed against the side of the end *7* of the short strip *A*. The second layer is laid on top of this, but the pieces are arranged as in *Fig. 2*, so that the joints are staggered. The third layer is laid down as in *Fig. 1*, the fourth layer as in *Fig. 2*, and so on alternately. By following this plan the joints do not come together in adjoining layers. The pile should be built up in this way until it is an inch thick.

The end *A*, however, should be left out and staggered into place after the coils are placed on the core. *Fig. 3* shows a photograph of the iron core thus assembled and taped.

3. Insulation.—When the laminations are assembled they should be bound together with friction tape leaving out the end piece *A*. The iron when thus bound will hold together at the ends, *1*, *2*, and *3*, *4*, *Fig. 2*. The tape should be wound around the iron tightly and be overlapped as shown in the figure. Long strips of empire cloth, 8 mils thick and 8½ inches wide should be tightly wound around the legs *C* and *D* of the core until at least 10 layers are placed in position. They should then be taped as shown in *Fig. 3* in order to hold them in place.

It is necessary to thoroughly insulate the iron from the coils. No half way measures will do. When the transformer is in operation, high voltage surges, from the oscillation circuits, strike back into the transformer, and, unless the latter be highly insulated, it will break down.

The primary should be just as thoroughly insulated as the secondary. This layer of empire cloth should be about ¼ of an inch thick.

4. The Primary.—By referring to tables 1 and 2, it is seen that 666 turns of number 15 double cotton covered magnet wire is necessary for the primary. In an ordinary power transformer, these turns would be made of a smaller wire, with 1,200 turns instead of 666 turns; but in this case less turns are used and more amperes are allowed to flow, thus accomplishing the same result. This works the iron at a higher density. Larger wire has to be used in order to carry the increased amperage without undue heating.

In order to build the primary, it is necessary to have a form upon which to make the windings. *Fig. 4* shows the details of such a form. Prepare a rectangular block 15 inches away from you, winding the wire on tightly and evenly from the end *B* to the end *D*.

Have some hot paraffine at hand and paint the winding with it. The paraffine will hold the windings firmly in place. Keep on with the winding, putting the second layer on top of the first, back to the point of beginning.

Upon reaching *B* with the second layer, cut the wire and bring out a terminal *1*, six inches long. There are now 222 turns on the coil. For the third layer put the end of the wire through the hole *1* and solder it to terminal *1*. This forms the first tap.

Wind on this layer from left to right and upon reaching *D* cut the wire and bring out the terminal *2*. Through the same hole put the wire for the next layer, soldering it to *2*. Proceed in this manner until six layers have been put on, bringing out taps at *3* and *4*, ending finally with *5*. These taps should be labeled as designated in the figure so that no mistakes can occur.

They should be carried to the adjustable rheostat on the cover of the transformer, *Figs. 12* and *13*. We thus have an adjustable rheostat on the primary of the transformer itself, consisting of 222 turns on the first tap, 333 turns on the second tap, 444 turns on the third tap, 555 turns on the fourth tap, and 666 turns on the terminal *5*.

With the 666 turns cut in, this transformer will develop about 5,890 volts on the secondary and 3.6 amperes will flow. As the turns are cut out more amperes will flow and higher voltages will be developed on the secondary. With the 222 turns cut in, 17,621 volts will be developed on the secondary.

If desired, 222 turns only need be put on the primary and this will require only 11,879 turns on the secondary instead of 35,564 turns in order to develop 5,890 volts on the secondary.

All of the transformers given in the table 1 up to the two kilowatt can be modified in this way, making them much cheaper. In this case an impedence or a water resistance must be put in series with the primary to choke back the current, as will be explained later. I much prefer the second method, as the amperages and voltages can be much better controlled by the impedence or water rheostat.

Take the completed coil off the lathe. Remove the end blocks, pulling the wires out through the holes, which should have been made large enough so that this can be easily done. The coil should now be taped lengthwise with either cotton or friction tape. When completed it is to be thrust over the leg *D* of the iron core as shown in *Fig. 11*. The ends of the coil should be ½ inch away from the iron. It will require about 3½ pounds of number fifteen wire to put on the 666 turns and about one-third as much to put on the 222 turns.

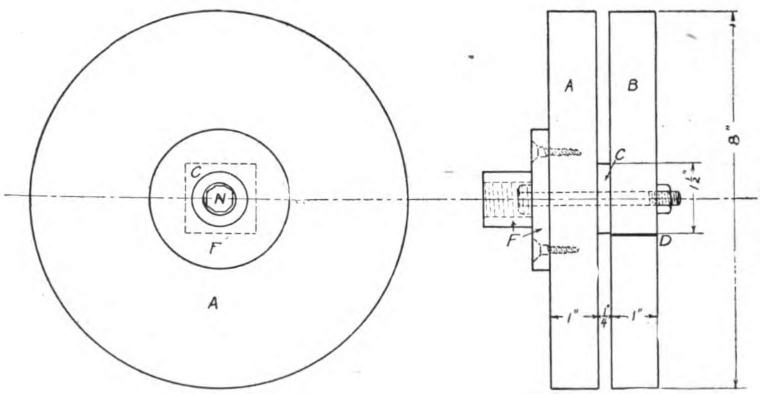


Fig. 5. Form for winding secondary.

5. The Secondary.—If 666 turns are put on the primary, it will require about 6½ pounds of number thirty-four double cotton covered magnet wire. If 200 turns are used on the primary, it will be necessary to use only 3 pounds of the number 34 wire, D. C. C., in order to develop 8,000 volts. This would require 14,513 turns on the secondary.

3,000 to 5,000 volts in a transformer is all that is necessary for a transformer for wireless or high frequency demonstrations, especially for all transformers up to the kilowatt size, but the higher voltages are better for large pieces of apparatus or very large aerials.

If the smaller number of turns are put on, the core does not need to be as long nor as wide as in the other case, and it should be modified accordingly.

6. **The Form.**—A form is necessary upon which to wind the secondary. The secondary coils should be wound in flat pie coils. The form for this is shown in detail in *Fig. 5.*

Cut two circular blocks *A* and *B* 1 inch thick and 8 inches in diameter. The coils are to be made ¼ of an inch thick. They should not be made any thicker than this. If they are made too thick, they will break down between turns and all the work will have to be done again.

Prepare a little block *C* one-quarter of an inch thick and about 1½ inches square. This square should be large enough so that the coil when wound will slip easily on to the insulated leg of the transformer.

Obtain a bolt *N* 2½ to 3 inches long. Bore holes through the centers of the blocks *A*, *B* and *C* large enough to admit the bolt. Screw the circular block *A* to the face plate *F* and nail the block *C* to the block *A*.

Cut out two circular pieces of paper and make square holes in their centers the size of the block *C*. Paste them on to the inner surfaces of *A* and *B* with hot paraffine.

The circumference of the block *C* should not be perpendicular to *A*, but it should slope slightly from *A* to *B*, so that the coil when wound can slip off the form easily. On the circumference of *C* paraffine a piece of paper, so the coil cannot stick to the wood.

Bore a hole through the plate *B* at *D*, through which to put the end of the wire. Bolt the plates thus prepared to the face plate *F*, as shown in the figure.

By means of the face plate, screw the form to the lathe. If no lathe is at hand, then an arrangement similar to that for winding the primary should be made. The more slowly the coils are wound, the more turns it is possible to get in a given space.

Melt two or three pounds of paraffine in a galvanized iron pail and place the spool of number thirty-four wire into the hot paraffine, and let it stay there until it is thoroughly heated.

Take it out and run a rod through a hole bored through the center of the spool.

Take two blocks a foot in length and bore holes near their ends large enough to receive the ends of the rods. Fix the blocks in an upright position and run the ends of the rod through the holes, so that the spool can unwind freely as the wire is wound onto the form.

On the form thus prepared, wind about an eighth of an inch of paraffined string. Put the free end of the wire through the little hole *D*, *Fig. 5*, from the inside outward, leaving the free end about a foot long. Drive a tack into the outside of the form and secure the wire to it.

7. **The Winding.**—Begin to wind, turning the form away from you. If you have a lathe, the winding can be done very rapidly, but it will be done at the expense of less turns in a given space. If the winding be done slowly by hand, the turns can be laid on more evenly, and as they will not cross one another so much as in the rapid winding, many more turns can be put on. The number of turns given in the table is for the fairly slow winding.

Proceed to wind until the form is filled to a depth of two inches. If the wire on the spool begins to get cool before the winding is completed, take the spool off the rod without breaking the wire, and put it in the hot paraffine for a short time.

If the spool is kept in the paraffine during the winding, too much paraffine will go on to the form with the wire, and this will reduce the number of turns that can be put on the form. The paraffine makes the wire stick together so that it can be easily removed from the form without falling apart.

During the winding of the coil, it should be tested from time to time to see whether it is open. The wire may be broken and hold together firmly because of the cotton insulation. If a ringing testing set is at hand, this can be done without cutting the wire or disturbing the insulation. Attach the free end of the coil to one binding post of the testing set. Attach another wire to the other binding post, and, to the free

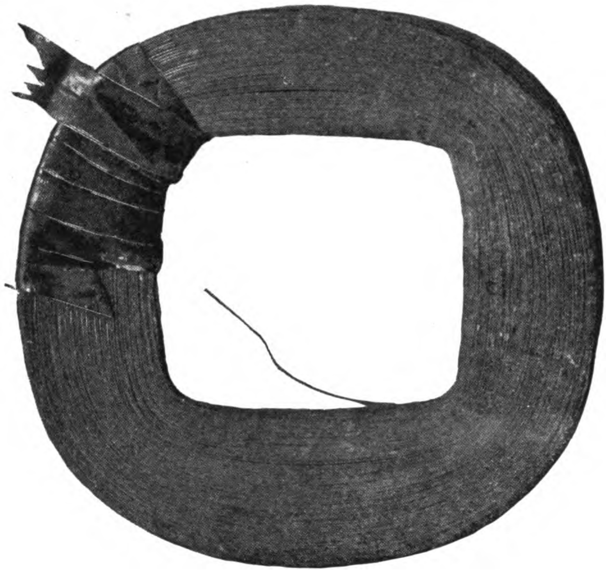


Fig. 6. Secondary coil, showing method of taping.

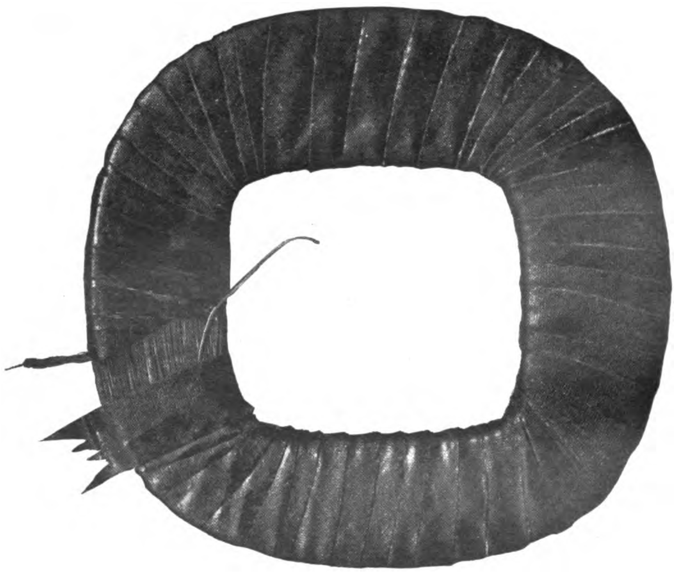


Fig. 7. Secondary coil, showing taping nearly completed.

end of this wire attach a sharp metallic point. This point can be thrust through the insulation at any place on the wire and the bell can be rung in the usual way. If you have no testing set, make one in the following manner: Make a form of wood two inches wide, three inches long and an inch thick. Paraffine some paper onto the wood. Then put two or three layers of unparaffined paper over this. Wind on this form from five hundred to a thousand turns of the thirty-four wire, or, better still, the same number of turns of number thirty-six wire. When the winding is completed, drive out the form and tape the coil. Obtain a pocket compass and put inside of the coil. Bring the terminals of the coil to binding posts, and you have a cheap testing set. Use one or two dry cells on this galvanometer. A telephone and battery can be used instead of the above. This is the best method.

Having completed the winding of the coil, remove the form from the head, take out the bolt, and, with the thin blade of a table knife, loosen the outside circular block of the form, inserting the blade of the knife under the paper next to the wood and *not* next to the wires. The paper separates easily from the wood. In the same way separate the coil from the other block of the form. Test the coil to see that it is not open.

8. Taping the Coils.—Obtain empire cloth about eight mils thick and cut it into strips about three-fourths of an inch wide. Do not cut the cloth parallel to the edge of the sheet, but cut it in strips from corner to corner. It will be much stronger if cut in this way.

To put on the tape, take the coil in the left hand, see *Fig. 6*, letting the outer terminal of the coil run to the left and the inner terminal toward the right. Take the tape in the right hand and place one end about the middle of the upper side of the coil, as shown in the cut. Carry the tape away from you around the coil, allowing it to lap over about half of its width. When the end of the strip is reached, place the end of another strip on top of the end of the strip just put on and proceed with the taping.

As you reach the point of beginning, allow the inner terminal of the coil to run on around in the way in which it is wound, so that it will come out of the taped coil in the same direction in which it is wound, as shown in *Fig. 8*.

The tape should now be wound close up to the outer terminal, leaving it free. Do not wind it in as was done with the inner terminal. Allow this terminal to come out of the tape in the same direction in which it is running around the coil, as shown in *Fig. 8*. The tape can now be carried beyond the outer terminal a short distance until the inner terminal is well taped in as shown in the cut. The free end of the tape should now be tucked under the last turn of the tape and drawn tightly. If the coil is taped in this way, the direction in which the wire is wound on the coils is easily seen without taking off any of the tape. This will save trouble.

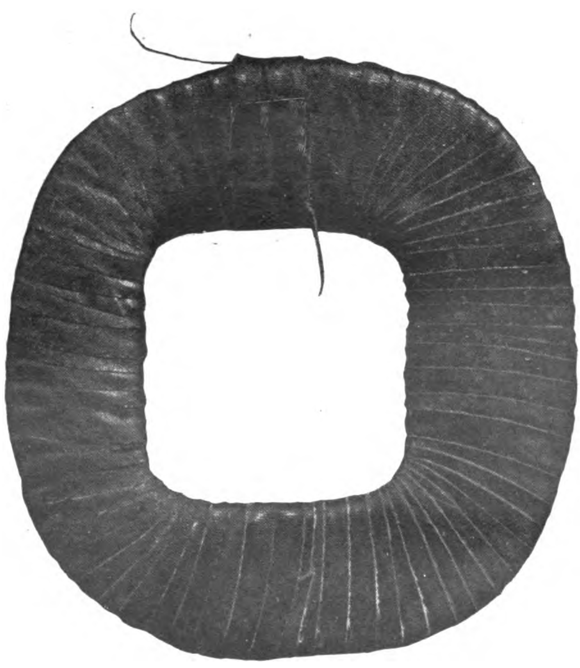


Fig. 8. Secondary coil, showing taping complete.

In bringing out the terminals, care should be taken not to let the wire kink up as shown in *Fig. 7*, so as to cross any of the turns of the coil, as there is danger of the coil breaking down across the turns. In this manner make twenty-six coils.

9. Assembling the Coils.—Before assembling the coils on the core, they should be grouped together in pairs, the insides of the coils being joined together, as in *Fig. 9*. If the current be supposed to enter the coil *A* at *D*, the inside of *A* should be joined to the inside of *B*, so that the current runs around the core in the same direction as it is running in *A*. In order to accomplish this, put the coil *A* on top of the coil *B* so that the two free ends, *D* and *C*, are running in opposite directions.

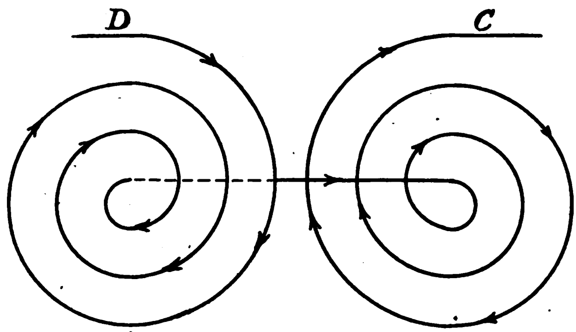


Fig. 9. Method of joining coils in pairs.

If this latter point is attended to, there will be no danger of getting them together wrong. All connections should be soldered. Before assembling these coils in pairs, cut circular discs of empire cloth, an inch larger in circumference than the taped coils. Cut out their centers so that they will fit over the core of the transformer. Put two of these between the two coils of each pair.

After they are joined in pairs, assemble the pairs on the core, so that the end *C* of the second coil of the first pair joins to the beginning *G* of the first coil of the second pair, continuing on around the core in the same direction. This is easily accomplished, if the end of one pair and the beginning of the other pair are coming out in opposite directions, as in *Fig. 10.*

If *A* and *B* are the first pair and *E* and *F* are the second pair, then the end *C* of the first pair should join to the beginning *G* of the first coil of the second pair. The inside of *E*

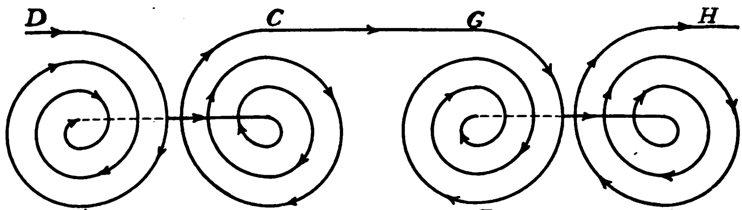


Fig. 10. Method of joining pairs.

is connected to the inside of *F* as in the first pair, coil *E* being placed on top of the coil *F*. Thus *D* and *H*, the beginning and end of the four coils, come out in opposite direction, and the wire is running around the core in the same direction.

Each pair should be assembled in the same manner relative to the pair before it. Four discs of empire cloth should be put between each pair of coils. In assembling the pairs, it should be noticed that the outside end of one pair in connecting to the outside end of the adjoining pair should not turn back. If it does, it is wrong; it should continue on around and not turn back on itself.

When assembled, the coils should not be pinched tightly together. They should be loose so that the oil or wax can get down between them easily. In order to keep them apart they can be wound with string, as shown in *Fig. 11.* If the transformer is to be in continual use, these coils should be assembled so that the oil in which they are to be immersed can circulate all around them.

This can be easily arranged in the following manner: Cut a circular disc of stiff fullerboard about an inch greater in diameter than the taped coils. Cut a circular hole in the center of it, so that it will fit snugly over the insulated leg of the transformer. Take the paraffined string off the inside of the coils before taping them.

Wind coarse thread or string around each taped coil in the same way as the tape is wound, but the string should not be wound tightly together. Let each turn of the string be from a quarter to a half of an inch apart. See *Fig. 11.* Place the fullerboard between the coils thus prepared, and wind string around the coils and fullerboard, binding the coils firmly to the board.

The coils are thus held one-eight of an inch away from the core of the transformer. The thread keeps the coils from fitting tightly to the fullerboard. Assemble the pairs thus prepared on the core, putting four thicknesses of empire cloth between the pairs, or put one thickness of fullerboard between them and two thicknesses of empire cloth.

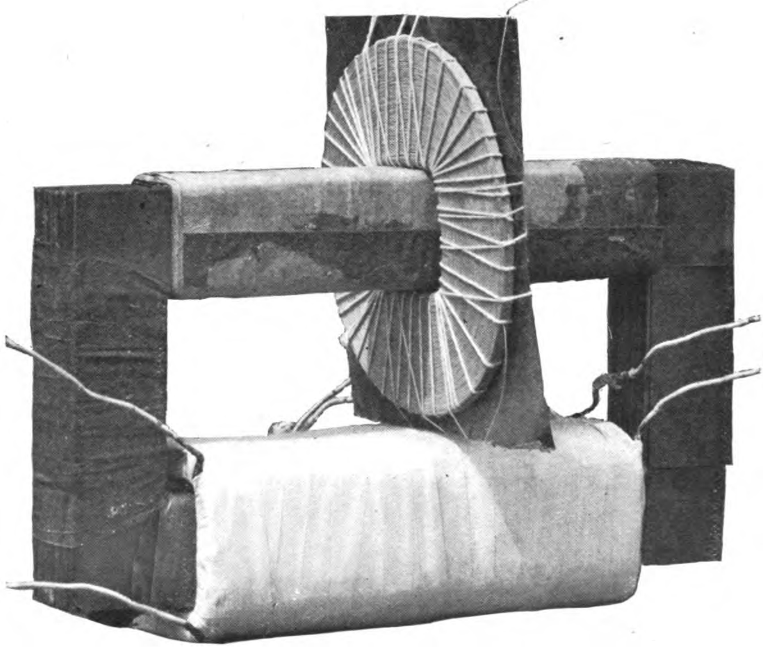


Fig. 11. Transformer core with primary and one pair of secondary coils in place.

When arranged in this manner, the oil can circulate all around the coils without obstruction. The oil not only insulates them well, but it also cools the coils by circulating. The hot oil rises to the top and flows over to the side of the case, where it is cooled and returned to the coils again. If the transformer is to be in constant use, this is necessary.

Fig. 11 is a photograph of a kilowatt transformer, with the primary in place on the lower leg. The upper leg has one pair of the coils, just described, in place. These coils are not taped. String is wound around them and they are then fastened to the fullerboard by string, as described above. This allows the oil to come directly in contact with the coils. On this account this is better than taping them. More empire cloth should be put between the pairs of coils than in the other case. Taping the coils makes them mechanically stronger, however, and they are less liable to injury.

The first and last coil of the secondary should be from a half inch to an inch away from the end iron of the transformer core. Before assembling the coils on the core, it is well to put two or three thicknesses of fullerboard and as many of empire cloth next to the iron, and, when the coils are all assembled, put on the same amount before staggering in the end pieces. If the latter method of assembling the coils is used, they should be pushed snugly together, but not pinched tightly, and the ends between the end coils and the iron can be filled with wooden wedges previously boiled in oil to expel air and moisture. These wedges hold the coils firmly in place. The latter method is much the better method for assembling the coils, even if they are to be put up in the wax preparation. The end pieces should be staggered into place as soon as the coils are assembled, thus completing the magnetic circuit.

10. Insulation.—The wax preparation for imbedding the transformer is made as follows: One pound of beeswax, one and one-half pounds of paraffine and four pounds of rosin. Melt in a galvanized iron dish until thoroughly mixed. Then heat until all moisture is driven off. If too brittle, use less rosin. If too soft, use less paraffine. The beeswax is quite expensive and can be omitted. Petrolatum or vaseline can be used to advantage, about one part in seven being mixed with the other ingredients.

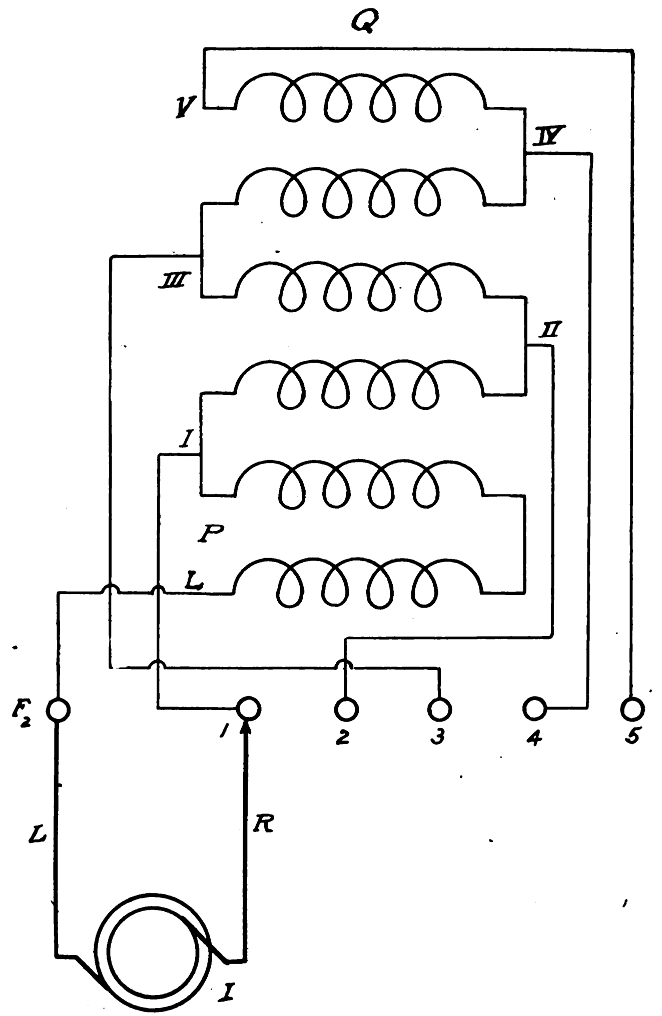


Fig. 12. Transformer connections where binding posts are used. I, alternator supplying the current; L, lead to binding post F_2: 1, 2, 3, 4 and 5, binding posts; I, II, III, IV, V, taps; R, adjustable lead; Q, coils on core.

If the transformer is small, it can be conveniently put in a box of the proper size and the hot wax poured in around it and allowed to cool. If the transformer is to be put in oil or if it is a large one, a galvanized iron box is necessary. Double boiled linseed oil or transformer oil can be used. The taps from the primary should be brought out to binding posts on the cover in the manner described below.

11. **Rheostat.**—If the voltage of the secondary is below twenty thousand, and the cover is a wooden one, the secondary taps can be brought to binding posts on the cover. If it is above twenty thousand, bring the secondary terminals out through hard rubber tubes.

Fig. 12 is a diagram of the connections. *I* is the alternator that supplies the current for the house or the socket into which the leads *L* and *R* are plugged. *F2* is the binding post, which is connected to the terminal marked *L* of *Fig. 4*. It comes from the coil nearest the core.

1, 2, 3, 4 and *5* are the binding posts to which the taps *1, 2, 3, 4* and *5* of *Fig. 4* are taken. They are represented in this figure by the characters *I, II, III, IV* and *V*. The lead *R* is adjustable so that it can be attached to the post *1, 2, 3, 4* or *5*. When attached to *1*, the highest voltage is developed, as only two coils are then cut in. When attached to *2*, three coils are cut in, etc., until all the coils are cut in at *5*.

This diagram represents the primary connections only. The secondary terminals should be brought out as far as possible from the primary and should be attached to binding posts. This arrangement can all be put on the cover of the transformer. When two coils only are cut in, they should be those nearest the core. All connections should be soldered, even to the binding posts from the taps.

In *Fig. 13* the connections are shown for a rheostat to be located on the cover of the transformer. The leads *L* and *L1* come from the source of electrical energy and attach to the binding posts *F* and *F1*. The binding post *F* is connected to the tap marked *L* in *Fig. 4*. The binding post *F1* is attached

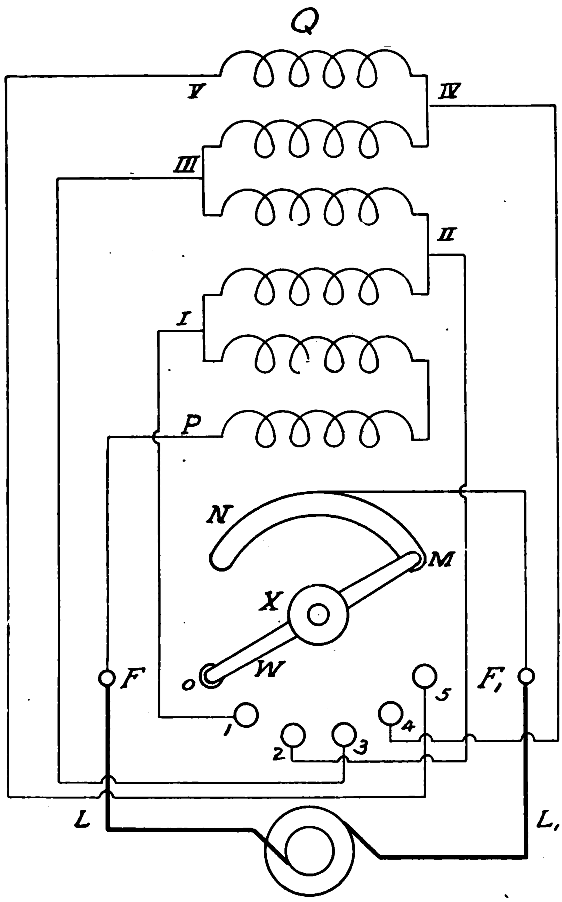


Fig. 13. Primary transformer connections to rheostat on cover. L, L_1, leads from plug to binding posts; F, F_1, binding posts; P to Q, coils of primary; I, II, III, IV, V, taps from primary coils leading to points 1, 2, 3, 4 and 5; NM, curved brass contact piece; WM, wiper; X, knob of rubber for turning wiper; O, off point; 1, 2, 3, 4, 5, contact points.

to a curved brass piece *NM*, upon which one arm of the wiper *XM* slides.

The other end of the wiper rests on the off point *O*. This point is not connected to anything and when the arm of the wiper rests on it, the circuit is open. By means of the knob X, the wiper can be turned so as to rest on *1, 2, 3, 4* or *5* successively, thus cutting in more and more turns, until they are all cut in. When resting on *1*, two coils are cut in; on *2*, three coils, etc. The points *0, 1, 2, 3, 4* and *5* should be made of brass turned out in the lathe. The heads should be a quarter of an inch in diameter, at least, and an eighth of an inch thick. The part that goes through the wood should be one-eighth inch in diameter, and long enough to go through the wood. Thread this part and make a couple of nuts to fit it. Machine screws can be used for this purpose if you have no lathe. Obtain screws of the right size and file the tops down flat. They should be put near enough together so that the arm W makes contact with one before it leaves the other, otherwise the point of the wiper will fall down between two points. This should never be adjusted while the transformer is running, or the coils will be short circuited and this would burn out the transformer.

The wiper W can be made of one-sixteenth inch spring brass, or better of phosphor bronze. The knob X should be turned out of rubber or fiber. Bore a hole an eighth of an inch in diameter through the phosphor bronze strips MW. Take a piece of one-eighth inch brass rod, long enough to go through and beyond the wood of the cover a quarter of an inch. It should also project a half an inch into the knob X. Insert it through the hole in WM and solder it firmly in position. Thread both ends of the brass rod. Bore a hole in the knob and thread it to fit. Screw it on to the upper side of WM.

Obtain a brass tube that will allow the one-eighth inch brass rod to be thrust through it. Cut it off the proper length to form a sleeve for the rod to turn in.

Bore a hole in the wood a little smaller than the sleeve and drive it tightly into position. Insert the rod and screw a nut on from below. Head it on so that it cannot come off.

Stops should be placed at M and N to prevent the arm XM from sliding off the brass piece NM.

12. **Impedence.**—This rheostat as described here is an excellent one for impedence. The impedence is built just the

same as a transformer, except that no secondary is wound on it. In this case *F* and *F1* are connected in series with the primary of the transformer with which it is to be used.

These high potential transformers should be put up in oil or wax preparation. If they are below 10,000 volts on the high side and are carefully insulated, they will stand it for a while without breaking down; but there is a static discharge developed between the coils of the secondary, that will sooner or later cause it to break down. The only safe way is to fix them so they cannot break down.

Leads of flexible lamp cord should be soldered to the terminals of the primary and secondary, and these should be soldered to the rheostat terminals on the cover.

The leads should be long enough so that the cover can be held at least at an angle of sixty degrees while doing the soldering. After all is finished, a hot preparation of the wax should be poured into the box containing the transformer, until it is covered to the depth of an inch. As it cools, add more of the preparation, since it shrinks on cooling. When cool lower the cover and screw in position.

13. **Voltages.**—If a high voltage transformer is desired, it is not necessary to put 666 turns on the primary; 222 turns, only, will do, but an impedence or water rheostat must be used in series with the primary to regulate the flow of current.

In this transformer 5,890 volts are developed in the secondary with 666 turns in the primary, and 35,564 turns in the secondary; 555 turns develop 7,048 volts; 444 turns develop 8,810 volts; 333 turns develop 11,741 volts; and 222 turns develop 17,621 volts.

This transformer is designed to stand 20,000 volts. I have found the 10,000 volts to be better than 20,000 for working the high frequency apparatus described in this book. It gives more amperes in the secondary.

In the above, double cotton covered wire is used. Single cotton cover will raise the voltage to 7,300 at the lowest, to 22,000 at the highest. For higher voltages, increase the length of the core and put on more coils.

14. A Very Cheap Transformer.—A very cheap transformer that will work well can be made by changing this design a little. Make the iron core 5½ inches wide by 8½ inches long, with a square inch cross section as before. Wind the secondary coils to a depth of 1 inch or a little more. This will put on 1,000 turns per coil. Make 10 of these coils instead of 17 or 18 as in the former case.

Wind on the primary two layers, one of 110 turns, and bring out a tap. Put on the other layer of 110 turns, thus giving 220 turns in all. The 110 turns will give 10,000 volts and the 220 turns will give 5,000 volts.

Put a water rheostat in series with the primary and regulate the current. With a 200-watt transformer of this type and 2½ amperes flowing in the primary, one can send 30 miles overland from a 200-foot horizontal aerial 40 feet above ground, or 30 miles with a 70-foot vertical aerial.

A transformer of this kind will not cost more than seven dollars and a half for the materials. All of the designs given in the table can be modified in this way. In every case, however, the current must be kept down to the proper amount by a water rheostat.

CHAPTER II.

TRANSMITTING APPARATUS.

1. The Water Rheostat.—In order to prevent too much current from flowing into the transformer when it is being used for wireless or for high frequency work, it is necessary to use a water rheostat or an impedence. The water rheostat is very much cheaper than the impedence, and it is very useful and handy. With it the amount of current can be regulated easily and minutely; and, since the amount of current has much to do with the tuning, as we shall show later, it is important to be able to regulate it very closely.

With 666 turns in the primary, the rheostat is not necessary, but, as the turns are cut out to secure higher voltages, it becomes necessary.

Obtain a glass battery jar or a glazed crock, holding about a gallon of water. See *Fig. 14* for details of construction. Cut two pieces of galvanized iron, *G* and *Q*, to fit in the jar, making *Q* a little smaller than *G*. To *G* solder a number 12 rubber covered copper wire, and attach it to the binding post

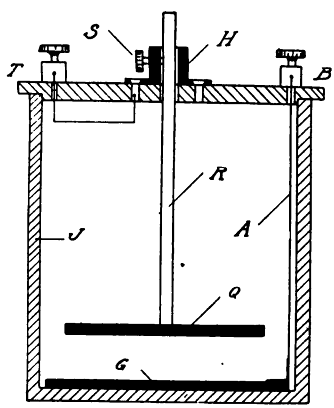


Fig. 14. Water rheostat.

G and Q, galvanized iron plates; J, glass battery jar or crock; A, rubber covered lead to G; R, brass rod; S, thumb screw; H, brass bearing; T, B, binding posts.

B. Prepare a wooden cover for the jar on which the binding posts *T* and *B*, and the brass bearing *H* are placed.

Solder a brass rod one-eighth of an inch in diameter to the galvanized iron plate *Q*. Prepare a brass bearing *H* with a thumb screw *S*, so that the rod *R* can slide freely in *H*, and fasten in any position by tightening the thumb screw *S*. Connect the binding post *T* and the brass bearing *H* by a number 12 copper, rubber insulated wire. Solder the connections. If this jar be nearly filled with water in which a little salt is dissolved, it makes an excellent rheostat.

2. **The Impedence.**—Instead of a water rheostat, an impedence may be employed. The impedence is more economical, as the current is choked back by the inductance, or back electromotive force of inductance. The water offers a resistance and is heated by the current. This heating consumes energy. The impedence is made on the same principle as the transformer, without any secondary.

Proceed to build the impedence as directed for the primary of the transformer in *Figs. 1, 2, 3* and *4*. They need not be so heavily insulated, however. No empire cloth need be used.

Cover the iron core pretty heavily with tape. Wind on the form as described, putting a layer of paraffined paper between each layer. Instead of making the coils as long as the core, make them only half as long and bring out taps every fifty turns. It would be better still to bring them out every twenty-five turns.

The coils should then be made one-fourth as long as the core. Each coil should be thoroughly taped with cotton tape. They should be assembled on the core with fullerboard between each coil and connected in series. Join the inside of one coil to the outside of the following one, and see to it that the turns continue on around the coil in the same direction.

If coils are put on both legs of the core, the coils on one leg should go around the iron in the opposite direction to those on the other leg, the same as they go on an electromagnet.

Bring the taps out to a rheostat on the cover as described for *Fig. 13*. In this case, however, there would be more points. Imbed the impedence in oil or wax. The wire should be the same size as the wire in the primary of the transformer with which it is to be used. It is better to use double cotton covered wire for the impedence. In case the impedence is to be used, the transformer need have but 200 turns or less in the primary. The impedence itself should have at least 250 turns.

The water rheostat is a very handy piece of apparatus and much cheaper than the impedence.

3. **The Condenser.**—In order to accumulate the electricity and discharge it across an air gap, in order to set up electric oscillations, a condenser is necessary. Procure 16 or 20 plates of common window glass, 8 by 10 inches. Obtain a couple of pounds of lead or tin foil, such as is sold by seed merchants.

Shellac the tin foil on to both sides of the glass plates, leaving about one inch margin on each side, if the voltage is about 10,000.

If the voltage of the transformer is 20,000, leave a two-inch margin on three sides, and a three-inch margin on the fourth side. In order to shellac the tin foil on the plates easily, the following method should be pursued. Either buy the shellac already mixed or put orange shellac in alcohol and allow it to dissolve.

Fill a quart bottle one-quarter full of the dry shellac, and then fill the bottle with wood alcohol. Allow it to stand twenty-four hours. Shake well and dilute with alcohol until it is very thin. Cut the tin foil to the proper size. With an ordinary paint brush, paint the glass with the shellac, and immediately apply the tin foil, painting the surface over with the shellac.

Have at hand a hard rubber roller, such as is used by photographers in rolling down photographs upon cardboard when mounting them. Keep the roller moist with the shellac, and proceed to roll down the tin foil until it fits smoothly.

If the roller is not kept moist by dipping in the shellac, the tin foil adheres to it instead of the glass.

Fig. 15 gives the details of the condenser, and *Fig. 16* is a photograph of it. Cut two boards *D* for an upper and a lower base.

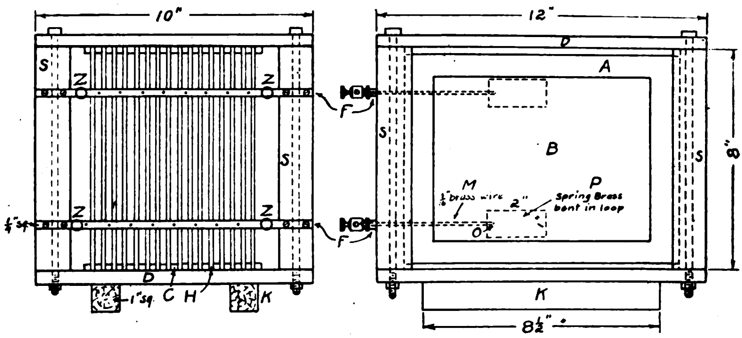


Fig. 15. Condenser.

Nail cleats *K* on the lower base to serve as legs and to keep it from warping. Provide strips of wood *C*, an eighth of an inch wide and 10 inches long. Nail them on the upper and lower bases, parallel to the 12-inch edge. They should be far enough apart so that the glass plates can easily slide in the grooves *H*.

Take four posts *S*, 8 inches long and 1½ inches square. They should be long enough to allow the plates to slide in easily between the upper and lower bases *D*. Screw or bolt the top and bottom to these posts, putting the posts at the four corners. The bolts are here shown going through from the top to the bottom.

If screws are used, eight strips of wood, ⅛ of an inch thick, 1½ inches wide and 10¼ inches long, should be nailed on each post, being also nailed to the upper and lower bases in order to make the frame strong. Obtain brass pieces *F*, 10 inches long and ¼ inch square. Drill holes in the brass and screw them on to the posts on the same side of the condenser, as shown in the photograph and cut.

In the upper brass strip, the holes should be drilled directly opposite alternate spaces between the plates. In the lower brass strip the holes should be opposite alternate spaces, but not opposite the same spaces as in the upper brass piece.

Instead of the brass strips *F*, a helix of brass wire can be used. Place wooden strips in place of the brass strips. Upon the wooden strips fix the wire helix.

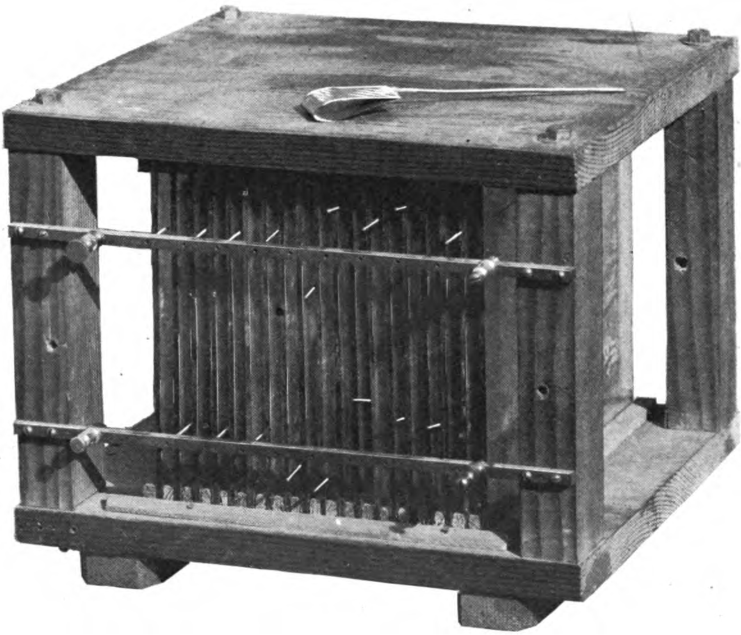


Fig. 16. Condenser, showing brass contact piece on top.

Obtain sixteen pieces of spring brass wire large enough to slide into the holes just drilled. Cut this wire into lengths about five inches long. From thin spring sheet brass cut strips an inch wide and four inches long. Double these strips into springy loops, bringing the ends together.

Punch a hole through the doubled strips near the end and insert one end of the five-inch brass wires. With pliers bend over the end and pinch it down tightly. Solder in place.

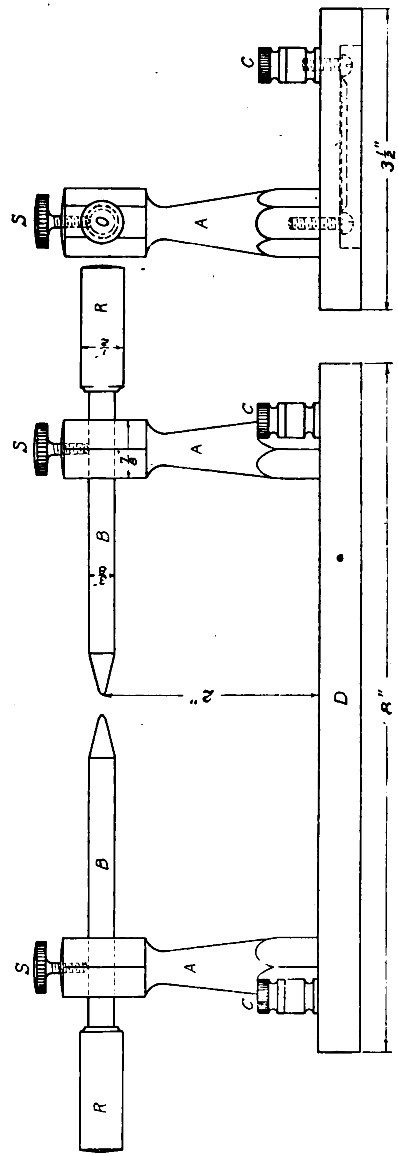


Fig. 18. The spark gap.

C, C, binding posts; D, base of rubber or wood; A, brass posts; B, electrodes; R, hard rubber handles; S, thumb screws.

One of these completed contacts is shown on top of the condenser in *Fig. 16*.

Push the prepared strips into every other space between the glass plates above and below, fitting the wires into the holes already prepared. Put two binding posts on each brass strip, as shown in the photograph, in *Fig. 16*.

Fig. 17 shows clearly the arrangement of the clips. *A* and *B* are the brass strips, *C* the glass plates, and *D* and *E* the spring contacts in position.

This is a top view and shows them coming out on opposite sides instead of out on the same side, as shown in the cut and photograph. When it is desirable to cut out a plate, merely pull a wire out of the hole and push it up or down out of the way.

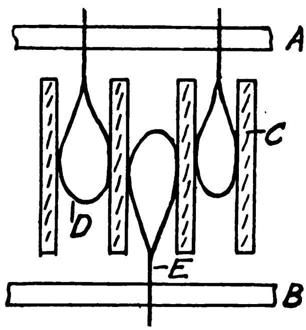


Fig. 17. Method of arranging spring contacts in condenser.

Instead of boring holes in the brass strips, phosphor bronze clips can be soldered on to the strips opposite every other hole. The brass wires can then be pushed down into the clips or be easily pulled out. The clips are much handier than the holes.

A wire helix is handier still, as the brass rod can be easily pushed into the helix or pulled out. This is similar to the lead pencil holder made of a helix of wire.

4. The Spark Gap.—A spark gap, through which the charged condenser can discharge, is necessary in order to set up the oscillations in the aerial. See *Fig. 18* for the details.

Upon a base board 8 inches long and 3½ inches wide, mount two binding posts *C*.

Prepare two standards *A*, out of brass, about three inches high. Bore holes in the upper part of these posts, large enough to admit the zinc or aluminum electrodes *B*. These electrodes can be made of battery zincs. The aluminum is better than the zinc, but the zinc is very good.

Make two set screws *S* for clamping the electrodes in place. Connect the binding posts *C* to the posts by No. 12 magnet wire. The base *D* can be made of fiber, hard rubber or wood. The wood, however, should be very dry or the current will break across from post to post along the wood and spoil the spark gap. The wood will char and an easy path is formed for the current.

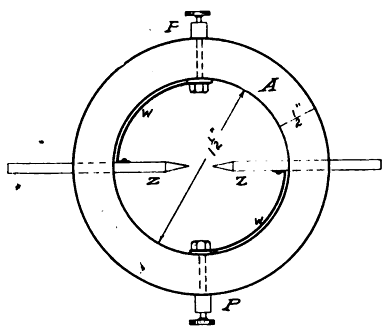


Fig. 19. The anchor spark gap.

5. **The Anchor Spark Gap.**—An anchor spark gap can be made similar to the one just described, but smaller. If desired, one like *Fig. 19* can be constructed very easily. Out of half-inch hard rubber or fiber, cut a ring ½ inch across and 1½ inches inside diameter. In this ring fit binding posts *P* and *P*.

Bore holes large enough to admit small zinc rods *Z*. Connect the electrodes *Z* to the binding posts *P* by flexible lamp cord *W*. The rods *Z* can be threaded and screwed through nuts fastened to the ring if desired.

This spark gap is to be put in series with the aerial. The aerial should be attached at *P*, and the other terminal *P* should lead to the sending helix. This serves to break the connection to the ground through the sending helix, when the receiving apparatus is cut in.

6. **The Sending Key.**—Purchase an ordinary Morse key. Remove the points at *A* and *B*, see *Fig. 20*, and solder in their place two pieces of silver as large as dimes. In soldering them on, see that their surfaces are flat and come squarely together when the key is closed. Fifteen to twenty amperes can be taken through these contacts without any trouble. This idea was suggested by Mr. Dean Farran of the Polytechnic High School.

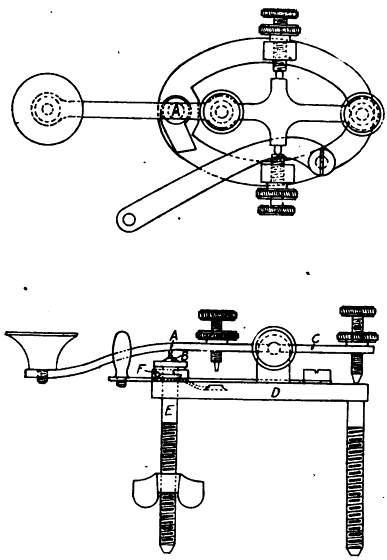


Fig. 20. The Morse telegraph key.

If you have a lathe and desire to make your own key, the details are shown in *Fig. 20*. The binding post *E* is insulated from the base *D*, which is made of metal, by a hard rubber washer *F*. Platinum points can be used instead of the silver, but they are expensive and the silver works very well.

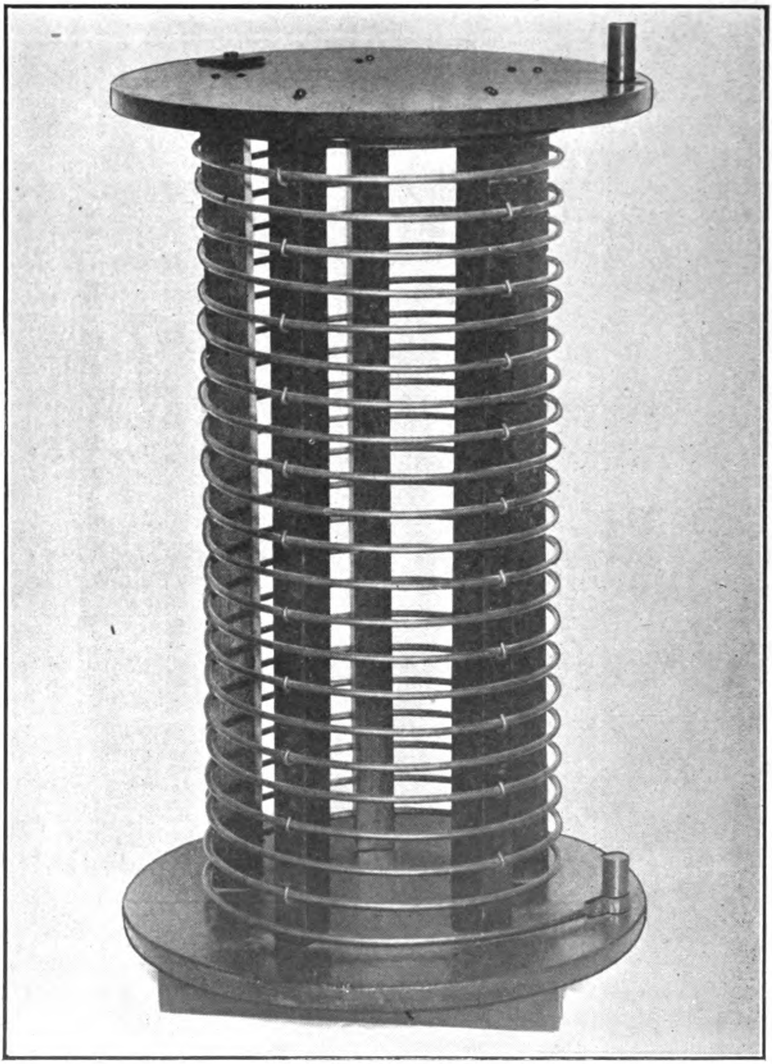


Plate II. Photograph of sending tuning helix described in Fig. 21 and shown in Plate X.

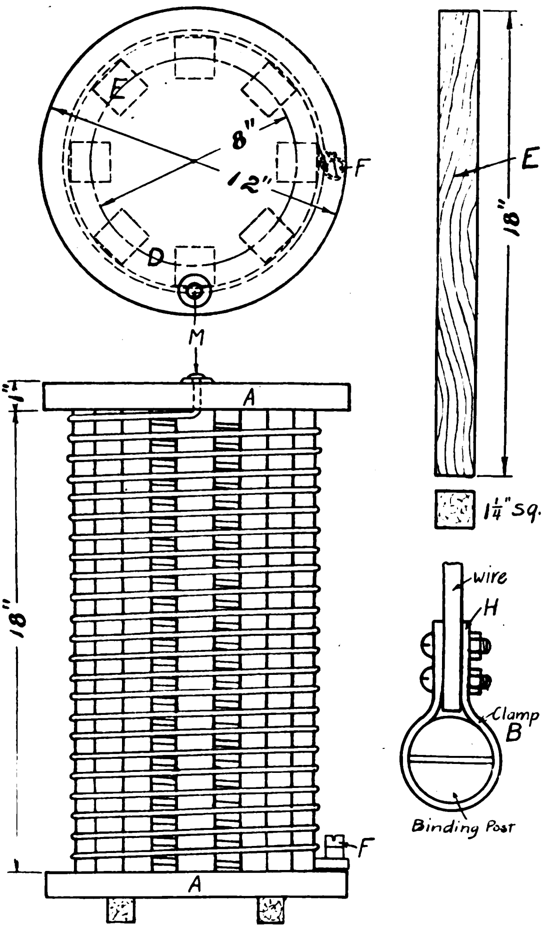


Fig. 21. The sending helix.

7. **The Sending Helix.**—The details of the sending helix are shown in *Fig. 21.* Cut out two circular blocks *A* of dry wood, one inch thick and one foot in diameter. Screw two cleats to each to prevent them from warping. Prepare eight strips of wood *E*, 8 inches long and 1¼ inches square.

Describe circles eight inches in diameter upon the upper part of the lower base and upon the lower part of the upper base. Divide each circle into eight parts, and, with screws, fix the posts in position around the circle, as shown in *Fig. 21*.

Upon the lower base fix a large binding post *F*, ¾ of an inch high and ½ an inch in diameter. Make a brass strap *H*, ¼ of an inch wide out of brass ⅛ of an inch thick, having a shank 1½ inches long.

Put the strap around the binding post and bolt it to the wire as shown at *H* in the cut. Obtain about 40 feet of No. 5 spring brass wire. This is the wire to one end of which the brass clamp *B* is bolted. This wire should be wound on the helix, making turns about ¾ of an inch apart.

In order to get the distances, tie a string to the binding post and wrap it once around the helix, letting the end of it be ¾ of an inch above the base of the helix. Mark on each post the place where the string rests. Take the string off and with a ruler lay off marks on each post, ¾ of an inch apart, beginning ¾ of an inch from the first mark on each post.

Clamp the wire to the post *F*, and wind it on, letting it follow the marks. It will go on spirally, making from 20 to 22 turns. Fasten the last turn to a binding post *M* or let it end without any attachment.

The wires can be held in place in several ways. Screw eyes can be screwed in at each mark and the wire can be threaded through them. They can also be fastened on with double pointed brass or steel tacks.

Three lead wires from the helix should be prepared. These wires should be made of heavy rubber insulated lamp cord. The ends of the wires can be merely hooked on to the wires of the helix, but it is best to make phosphor bronze clips to which the ends of the three wires can be soldered.

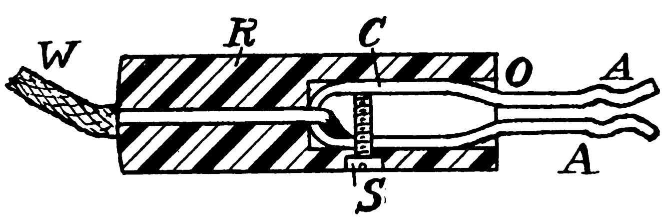


Fig. 22. Contact clip, made of rubber and phosphor bronze.

The clips can be made as follows: Bend a piece of phosphor bronze *A*, *Fig. 22*, back on itself at *C*, making *CO* about 1½ inches long. The strip should be about ⅜ of an inch wide.

Shape the end *A* to fit the wire on the helix, making it smaller, however, so that when it is shoved on, it will spring down on the wire and hold fast. Over the end *C* put a hard rubber handle *R*, having first soldered the wire *W* to the end *C* of the bronze clip. Put a screw in at *S* to hold the bronze clip in place.

CHAPTER III.

THE AERIAL.

1. **The Mast.**—A vertically or horizontally suspended conductor, grounded at one end, but otherwise insulated, will have a current of electricity set up in it, if cut by the electro-magnetic waves in the ether. This wire can be stretched from building to building or between two poles, thus forming a horizontal aerial; or it can be suspended vertically from a pole.

The higher the aerial the better, but good results can be obtained frow low aerials. They should be at least 30 feet from the ground. Generally a mast from 60 to 75 feet can be easily erected. The mast can be raised directly from the ground, or a pole can be put on top of the house. It depends entirely upon circumstances whether the one or the other method is used. Sometimes a tree 60 or 70 feet high can be

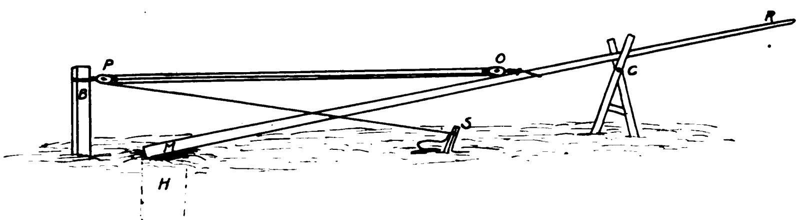


Fig. 23. Method of raising pole.

obtained. Such a mast can be easily erected in the following manner: (For details see *Fig. 23.*) Dig a hole *H* in the ground about 3 feet deep. Slant one side of the hole so that the butt *M* of the pole comes against the other side of the hole. Make a horse *C* about 6 feet high and lift the pole into the crotch. To the middle of the pole attach a block and pulley *O*.

Set a stake *B* in the ground and attach another block and pulley to it. Lift the pole *R*, and shove the horse *C* toward the hole, at the same time tightening the rope at *S*. By following this method, the pole will finally drop into the hole.

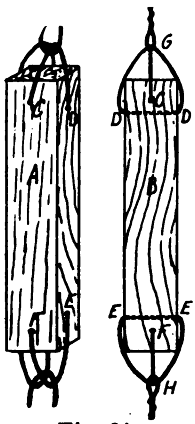


Fig. 24.
Insulators.

2. **Guy Wires.**—Before the pole is erected, however, guy wires should be attached to it, as shown in *Fig. 25*. These wires must be thoroughly insulated or they will absorb the energy of the electro-magnetic waves and conduct it to the ground in the form of an electric current. Cut blocks of dry wood, *A* and *B*, *Fig. 24*, 8 inches long and 1½ inches square. Bore holes about an inch from the two ends at *C* and *F*.

On the adjacent side of the block at *E* and *D*, an inch and a half from the end, bore holes at right angles to the first holes. From 12 to 18 of these will be necessary. Boil them in hot paraffine for an hour or so, until air bubbles cease to come from them. They will then make fine insulators.

Obtain six coils of galvanized iron clothes line wire, three of them 100 feet long and three of them 50 feet long. Buy one extra piece 50 feet long. This wire should be stranded wire, about seven strands to the wire. Cut pieces from the extra wire about 3 feet long, and thread them through the holes, as shown in *Fig. 24*, joining the two free ends together. To thread the wire, put one end through one hole *F*. Put this end through the hole *E*, forming the loop behind block *A*. Bring the two free ends of the wire together, forming the loop *EF* in front of the block *A*. The two loops can be made of separate pieces of wire if desired. Through the loops thus formed, the guy wires can be placed. These form convenient and excellent insulators.

Wire three insulators at the top of the pole and three at the middle of the pole, as shown in *Fig. 25*, *I*. A wire band should be put around the pole first. The insulator should then be wired to the wire band by a separate wire. Have the three insulators distributed equidistant around the pole at the middle. Those at the top should be spaced so as to come between those in the middle, so that the six insulators are equally distributed around the pole. Loop the guy wires into

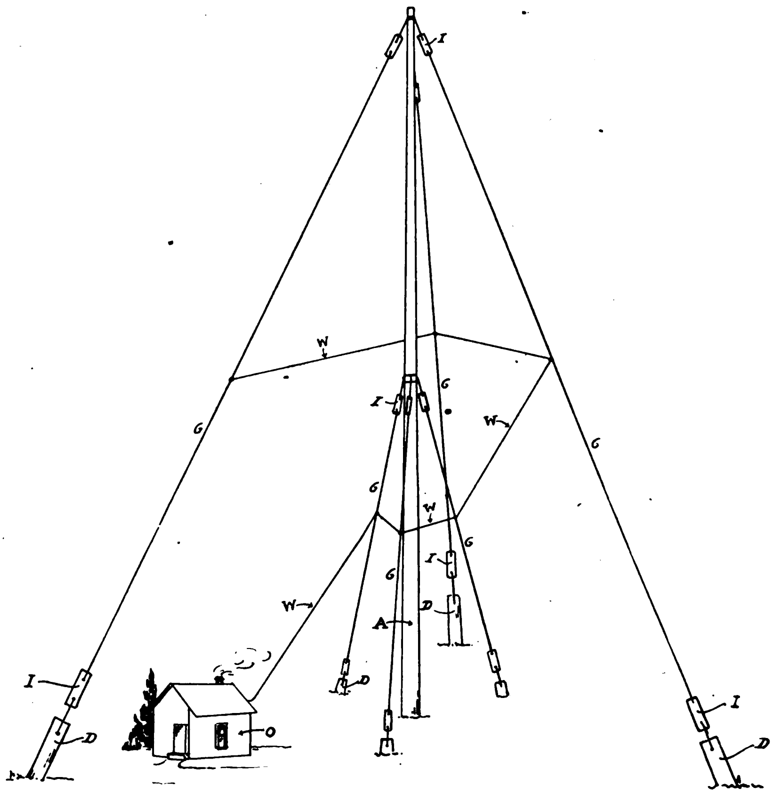


Fig. 25. Pole and guy wires connected to form an aerial.

the loops on the insulators, as shown in *Fig. 24* at *H* and *G*. Wire a block and pulley to the top of the pole, and reeve a rope through it long enough to form an endless rope to the ground, the rope being twice as long as the pole is high.

When all is ready, raise the pole as already described. If sufficient help is at hand, the pole can be raised by having three persons steady the pole by holding the guy wires, while two or three others raise the pole. These latter persons should have long poles with spikes in the ends of them. By jabbing the spikes into the pole and pushing, the pole can be raised.

3. Dead Men.—Six dead men to which to attach the guys should be prepared as follows: To a two-by-four *A*, *Fig. 26*, nail cross pieces *B* and *C*, at right angles to one another.

Bury the end on which the cross pieces are nailed in the ground, placing the dead men equal distances apart around the pole, putting three of them 15 feet away from the pole, and the other three 20 feet away from the pole. Fix wire loops to the dead men in the same manner in which the wire was threaded into the insulators in *Fig. 24*.

Wire the insulators to these. Put the lower ends of the guy wires through these loops, and tighten them evenly all around until the pole is straight.

These insulated guy wires in themselves form an excellent aerial. If they are connected together, as shown in *Fig. 25* at *W*, and the connecting wires are brought into the instruments, excellent results are obtained. This is true if the guy

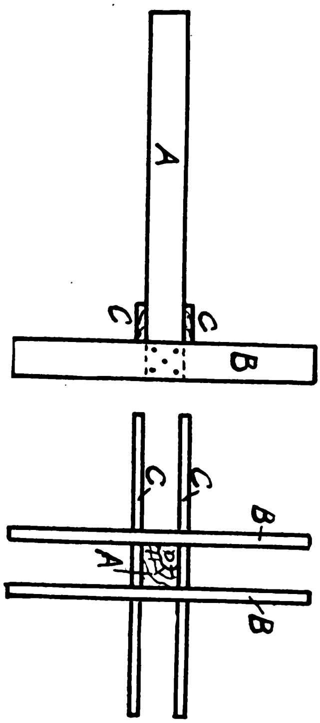


Fig. 26. Dead men.

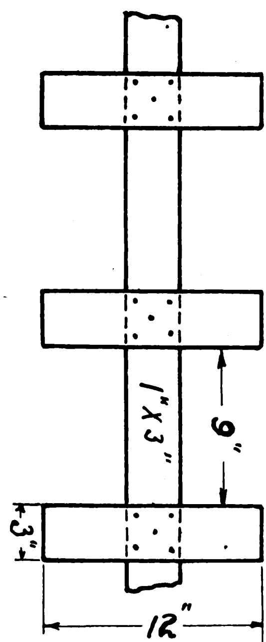


Fig. 27.

wires are made of galvanized iron wire. Iron wire will not do as well for an aerial. It works, but not nearly as well.

This pole can be put up in two or three sections. Put up the first section as just directed. Each section should be guyed. In order to climb to the top of the first section, make a ladder as shown in *Fig. 27*. Take a one-by-three as long as the section or 3 feet shorter. Nail cross pieces on it, made of one-by-threes, at intervals of 1½ feet. Stand this up against the section already raised. Let the lower end rest on the ground and wire the bottom of it to the pole. Wire it to the pole at intervals of 3 feet, wiring it as you climb. This makes a solid and substantial thing to stand on while working at the top of the pole. If you have climbers and know how to use them, the ladder is not necessary.

To put up the second section, attach a block and pulley to the top of the section already up. Raise the second section, with the guy wires attached to it, against the first section. Put one end of the rope through the pulley and bring it down, attaching it to the bottom of the second section.

Put a rope loosely around the two poles at the top. Climb the pole and have some one pull on the rope, thus raising the second section vertically while you steady it. Three persons should also hold the guy wires as it goes up, in order to keep the section from falling over. When the section is raised so that it overlaps the first section by 2 feet, wire it firmly to the first section and attach the guy wires so as to hold the section straight in place.

If three sections are to be put up, the second section should be raised against the first. Raise the third section as just described, and wire it to the top of the second. Then raise the two sections as described for the raising of the second section. If the pole is to be put on a building, it can be raised in a similar manner to the one just described and be guyed to the house instead of to dead men buried in the ground.

4. **The Aerial.**—There are several kinds of aerials, but they may be divided into two types, the vertical and the horizontal aerials. In the horizontal aerial, the wires are stretched between two masts, two buildings or two hills. One or both

ends may be brought down to the instruments. If both ends are brought in, it is a looped aerial.

The vertical aerial is hung nearly vertical from the pole. It may have the lower end brought in to the instruments, or it may have the wires all connected at the top, the wires being brought in to the instruments in two groups, thus forming a looped aerial.

The higher these wires are strung, the greater the distance over which the plant can be operated. The horizontal aerial is better than the vertical one. The more wires there are and the farther they are apart, the farther they can be made to operate, both in receiving and sending. The wires should be as large as possible in order to have as little resistance as possible.

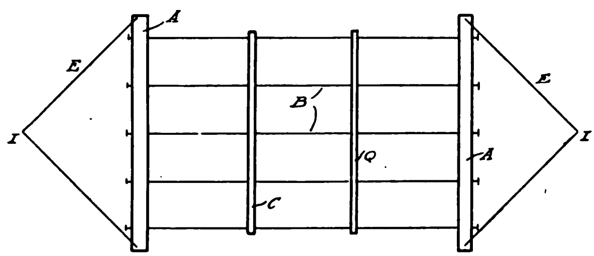


Fig. 28. General plan of aerial.

Take two pieces of dry wood *A, Fig. 28,* long enough so that the wires will be about one foot apart. These are called spreaders. In this case we will put in five wires. The spreaders must be about 6 feet long. They should have a cross section of at least 1¼ inches for a vertical, and 1½ inches for a horizontal aerial. Bore five holes in them a foot apart and put the wires through.

Through the ends of the spreaders *A*, bore holes and insert a stout rope *E*. Insulators described in *Fig. 24* should be attached at *I*. Stretch the aerial horizontally along the ground and put on additional spreaders *C* and *Q* to keep the wires apart. The number of these necessary depends on the length of the aerial. They may be made of wood or wire.

At the other free end of the aerial, attach a long rope to the insulator. Solder all of the wires of the aerial together at the lower end, and solder on a leading-in wire.

It is better, however, to bring all of the wires down to the instruments. In this case each one of the wires of the aerial, shown in *Fig. 28,* should be brought down and twisted together into a cable. The cable is then brought in to the instruments. This is very much better, as the resistance of the aerial is very much lessened. Form a knot in the endless rope that runs through the pulley at the top of the pole, and tie the insulator at the upper end of the aerial to the knot.

When all is ready, pull the aerial up into position. Tie the rope at the lower end of the aerial to a dead man, pulling the rope taut. Conduct the leading-in wires in to the instruments, carrying them through porcelain insulators set in the walls or windows.

5. **Types of Aerials.**—*Figs. 29* and *30* give different types of simple aerials. The methods of connection to the instruments are given in *Figs. 31, 32, 45, 50, 51, 52, 53* and *59. Figs. 31, 32* and *59* show the method for looped aerials, *59* being the best. *D* is the detector. In the simplest case, the lower end of the aerial is brought to one terminal of the

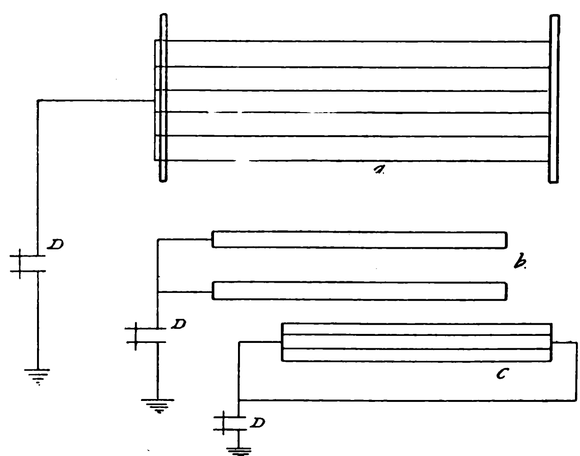


Fig. 29. Method of grouping wires in aerial.

detector and the other side of the detector is grounded. *a, b* and *c, Fig. 29,* show different methods of grouping the wires. In *a* they are all connected together in parallel, and one lead wire is used. This wire should be as large as possible. If the wire is made of many strands of small wire, it is better than one large wire. In *b* the aerial is divided into two groups, and in *c* the top of the aerial is brought in to the instruments as well as the lower end.

Fig. 30 is an example of a fan-shaped aerial.

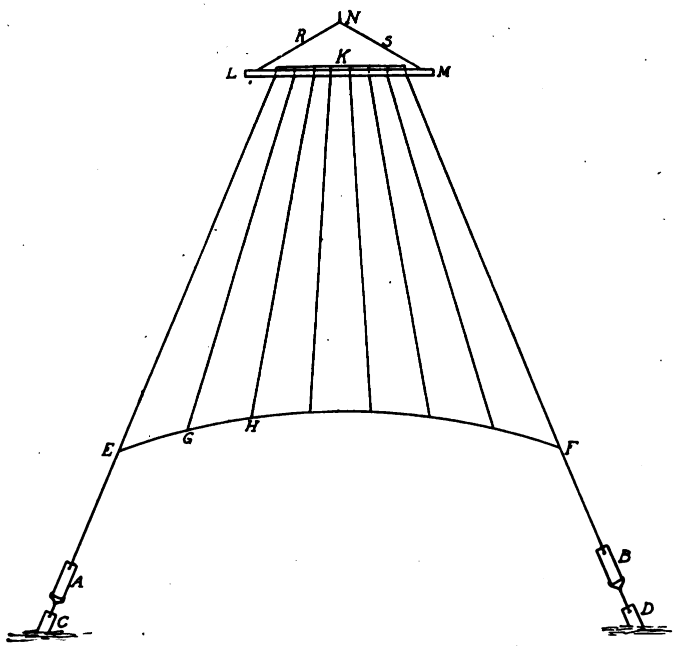


Fig. 30. Fan-shaped aerial.

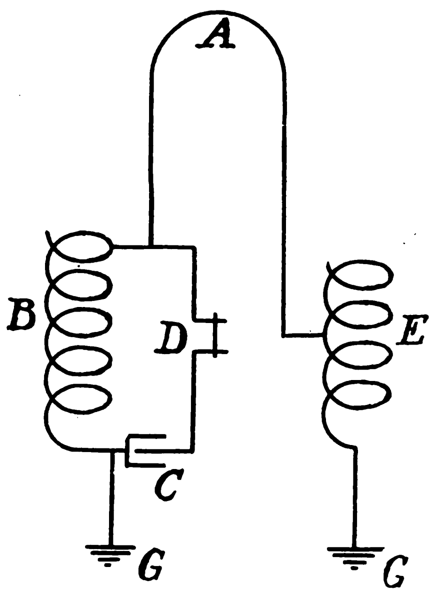
The wires are all connected together at the top and brought down, spread out in the shape of a fan. The wires are about 6 inches apart at the top at *K*. *R* and *S* are ropes attached to an insulator at *N*. *EGHF* is a wire connecting the wires together at the lower end. From *E* to *G* and *G* to *H* is about 5 feet, etc. The further they are apart the better. This distance will, of course, depend upon the space at one's disposal. *B* and *A* are insulators and *D* and *C* are dead men.

One wire may be attached to *EF* and be brought in to the instruments or a wire may be brought in from each wire of the aerial, being formed into a strand before being taken in.

If this group of wires faces south, another group similar to this, but facing east or west, will greatly add to the power of the station. If the waves come in edgewise to the aerial, the effect is not as good. In fact, an umbrella aerial is about the best thing in the line of vertical aerials.

Put in dead men, as indicated in *Fig. 25*. Bring down from the top of the pole as many wires as you desire. The wires should be attached in the same manner as the guy wires are attached, and all should be connected together at the top, the guy wires, of course, forming a part of the combination.

Using the guy wires about 10 feet from the ground as fixed points, run a large wire around, connecting the guy wires 10 or 15 feet from the ground. Attach the lower ends of



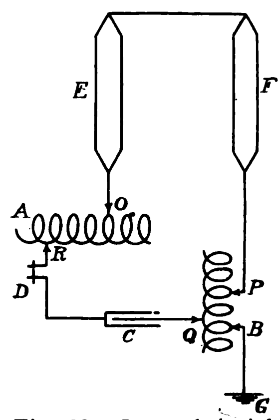


Fig. 32. Looped aerial, Shoemaker system, showing aerial as part of closed oscillation circuit.

Fig. 31. Looped aerial, showing different arrangement. BDC, closed oscillation circuit; B, tuning coil; D, detector; C, condenser; G, ground; A, aerial; E, static tuning coil.

the other wires to it. This secures a large capacity with equal surfaces exposed in all directions, so that the aerial can receive and radiate as strongly in one direction as in another.

Experiment indicates that the waves can be directed to a greater or less degree.

If the aerial is horizontal, the waves are radiated more strongly in the direction in which the aerial points, and the radiations from the end where the instruments are located are stronger than from the other end.

The horizontal aerial is an excellent type, since it can be easily looped. *Figs. 31* and *32* are examples of looped aerials. The loop *A*, *Fig. 31*, may be horizontal or vertical. The two leads are brought in to the instruments. One is connected through a variable inductance *E* to the ground.

The other end is connected to a closed oscillation circuit *BDC*, the junction of the inductance *B* and the condenser *C* being grounded at *G*. *D* is the detector across which a telephone is shunted. This is an excellent combination for short waves. *Fig. 32* gives the Shoemaker system of looped aerial. This connection is excellent for both long and short waves. Four adjustable contacts are shown.

The horizontal portion *A* of the looped aerial should be as long as possible and composed of as many wires as it is possible to string up. The greater the number of wires, the greater the capacity and the greater the power of the station.

The wires are grouped into two sets, connected at the top. The two groups should be as far apart as possible.

In general, the higher the aerial, the greater the number of wires in it, the farther they are apart, and the longer the horizontal part, the greater the power of the station.

Instead of making the aerial of galvanized iron wire, it can be made of copper or aluminum wire. Stranded wire is better than large single wire. No. 12 aluminum, however, makes an excellent aerial. Copper wire is excellent on account of its low resistance, but it stretches very easily. Prosphor bronze wire is excellent. It does not corrode easily, possesses great tensile strength and its conductivity is good.

It is more expensive than aluminum and is more difficult to obtain.

6. **The Ground.**—The ground for the aerial should be a good one. Water pipes will do, but it is better to sink sheets of zinc, copper or galvanized iron deep into moist ground. Zinc and copper are rather expensive, and as galvanized iron is all right, it is best to use it. Dig a hole in the ground as deep as possible; 3 feet is sufficient, but 6 feet is better.

It is handy to dig the hole in the shape of a trench long enough to enable one to work in it comfortably.

The sheets of galvanized iron should be at least 2 x 3 feet. The larger they are, the better, however. Solder No. 12 or No. 10 wire on to the sheets, and bury them in the trench, placing them flat on the bottom, or edgewise in the trench. Lead the ground wire in to the instruments.

Keep the trench moist all the time by running water into it from the hose.

CHAPTER IV.

RECEIVING INSTRUMENTS.

1. The Detector.—Various names have been given to the devices which render audible the oscillations taking place in an aerial.

The term detector covers them all. Cymoscope is used by Flemming in the same sense. The term microphone applies only to those classes of detectors that depend upon the light contact of conductors, giving a variable resistance. A great many kinds of cymoscopes have been invented, but only those that are the most practical and easiest to use will be described here.

If the contact between two dissimilar metals be oxidized, the resistance at the point of contact is considerable. If this contact be placed in an oscillation circuit, the voltage at the point of contact, due to the current in the aerial, rises to a value such as to break down the resistance and the current flows. The potentiometer is adjusted until the voltage of the local battery just fails to break down the resistance.

The simplest microphone is formed by placing a needle across two pieces of electric light carbon. The carbons should be brought to a sharp edge and the needle laid across the edges.

The carbons can be held in metal clips, connected to binding posts. A telephone, a battery and a potentiometer should be shunted around the detector, as shown in *Fig. 53*.

This, however, is a very troublesome and imperfect piece of apparatus. An excellent detector can be formed in the following manner: In *Fig. 33*, *A* is a piece of fiber or rubber 2 inches square and ½ inch thick. Place two binding posts *B1* and *B2* upon this base, as shown in the cut. Take a piece of flat brass *C*, ½ inch wide and 3/16 inch thick. Bend this into the form of a letter "S," making one flange *F1* ¼ inch long, and the other flange *F2*, ⅞ inch long.

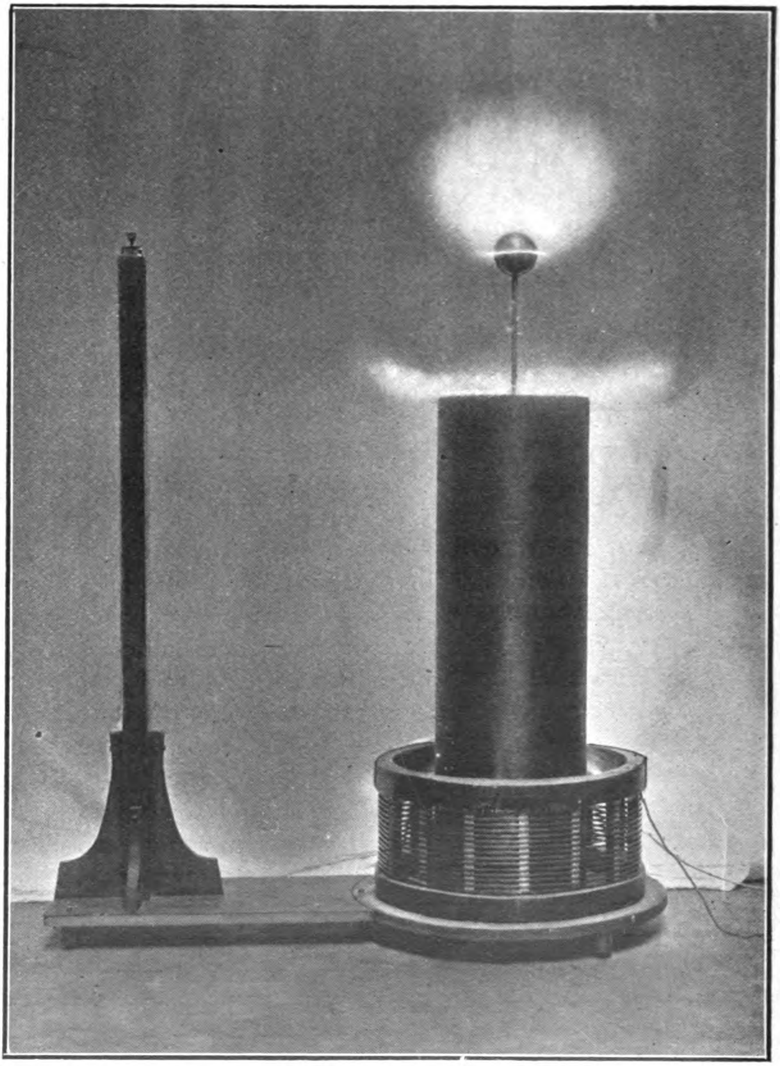


Plate III. Oudin resonator, showing spray discharge around upper edge and around ball terminal.

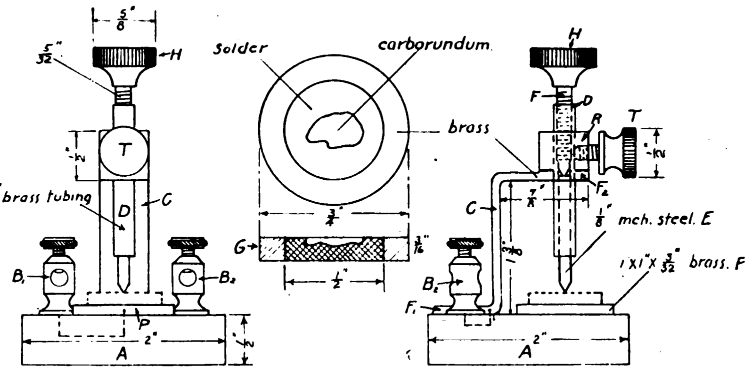


Fig. 33. Detector holder for crystal detectors.

Bore a hole in the flange *F1* and fasten it to the base between the two binding posts with a machine screw. The binding post *B2* does not rest on the flange. Connect the binding post *B1* to the quarter-inch flange by means of a wire, as shown in the cut. All joints should be soldered. The binding post *B1* can be put right on the flange instead of using the machine screw if desired.

Obtain a brass rod ½ inch in diameter, and saw off a piece ½ inch long, to form the bearing *R*. Through the center of this bore a hole ¼ inch in diameter. Solder this on to the end of the flange *F2* as shown, and drill a hole in the flange of the same size of that in the piece *R*.

Into the side of *R* fit a thumb screw *T*. Obtain a brass tube *D*, 1¾ inches long and large enough to slip easily into the hole in *R*. Thread this at the upper end to take a screw *F*, upon which is fitted a milled head *H*.

Obtain a brass or steel rod *E* to fit the inside of the tube *D*. The rod *E* is loose and is not threaded. This should be long enough to reach from the end of the screw *F* to the metal plate *P*. The screw *F* should be pointed so as to bear on the top of *E* with the least friction. *E* should be pointed at its lower end. Immediately under this fix a brass plate *P* and connect it to the binding post *B1* by a wire.

Cut out a ring *G* of brass ¾ inch in diameter. In the center of this place a piece of carborundum or other material to be used as a detector. Melt some solder and flow it in around it in order to hold it in place. Insert this under the metal point of the rod *E*. The rod *E* can be made shorter and be fastened to *F* by a spring if desired, so that the pressure upon the carborundum can be regulated.

Instead of soldering the carborundum in the ring, three screws 120 degrees apart can be fitted into the ring *G* so as to bite the carborundum when screwed toward one another. This is very convenient, as any material to be tested can be thrust in and held in place. This forms a very good detector, but in order to make it, one must have a lathe.

A much cheaper and a better detector may be made in the following manner: In *Figs. 34* and *35*, *B* and *F* are binding posts and *D* is a brass plate connected by wire to the binding post *B*. *A* is a phosphor bronze strip made from sheet phosphor bronze. This is connected to the binding post *B* and bent over to rest on the detector material *C*, held in its brass cell. The spring *A* can be made to bear more or less heavily upon the material by bending it more or less.

The spring *A* could be arranged to come out horizontally from a post *B* and an arm carrying a thumb screw above *A* can be fixed in place, in order to make the point of the spring bear more or less heavily upon *C*. *Fig. 36* is a photograph of this detector.

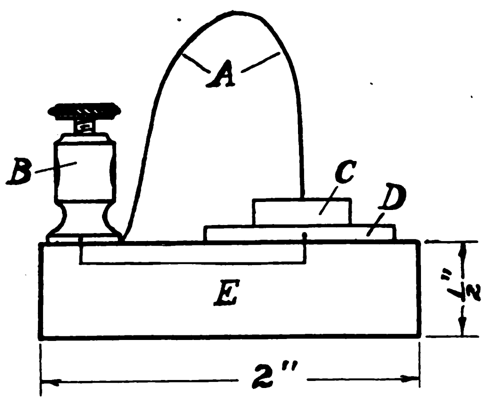


Fig. 34. Crystal detector holder, side view.

The crystals of many metallic ores are good detectors. Flemming calls them crystal rectifiers. They allow the current to flow in one direction, but not in the other, and they thus shunt an undirectional, intermittent current through the telephone.

After some time these crystals polarize, and it is necessary to let them rest for a while. They then recover. Consequently, it is best to have a number on hand. Crystalline iron pyrites makes an excellent detector. F. W. Braun of Los Angeles has a supply on hand, which he offers for sale in small amounts.

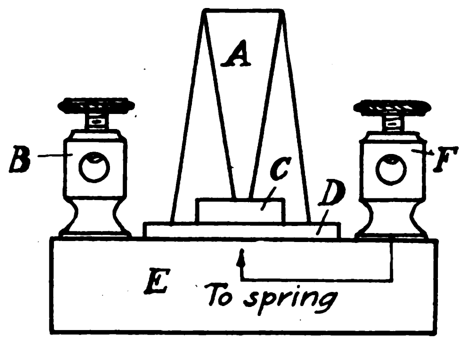


Fig. 35. Crystal detector holder, front view.

The perikon detector is made by placing zincite in contact with chalcopyrite. It is sensitive, but polarizes very easily. While it seems to be somewhat more sensitive than iron pyrites, it is not as hardy. Iron pyrites does not polarize easily. In fact, a high frequency discharge, direct from the sending circuit, can be sent through the iron pyrites without throwing it out of working order. It works all right for a long time before it needs rest.

Perikon, on the other hand, is polarized very easily. Unless it is disconnected from the receiving circuit when sending, it is thrown out of adjustment.

Any sulphide or oxide is apt to prove a good detector. When metals are exposed to the air they tarnish or rust, due

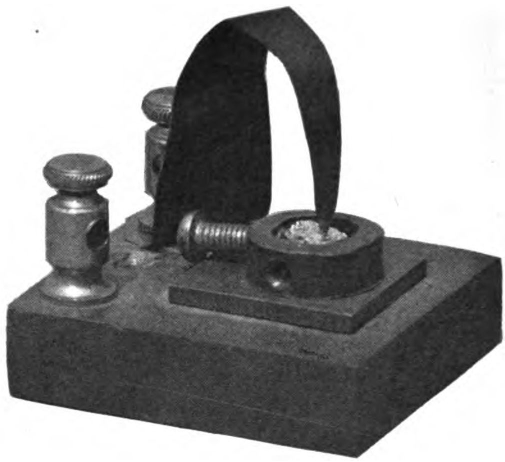


Fig. 36. Photograph of crystal detector, detailed in 34 and 35, showing iron sulphide or iron pyrites in position.

to the oxygen of the air uniting with them. These oxides are not good conductors of electricity, and consequently they form good detector contacts.

Carborundum makes a good detector. Silicon is still better, but iron sulphide is better yet. This iron sulphide is known popularly as "fool's gold." All varieties do not work. It is the bright crystalline variety that does the work.

The fact that iron sulphide works excellently under considerable pressure, makes it a very practical and convenient ore to use for this purpose.

Ordinary galena or lead sulphide also makes an excellent detector. It is not as good as the iron sulphide, but it is a good practical ore that works under pressure and remains in order when once set in place. The iron sulphide is excellent in that respect, if the form of detector holder is used as shown in *Figs. 34* and *35*.

The iron sulphide was called to my attention first by Mr. A. E. Abrams, of 912 Edgeware Road, and the form of detector holder shown in *Figs. 34* and *35* was first used by Mr. Roy Zoll. This phosphor bronze makes an excellent contact for the purpose of a detector. The lead sulphide was brought to my notice as a detector by Mr. Dean Farran.

These metallic oxides and sulphides when held in contact with one another make excellent detectors. The lead sulphide and iron sulphide in contact make an excellent combination, but none of them are as good as the iron sulphide alone.

All points on the surface of these oxides and sulphides do not work. The point of the phosphor bronze should be moved around until a sensitive point is found. It will not do to polish the iron sulphide, as it seems to destroy its sensitiveness.

When two different metals are brought into contact, a difference of potential is developed, and a current of electricity flows when the circuit is completed. The current is very weak, however, and the difference of potential very small. If an oxide of the metal is present, the voltage is not enough to break down the resistance.

When the current comes down the aerial, the voltage is just sufficient to break down the resistance of the oxide. A current then flows and a buzz is heard in the telephone. These detectors are practical because they are delicate and reliable. They do not get out of order easily and they are cheap.

The electrolytic detector is very sensitive and popular for long distance work. It is extremely sensitive and easily put out of order. The Walloston wire burns out continually, making careful and continual adjustment necessary.

They can be made in the following manner:

This is made in a manner exactly similar to the detector described in *Fig. 33*, except that the brass plate *P* is left off and in its place is substituted a glass carbon or platinum thimble, shown in *Fig. 37* as *6*.

In order to make this thimble, take a test tube or other glass tube and soften it in the flame of a bunsen burner about half an inch from the end. Draw it out and seal it off.

Keep it warm in the flame and thrust a piece of platinum wire through the soft glass, until a small portion *P, Fig. 37*,

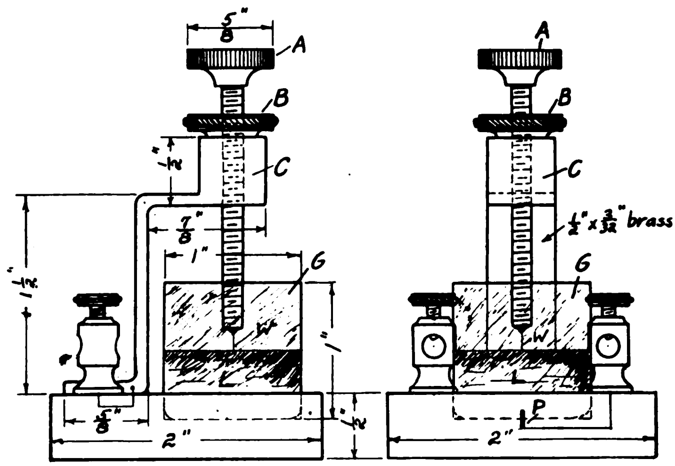


Fig. 37. Electrolytic detector, showing side and rear view.

sticks through. The base should be rounded and somewhat flattened in the flame. Close the air hole of the bunsen burner and cool the thimble in the flame, allowing it to become covered with soot. Turn the flame down and cool it a little more in the flame. This anneals the glass so that it is not brittle.

Round out a hole in the base *2, Fig. 37,* for this to fit into. Solder a copper wire to the platinum wire and carry it to a binding post. Attach the other binding post to the S-shaped brass arm. The thread of the screw *C* should be very fine. Solder on to the end of the screw *C* a small piece of Walloston wire *W*. Put a 10 per cent solution of nitric

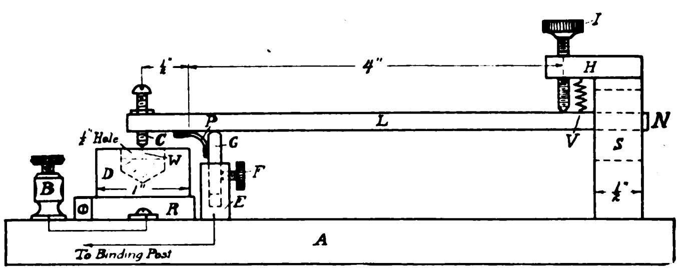


Fig. 38. Electrolytic detector.

acid into the cup. It requires considerable skill to make this detector.

An easier one to make is shown in *Fig. 38*. *A* is a base 6 inches long and 2 inches wide, upon which are two binding posts *B*. A piece of brass *S* similar to the brass piece *C* in *Fig. 33* is fixed to the base at the end, opposite the binding posts *B*.

A thumb screw *I*, threaded to a nut *H*, has its end resting on a lever *L*, pivoted at *P* by a piece of spring sheet phosphor bronze. A spring *V* holds the end *N* of the lever against the point of the screw *I*. A groove is sawed in *S*, thus giving the end of the lever *N* free vertical play.

This lever is made of brass 4 inches long from the pivot *P* to *I*. The end *PC* is ¼ of an inch long. The binding post *E* is 1 inch high. A brass rod *G* slips in the binding post *E*. This rod can be held in any position by the set screw *F*.

The set screw *C* is ½ inch long. To its end is soldered a Walloston wire *W*. *D* is a carbon cup, ¾ of an inch deep. Fit a band of phosphor bronze *R* tightly around this cup and solder it to the binding post *B*. From the binding post *E*, conduct a wire to the other binding post *B*. Put a 10 per cent solution of nitric acid in the cup. The carbon cup can be obtained of dealers in wireless apparatus or one can be made from an ordinary electric light carbon.

The latter, however, is very porous and one has to keep filling it constantly. The acid can be put in with a pipette, such as is used for filling fountain pens. The thread on *I* should be as fine as possible. When the long arm of the lever *L* is moved by turning the thumb screw through a distance *I*, a distance of $^1/_{100}$ of an inch, the Walloston wire moves only $^1/_{16}$ of that distance, or $^1/_{1600}$ of an inch.

The Walloston wire in this case does not move perpendicularly. By modifying this a little, a still finer adjustment can be obtained, and the Walloston wire remains stationary. Instead of soldering the Walloston wire to *C*, obtain a glass tube a little larger than the brass rod *C*. Close the tube at one end in the bunsen flame. By means of plaster of Paris cement the brass rod *C* in to the glass tube. This glass tube should be long enough to reach ⅛ on an inch into the liquid.

Provide another post similar to *E*, and arrange a plunger similar to *G*, to which solder an arm at right angles. To this arm solder a rod similar to *C*, and to the end of it solder the Walloston wire.

By means of this the Walloston wire can be lowered into the cup until it just touches the liquid. Then by means of the thumb screw *I*, the water can be raised or lowered around the wire. If the plunger moves 1/1000 of an inch into the water, it does not have its surface moved through any such distance, but through a distance very much smaller.

By having the glass tube small enough, an exceedingly fine adjustment can be obtained.

2. **The Tuning Coil.**—The tuning coil can be of various lengths and diameters. If they are very large, however, they will not be sensitive enough. The change in inductance is then too large for each change of turn due to the sliding contact. A convenient form is made as follows: Obtain a piece of hard rubber, fiber or dry wood, 1 foot to 15 inches long, and 2¾ inches in diameter. The wooden piece should be turned down in the lathe to the required size.

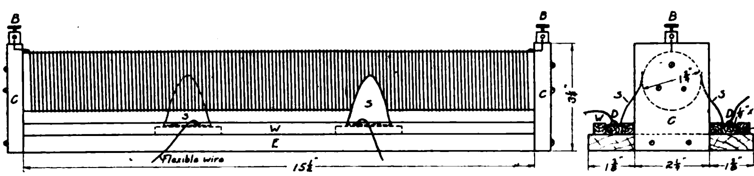


Fig. 39. Tuning coil.

Fig. 39 gives the details of such a coil, and *Fig. 40* is a photograph of the same coil. If possible, cut a helical groove on this cylinder having 20, 22 or 24 threads to the inch. In this groove wind tightly No. 20, 22 or 24 bare copper, brass or phosphor bronze wire.

Phosphor bronze wire is the best, as it makes excellent electrical contact. If you have no lathe, wind the wire on tightly and space it as evenly as possible by winding string between the wires. The wires should not touch. If the core is made of wood, it should be boiled in paraffine. Before beginning to wind, set a screw in one end, to which fasten the wire. At the other end fasten the end of the wire to a screw, and carry the terminals to binding posts upon the end supports *C*.

These ends should be large enough to raise the coil free of the base, in this case about 2½ inches square and 1 inch thick. Before putting the helix in position, it should be thoroughly shellaced. Screw the end pieces to the base end, and set screws through the end pieces into the ends of the helix. If the helix is made of tubing, put wooden plugs in the ends of the tubes. The base should be about 5 inches wide.

Take two pieces of phosphor bronze sheet 2 inches long and 1 inch wide. Cut off on two sides so as to form a triangular piece *S*, *Fig. 39*, similar to those shown in the photograph, *Fig. 40*. Prepare a block *D*, 2½ inches long, ½ inch wide and ⅜ inch thick. Place this block about an inch from the helix on the base and parallel to the helix. On each side of the block nail strips of wood *W* as long as the base and as thick as the block, forming a groove in which the block can slide parallel to the helix. Bend the phosphor bronze strip *S* until it makes good contact with the helix. Put a similar arrangement on the other side, thus forming two sliding contacts. Solder flexible wires to the phosphor bronze pieces.

If desired, the helix can be wound with double cotton covered copper wire. In this case wind the wire close together. When finished shellac it. Allow it to dry and then shellac again. Do this several times. When thoroughly dry, scrape or file off the insulation where the contact is to run. In the bare wire helix, the wire should be sand-papered where the contacts are made. This is cheap and easily made, but it serves the purpose very well. If desired, the coil can be enclosed in a box. The grooves in which the block runs can be made inside of the box and a rubber knob can be fastened to the block, a slit being made in the box for the knob to slide in.

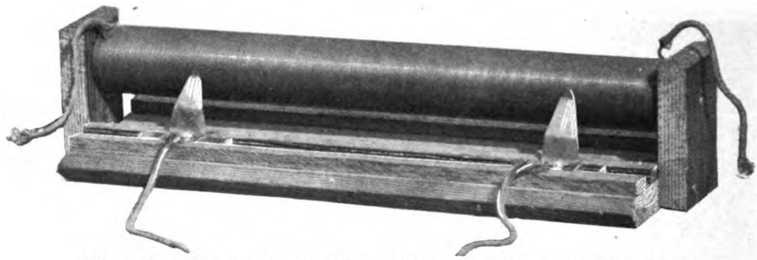


Fig. 40. Photograph of tuning coil shown in Fig. 39.

Instead of wooden slides as here described, they can be made of brass, as shown in the photograph of a receiving set in *Figs. 45* and *46*. In this set a square brass tube fits and slides over a square brass rod, the phosphor bronze contact being soldered to the square brass tube. A machine screw has its head soldered to the square brass tube and the rubber handle is screwed to it. This makes a neat arrangement. The complete tuning set shown here will be described later.

3. **The Receiving Condenser.**—The receiving condenser can be made adjustable or non-adjustable. A suitable non-

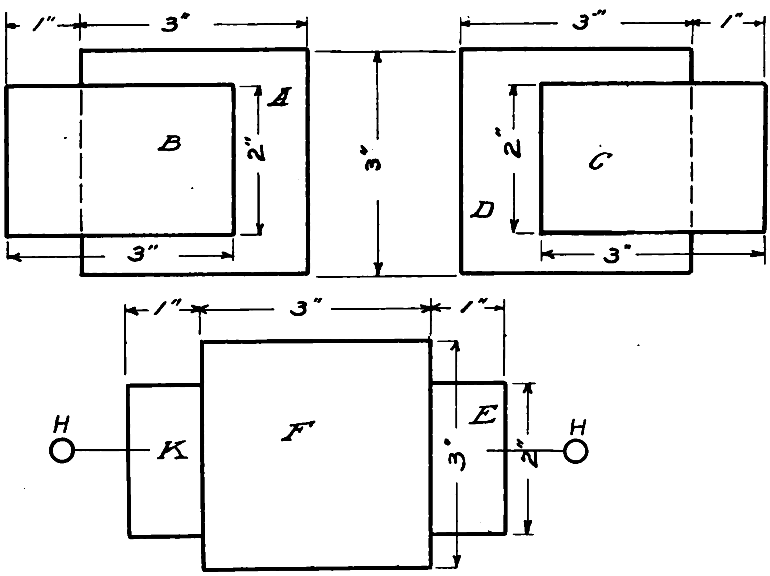


Fig. 41. Paper condenser.

adjustable condenser can be made in the following manner: Cut good type-writing paper into pieces 3 inches square. Melt some paraffine and immerse the slips of paper in the hot paraffine, until the bubbles of air cease to come from them.

Cut strips of tin foil 2 inches by 3 inches, and lay them down as shown in *Fig. 41*. Upon a piece of the paraffined paper *A*, place a strip of tin foil *B*. Over this lay a strip of paper *D*, and upon this a strip of tin foil *C*, as shown in the cut.

The two pieces of tin foil are thus separated by paraffined paper, and their ends come out on opposite sides of the condenser.

Pile up alternate sheets in this manner until sufficient number are placed together.

Place the assembled condenser *F* in a vise or under heavy weights in order to make it as solid as possible. If the condenser is loose it will make the signals sound mushy. Only a very few of these sheets are required.

About ten plates make a good condenser. The free ends *K* and *E* should be soldered to copper wires and be brought to binding posts *H*. With a little practice this soldering can

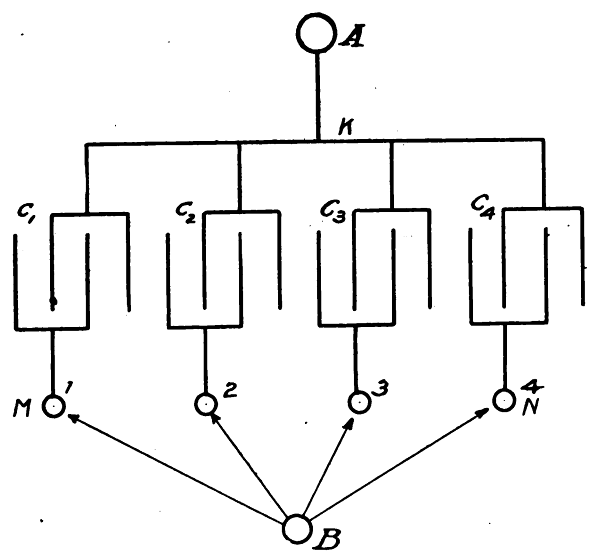


Fig. 42. Connection for condenser rheostat.

be easily done. It is best to enclose this condenser in a box and surround it with paraffine chips.

The adjustable condenser can be easily made by making four or five of these simple ones of two or three sheets each. Assemble them as shown in *Fig. 42*. The separate condensers *C1*, *C2*, *C3* and *C4* can be piled on top of one another, provided the wires and plates on the side *B* are separated from one another by paraffined paper. On the side *A*, solder the plates all together. On the side *B* solder wires to each set. Bring them out to separate binding posts *1*, *2*, *3* and *4*. Connect the side *K* to a binding post *A*. Provide a second binding post *B*, and bring four wires from it to binding posts *1*, *2*, *3* and *4*. By disconnecting any one of these wires, its particular condenser is cut out.

A convenient wiper can be made of phosphor bronze. Cut a triangular piece of phosphor bronze, one angle being at *B* and the other two angles at *M* and *N*. Of this make a rheostat similar to the one in *Fig. 13*, except that the wiper *W* is a large triangular piece made to cover all the points when all of the plates are cut in. With a swivel joint at *B* and a hard rubber thumb piece, the wiper can be made to include as many or as few of the plates as are desired.

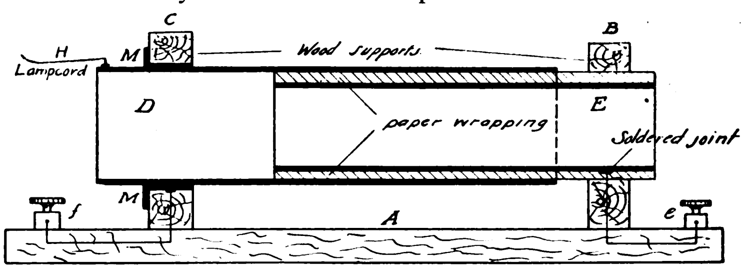


Fig. 43. Brass tube condenser.

Fig. 43 shows a condenser made out of brass tubes and empire cloth. Procure two brass tubes *E* and *D*, so that one can slip into the other with 1/16 or ⅛ of an inch to spare. Make a base *A* of wood about 4 inches wide and a little longer than the tubes.

Place binding posts *e* and *f* on this base. Prepare two end pieces, *C* and *B*, 4 inches wide and 3 inches high. Around the tube *E* wrap paraffined paper or empire cloth, until the tube *E* with the coating can slide easily into the tube *D*. The cloth or paper should be glued to *E* and thoroughly dried.

Bore a hole in the end piece *B* just large enough to receive tightly the cloth covered end of the tube. Solder a wire to the end of *E* and carry it to the binding post *e*. A hole should be bored large enough in the end piece *C* to receive a collar of brass *M*, this collar being large enough on the inside to allow the tube *D* to slide easily, at the same time making electrical contact. Solder a wire to the collar *M* and carry it to the binding post *f*. By sliding *D* back and forth the capacity of the condenser can be easily varied.

Instead of being made to slide in the collar *M*, the tube *D* can be made to slide in the wooden end piece *C* and a flexible lamp cord *H* can be carried to the binding post *f*. This cord should be long enough to allow for the adjustment of the slide. This makes a very delicate condenser.

A mica adjustable condenser can be made on the same plan as the paper one in *Fig. 38*. Instead of tin foil, use very thin copper sheet and instead of the paper use very thin mica sheets. Glue or mucilage very thin paper on the mica sheets. Glue a copper and a mica sheet together, allowing the copper sheet to project over on one side and fall short on the other, as shown in *Fig. 41*.

These plates should be about 5 inches long and 3 inches wide. Assemble the pairs as in the other condenser and solder the copper plates on each side together. By pulling or pushing on *E* and *K*, *Fig. 41*, the sheets can slide on one another and as much or as little of the plates can be included as desired. This is similar to the tubular condenser just described, but of much greater capacity.

The whole should be arranged in a box, and the copper plates at *K* should be bolted to one side of the box, a wire being led from the bolt to a binding post. The other side of the condenser *E* should have a flexible lamp cord soldered to it which should be carried to a binding post, the wire being long enough to allow of its being adjusted.

4. The Potentiometer.—No potentiometer is needed with silicon, iron sulphide or lead sulphide, as no batteries are used with these detectors. A potentiometer can be used to advantage with carborundum, although the carborundum can be used without it.

Fig. 44 gives the details for an adjustable potentiometer. Take a block of wood *CD* about 11⅜ inches long. Turn it down in the lathe so that the part *WE* is 9⅜ inches long and 2¼ inches in diameter. Turn out notches *N* ⅜ of an inch wide, ⅜ on an inch apart and ¾ of an inch deep. This gives eight notches, with 100 ohms to the notch. If more resistance is desired, make the core longer.

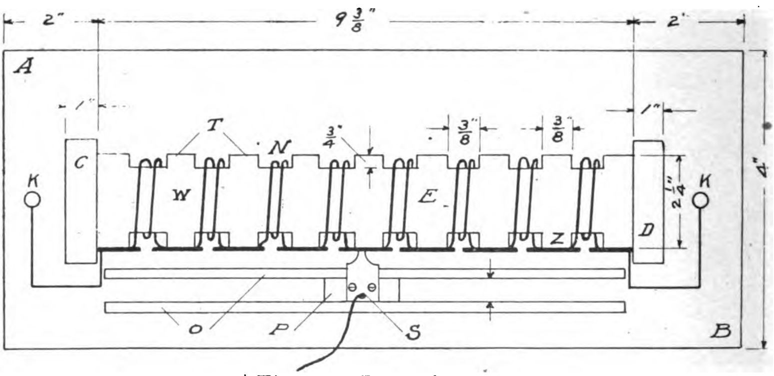


Fig. 44. Potentiometer.

In these notches wind No. 36 single silk covered copper wire. It should be wound non-inductively. In order to do this, wind off on another spool about half the wire needed. Put the two spools of wire on a shaft so that they can unreel easily. Solder the free ends of the wire together and wind in the notches until they are nearly full. This gives about 100 ohms to the notch. Two other similar cores should be prepared, one having 10 ohms to the notch and the other 1 ohm to the notch.

The flange *T* should be flattened either on the top or side and a brass strip *Z* should be screwed to the flanges, two screws being set in each flange. Saw the brass strip in two over each coil, thus dividing it into nine separate pieces.

When each notch is full, it will be found to have two terminals. Solder one of these terminals to the brass section on one side, and the other terminal to the brass section on the other side. The coils are thus joined in series through the brass sections.

Prepare end pieces *C* and *D* 3 inches square. Make a base of wood 6 inches wide and 13⅜ inches long. Fasten the end pieces *C* and *D* on to the core *WE*, and fasten the end pieces to the base.

Make a block *P* of wood 2½ inches long, ½ inch wide and ⅜ inch thick. Upon this piece fasten by means of screws a triangular contact, made of phosphor bronze similar to those in *Figs. 39* and *40*.

The tip should be made large enough to cover the spaces between the brass pieces *z*. Put on the wooden strip *O* so that the block *P* can slide snugly between them. By bevelling the pieces *O* and the slider *P*, it cannot come out of the groove.

Solder flexible lamp cord to the phosphor bronze contact piece. Solder wires to the brass end pieces and conduct them to the binding posts on the base.

If three of these potentiometers are made, they can all be assembled on the same base. The sliding contact may be on the side, or on top, as shown in the photograph in *Fig. 46*. The circuits for these potentiometers are shown in *Figs. 45* and *53*. Instead of wooden slides as here described, metal slides can be provided as shown in *Fig. 46*.

Fig. 45 is a diagram of a complete oscillation circuit composed of a tuning inductance, condenser and potentiometer arranged on the same base. *B* is the tuning inductance, *P* the potentiometer and *C* the condenser. *Fig. 46* is a photograph of the instrument. The condenser is inclosed in the back part, the rheostat only being shown on the cover.

In *Fig. 45* the binding post, marked *1*, attaches to one side of the condenser, marked *R*, to the ground, marked *G*, and to the lower rod of the sliding contact, marked *D*. The bind-

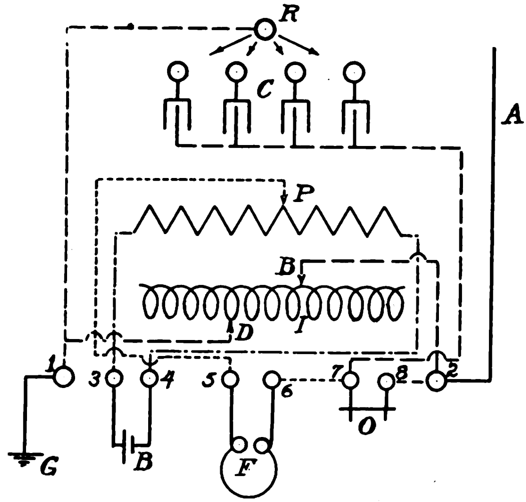


Fig. 45. Connections for receiving set shown in Fig. 46. 8 and 4 should be connected, although not shown in the cut.

ing posts *3* and *4* are attached to the extremities of the potentiometer *P*, and also to the battery *B*.

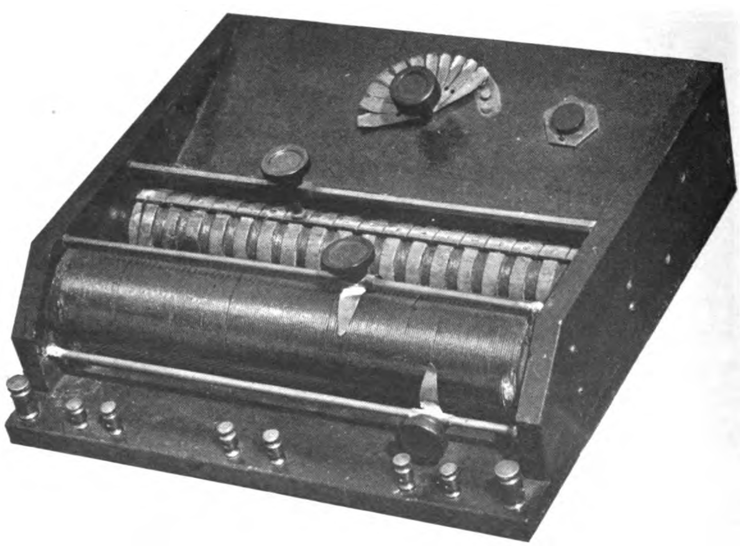


Fig. 46. Photograph of tuning set.

Binding posts *5* and *6* are for the telephone. Binding post *5* attaches to the sliding contact of the potentiometer *P*, and binding post *6* attaches to binding post *7* of the detector *O*.

Binding posts *7* and *8* are for the detector. Binding post *8* attaches to the aerial binding post *2*. It should also attach to binding post *4*. This attachment is not shown in the cut. The aerial binding post *2* also attaches to the sliding contact *B* of the tuning inductance.

A photograph of this instrument is shown in *Fig. 46*. The button in the upper right-hand corner is intended as a detector switch, but the connections are not shown in the cut.

This can be connected up in any other way desirable. This connection here enables one to include any part of the tuning inductance or as much of it as one wishes in the oscillation circuit.

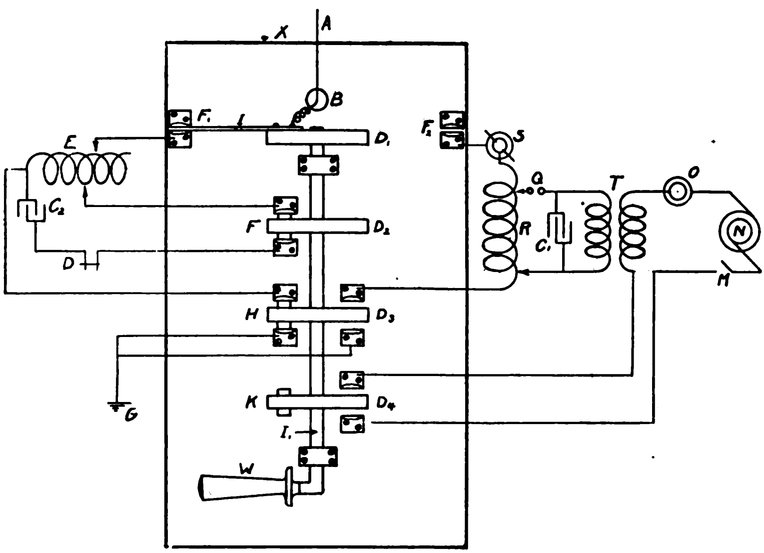


Fig. 47. Switch for changing from sending to receiving.

5. The Sending and Receiving Switch.—It is very convenient to be able by one movement of the hand to switch from the sending to the receiving apparatus. When the switch is thrown to the receiving position, it should cut in the aerial, the ground and the oscillation circuit of the receiving set.

When the switch is thrown to the sending position, the ground of the receiving side should be broken, and the ground on the sending side should be made. At the same time the detector circuit should be broken and the aerial be switched from receiving to sending. The arrangement is shown in detail in *Fig. 47*.

Take a dry, well seasoned board 1 foot wide and 2½ feet long, and 1 inch thick. Place a binding post *B*, 2 inches from the end *X* in the middle of the base. Cut four circular blocks *D1*, *D2*, *D3* and *D4*, out of fiber, rubber or dry wood. These should be about 3 inches in diameter. Bore a 1-inch hole through the center of each, and mount them on a wooden rod *L*, 16 inches long and 1 inch in diameter.

Mount this rod upon bearings so as to swing it free of the base. Place a handle *W* on the end of the rod, as shown in the cut. Fasten a piece of brass rod *I*, 6 inches long, ¼ inch wide and ⅛ inch thick, upon the circular block *D1*. On each side of this block and 6 inches from it, arrange spring clips *F1* and *F2* made out of phosphor bronze similar to the contact clips on the tuning coil.

Place two of them at *F1* and two of them at *F2*, making them shallow, so that the rod *I* just makes good contact. Attach the aerial to the binding post *B*. Bring a flexible lamp cord from the binding post to the brass piece *I*. By throwing the switch to the left, the aerial is connected to the tuning coil *E*, and by throwing it to the right it is connected to the sending helix *R*, through the anchor gap *S*.

Put brass bolts through the blocks *D2*, *D3* and *D4*, at *F*, *H* and *K*, and on each side arrange clips as shown, so that the ends of the bolts will be forced down between the clips, thus forming connections at these points. To one of the clips at *F*, bring a lead from one of the adjustable clips on the tuning coil, and to the other one of the terminals of the detector *D*.

To the upper clip at *H*, bring a wire from between the condenser and the tuning helix. Attach the lower clip to the ground *G*. On the sending side, attach the upper part of the sending helix to clip *F2* through the anchor spark gap *F2*. Attach the lower end of the sending helix *R* to the upper clip at *D3*. Attach the ground to the lower clip at *D3*. At *D4* attach the two terminals of the primary circuit as shown.

N is the source of the alternating current, and *O* is a water rheostat for regulating the flow of the current. *C1* is the condenser, *T* is the transformer, *NM* is the key in the primary circuit for sending. *G* is the ground, *D* the detector, *C2* the receiving condenser, *E* the receiving tuning coil and *A* is the aerial. *Q* is the spark gap.

Chapter V.

OPERATION OF THE TRANSFORMER, SENDING AND RECEIVING SETS.

1. **Sending.**—The sending and receiving circuits are given in *Fig. 47* in connection with the sending and receiving switch. A circuit for sending is given in *Fig. 48*.

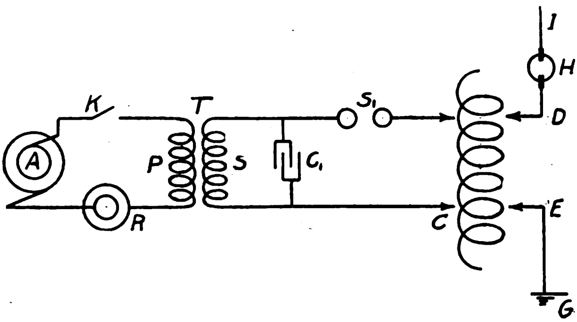


Fig. 48. Sending circuit, non-inductive.

A, alternator; R, water rheostat; P, primary; S, secondary; T, transformer; C_1, condenser; S_1, spark gap; C, tuning helix; C, S_1, C_2, closed oscillation circuit; IHDEG, open oscillation circuit; I, aerial; H, anchor gap; D and E, sliding contacts.

A is the source of the alternating current. *K* is the key for sending, and *R* is a water rheostat or an impedence in series with the primary *P* of the transformer *T*, the construction of which was worked out in the previous pages.

If the transformer is a small one, ordinary lamp cord can be used as leads from *R* and *K*. These leads should be attached to an electric light plug and the plug should be screwed into the ordinary electric light socket. It is also advisable to have a switch in series with the primary in order to cut the current off entirely when not in use.

The terminals of the condenser C_1 are connected to the terminals of the secondary of the transformer *T*. If the key *K* be closed, a certain load is thrown upon the transformer, and the condenser allows a current to alternate through it, depending upon the capacity of the condenser; the larger the condenser, the greater the current in the primary.

Attach one side of the condenser to the lower part of the helix at *C*. Attach the other side of the condenser to the spark gap *S1*. From the other side of the spark gap lead a wire to the sending helix, a few turns above the point *C*.

If the key *K* be closed, the condenser draws a load as before, but when the condenser is charged to its full voltage, a discharge takes place across the spark gap and oscillations are set up in the closed oscillation circuit, consisting of *C1*, *S1* and the inductance *C*.

If the aerial be connected at *D* through an anchor spark gap, and a ground be attached to the lower end of the helix at *E*, the open oscillation circuit *IHDEG* is formed and a minute spark passes across *H*.

With the 666 turns of the transformer cut in, any number of amperes from ¼ up to 3½ amperes can be allowed to flow by adjusting the water rheostat *R*. If talking to anyone near by, use only ¼ ampere. With ¼ ampere and a 60-foot aerial, one can easily work from one to two miles, only a tiny spark passing at *H*. If it be necessary to use more current on account of interference, or if desirable to work to a longer distance, cut in more current by means of the rheostat.

When small current is used, the spark gap *S1* must be very small. As more current is cut in, open the spark gap *S1* so as to keep a clear, even sounding spark, free from arcing. With all the primary cut in, the secondary develops about 5,890 volts. If everything be in resonance, the spark gap can be opened to ¼ inch, when 3½ amperes are flowing. As the current is cut down by cutting in resistance, it is necessary to cut down the sparking distance. If the rheostat is cut out and 555 turns are cut in, the secondary develops 7,624 volts. 444 turns gives in the neighborhood of 9,000 volts, 333 turns about 13,000 volts, and 222 turns about 19,000 volts. 100 turns will give 39,000 volts. These voltages are developed only when the proper amount of current is allowed to flow. The water rheostat should be used in each case to regulate the flow.

The spark gap practically shorts the secondary, and if the water rheostat is not used, an excessive current flows, the voltage drops across the primary and the transformer is heavily overloaded. The spark gap arcs and a very poor result is obtained.

If no condenser be put in the secondary, a regular electric light arc can be drawn from the terminals of the secondary. This arc is of no use in the production of wireless signals or high frequency manifestations, as its frequency is only 50 or 60 cycles per second. If too little condenser be used, the spark discharge arcs more or less and destroys the oscillations. Hence enough condenser must be cut in to prevent this arcing.

With 555 turns about 4 amperes should be allowed to flow; 444 turns, 5 amperes; 333 turns, 6.6 amperes; and 222 turns, 10.5 amperes.

In this connection it must be remembered that this is a 200-watt transformer. Now a 200-watt transformer, if properly designed and used, should use only 2 amperes. With 1,200 turns in the primary, this would give 2,400 ampere turns. If turns are cut out, more current must be allowed to flow to get the same number of ampere turns.

The product of the amperes by the turns in each case above gives approximately 2,400 ampere turns. If no rheostat be used, it is found that more current flows in each case than is designated above. Hence when the turns are cut out, the rheostat must be used to regulate the current to the right amount.

Even if this be done, the iron is being worked at higher and higher densities, and the transformer is not a 200-watt, but much higher. If 10 amperes are allowed to flow, the iron is being worked beyond the point of saturation, and, although 10 amperes are flowing in the primary, the iron cannot transform it, and the transformer is being worked at a large loss. Therefore, as the turns are cut out, the current should not be allowed to rise as high as 10 amperes.

Furthermore, the No. 15 wire of the primary can carry 10 amperes only intermittently and for a very short time without heating. It can carry 5 or 6 amperes intermittently for some time without undue heating, and in this transformer at all voltages only that amount should be allowed to flow at most.

By using the water rheostat, when cutting out turns, any of the above voltages can be used and as much current allowed to flow as will work the best in each case. When the higher voltages are used, the spark gap can be opened wider and wider.

In the operation of the transformer for wireless and for high frequency experiments, many difficulties will be encountered that can only be overcome by experience and practice.

To start with, just enough condenser should be cut in to prevent arcing when a small current is flowing. Tune by varying the turns included in the sending helix between *C* and *S1*, *Fig. 48*, until the best result is obtained. Now vary the current and the spark gap until the result is improved.

If there be any redness in the aerial spark gap or in the oscillation spark gap, too little condenser is being used and more should be added.

Just five factors are concerned in this operation, viz.: 1, current; 2, voltage; 3, condenser; 4, spark gap; 5, inductance. In order to secure the best result, it is necessary to adjust these five factors until they act in perfect harmony.

When the red transformer discharge is produced in either the closed oscillation circuit or in the aerial spark gap, no electro-magnetic waves are set up in the ether that are powerful enough for the purpose of wireless. The white oscillatory discharge of the condenser is necessary.

These factors should be adjusted until the aerial spark is fat and white. The aerial spark should not be long, but it should be very short, white and fat. Both the aerial spark and the condenser spark should have a good tone also. It should neither be ragged, nor hissing in tone.

This method of tuning is rough, but by patient work one can become skilled so as to get excellent results. Another method will be given later in the chapters on theory.

The wave length sent out depends upon the length of the aerial, its height and shape, the amount of wire in it, and the amount of turns included in the tuning helix. By raising or lowering the point *D*, *Fig. 48*, the wave length is changed. The open oscillation circuit has a natural time period and fixed wave length. The closed oscillation circuit *C1*, *S1*, *C* must be tuned to this by varying the number of plates included in the condenser and the number of turns included in the helix between the points *S1* and *C*. If too much current be used, more condenser must be used and the closed oscillation circuit is thrown out of tune with the open oscillation circuit.

When the closed oscillation circuit is tuned to the open or aerial oscillation circuit, the best work can be done.

Even in this case two wave lengths are sent out by the aerial and further adjusting should be done to get these two waves as near together as possible.

The importance of regulating the current is very great. As has been said before, this can be done by an adjustable impedence, a water resistance, or a resistance made of any of the resistance wires, such as german silver or climax wire.

Do not be discouraged if you are not able to accomplish great results right away. Practice works wonders. Be patient and in time you will acquire the skill of manipulation that is necessary to success.

Remember that big transformers on little aerials can accomplish nothing to what the right size transformer can accomplish. An aerial has a certain capacity and it can be charged to hold only a definite amount of electricity. When this point is reached, it is folly to try to pour more electricity into it, because it will leak out into the air in every direction and also be wasted as heat in the spark gap. The energy is not only wasted, but it acts as a detriment as well. The right amount of current is necessary to perfect tuning and tuning accomplishes results. It is surprising what can be done on small current with small transformers and proper tuning.

As time passes and skill is acquired, you will be able to accomplish more and more with the same apparatus.

Care should be taken not to interfere with the commercial companies in their work. In order not to do this, it is necessary to have a delicate detector so as to know when far-away stations are working with them. With the detectors and telephones described here, there need not be much danger of annoying them. Always listen first before sending, in order to know whether the way is clear.

When high frequency apparatus is to be operated, it is put in the place of the tuning helix of the aerial and adjustments and tuning is proceeded with in the same way.

Tune until the longest sparks can be obtained from the apparatus.

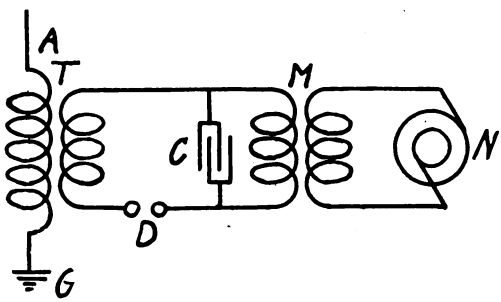


Fig. 49. Inductively connected sending circuit.
M, transformer; N, alternator; C, condenser; D, spark gap; T, air core transformer; A, aerial.

The tuning circuits used here are known as the direct connected or loosely coupled method. Close coupling and inductive connections can be used instead, if desired, but it requires more skill to obtain results. *Fig. 49* gives the inductive method. *N* is the source of electrical energy, *M* is the transformer, *C* is an adjustable condenser, *D* is a spark gap and *T* is a Tesla coil, having four turns in the primary and from twenty to forty in the secondary. The primary and secondary are close together and imbedded in wax or oil.

This construction of the Tesla coil will be described later. The inductive method both in sending and receiving is used where selective tuning is necessary. Selective tuning is difficult and should not be attempted by the amateur until he has mastered the other method. The ratio and number of turns must be accurately adjusted to the aerial used and tuning is accomplished by adjusting the condenser.

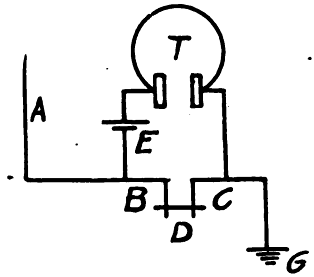


Fig. 50. Simplest form of receiving device.
A, aerial; D, detector; G, ground; E, battery; T, telephone.

2. **The Receiving Circuits.**—The simplest kind of a receiving circuit is shown in *Fig. 50.* *D* is the detector to which the aerial is directly joined. The ground *G* is attached to the other side of the detector. A telephone *T* with or without the battery *E* is shunted around the detector as shown in the cut. Without the battery and by the use of the iron pyrite detector, this works excellently for short distances.

No tuning can be done, however, and noises, due to induction, are very strong, owing to electric light circuits and

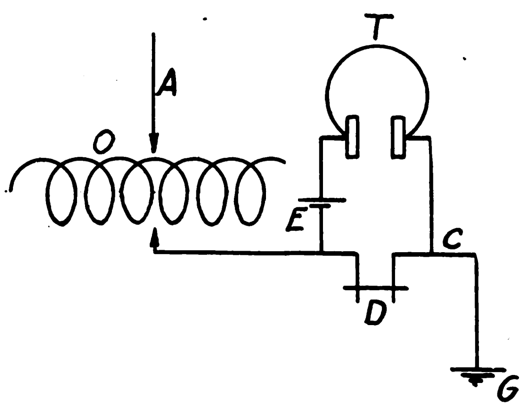


Fig. 51. Receiving circuit with tuning coil added.

car line circuits. The noises in the telephone are very annoying and long distance work is impossible. If a battery be used, a potentiometer should be used in series with it and the telephone in order to regulate the voltage across the detector.

With the silicon and iron sulphide detector, however, no battery is necessary. In fact, unless one has a potentiometer containing a high resistance, the battery is a detriment.

A great improvement is secured by adding a tuning coil as shown in *Fig. 51*. By this means the induction or humming in the telephone is partly cut out and tuning is made possible.

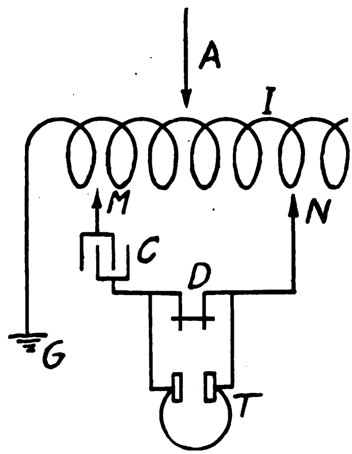


Fig. 52. Receiving circuit, with tuning coil I and condenser C added, forming closed oscillation circuit MCDNI, non-inductively connected.

Longer distances can be worked over and near-by stations come in louder.

A still greater improvement is secured by including a condenser in the circuit, as shown in *Fig. 52*, thus forming a closed oscillating circuit. In this figure, *A* is the aerial which should be attached to a sliding contact. *I* is the tuning coil described in *Figs. 39* and *40*. *G* is the ground. *D* is the detector with a sliding contact at *N*. *C* is the condenser described in *Figs. 41* and *42*. Its connection to the tuning coil at *M* may be sliding or fixed. *T* is the telephone shunted around the detector.

The detector *D*, the tuning coil *I* and the condenser *C* form a closed oscillation circuit in which close tuning can be accomplished. All low frequency waves due to electric lights, motors and street cars fail to set up oscillations in the closed circuit, because their time periods are not the same as that of the closed circuit. When waves having the same periods of frequency of oscillation arrive, they set up oscillations in the closed circuit, when that is adjusted by changing the inductance and capacity so as to secure resonance. All this will be explained later.

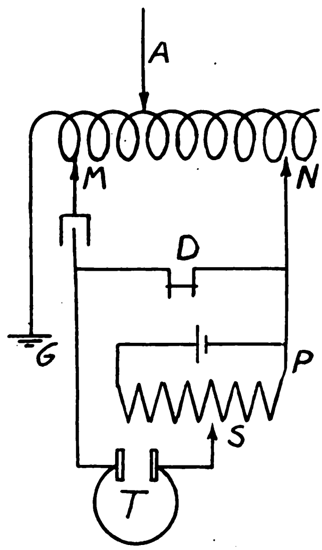


Fig. 53. Receiving circuit, with potentiometer, P, added.

A, aerail; M, condenser sliding contact; N, detector sliding contact; G, ground; S, sliding contact on potentiometer P; T, telephone, non-inductively connected.

Wherever battery is used, a potentiometer should be used. *Fig. 53* gives the connections for the potentiometer and the telephone *T* described in *Figs. 45* and *46*, except that *N* and *A* are connected to the same slide. The battery is shorted through the resistance *S*. One terminal of the telephone is attached to the condenser and detector. The other terminal of the telephone is attached to the sliding contact of the potentiometer.

The resistance, battery and telephones can be put in series if desired. With the electrolytic detector the potentiometer is a necessity. It is useful with carborundum, but with iron pyrite and silicon it is absolutely unnecessary.

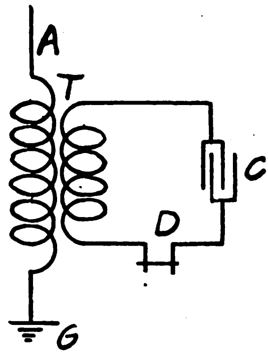


Fig. 54. Inductively connected receiving set.
T, Tesla coil or air core transformer.

This receiving set is a direct connected or loosely coupled one. For selective tuning the inductive connection shown in *Fig. 54* is necessary. *T* is a Tesla coil having twice as many turns on the primary as on the secondary. They are wound one over the other. They must be made to harmonize with the aerial with which they are to be used.

The circuits shown here are fundamental. No attempt will be made in this book to present the modifications and their names. One or two modifications will be given further on, in connection with the theory of the subject.

With the circuit shown in *Fig. 53* and with the apparatus described, the boys of Los Angeles have been able to do some pretty keen work.

The condenser and inductance can be made very carelessly. In fact, if the inductance be made by winding some No. 24 cotton covered wire on a cylinder of wood and the insulation be scraped off to allow the contact point to rest on the metal, and if the condenser be made up of a few sheets of tin foil and paraffined paper, everything will work all right provided one has the right detector and telephones.

The detector is the most important piece of apparatus of the whole receiving outfit. One may have the finest apparatus in the world, but if the detector is not sensitive, one cannot work over anything but very short distances. One may have the worst looking apparatus in the world, but if the detector is all right, one can work over long distances with ease.

3. **The Telephone.**—Next to the detector, the telephone is a most important piece of apparatus. It is not an easy matter to get a good telephone. Their sensitiveness is usually quoted in ohms, but it must be remembered that the resistance is a detriment to a telephone rather than a help.

It is not the resistance that makes the telephone sensitive, but the number of turns of wire around the magnets. It is the number of ampere turns around the poles of the permanent magnets of the telephones that does the work. One turn of wire carrying one ampere is an ampere turn. One turn of wire carrying two amperes is two ampere turns. Ten turns of wire carrying one-tenth of an ampere is one ampere turn.

Since the telephone has to do with very weak currents, a great many turns, the more the better, must be put around the poles in order that the weak current may set up the lines of force necessary to influence the diaphragm of the telephone. As the number of turns increases, the resistance increases, and this resistance weakens the current.

To begin with, the ampere turns increase in their effect faster than the effect due to increase in resistance. But as the turns are laid on, the wire in one turn becomes longer and hence each turn has more resistance. Finally a time is reached where the effect due to resistance is greater than the effect due to the ampere turns, and it does no good to go on adding turns. Furthermore, as the turns are put on they are further away from the core of the pole, and for this reason their effect is less for each turn. Thus it is seen that as the turns are put on, the resistance begins to rapidly increase and the effect of the ampere turns to decrease.

Because a receiver is a 2,000-ohm receiver and costs from $7.00 to $12.00, is no sign that it is a good receiver for wireless.

The thinness of the diaphragm and the air gap between it and the poles of the magnets are also factors in its sensitiveness.

For long distance work the diaphragm should be very close to the poles of the magnets, but not near enough to reach them in its vibration.

The thinner the diaphragm the greater the magnetic reluctance, but this is offset by its greater sensitiveness due to its thinness. If the permanent magnets are too strong, the iron of the diaphragm becomes saturated and the telephone becomes less sensitive.

It is commonly supposed that the telephone will not respond to high frequency alternating currents, but this is a mistaken idea. If the connections be made for sending as shown in *Fig. 75*, the telephones can be disconnected from the apparatus entirely, and when one is near the aerial with them, they respond loudly and clearly. If one terminal of the telephone is taken in the hand and the other is allowed to hang freely, the effect is greatly increased.

The telephone thus becomes a detector to very high frequency waves in the ether. If the telephone is shunted around the condenser, it works about as well as when it is shunted around the detector.

If the ordinary connections are made, as is usual when sending, and the above experiments are tried, the telephones will be silent. In the latter case the frequency is much lower.

Pulsating lines of force are probably set up in the telephone and these act independently of the molecules of the iron, but set up eddy currents in the diaphragm. The reaction between the field set up by these eddy currents, and the field of the permanent magnets must be responsible for these results.

The strength of the magnets is another factor in making a good telephone. It is very difficult to make magnets that will stay permanent. A great many of the magnets in the telephones lose their strength quickly and then they are useless.

The telephones are quoted in terms of their resistance, because that is the easiest way to quote them.

I have a 75-ohm receiver on my desk that is better than any 2,000-ohm receiver, with one exception, that I have yet examined. It is one of the Bell telephones that is used in a house telephone set, but it is very sensitive. I have pitted several navy telephones against it, but for long distance it is better than any of them. However, I tried, a few days ago, one of the Collins wireless telephones and found it to be excellent. It was very much better than my 75-ohm receiver. The magnets were strong and the telephones were very sensitive on long distances.

4. To Operate the Receiving Instruments.—First adjust the detector until the static is plainly heard. By static is meant the crackling that one hears in the telephones when everything is in good adjustment. This static is due to a great many different things. The sparking of the trolley upon the street cars, and the effects due to atmospheric conditions, cause it. Lightning discharges far or near cause it, as well as electromagnetic waves from the sun.

A sensitive point is found by moving the crystal about until this result is obtained. All points are not equally sensitive. Some parts of the crystal will be found to be dead entirely.

Having found such a point, slide the contacts on the tuning inductance back and forth until something is heard. If some one is working, you may get them faintly. Then adjust the sliding contacts until the signals are at a maximum. Set the condenser on different contacts and readjust the inductance, until the right amount of condenser is found for any particular station. It will be found that a small condenser is better for long distance, while a large condenser will bring in near-by stations the louder.

If a potentiometer and battery are being used, the resistance of the potentiometer must also be adjusted for the best result.

If too much condenser is used, the sounds become mushy and finally weak. The right amount of condenser renders the sounds in the telephone sharp and clear.

The coherer is not described in this book. It is not as sensitive as the detectors here described. If any mechanical work is done, however, such as ringing bells, etc., the coherer is necessary. It is described in other books.

5. **Working Distance of a Station.**—The working distance of a station depends upon several factors: The height of the aerial, the amount of wire in it, their distance apart, the amount of the aerial that is horizontal, its location, and last, but not least, the skill of the operator.

The greater the capacity the aerial has, the more energy it can handle and the more powerful the waves that it can send out. Height is only one factor. Although height above the ground decreases the capacity of a suspended wire with reference to the ground, it actually increases the capacity for a vertical aerial because it adds more wire to it.

The great mistake is usually made of using more current in the closed oscillating circuit than the capacity of the aerial warrants. The aerial has a fixed oscillation constant, due to its capacity and inductance. These factors cannot be varied very much, and if a large current is used in the primary of the transformer, more condenser must be used in the closed oscillation circuit in order to handle the additional current. This throws the closed oscillation circuit completely out of tune with the open radiating circuit and consequently good work cannot be done. Less current and better tuning would reach much farther.

In order to have a long distance station, then, it is necessary to increase the size of the aerial. This can be done by making it higher or by increasing the number of wires in it.

The addition of more powerful transformers will accomplish nothing, provided the aerial is already working up to its full capacity.

An aerial must be very large to require a kilowatt transformer to properly operate it. The aerials usually put up by the boys will operate best upon a 200 to a 300-watt transformer. In this case the iron used in the core must be of the best.

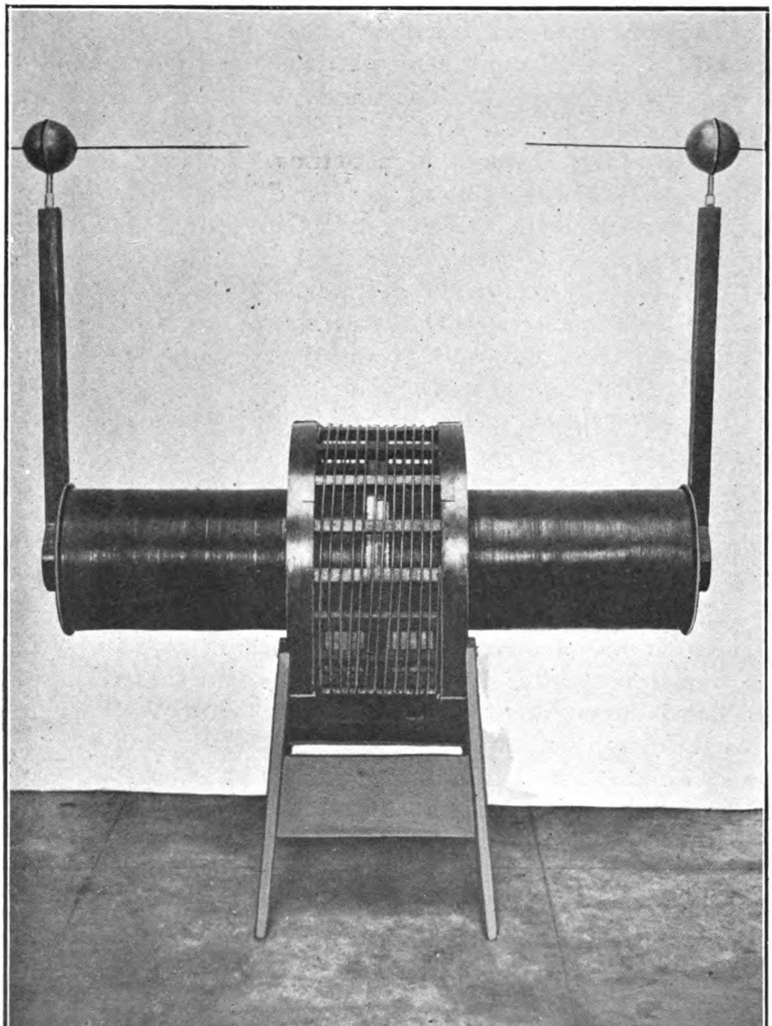


Plate IV. Photograph of Tesla coil or air core transformer, built at the Los Angeles Polytechnic High School. 36-inch maximum spark.

CHAPTER VI.

HIGH FREQUENCY APPARATUS.

1. **The Tesla Coil.**—The phenomena that can be produced with high frequency apparatus is very beautiful, interesting and instructive.

With a 200-watt transformer, condenser and spark gap described in this book, and the following apparatus, X-ray tubes, Crooke's tubes and Geisler tubes can be run. For these experiments Tesla coils or Oudin resonators are necessary. They can be made in all sizes. The smaller ones do not cost very much.

The lengths of these coils should be about three and a half times their diameter, and the primary should be about twice the diameter of the secondary.

The design given here is for a large size, suitable for a kilowatt transformer, developing 10,000 or 20,000 volts on the high side. Smaller ones should be made for the 200-watt transformers.

Cut out of inch wood four annular blocks, *A* and *B*, *Fig. 55*, 2 feet in diameter, making the rings 2 inches wide. Dowel and glue them together in pairs, crossing the grain of the wood so as to form the two blocks *A* and *B*. The rings can be cut in parts of arcs of circles and then assembled, glued and doweled together. See photograph of complete coil, *Plate IV*.

Divide the circumference of the rings into 16 or 18 parts and bore ½-inch holes *D* in the rings. Obtain as many pieces of wood *E*, 1 inch square and 9 inches long. Turn down each end a distance of ½ inch to fit the ½-inch holes in the rings *A* and *B*. Fit these into the holes so as to form the cage *ABFD*.

Cut out of inch stuff a couple of circular blocks *H*, 20½ inches in diameter. Glue and dowel them together, crossing the grain so as to form the center piece *H*. In the center of this block make a square hole 2 inches by 2 inches.

Out of inch stuff cut 12 circular blocks *I* and *G*, and

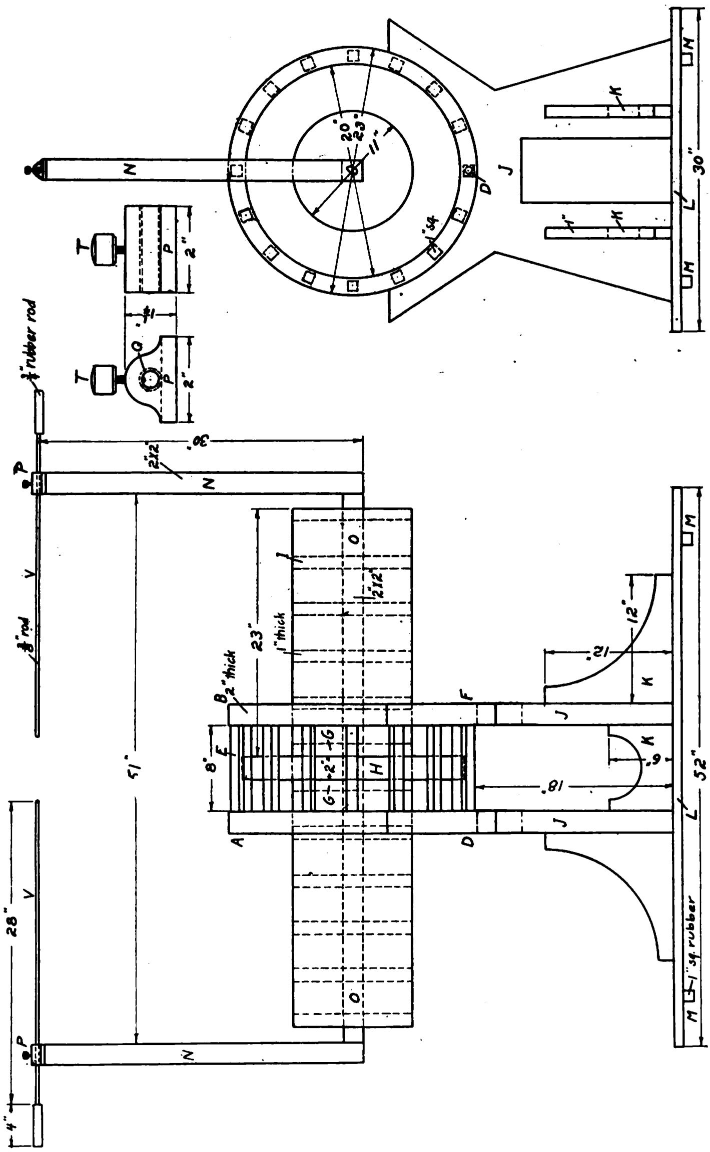


Fig. 55. Tesla coil shown in Plate IV.

in their centers cut holes 2 inches square. Fit one of these on each side of the block *H*, gluing and doweling them together.

Obtain a piece of wood *O*, 2 inches square and 51 inches long. Put the combination block *HG* upon the center of this piece *O*, and fix it firmly in position. Arrange the other blocks five on each side, equidistance along *O*, as shown at *I* in the cut, placing two of them at the extreme ends of *O*.

Over the blocks *I*, on each side of *H*, wrap leatheroid, an insulating paper. Wrap this around three or four times in order to form a stiff drum. On the drum thus formed, wind 850 to 1,000 turns of No. 24 single cotton covered magnet wire. Do not let the wires touch. They can be spaced in the following manner:

Put the drum in the lathe or suspend it otherwise, so that it can be rotated. Make a loop of copper wire, having a diameter equal to the spacing desired. Attach a weight to the loop and put it over the drum, allowing the weight to hang below. The loop should be long enough to allow the weight to hang about 2 feet below the drum. Start on the left to wind, turning the drum away from you. After putting on the first turn, place the guide wire by the side of the turn just wound. As you wind, the guide wire will move along and attend to the spacing, the guide wire being between the turn just wound and the turn just going on.

When the middle of the block *H* is reached, bore a hole in it. Break the wire and carry the end through. Splice the broken ends and go on with the winding. Put screws into the end blocks and solder the wire to the screws. Assemble the pieces *E*, and one side of the cage, using glue. Place the cage thus half assembled over the drum, fitting the middle of the pieces *E* on to the piece *H*. Put glue on the ends of *E* and put on the end *AD*. Drill holes in the middle of each piece *E* and into *H*. Drive pegs into these holes, in order to hold the cage *ABFD* firmly in place on *H*.

Prepare two supports *J*, 18 inches high and 1 inch thick, and four braces *K*, 12 inches long and 12 inches high. The support *J* should be rounded out to fit the cage.

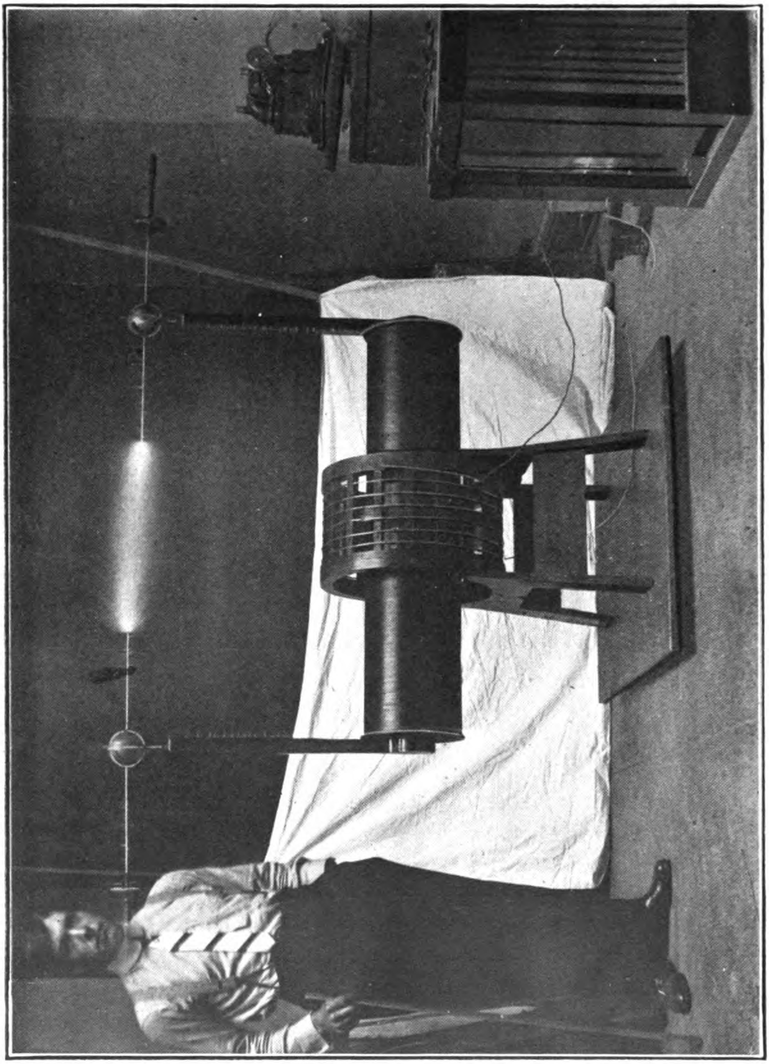


Plate V. Photograph of Tesla coil, shown in Plate IV, giving a 24-inch discharge. Exposed 10 seconds. Made by Mr. Parke Hyde, a pupil of the Los Angeles Polytechnic High School.

Support the whole upon the base *L*, 52 inches long and 30 inches wide. Take two pieces *N*, 2 inches by 2 inches and 30 inches long. Cut from fiber or wood two circular end pieces, not shown in the cut, a little larger in diameter than the drum. Cut a hole in them large enough to admit the end of the piece *O*. Put them over *O* and screw them to the end piece already there. Saw off *O* flush with this end piece and put *N* in place solidly against this end piece, screwing it to *O* and the end piece. Take two pieces of brass *P*, 2 inches square and 1/8 inch thick. Obtain two brass tubes 2 inches long and 1/2 inch in diameter. Melt some solder and fill the tubes with it. Through the solder bore holes 3/8 inch in diameter. Thread a binding post *T* in the tube. Solder the brass tube *Q* to the brass piece *P*. Screw these on top of the posts *N*.

Obtain two aluminum rods, 3/8 inch in diameter and fix 3/8-inch rubber handles upon them. Put the aluminum rods through the tube *Q*. Run wires from the terminals of the secondary to the brass pieces *P* and solder it to them.

Obtain about 60 feet of No. 5 spring brass wire and put around the cage *ABDF*, putting the turns about 3/4 inch apart, thus having 10 turns on the primary.

2. The Oudin Resonator.—The drum for the Oudin resonator is made like that for the Tesla coil, with the exception that the middle piece *H* is left off and the leatheroid is wound continuously from end to end. *O*, *Fig. 56*, is the drum, 11 inches in diameter and 36 inches high. On this is wound from 800 to 1,000 turns of No. 26 D.C.C. wire. The primary cage is made the same as in the other case. The two are assembled upon the base *B*, which rests upon rubber legs *I*. The cage *A* and the drum *O* are screwed to the base after being centered.

F is a brass rod driven into a hole in the center post, and *K* is a brass ball surmounting this rod. *M* is an upright post having dimensions shown in the cut, and *C* is a binding post for the ground wire. The basket *A* is made the same as for the Tesla coil. Connect the bottom of the primary to the bottom of the secondary.

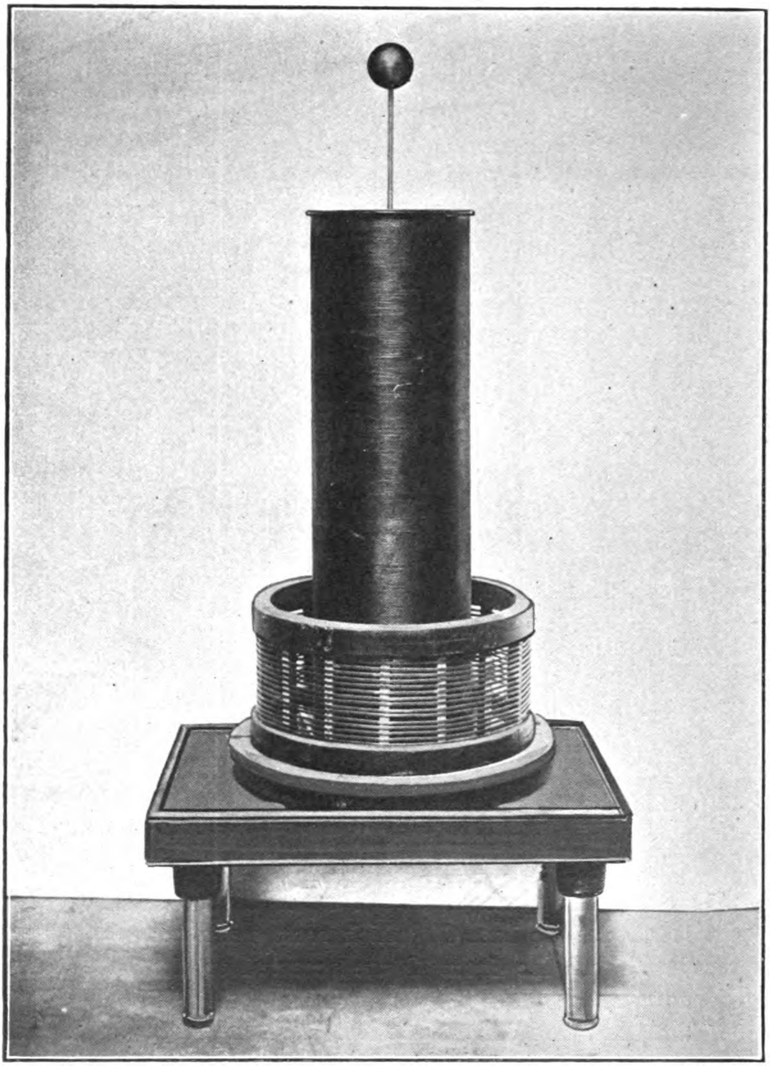


Plate VI. Photograph of Oudin resonator, 24-inch spark, made by Mr. Parke Hyde, a pupil of the Los Angeles Polytechnic High School.

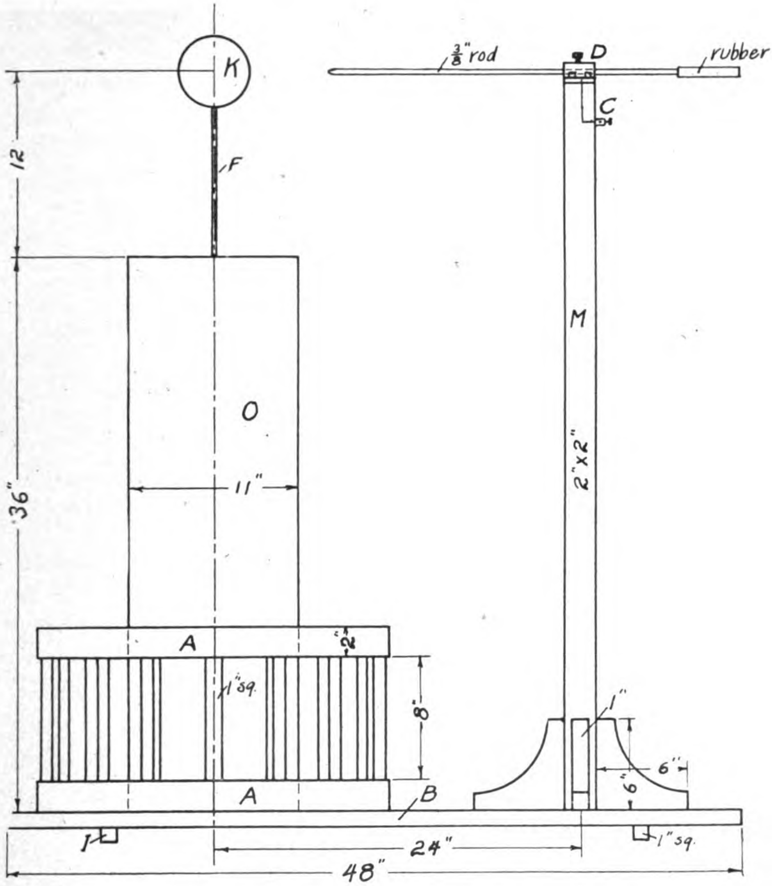


Fig. 56. Drawing of Oudin resonator shown in Plate VI.

3. **Operation.**—In order to operate the Tesla coil or the Oudin resonator here described, a kilowatt transformer is necessary.

Either 20,000 or 10,000 volts can be used, but we have found that 10,000 volts give us the maximum results. The condenser for operating these coils must be larger than the one described in *Fig. 12.* Obtain 12 plates of window glass 18 inches by 24 inches. Leave a margin of at least 2 inches on three sides, and, on the third side, where the contacts are to come out, leave a margin of 4 inches. Follow the general plan given in *Fig. 15*. A helix of spring brass wire can take the place of the brass rods *F* if desired. Then the contacts can be made by merely slipping the contact rods in between the turns of the helix of brass. On the right of *Plate IV* this condenser can be seen.

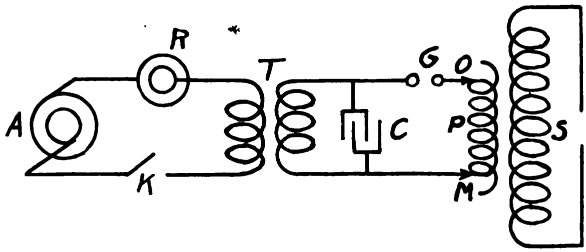


Fig. 57. Diagram of connections of Tesla coil shown in Plate IV.

To operate the Tesla coil the connections should be made as shown in *Fig. 57*. The source of alternating current *A* is connected in series with the water rheostat *R*, and the primary of the transformer *T* and a switch *K*. The terminals of the secondary are connected to the condenser *C* as shown. From the same terminals of the condenser, wires are conducted to the primary of the Tesla coil *P*. Tuning is effected by moving the contacts *O* and *M* from turn to turn, and by adjusting the plates in the condenser. *G* is the spark gap.

With a kilowatt transformer, pulling a load of 20 amperes in the primary, we have obtained a 36-inch spark with the Tesla coil, shown in *Plate IV*. This overloads the transformer, but does no harm for short intervals of time.

To operate coils of this size requires from 15 to 25 amperes, and a 2-kilowatt transformer would be much better; however, they work very well with a kilowatt size, provided it is overloaded in order to get the proper amount of energy.

The water rheostat, the condenser, the primary inductance of the Tesla coil, and the spark gap should be regulated until the maximum result is reached. It works best on 20,000 volts.

When resonance is obtained, the ends of the coil send out a beautiful spray and a 36-inch spark passes between the terminals of the coil. The spark points should be filed clean and smooth and they should be kept that way.

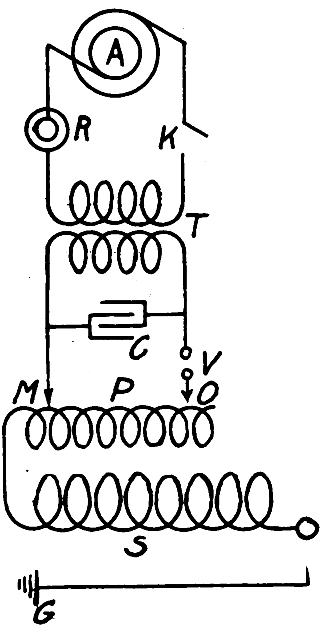


Fig. 58. Diagram of connections for Oudin resonator shown in Plate VI.

The connections for the Oudin resonator are given in *Fig. 58*. The connections are similar to those given in *Fig. 57*, except that the bottom turn of the secondary is connected to the bottom turn of the primary. The inductance is varied by attaching the point *O* to the top of the primary turns, and then by moving *M* up or down, until resonance is obtained, the water rheostat, the condenser and the spark gap being adjusted at the same time. This resonator works the best on 10,000 volts. It will do well on 20,000, however, but 10,000 gives the longest streamers.

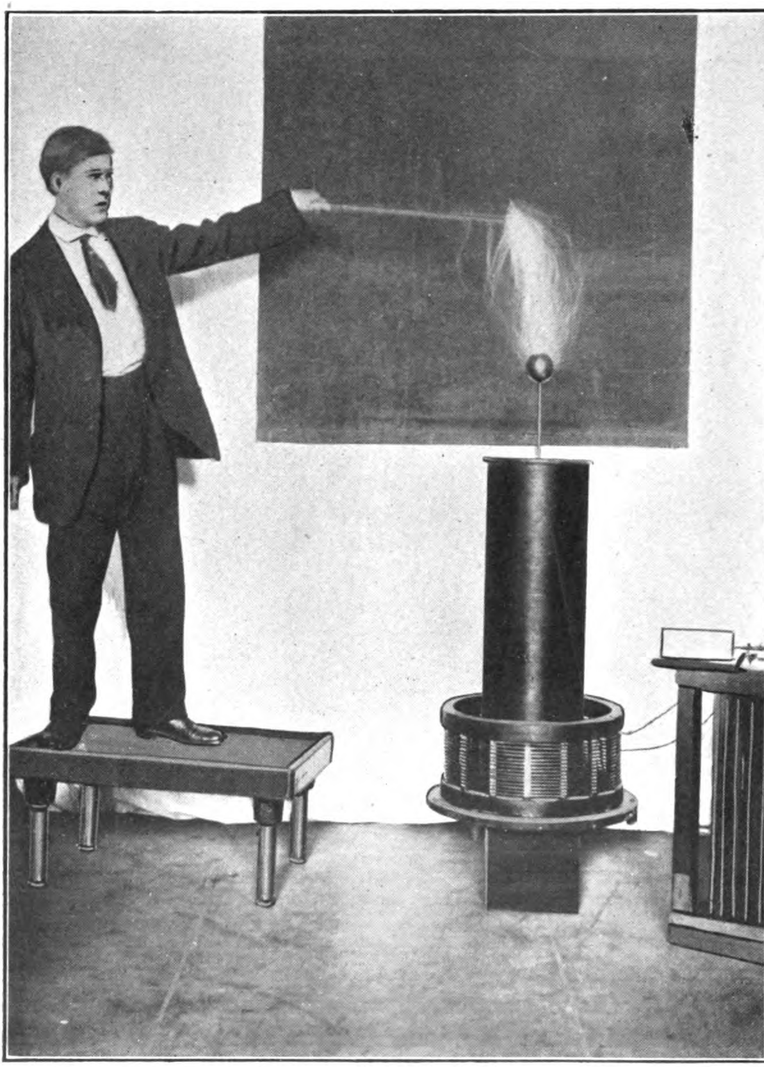


Plate VII. Taking a 16-inch discharge into the body from the Oudin resonator. Exposed 10 seconds.

We have obtained streamers 2 feet long from the brass ball and have been able to take them through the body without harm.

To do this a person should stand on an insulating stand made of wood, supported on glass legs. See *Plate VII.* Take a metal rod in the hand and approach it to the terminal *K*, *Fig. 56.* The spark will pass to the rod and the current will oscillate into and out of the body. If everything is in resonance and the spark gap is not too wide open, one does not feel the discharge at all.

If the spark gap is wide open, the current causes the muscles of the arm to contract somewhat, but not disagreeably. In doing this a person should not make a good ground, as the shock then becomes very disagreeable. In all our experience with a kilowatt transformer and this apparatus, no one has received the slightest injury.

On one occasion, while the coil was running full blast, one of our students fell upon the top of the condenser and received no injury, although it scared him somewhat. These high frequency oscillations are not dangerous and the reasons for it will be given under the head of the theory.

Geisler or vacuum tubes held in the hand anywhere near these coils light up brightly, without any contact with the apparatus.

The two instruments just described are not fit for wireless. Although they send out waves, there are too many turns in the secondaries and they do not work as well as the simple tuning helix described in *Fig. 21.*

Small coils can be made for the 200 or 300-watt outfits by merely varying the size, making the length 3½ times the diameter and the primary twice the diameter to the secondary.

An Oudin resonator that will light a lamp through the body and work well on 300-watt transformer, is made as follows: Make a drum 10 inches long and 3½ inches in diameter. Put on about 300 turns of No. 34 D.C.C. wire. Make a primary cage 7 inches in diameter and 3½ inches high. Put 10 turns of No. 10 bare copper wire on this, and connect the

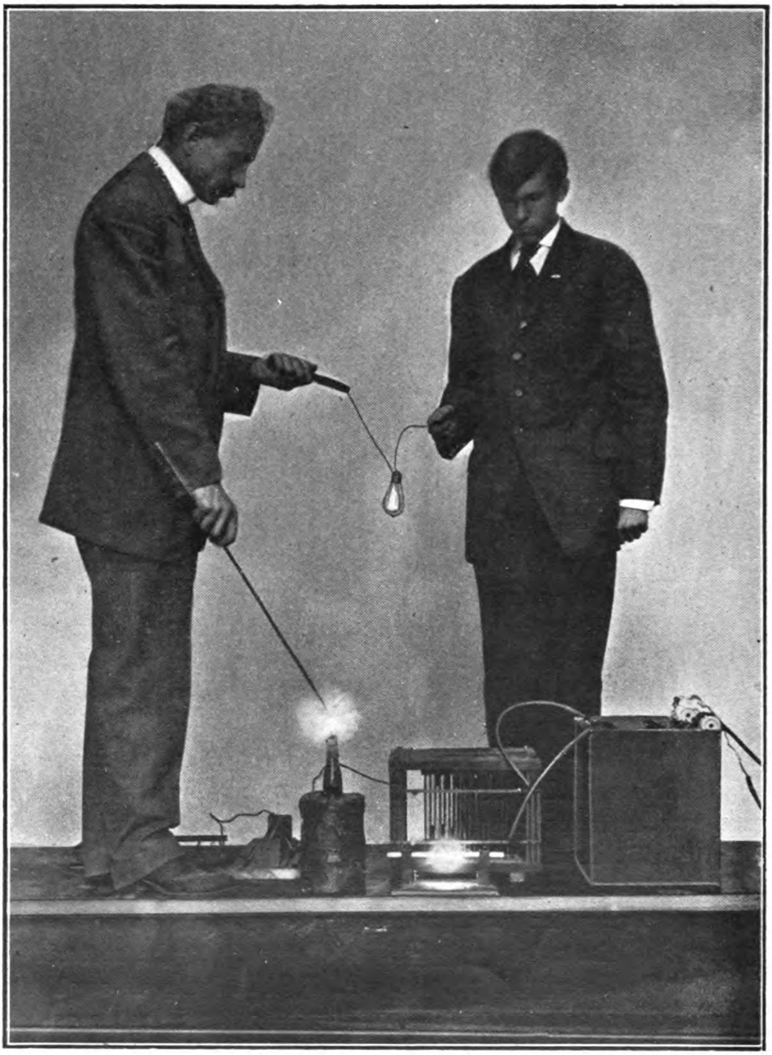


Plate VIII. Photograph of lighting the lamp through the body from a small Oudin resonator. 220-volt, 110 16-candle-power lamp brought to full candle power.

bottom of the secondary to the bottom of the primary. The copper turns should be spaced evenly. In order to light the lamp, connect as in *Fig. 58*.

Tune until a good hot spark is obtained, by approaching a rod held in the hand near the terminal of the Oudin. Take an ordinary 110-volt 16-candle-power electric light and solder copper wire to the outside and inside contacts. Solder on to the ends of these wires brass pieces about 4 inches long and 2 inches wide for the purpose of handles. Brass tubes, however, make good handles. Put one terminal wire of the lamp on the terminal of the Oudin and take the other terminal in the hand. Stand on the insulating stool and turn on the current. The current surges into the body and back again through the lamp, lighting it to full candle power if everything is in resonance.

A better piece of apparatus for this purpose is made as follows: Take an ordinary quart beer bottle. A two-quart bottle is better if it can be obtained. Wind No. 34 wire on the bottle, beginning at the bottom and finishing at the shoulder of the bottle. Bring the top terminal up to a brass rod fixed in a cork in the bottle. Imbed this in an inch of wax. Take No. 12 rubber covered wire and put five turns of it around the bottom of the bottle, winding the turns as closely together as possible, and as near the bottom as possible. Connect as shown in *Fig. 58*. Vary the plates until the best results are obtained. Take off a turn or put on a turn and by trial determine the number of turns that accomplish the best result. After this is done, imbed the whole thing in a preparation of wax, to a depth of a couple of inches.

This insulation is necessary to obtain the best result, as there is heavy leakage between turns without it. There is a tendency to break down between the primary and the secondary, but it can be easily repaired. If it be worked on 10,000 volts, it works better than on higher voltages and it does not then break down. Tune as with the other Oudin, with the water rheotsat, condenser and spark gap. The primary of the Oudin in this case is fixed so that it cannot be varied.

To light the lamp between two persons, let one person

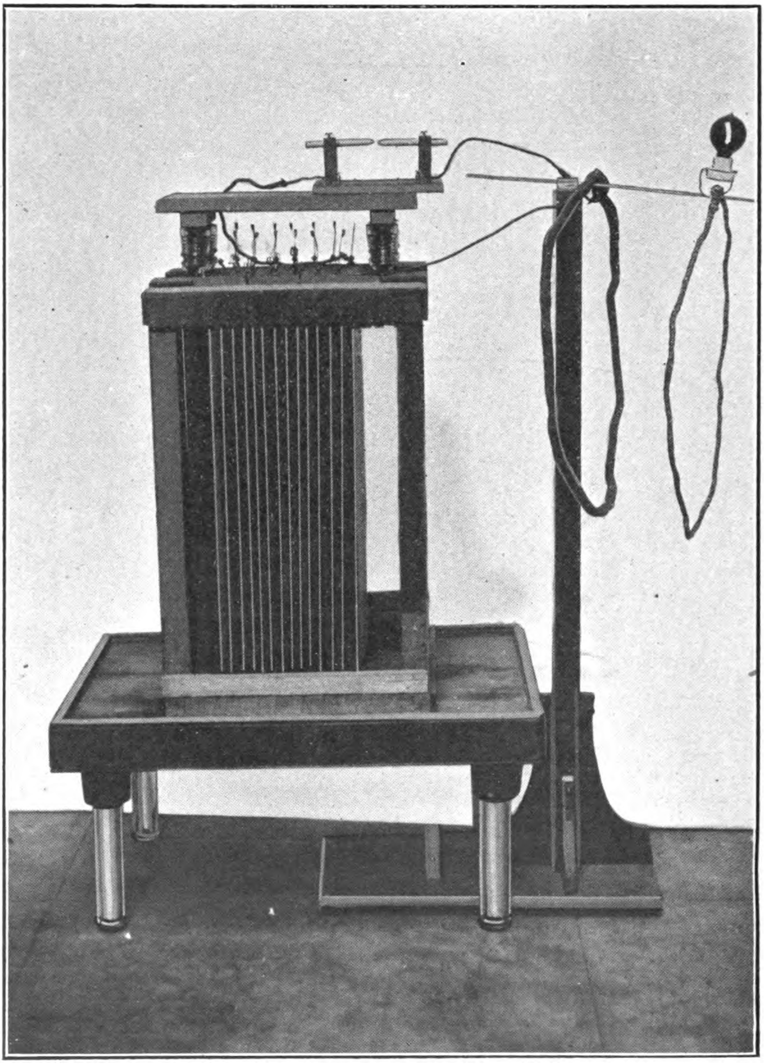


Plate IX. Photograph illustrating transformer action by lighting lamp in the secondary.

stand on the insulating stool (see *Plate VIII*) and take a brass rod in one hand. Let another person stand on the ground. Let the person on the stool take one terminal of the lamp in one hand and the person on the ground grasp the other terminal of the lamp. Turn on the current and approach the rod to the terminal of the Oudin, touching the terminal of the Oudin with the rod. The lamp will light up to full candle power if everything is in resonance (see *Plate VIII*). To secure this the spark gap should not be too close together nor yet too far apart. Adjust the spark gap until the maximum result is obtained.

This bottle Oudin operates Crooke's tubes and Geisler tubes beautifully. Stand on the insulating stool, taking an aluminum rod in one hand and the tube in the other. Set the apparatus to going and touch the terminal of the Oudin with the aluminum rod. The tube will light up. If everything is in resonance, the tube will shine brightly. Wave it back and forth in the air. Let a second person take hold of the end of the tube and then touch the Oudin with the rod. The tube will shine brightly. Sparks can be drawn from any part of the body of the operator and sparks can be taken on the bare hands between the two operators.

Let each person take a brass rod in his mouth. Let the one on the stand touch the Oudin with the rod and let the second person move himself near, so that a spark can pass between the brass rods.

All of this phenomena takes place without the operators feeling anything, except when the sparks are taken on the bare hand. Then the discharge stings and burns. If done very much, sores will be formed on the hands, due to the burns.

Let one person stand on the insulating stand and touch the terminal of the Oudin. Let another person take a vacuum tube in the hand and walk around near the other. The tube will light up several feet away. The more powerful the apparatus, the farther away the tube will light. We have succeeded in lighting them at a distance of 6 feet.

To demonstrate the principles of the transformer, construct a couple of coils as follows (see *Plate IX*): Make one coil of No. 12 rubber covered wire, 24 inches in diameter, containing 7 turns. Wind these turns closely together irregularly and tape them together, allowing the free ends to come out within 4 to 6 inches of each other. Make a second coil of No. 16 rubber covered wire, putting 4 turns in it. Make this 24 inches in diameter, and tape it the same as the first. This is the secondary. Attach an ordinary lamp socket to the terminals of the secondary. Attach the primary to the oscillation circuit in place of the Oudin, as shown in *Fig. 58*. Tune by varying the condenser and water rheostat. Set the current to oscillating and bring the secondary near the primary, a 110 16-candle-power lamp being first placed in the socket. The secondary should be held so that the plane of its coil is parallel to the plane of the primary. When at the right distance, the lamp will light up without having any electrical connection with the primary. Turn the secondary in different positions and note the results.

CHAPTER VII.

AMATEUR STATIONS AND SELECTIVE TUNING.

Many boys and amateurs are establishing wireless telegraph stations in every section of the United States. These stations are a source of never-ending delight to the boy who has scientific tastes.

He finds here a means within his reach, by means of which he can study electricity from both a theoretical and a practical standpoint. The mere theoretical study of scientific subjects is unsatisfactory. One reads of course of the things that others have done, with great interest; but the subject remains a mystery, unless one can become familiar with it by actual contact.

Wireless telegraphy furnishes a means for that contact, and that is why it is becoming so popular with many people. It furnishes an avenue along which a boy may expend his leisure time, much to his profit and enlightenment.

Los Angeles has its share of boys whose minds turn toward the natural phenomena of nature. Electricity is fascinating to all boys, and wireless telegraphy gives them the opportunity to become familiar with alternating current phenomena at a small cost. This is of immense practical value to them, because the phenomena of wireless telegraphy is the phenomena of the commercial alternating current, and the knowledge they obtain here will be of great value to them in the electrical field of the commercial world.

When so many stations are operating, interference becomes serious; and this problem of interference must be solved before wireless telegraphy or telephony can possibly become a commercial success.

If the wireless companies now in the field were doing a large business, it would be necessary for each company to occupy the field all of the time, night and day. Under present conditions, only one sending station can operate at a time. When one station is sending, all stations far and near are affected by the waves sent out by that station, and, if the station is a strong one, no other station can receive any one except the sending station.

If five stations are sending in the same region, then every station that is not sending hears in his telephone a confused buzz, the result of the mixture of the waves of all of the sending stations. If one of the sending stations has a tone to its buzz radically different from all of the others, the skillful operator can pick out that particular one and read it.

If some of the sending stations are weaker than others, owing to distance or to low power, then the strongest signal can be read. If a dozen people are talking all at once in a room, one can pay attention to one of them and understand what he is saying, even though the others are talking.

The solution of interference is not to be found by driving the amateurs out of the field. It would be very unfortunate, indeed, if our Congress were to take action giving a monopoly of the space above and about us to any corporation or set of corporations. The development of aerial navigation and wireless telegraphy demands that the air, the same as the surface of the ocean, be kept a public highway.

Selective tuning offers a complete solution of this problem.

For selective tuning, undamped continuous waves are necessary. Condenser discharges at the frequencies now in use give a train of damped oscillations as shown in *Fig. 79*. No selective tuning can be effected on a wave of this nature.

Continuous undamped waves, like those in *Fig. 60*, are necessary. These undamped waves would give an effect like that in *Fig. 84*. If these waves could be rectified as in *Fig. 69*, a still better effect might be produced.

It will be observed that in *Fig. 79* there is considerable distance between the maximum value of each discharge. This leaves a blank between the discharges. The higher the frequency, the smaller this blank.

Referring to *Fig. 84*, it will be seen that there is a blank interval between the maximum value of the continuously sustained oscillations. If these oscillations could be rectified, a greater effect would be produced.

The higher the frequency, the closer the maximum values. This high frequency produces a short wave length. Fessenden has solved the problem of selective tuning by the use of a high frequency alternator. Poulsen and The Collins Wireless Telegraph Company have solved the problem by use of the direct current arc.

I do not maintain that the amateur should be allowed to obstruct the growth of wireless telegraphy. He is not doing so. He is in fact advancing its interests. If no amateurs were in the field, the problem would be just as serious, because only one station of only one company could work in the same region at a time, and this fact alone would render wireless telegraphy useless commercially.

The amateur is then only bringing to the front, more forcibly, the necessity for selective tuning. If selective tuning is impossible, the only remedy is government ownership of wireless, not for commercial use, but for the uses to which it is now putting it.

Wireless telegraphy and telephony have no commercial use unless selective tuning is possible. Theoretically, selective tuning is possible, and there are two commercial companies in the field today in the United States, who claim to have solved it.

The Collins Wireless Telephone Company claims to have solved selective tuning to such an extent that they can work beside the most powerful wireless telegraph stations, absolutely without interference.

The company that owns the Fessenden patents claims to have accomplished the same thing for wireless telegraphy. The time is close at hand when these companies will demonstrate what they can do in this line. Selective tuning thus solves the difficulty without driving any one off the public domain.

Tuning is possible with the circuits given in this book. If stations differ radically in their wave length, they can be received on different parts of the closed oscillation circuit, and in this case, when one is coming in loud, the other is coming in weak.

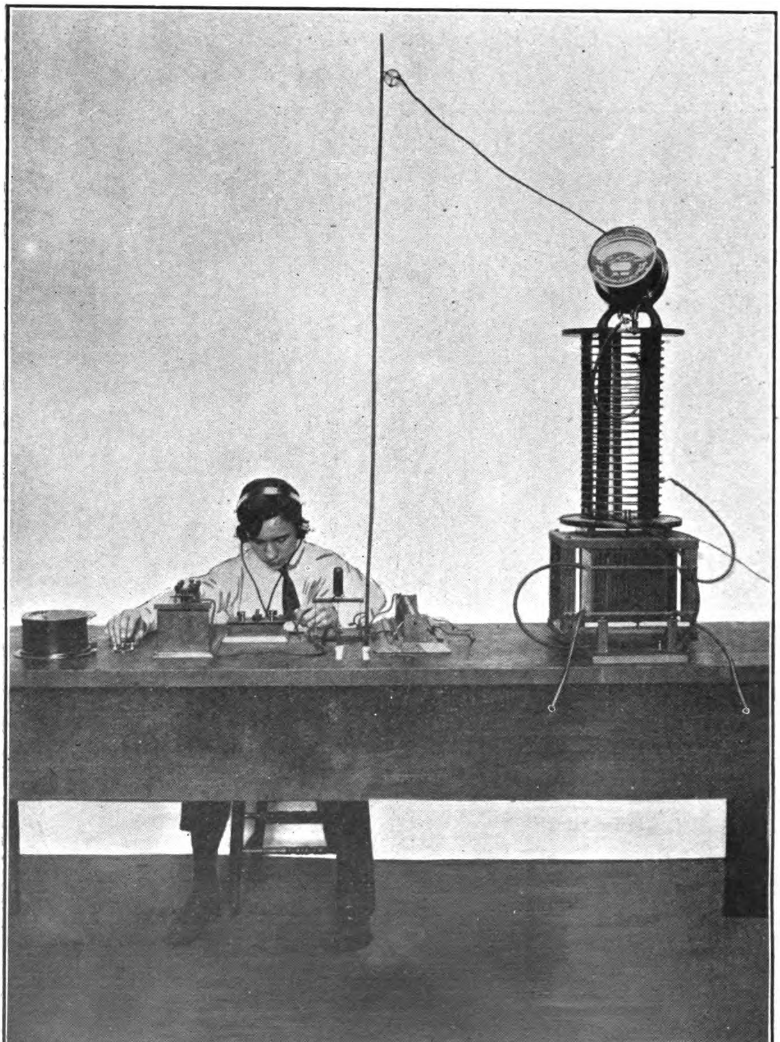


Plate X. Photograph of interior of station at the Los Angeles Polytechnic High School. Sending outfit on the right. Receiving set in the center.

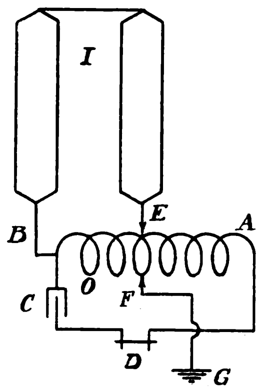


Fig. 59. Receiving circuit. Non-inductive. Excellent for tuning out short waves.

Fig. 59 is an excellent circuit for this purpose. Mr. Farran tried this circuit for the first time, some few days ago, and found it to be excellent, not only for tuning out near-by stations with short wave lengths, but also for bringing in distant long wave stations strongly. We had been using the Shoemaker connections shown in *Fig. 32* with excellent results, but it is not very selective.

In the connections shown in *Fig. 59*, the closed oscillation circuit *AOCD* is joined to the looped aerial *EIB* by a movable contact *E* and a fixed point *B*. *B* is attached at the junction of the condenser and the inductance. *D* is the detector around which the telephone should be shunted. *F* is a movable contact for the ground. The condenser *C* is adjustable.

When *E* and *F* are in the middle of the tuning coil, all short waves ground and become very weak or silent entirely. All long waves set up oscillations in the closed circuit. With this arrangement we were able to tune out the boys in near-by stations and read TM, the government station at Point Loma, Cal., 100 miles away, or PI, the United Wireless station at Catalina, fifty miles away.

The station on the Polytechnic High School was established in the fall of 1908. It is stretched horizontally, between the science hall on 20th St., and the main building on Wash-

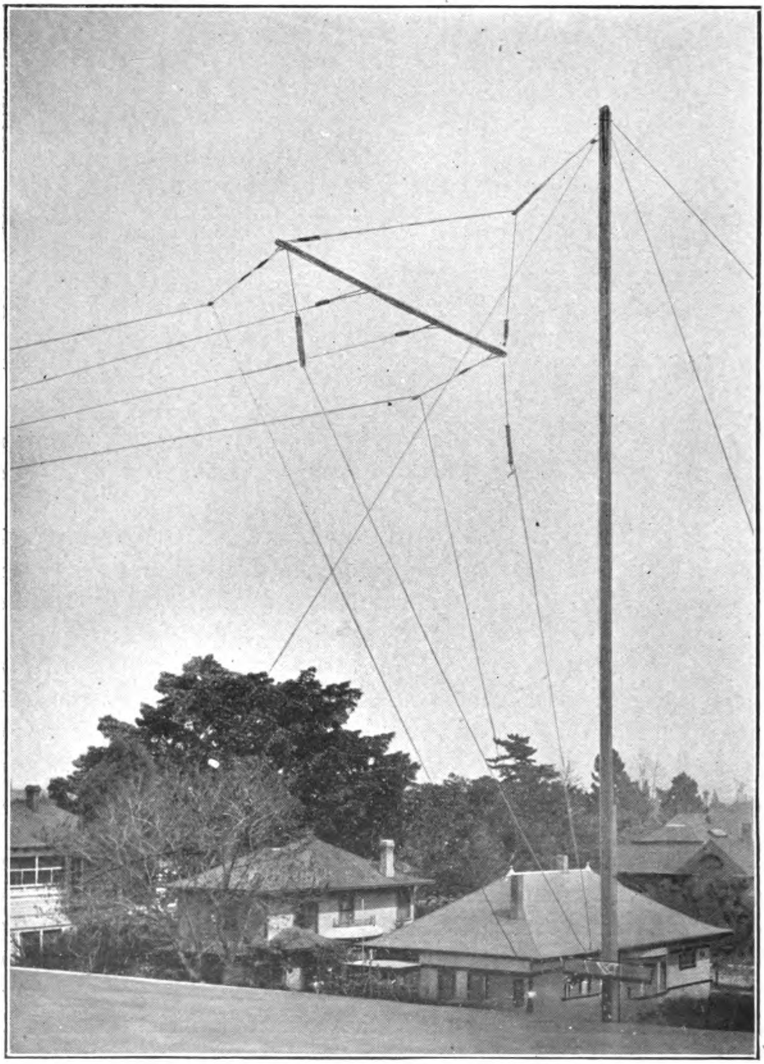


Plate XI. Photograph of one end of the aerial on the Los Angeles Polytechnic High School, roof of Science Hall.

ington St. It is about 35 feet from the ground at one end and 50 feet at the other, being 20 feet above the roof of the building part of the way, and 30 feet the rest of the way. It points north and south. The aerial is composed of four strands of No. 12 aluminum bare wire, 200 feet long. They are joined together at the Washington St. end and are brought, side by side, about 2 feet apart, to a pole on top of the science hall. Here two leads are brought down into the office through a skylight. One lead comes from two of the wires on one side, and the other lead comes from the two wires on the other side.

The 20th St. end is shown in *Plate XI*, and the interior is shown in *Plate X*. The aerial thus has 800 feet of wire in parallel. There are two leads 60 feet long. This makes 720 feet of wire in the aerial. The aerial can thus be used as a looped one or otherwise, as desired.

The receiving instruments are similar to those described in this book, and they are connected as shown in *Fig. 59* or *Fig. 32*. The detectors used are silicon, iron pyrite or perikon. The best work has been done with the pyrite. The perikon is very sensitive, but not as reliable as the pyrite. The Collins 2,000-ohm receivers are used with no potentiometer or battery. A 75-ohm Bell telephone is also used that is very sensitive.

In the sending, a 1-kilowatt transformer is used, giving 20,000 volts on the high side. The Massie connections are used for a hook-up. With this outfit, Mr. Farran has been able to send as far south as San Diego and out to sea far north of Santa Barbara, covering 100 miles south and at least 180 miles north. This was done on 2½ amperes in the primary of the transformer. The current was cut down with a water rheostat and only a $^3/_{16}$ inch spark was used.

The ships, communicated with, read us with ease and said that the station came in strong and clear. This means, of course, that the station was reaching much farther, but we have not been able to test to farther distances.

In receiving we have been able to hear the U. S. warships in Magdalena Bay, 725 miles in an air line south, and Table Bluff, 560 miles north.

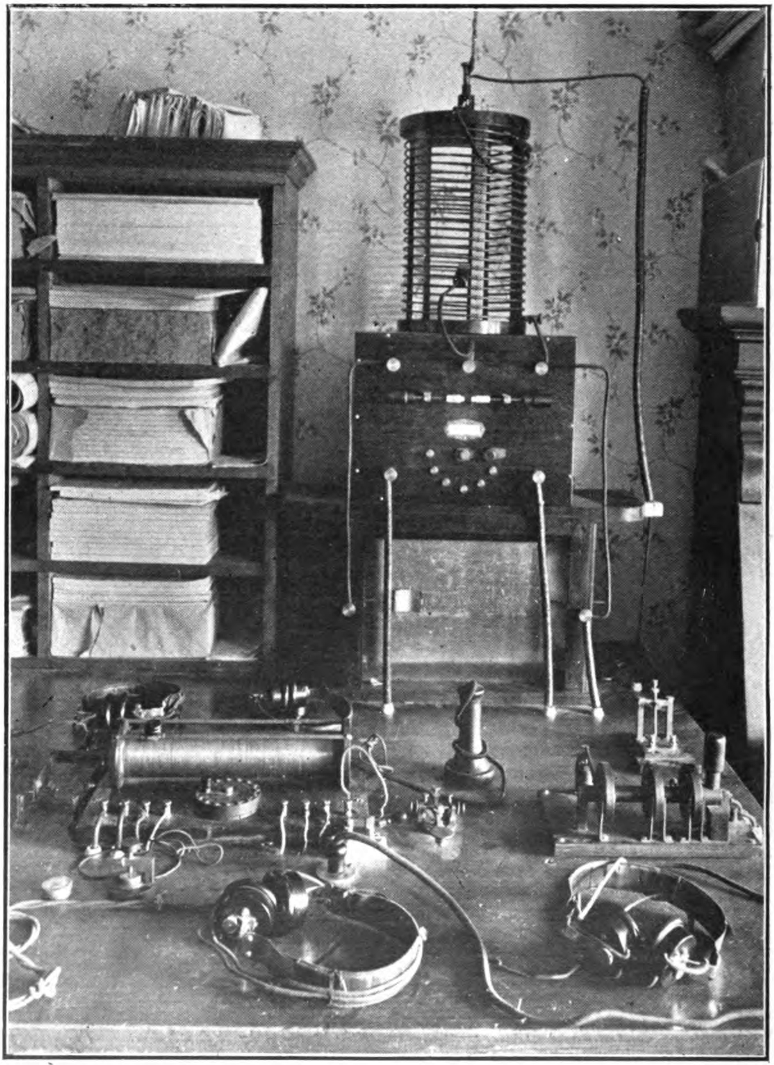


Plate XII. Photograph of station of the Southern Pacific Telegraph School, 542 Central Ave. Apparatus made by a Los Angeles boy.

We have thus been able to work with ships at sea both receiving and sending, to a distance of at least 180 miles, using in sending only 2½ amperes. The aerial tunes on this many amperes. We are able to get the Farallones and the San Francisco stations at night, 368 miles north in an air line. Magdalena Bay was received in the daytime, but Table Bluff at night.

Mr. Roy Zoll was the first boy to install a sending and receiving outfit in the city, so far as I know. Mr. J. T. LaDu and myself had installed small sending outfits some time previously.

Prior to this time there were some receiving stations, but none equipped with sending instruments. We used power transformers from the first.

Mr. Zoll's first aerial consisted of two baskets, 27 feet long, strung up on a 75-foot pole. Each basket had four No. 18 copper wires in it, arranged around circular hoops 1 foot in diameter. The two baskets were 2½ feet apart. With this vertical aerial and a carborundum detector, he was able to hear the fleet of sixteen battleships on their trip up from Magdelena Bay in April, 1908, long before they reached San Diego.

Mr. Zoll's station is located on the top of a hill. His pole is made of a eucalyptus tree, 75 feet high. He used ordinary Bell telephone receivers. Point Loma and the United Wireless station in San Diego, the San Francisco stations and the Farallones were all picked up by him before any of the rest of us heard them. Some time later he added to these baskets two loops each, containing three wires 70 feet long. These branches were joined together at the top, and they spread apart 64 feet at the bottom. With this aerial his range was considerably increased. He was able to receive the following stations, besides those already heard: SV, Tatoosh Island, Washington; and SP, Navy Yard, Puget Sound, 1,000 miles north.

Later he stretched three wires 160 feet horizontally from the top of his pole to another pole, and stretched two radiating wires from this, one 140 feet long and the other 180 feet long, making in all 1,320 feet of wire.

After the first change iron sulphide was used as a detector. With this aerial he heard the West Virginia at Magdalena Bay, 725 miles south.

Mr. A. E. Abrams was among the first to install a receiving and transformer sending outfit. His pole is 71 feet high. It is on the top of his house. The aerial consists of four wires 75 feet long, of No. 18 bare copper wire. The spreaders are 10½ feet long.

His transformer is a 350-watt. The primary consists of four layers containing 166 turns, tapped at five points. His secondary has 75,000 turns of No. 36 D.S.C. The coils are ⅛ inch thick with ⅛ inch space between them. The iron core is 16½ inches by 5½ inches, with a cross section of 2½ square inches.

In receiving he has heard as far north as Cape Blanco and south of San Diego.

Mr. D. Whiting of 627 St. Paul St., located on the hills, has a pole 120 feet high. The aerial is 140 feet long, containing six wires, arranged in a loop system. The leads are 60 feet long. He uses a 2-kilowatt transformer of 40,000 volts. The iron in the transformer is ordinary sheet iron. DeForest connections are used in the sending.

His receiving sets are connected according to the Shoemaker and Massie systems. He has a pair of Collins Wireless telephones and uses silicon, iron pyrites, perikon and electrolytic detectors.

He has been able to receive as far north as Tatoosh, 1,000 miles, and as far south as Magdalena Bay, 725 miles.

The Southern Pacific Telegraph School, 542 Central Ave., has a wireless station. The aerial is a horizontal one, 65 feet high at one end and 45 on the other. It is composed of 10 strands of No. 12 copper wire. They are all connected together at the upper end and brought in to the instruments at the other end by one lead. They have a 1-kilowatt transformer and apparatus made by a Los Angeles boy. *Plate XII* is a view of their sending and receiving outfits. This school is owned and managed by Mr. F. D. Mackay. Facilities are presented here for a training in railroad telegraphy, commercial telegraphy and wireless telegraphy.

Plate XIII is a photograph of the author's station. The house is 35 feet high and the pole is 40 feet high, thus giving 75 feet above the ground. Aerials of various kinds have been tried. The one now in operation is as it appears in the cut, with the exception of a small wire which connects all of the guy wires together. This wire was too small to photograph. There are in all twelve guy wires, although only ten can be seen in the cut. Two of them are so nearly in line with the pole as to be invisible.

Three of them are 85 feet long, four of them 35 feet and five of them 50 feet long. This gives a total length of 645 feet. They are all connected together at the base and a lead is brought in to the instruments. They are all thoroughly insulated from the pole, the house and the ground and are unconnected at the top. Provision is made also for swinging up any kind of an aerial besides. The lead wire goes in at the rear of the building.

The guy wires themselves, however, form such a good aerial as to make another unnecessary. With these guy wires and the use of 2½ amperes, we have been able to send to Catalina, 50 miles away, and San Diego, 100 miles away. In receiving we have heard all of the San Francisco stations at night, 365 miles away. We have also heard the warships in San Francisco Bay.

We have used a 166-watt transformer and a kilowatt transformer at this station. We used a Collins 2,000-ohm telephone and a very sensitive Bell telephone receiver of 75 ohms resistance. The detectors used were carborundum, silicon and iron pyrites. Our best work was done with iron pyrites.

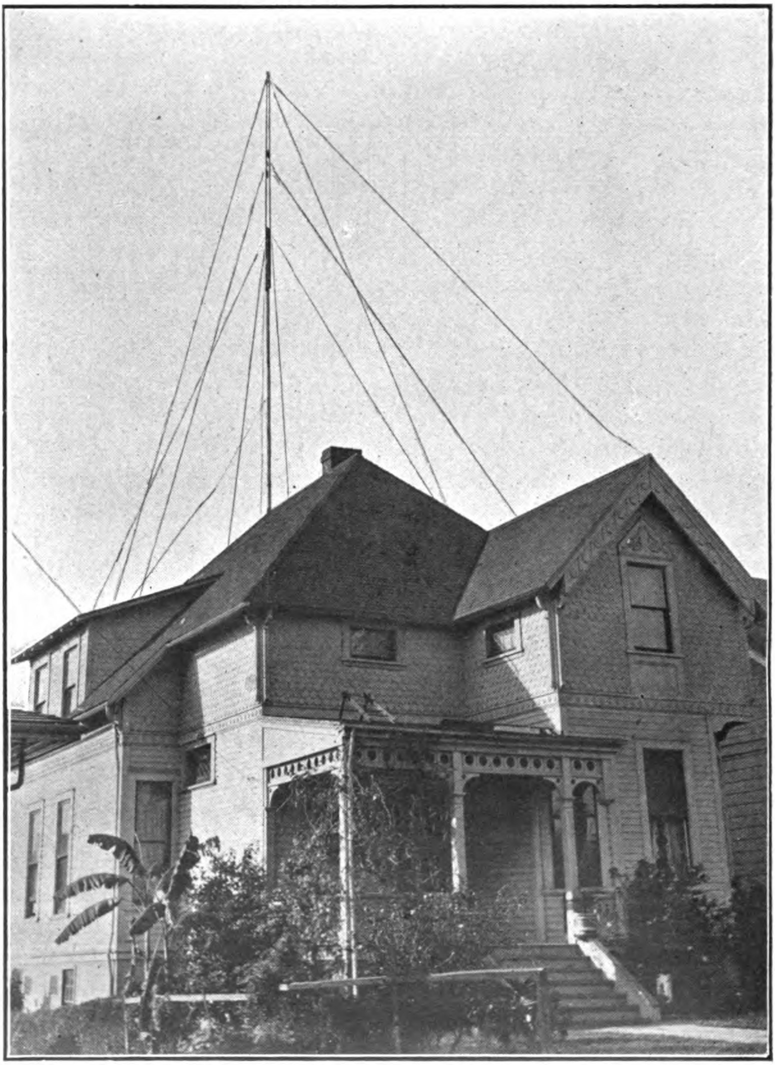


Plate XIII. Photograph of the aerial on the author's residence. Guy wires used as an aerial.

Chapter VIII.

NATURE OF ELECTRICITY.

1. **Energy.**—Electricity is a form of energy, and since all forms of energy are forms of matter in motion, we are justified in saying that electricity must be some form of moving matter.

The hand in motion is one kind of energy; the air in motion, water in motion, and a bullet in motion are forms of energy.

All forms of energy with which we are thoroughly acquainted have just two factors, mass and motion, nothing else. In the kinds mentioned above, the energy is conveyed from one place to another by the mass moving bodily from one place to another, where it delivers up its motion to whatever it comes in contact with, and in the proportion that it gives its motion to some other form of matter it must lose motion. This is one way of transmitting motion from one place to another.

2. **Waves.**—In the ocean the wind blows upon the surface of the water hundreds of miles out at sea. The water is depressed under the pressure of the moving air. When the pressure of the wind is relaxed, the water is pressed upward by the pressure of the higher water around it, but, instead of coming to rest, it shoots upward beyond the level of the surface of the still water. This is due to the fact that when once in motion it must keep on moving until something takes its motion away from it. Consequently a hollow and a crest are formed. The water in the crest now falls and the water in the trough is pressed upward as before, thus setting up a vibratory motion in the water. While this is going on, however, a wave is sent out through the water and a succession of crests and hollows is formed.

Now while the water simply moves up and down, the wave motion goes forward over the surface of the water for hundreds of miles. If the wind keeps blowing, the waves will keep on coming and a ship hundreds of miles from the storm will be raised and lowered by the waves running under it.

This is another way of transmitting motion. These are called transverse waves. The wind is a form of moving matter which we may call wind energy. This moving air sets the water to moving up and down. We will call this water energy. This vibrating water sets up a wave motion in the water and the wave travels, but the water merely rises up and down.

This wave is a form of matter in motion also, but it is not the matter that travels. The motion is given by one set of particles vibrating up and down to other particles, which are caused to vibrate up and down and the motion is thus transmitted long distances where the water can deliver it to some other kind of matter.

A wave motor, for instance, consisting of a float which is caused to work machinery by its rise and fall can compress air. This compressed air can be used to run a dynamo, etc. Now through all this we have merely changes of motion from one kind of matter to another kind of matter, and it is the motion that is transmitted.

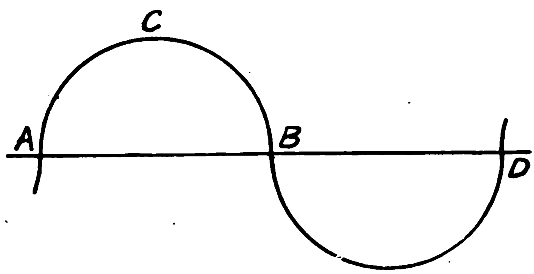


Fig. 60. Sine curve.

Fig. 60 is an illustration of this. *AD* is called a wave length and *AB* is half a wave length. *A*, *B* and *D* are called nodes in the wave. *C* is the crest of the wave and the lowest part of the wave is the trough of the wave. The distance from the crest of the wave to the trough of the wave measured perpendicular to *AD* is the amplitude of the wave. The number of complete waves formed per second is called its frequency.

If C falls to the trough and back again in one second, the wave has a frequency of a second and one wave is formed per second. If C makes two swings per second, two waves will be formed in a second. If three oscillations are executed, three wave lengths will be formed in a second, and the wave will have a frequency of three per second. The waves thus become shorter as the frequency grows larger.

3. **Light.**—Light comes to us from the sun and the stars. For a long time the nature of light was not known. Newton thought it to be a stream of corpuscles or little bodies shot out in all directions from the sun, but later it was shown to be due to waves like the waves in the ocean. This was proved to be so, and hence the motion going on in the sun is not brought to us by a stream of bullets, but by a wave which is set up in the sun by some vibrating form of matter. The only thing that can set up waves like those in the water is some form of matter that is vibrating back and forth. In order to have waves there must be something in which to set up the wave.

4. **Ether.**—Therefore men have concluded that all space is filled with a form of matter to which the name of ether is given.

This ether is made up of very fine particles so minute that it is useless to write down the figures which express their size. These particles have a very minute mass and they are vibrating with exceeding swiftness. Thus the earth, the sun and the stars are immersed in an ocean of matter through which they are all moving.

There is no such thing as matter without motion. As you sit in your chair reading you seem to be sitting still and the room about you seems to be still, but you are deceived. The particles of the body, of the wood and of everything about you are vibrating swiftly.

5. **Molecules and Atoms.**—These little particles are called molecules, and their motion of vibration is called heat. Thus heat is a form of energy, and it consists of little bodies of matter in motion. These molecules are very minute, but they

are in turn formed by a collection of still smaller bodies called atoms. The atoms were supposed to be the smallest particles of matter that could exist alone, when they were first discovered. The word atom means uncut, indivisible, and that name was given to them because, at that time, no finer form of matter was known and the chemists of that time could not divide them into finer forms. Until recently man was not able to show that the atom is divisible.

6. Corpuscles or Electrons.—However, J. J. Thomson and others have shown that electricity is made of little particles of matter, and these little particles have a mass that is somewhere near $^1/_{2000}$ the mass of the hydrogen atom. It was by means of the phenomena presented by radium, the X-ray and Crooke's tubes that they were able to do this. These little bodies are called corpuscles or electrons. J. J. Thomson supposes these corpuscles to be little bodies that carry negative charges of electricity.

It is much simpler to call these little corpuscles electricity than to call them bodies carrying electricity, because the one is just as probable as the other; since electricity in its final analysis has to come down to some form of matter in motion, we might just as well call these corpuscles electricity, until it is shown that electricity is some still finer form of matter. The corpuscles themselves are supposed to be made up of whorls of ether particles. Certain particles of the ether are grouped together and move together in a whorl, thus rarefying the ether at that point. Then if the atom is made of the corpuscles, ordinary coarse matter is a rarefication in the ether and the ether is very dense, although the particles of which it is formed are very minute, having exceedingly small mass.

On account of the fact that electricity can be produced from all forms of matter by friction, it was early recognized that electricity is present in all forms of matter. The phenomena of the Crooke's tubes has shown that radiant energy consists of a stream of these corpuscles, and, from this and other phenomena, it has been shown that these little bodies, constituting the negative electricity, come from the atom. It is thus shown that the atoms are at least made up of corpuscles as one of their constituent factors.

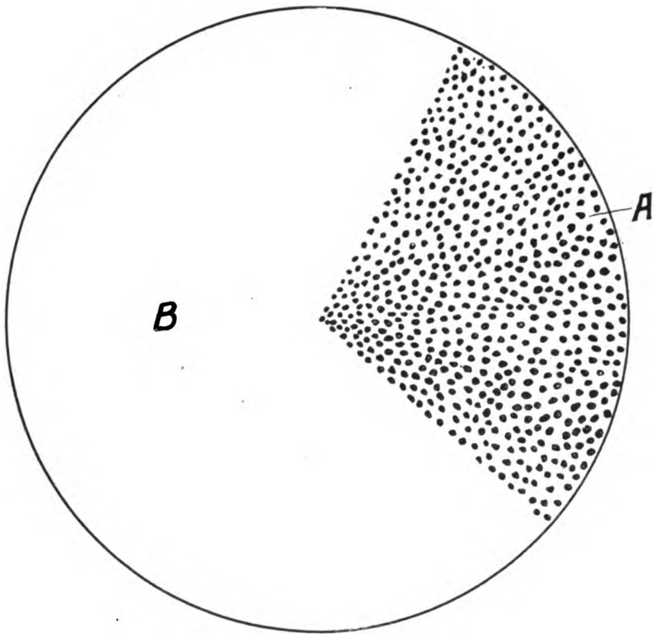


Fig. 61. Relative size of the atom and the corpuscles.

In *Fig. 61* let *B* represent a hydrogen atom. These atoms are so minute that it takes trillions of them placed side by side to make a line an inch long. If this represents one atom, then we have it enormously magnified. Suppose little dots *A* to be corpuscles. If the whole circle were filled with these dots as thickly as they exist at *A*, then there would be 2,000 of them in the circle. The oxygen atom would have sixteen times as many and other atoms of the elements as many more, depending upon their atomic weights.

Whenever electricity is generated, these corpuscles are torn loose from the atoms and either collected on insulating surfaces or sent streaming through a conductor; as soon as they lose the motion communicated to them by the generating machine or battery, they return again to the atom and cease to manifest themselves to us.

7. **Ether Waves.**—Three kind of waves are known to exist in that great ocean of matter, the ether; and these waves are set up by any source of energy such as the sun and the stars. What is it vibrating in the sun that causes these waves? They all travel with the same speed, 186,500 miles per second, or 300,000 kilometers per second.

The waves that affect the eye are called light waves. The wave length of light has been measured and has been found to range from .000076 of a centimeter for the extreme red to .000038 of a centimeter for the extreme violet.

The heat waves affect all parts of the body, causing the molecules to vibrate more rapidly. This causes the nerves to vibrate and we have a sensation which we call heat. The longest heat waves measured are .006 centimeters long. Heat waves are thus found below .000038 centimeters and not above .006 centimeters long. When the waves become longer than .006 they cease to deliver up their motion to the molecules and thus cease to be heat waves and become what is known as electromagnetic waves.

These last kind of waves range from .3 of a centimeter long up to many miles long. The longer the wave, the less ordinary matter interferes with it. All conductors, however, interfere with these long waves. Hertz showed, by a series of experiments, that light waves, heat waves and electromagnetic waves, are the same thing, differing only in wave length, and Maxwell proved the same thing mathematically.

The existence of free corpuscles in the sun has lately been demonstrated at the solar observatory on Mt. Wilson, near Los Angeles, Cal.

Dr. George Ellery Hale, in a lecture delivered at Blanchard Hall, before the Academy of Sciences, in Los Angeles, showed photographs of sun spots in both the northern and southern hemispheres of the sun. These pictures showed clearly that the sun spots are cyclonic storms in the sun's atmosphere. The storms rotated one way south of the equator and the opposite way north of the equator.

By means of the spectroscope it was also shown at the same observatory that strong magnetic fields exist in the center of these sun spots. Now the only thing that can set up magnetic fields are corpuscles moving in the same direction. Hence, Dr. Hale concluded that free corpuscles exist in the atmosphere of the sun, and when sun spots are formed, they are whorled about with the rest of the matter constituting the atmosphere of the sun.

The sun is so hot that these corpuscles can exist there in a free state. They have too much motion to allow them either to stay in the atoms or to group together to form new atoms.

By putting two and two together, it is safe to form the conclusion that these waves in the ether are caused solely by the motion of these corpuscles of electricity.

If the corpuscle moves slowly or oscillates slowly, it forms the electromagnetic wave; if it oscillates rapidly enough, it forms the heat wave; and if it oscillates still more rapidly, it produces the light wave.

A corpuscle oscillating back and forth in an aerial is moving comparatively slow, and hence it sets up an electromagnetic wave in the ether. If it were caused to oscillate much more rapidly, the wire of the aerial would become hot and heat waves would result; if it were caused to oscillate at a very high speed, the wire would become white hot and light waves would be emitted.

Thus when ordinary molecular matter is heated sufficiently, the corpuscles in the atoms are made to vibrate more violently and they thus set up waves in the ether.

If the rate of vibration is low, they produce electromagnetic waves; if still higher, heat waves; and if still higher, light waves.

8. Resistance.—By experiment it is found that some substances conduct electricity easily and others do not. Since the electric current is a stream of corpuscles, we can imagine that the atoms and molecules of a conductor obstruct their passage through the wire. They stand in their way, and the corpuscles knock against them and have to go around them in their passage through. This is called the ohmic resistance of the wire and it is usually designated by *R*.

9. Force.—All forms of matter in motion can exert pressure when they strike other forms of matter. This pressure is called a force. Force, then, can be defined as a pressure exerted by moving matter.

All forces, the nature of which we know, are due to pressure exerted by matter in motion. The wind can exert a force. Falling or flowing water can exert a force. Steam, composed of molecules of water vibrating very rapidly, can exert a terrific pressure, or force. All these are examples of known forces.

Gravitation, cohesion and adhesion are examples of forces, the nature of which are totally unknown to us. They are assumed to be attractions. Nobody has ever proved this, however. Newton assumed that gravitation was due to attraction and everybody since that time has assumed it, but Newton did not prove it, nor has anybody since Newton's time proved it.

Since all known forces are due to pressures, it is quite safe to assume that gravitation, cohesion and adhesion are also due to motions in the ether, whereby bodies made of corpuscles, atoms and molecules are pressed together by virtue of their interference with the vibrating ether.

10. Voltage.—Electricity in motion can exert a pressure. This pressure is called its voltage, or its electromotive force. It is usually represented by *E*. A current flowing through a wire, then, exerts a pressure. It also requires a pressure exerted by something to make a current flow in a wire. In order to understand this, we must know what is taking place in the ether when a current is flowing in a wire.

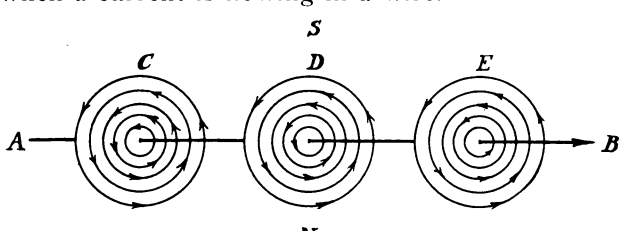


Fig. 62. Lines of force around a wire carrying a current.

Although electromagnetic waves can be set up in the ether, corpuscles of electricity, by themselves, have no power of making their way through it. The ether seems to be an absolutely non-conductor of electricity; in other words, the ether offers an immense resistance to the movement of corpuscles through it, but when the corpuscles are grouped into atoms or associated with atoms of certain substances, they seem to be able to move then with very much less resistance.

Silver is the best conductor known, and we can imagine that silver in some unknown way enables the electricity to move through the ether with but very little resistance.

11. Lines of Force.—How or why the ether offers such resistance is not known.

If a cardboard be placed around a wire, and a current of electricity be sent through the wire, iron filings sprinkled on the cardboard will arrange themselves in concentric circles. These circles are called lines of force. In *Fig. 62*, let *AB* be a wire and let a current pass through it in the direction of the arrow; then these lines of force shown at *C*, *D* and *E* will arise around the wire.

It is the moving corpuscle that sets them up. The corpuscle, in a way not known, being resisted by the ether, sets up a strain or drag in it in much the same way that a stone, when thrown in the water, drags the surface of the water down with it. As the stone goes on, the surface bounds back, springing above the surrounding surface in its backward motion. The water then oscillates and waves are produced. Concentric rings or waves are formed.

The corpuscle in the same manner forms concentric rings as it plunges through the ether. The rings begin at the corpuscle and move outward perpendicular to the direction in which the corpuscle is moving.

By Ampere's rule, the lines of force circulate in the direction of the arrows. If the current be reversed, the lines of force flow in the opposite direction. If the wire *AB* be bent up out of the paper to form a coil, then a north pole is developed at *N* and a south pole at *S*. If the wire was bent down into the paper, then the north pole would be at *S* and the south pole at *N*, the north pole always being in the direction in which the lines of force leave the inside of the coil and the south pole in the direction from which the lines of force enter the coil.

On this account two wires side by side, carrying currents of electricity in the same direction, attract one another, while two wires carrying currents in opposite directions repel one another. This can readily be seen from *Fig. 63*. If *AB* and *CD* are carrying currents in the same direction, then, at any point *E* where the lines meet, they coalesce and go around both wires as though they were one wire, as shown at *E* in *Fig. 64*.

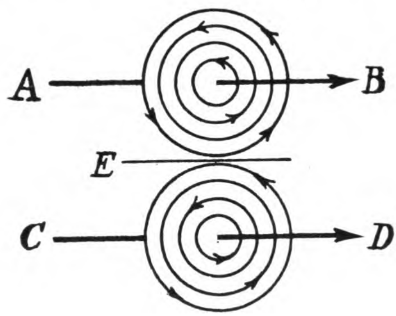


Fig. 63. Lines of force around two wires carrying current in the same direction.

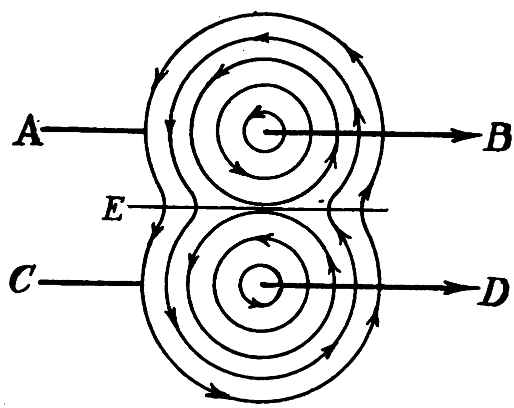


Fig. 64. Lines of force coalesce around wires carrying current in the same direction, and hence attraction occurs.

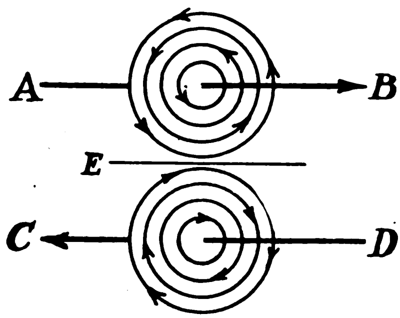


Fig. 65. Lines of force around wires carrying current in opposite directions, showing opposition and hence repulsion.

But if the current is going in opposite directions, as in *Fig. 65*, then they cannot coalesce and go around both wires, as they oppose one another. Hence the wires repel one another.

If the current is a direct, steady current, like that furnished by a storage battery, the lines of force stand still after the current is established. If the rate of flow of the current is changing, then the lines move. If the current is rising, the lines of force move outward away from the wire; but if the current is falling, the lines move toward the wire.

By experiment it is known that these lines of force set up a pressure in any wire that they cut. The lines must be moving in order to set up this pressure. If the ends of the wire be connected when it is being cut by these moving lines of force, then a current of electricity flows in the wire.

If the lines of force stand still and a conductor be moved so as to cut the lines of force, perpendicular to the direction of the wire, then a pressure is set up in the wire, and, if the ends be connected, a current flows in the wire.

Here again these lines of force consist of matter in motion. In this case it is a wave motion, however.

If iron filings be sprinkled on a piece of paper placed over a permanent steel magnet, these lines of force can also be observed. A piece of steel becomes a magnet when its molecules are arranged regularly by stroking it with another permanent magnet or by passing a current of electricity around it.

By a simple series of experiments, this can be shown to be due to an arrangement of the molecules of the steel. If the iron be soft and pure, the molecules will not stay arranged, and then the iron will be magnetic only when the current is flowing around it.

This latter is called an electromagnet. From this it follows that the molecules must be little magnets with poles, and, if this is the case, then corpuscles of electricity must be circulating around the molecules in the same direction in order to produce poles in them.

If wires are moved so as to cut these lines of force perpendicularly, then pressures will be set up in the wires. Magnets develop two poles, a north and a south pole, and it is well known that like poles repel one another while unlike poles attract one another.

The lines of force, however, repel one another. If they are flowing in the same direction, then they coalesce into one line and their sources are attracted, but if they are flowing in opposite directions, they will not coalesce and their sources repel one another.

In *Fig. 66*, for example, the lines flow from the north pole through the air to the south pole and back to the north pole from the south pole through the iron. If two poles be approached, they will either repel one another or attract one another.

If a north and a south pole be approached as in *Fig. 65*, the lines of force at *E* coalesce, since they are running in the same direction as they meet; but if two south poles be brought together, as in *Fig. 67*, the lines of force are running in opposite directions when they meet, and hence they oppose one another and repel.

12. **Amperes.**—The rate of flow of the current is called its amperage. It is usually represented by *I*. A current of electricity from a storage battery is called a steady direct current, because it has an even continuous rate of flow. A current of electricity from a dynamo is an intermittent direct current because the rate of flow is not always the same. If the dynamo has a frequency of 60 cycles per second, the

current rises from zero to a maximum and falls from a maximum to zero 120 times per second, but always in the same direction.

The direct current of a dynamo is a rectified alternating current. The current is rectified by the comutator. If slip rings are used instead of a comutator, then the current will be alternating. If the machine has a frequency of 60 cycles, there will be 120 alternations per second, and the current will rush first one way through the wire with great rapidity and then back again.

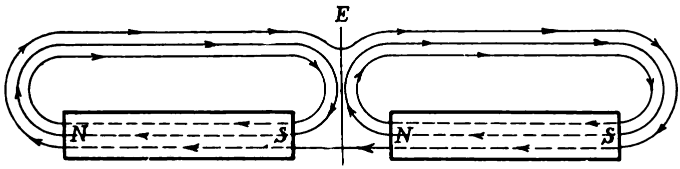


Fig. 66. Diagram showing lines of force around north and south poles of a magnet. Lines coalesce, and hence magnets attract.

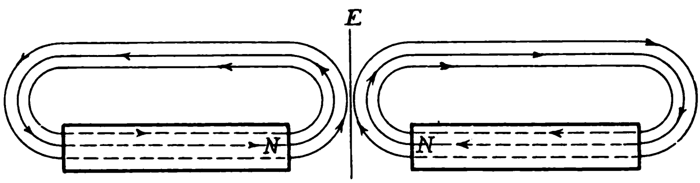


Fig. 67. Diagram of lines of force around two north poles, showing opposition and repulsion.

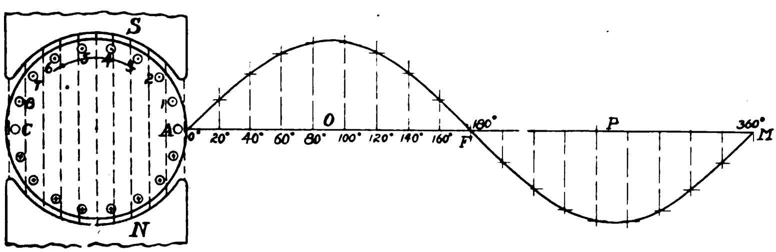


Fig. 68. Diagram of instantaneous values of current and voltage in an alternator.

13. The Alternator.—Let *Fig. 68* represent an alternator, in which *N* and *S* are the north and south poles of the field.

Let *ABC* be an armature revolving between the poles. Let the little circles represent cross sections of wires cutting across the lines of force.

If the armature be rotating in the direction of the arrow, the value of the current and pressure at *A* is zero, and at *1* it is a little greater, at *2* a little larger still, and at *3* still greater, while a little beyond *4* it is at a maximum. In the same manner it falls to zero on the other side. The current reverses at *C* and rises from zero to a maximum in the opposite direction.

If we lay out a line *AFM* equal in length to the circle and divide it into degrees, there will be 360 degrees in this line, 180 at *F*, one-half of the line; 90 degrees at *O*, one-quarter of the line; and 270 degrees at *P*, three-quarters of the line. Through the wires *1*, *2*, *3*, *4*, draw lines parallel to the line *AFM*. Lay off the points *20*, *40*, *60* and *80*, 20 degrees apart on the line *AF*. Erect perpendiculars at these points to the line *AF*. The points in which the parallel lines from *1*, *2*, *3*, *4*, and the perpendicular lines *20*, *40*, *60* and *80* cut each other respectively, represent the instantaneous value of the pressure and current developed in the wire at that point, by its rate of cutting the lines of force.

14. Sine Curve.—Draw a smooth curve connecting these points. Construct the balance of the curve in the same manner. This curve represents the rise and fall of the alternating current and its reversal in one revolution of the armature. This is called a sine curve.

From this it can be seen that the current has not the same value all of the time in the circuit, because at *A* the wire is running parallel to the lines of force and the pressure and current are zero. As it rotates it cuts across the lines, hence at *1* it is greater than at *A*. At *4* it is cutting the lines perpendicularly and here it has its greatest value, etc.

15. Rectified Curve.—If this current be rectified, then the curve is like *Fig. 69*. The lower part of the curve of *Fig. 69* is then in the same direction as the upper part of the curve, but the current rises and falls with the same frequency. Hence the corpuscles are not at the same density throughout the

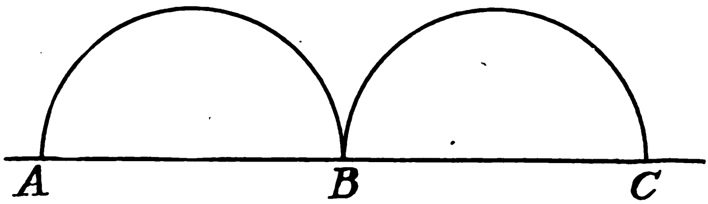


Fig. 69. Rectified sine wave.

wire. The alternating current is used largely in wireless telegraphy, while the direct is used in wireless telephony.

16. Origin of Pressure or Voltage.—When the conductors in *Fig. 68* are rotated across the lines of force, these lines resist the motion, due to the fact that the lines resist the motion of the corpuscles of which the atoms of wire are composed. The lines then drag the corpuscles loose from the atoms and press them along in the conductor.

As they are continually pressing these corpuscles along, by dragging more of them loose and pressing them along, it is the motion of the wire across the lines of force that produces the pressure or voltage of the machine.

The rate of flow of the corpuscles under this pressure is the amperage of the current, and the resistance that the wires offer to the moving corpuscles is the resistance.

In the alternating current there are other resistances besides that due to the ohmic resistance of the wire. Every alternating circuit has what is known as capacity and inductance.

In order to understand inductance, it is necessary to know something about what is known as inertia of matter.

17. Inertia.—Inertia is a property of all matter so far as we know. By inertia is meant that property of matter whereby it tends or persists in remaining in a condition of rest or motion. By virtue of this property, all matter resists being disturbed, and when once disturbed it persists in remaining in its new state.

To illustrate: A heavy wagon resting on a smooth road requires the expenditure of considerable energy to start it, but when started it can be kept moving easily. The question of weight is eliminated here. It is the mass of the wagon that we have to deal with and that mass resists being moved. The larger the mass, the more force it will require to start it. After it is once started, it does not require much force to keep it moving. When once moving it requires as much force to stop it as was exerted to start it.

The cause of inertia is not known, but it may be due to the resistance that the ether offers to a change of state in matter. That is, the ether offers resistance to any change in rate of motion or a change from a state of rest to a state of motion.

The lines of force or the strains set up in the ether by the corpuscles are due to the resistance which the ether offers to the motion of the corpuscles through it, and it is this resistance which constitutes the inertia of the electric current. It is only when the current is increasing or decreasing that this resistance is manifested.

18. Inductance.—This resistance is called inductance, and it is a constant. It is defined as that coefficient by which the time rate of change of the current must be multiplied in order to produce the back electromotive force of self induction. A steady direct current has no inductance. Inductance is present only when lines of force are rising or falling.

If *CDB* is the cross section of a wire in *Fig. 70*, and the concentric circles represent lines of force, due to a single corpuscle in the center of the wire, then these lines of force cut the wire *DBC* itself, and in doing so set up a pressure and a current in opposition to the corpuscle. This back pressure is known as the electromotive force of self induction.

If *A* is a second wire near the wire *DBC*, then the lines of force, due to a current moving down into the page, rise out and cut the wire *A*. When they do this, they tear loose corpuscles in *A* and set them to flowing up from the paper in the opposite direction to those in the first wire.

This is known as induction and the interaction between these wires due to the current, induced in *A*, setting up lines of force, swelling out from *A*, is known as mutual induction.

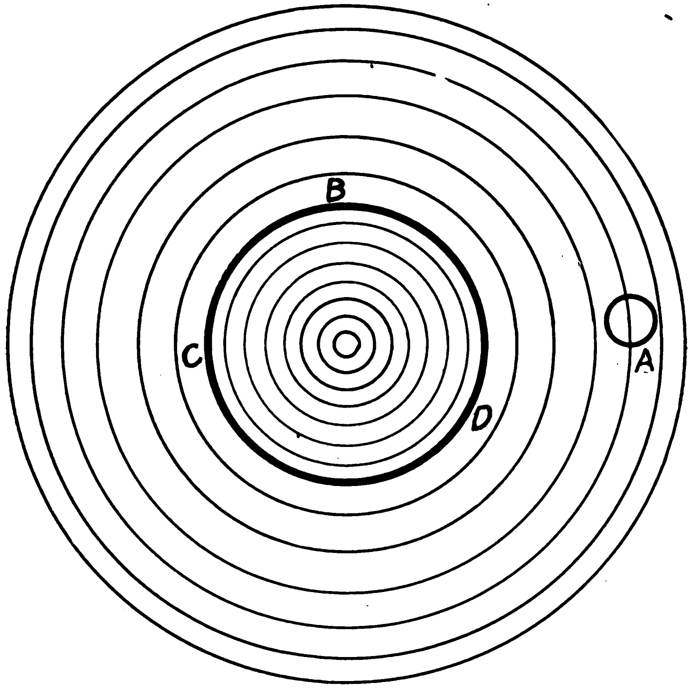


Fig. 70

These wires will then repel one another and their fields will oppose one another. If *CDB* has a current in it distributed evenly throughout its cross section, then each corpuscle sets up lines of force.

Since these corpuscles are all moving in the same direction, they attract one another and their lines of force coalesce more or less, as shown in *Figs. 63* and *64*. They thus assist one another, and their combined lines of force, in cutting the wire *CDB*, set up in it a back pressure parallel to the back pressure in *A* and in the same direction. This back pressure is called the electromotive force of self induction. The inductance of the wire is denoted by *L*. This *L* is a constant in any given fixed circuit, but the back pressure or E.M.F. of self induction depends upon the time rate of change of the current. If the current is changing rapidly, the back E.M.F. is stronger.

By referring to *Fig. 68*, it will be seen that the value of the current and pressure is changing rapidly at *A*. The current and pressure are zero here and as the wire rotates the value changes very quickly from zero to some value. As the wire rotates to position *2*, there is a rapid change in the value of the current, but less of a change than took place in its movement from zero to *1*. In moving from *3* to *4*, the current has just about reached its full value and hence the change in the value of the current is small. Hence the inductance is great at *A* and small at *4*, while the current is small at *1* and the E.M.F. of self induction is large. From this it is easily seen

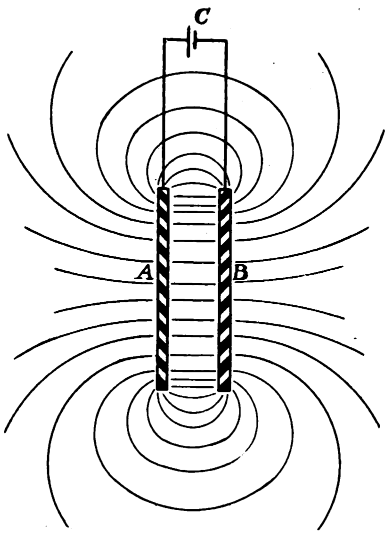


Fig. 71. Lines of strain around a condenser.

that the inductance and the current of the dynamo are 90 degrees apart, for when one is zero, the other is at a maximum. The inductance thus leads the current by 90 degrees.

19. Capacity.—If two conducting plates be put near one another in air and each one is connected to a battery as shown in *Fig. 71*, the plates become charged with electricity, and lines of force or strains are set up in the ether. If *A* and *B* are two metal plates and *C* is a battery, lines of force spring across from *A* to *B* between the plates, and they also proceed from *A* to *B* through the air around the ends of *A* and *B* as shown in the figure.

The air is an insulator and it is called a dielectric. The corpuscles are vibrating back and forth over the surface of the plates or in the air next to the plates and these lines of strain are set up. As the capacity is charged, the lines of force rise, and when it is discharged they fall towards the plates. These may be called electrostatic lines of force to distinguish them from the electromagnetic lines of force, and the space about the capacity is called an electrostatic field of force.

When a capacity is put in series with a source of alternating current, the current surges into and out of the capacity as it alternates, and thus the current practically flows through the capacity, although it does not actually go through the dielectric. A very weak current, however, penetrates the dielectric, because no dielectric is a perfect insulator. The higher the voltage of the charging current, the more the current goes through, and in case of high voltages the leak through the dielectric may be considerable.

When a capacity is charged by the direct current, the pressure of the charging current is at a maximum when the charg-

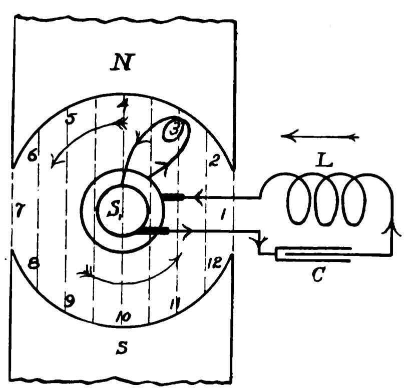


Fig. 72. Action of an alternator with an inductive and capacity load.

ing begins, and the back pressure of the capacity is then zero. As the capacity charges, its back pressure rises until it is equal to that of the charging current.

20. Capacity Reaction.—When the alternating current is charging a capacity, the action is somewhat different. In *Fig. 72*, let *S* and *V* be two slip rings upon which the coil *3* terminates. Let lines of force stream across from *N* to *S*, *N* and *S* being the north and south pole of the field of an alternator. Let *B* and *E* be brushes connecting the slip rings to an external circuit, containing the capacity *C* and the inductance *L*. When the coil *C* is at *1*, the pressure, current and inductance pressure of the machine are all zero.

As the coil moves from *1* to *2*, the current begins to flow, but it is weak. Its rate of change is large, however, and hence the inductance pressure is large, since its value depends upon the rate of change of current. The pressure of the machine is small. The condenser begins to charge.

As the coil rotates to 90 degrees, the current and voltage of the machine rise to a maximum, but since the back pressure of the capacity also rises, the current, after the coil has rotated a certain distance, reaches its highest value before reaching 90 degrees. This highest value is reached when the back pressure of the condenser reaches a value such as to oppose any increase in the current due to the pressure of the machine.

After the current reaches a maximum, it begins to decline. The pressure of the machine rises and also the opposing pressure of the capacity rises, the current decreasing all of the time, until 90 degrees is reached, where the pressure of the machine and capacity are at a maximum. The pressure of the capacity here is exactly equal to the pressure of the alternator and the current of the alternator is zero.

The inductance pressure also rose and fell with the rate of change of the current. Between *1* and *2* the inductance pressure was large, and it opposed the pressure of the alternator and acted with the pressure of the capacity. When the current reached a maximum, the inductance pressure became zero. As the current declined in value with the rotation of the coil toward 90 degrees, the pressure of the inductance again appeared, its value depending upon the rate of decay of the current, but in this case this pressure is reversed and it is exerted against the pressure of the capacity and with the pressure of the charging current.

The current ceases to flow at 90 degrees, since the capacity pressure and the pressure of the alternator are just equal, and the inductance pressure at this point is zero.

If an inductance *L* be placed in the external circuit, it can be adjusted so that its pressure offsets the value of the capacity back pressure on the decaying charging current, because the pressure due to the inductance assists the pressure of the machine. This prevents the capacity from charging on the rising current and allows it to charge strongly on the falling current. When this is done, resonance is secured.

From *4* to *7* the pressure of the alternator falls and the condenser begins to discharge. Its rate of change of discharge is high at first and hence the back pressure of inductance of the discharge current is large. Hence the back E.M.F. of inductance from *4* to *5* is large. The charging of the condenser is in the direction of the arrows. But the condenser discharge is in the reverse direction.

The pressure of the machine is also large, and this pressure and the back pressure of inductance check the discharge of the condenser. As the coil approaches *7*, the pressure of the machine drops rapidly. The current discharge reaches a maximum somewhere between *4* and *7*, when the pressure from the condenser has such a value as to prevent the pressure of the alternator and its inductance pressure from increasing the current. Then the discharge current of the condenser begins to decline. Hence the inductance pressure again rises, but this time acting with the pressure of the capacity and against that of the alternator. The exterior inductance *L* also acts in the same manner.

But here the discharge current is rushing into the other side of the condenser, and this inductance *L* is just great enough to offset the back pressure of the other side of the now charging condenser, and hence the condenser charges freely.

As *7* is reached the current from the machine is set up in the direction opposite to the arrows and assists the capacity discharge into its other side.

21. Resonance.—The same operation takes place from *7* to *12*, but in the reverse direction. The current thus flows from one side of the condenser to the other, back and forth through the machine, and if the capacity and inductance *L* are adjusted to the right values so that the pressure of *L* can just overcome the capacity pressure when acting against it, resonance is secured and a maximum result is obtained.

It is thus seen that at the beginning of charge and discharge, the current is checked by the inductance pressure until the current reaches a maximum, but at the maximum the inductance pressure, due to a falling current, assists the charging pressure and the capacity charges rapidly and freely, provided the value of the inductance pressure is adjusted to the right amount. If the inductance pressure of *L* is too large, its value is such as to destroy the pressure of the alternator and hence the current cannot be built up to a sufficient value to charge the capacity.

A capacity large enough to load the machine properly for the work in hand is used. Then the inductance is adjusted until a resonance value is secured as detailed above.

22. Condenser.—The term capacity is a term used to designate a fixed quality of a condenser due to the size of the condenser plates, their distance apart and the dielectric constant of the insulating material. A condenser is a contrivance for holding electricity, the same as a glass is a contrivance for holding water. The condenser is made of two conducting plates placed parallel to one another and separated by an insulating material. The insulating material may be air, glass, oil, etc.

When a condenser is charged as in *Fig. 71*, electrostatic lines of force spring across from plate to plate. The number of these lines per square inch or per square centimeter depends upon the voltage of the charging current, the distance of the plates apart and the nature of the insulating substance.

The insulating substance is called a dielectric, and the quality of the dielectric whereby it conducts electrostatic lines of force is called its dielectric constant. Different dielectrics conduct electrostatic lines of force differently. If air is taken as unity, then glass will conduct the electrostatic lines of force from six to nine times as easily as air. The oils generally have a dielectric constant of two times that of air.

Pure water has eighty times and glycerine fifty-six times the conductivity of air. Electrostatic and electromagnetic lines of force are both strains in the ether due to the corpuscle of electricity, but they are also different because glass has no effect upon electromagnetic lines of force, while it has a great effect upon electrostatic lines of force. The metal plates of a condenser act only as conductors of the current, and the charge resides in the dielectric.

The capacity of a condenser then depends upon; first, the dielectric constant or inductivity of the insulating material; second, the area of the conducting plates; and third, their distance apart. The farther the plates are apart the thicker the dielectric and the greater its resistance to the flow of the lines of force; consequently, less current will flow into the condenser under a given pressure.

The quantity of electricity that a condenser will hold depends upon its capacity and the charging voltage. The ampere designates the rate of flow of the current, the same as two quarts per second might designate the rate of flow of the water in a pipe, but neither one of these give us the quantity of electricity or water that has flowed. In order to get the quantity that has passed, it is necessary to multiply by the time it has been flowing.

Thus, 2 quarts of water per second flowing in a pipe in 10 seconds, gives 10 times 2 quarts, or 20 quarts, as the quantity of water that can be caught in a pail in that time.

In the same manner the amperes or rate of flow of the electric current, multiplied by the time it is flowing, gives the quantity of electricity that can be caught in a condenser.

For instance, a rate of flow of 2 amperes per second for 10 seconds gives 20 coulombs of electricity. The coulomb is the name for the quantity of electricity the same as the quart is for water. If Q stands for coulombs, I for amperes, t for time in seconds, and E for voltage or pressure, then $It=Q=CE$, where C is the capacity of the condenser, in farads.

In order to make the matter clear, see *Fig. 73*. Let D be a glass dish, with a spout A connecting with a funnel BC. Suppose the spout A to be filled with a resisting substance, like sand for instance, that obstructs the free flow of the water.

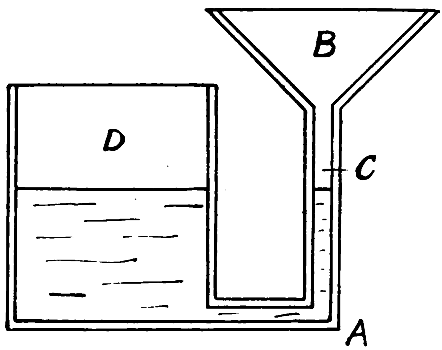


Fig. 73

Let the area of the bottom of the dish D, and the resistance in A be called the capacity of D for holding water. It is easily seen that this capacity does not mean the quantity of water that D can hold. In order to obtain the quantity of water D can hold, it is necessary to know the depth of the dish A. In order to know the quantity of water D will hold under any given pressure in BC, it is necessary to know the cross section of D, the resistance in A and the depth or pressure of the water in BC. If there is much resistance in A, the water will not rise in D as high as it stands in BC.

In this figure the area of the bottom of D and the resistance in A represent the capacity of the condenser. The resistance in A represents the resistance that the dielectric offers to the flow of the lines of force.

If BC be filled with water, the pressure exerted by the weight of the water will cause it to flow over into the dish D, and if there is no resistance in A, the water will flow into D until it is at the same height in both BC and D; but if there is a resistance in *A*, then it will exert a back pressure, and the water will not rise as high in *D* as it remains in *BC*.

If the spout *A* is increased in length, its resistance increases correspondingly, and the height to which the water will reach in *D* is proportionately less. In a condenser the same thing takes place. The pressure of the charging machine forces the current into the condenser until the back pressure of the condenser equals the charging pressure. The area of the plates and the resistance of the dielectric to the flow of the lines of force determine the quantity of electricity that will flow into the condenser, before its back pressure becomes equal to the charging pressure.

It is seen that the depth of the water represents the pressure or voltage of the current. If the depth be increased, then the quantity of water in the dish is increased. In the condenser, if the pressure is increased, the quantity of electricity in the condenser is increased. Since the electrostatic lines of force flow more easily through glass than air, a greater quantity of electricity will flow into a condenser having a glass plate for a dielectric instead of air, because the lines of force do not press back as much when glass is used.

The thing to be held in mind is that the capacity of a given condenser is a fixed quantity and that the amount of electricity a condenser will hold depends upon the voltage of the charging current. In *Fig. 73*, if the height of the water in *BC* is increased, the height of the water in *D* will be increased, although the capacity of *D* remains the same.

If the height of the water in *BC* increases until it is higher than the rim of *D*, then the water will overflow and *D* cannot be made to hold any more water. Also, if the pressure of a charging current be raised in a condenser, a point will be reached where the condenser will hold no more and the condenser will leak, sending out into the air a fine electric spray.

Suppose *D* and *BC* to be very high or deep. Then if water be poured into *BC*, a point will be reached where the glass can no longer stand the pressure and the glass will break.

If a condenser be put in oil so that it cannot leak, and if the voltage of the charging current be increased, a point will be reached where the glass can no longer stand the strain and the glass will break. The electricity resides in the dielectric and as the pressure increases, it soaks deeper and deeper into the dielectric, and when the pressure becomes great enough, it punctures the dielectric.

23. The Transformer.—The transformer or induction coil is an electric machine for the purpose of transforming electric currents from one amperage and voltage to another amperage and voltage. When the voltage is stepped up, the amperage is stepped down in the same ratio, and when the voltage is stepped down, the amperage is stepped up in the same ratio. The former is called a step-up transformer, and the latter is called a step-down transformer. The transformer is used on the alternating current and the induction coil on the direct current.

Transformers can be conveniently divided into three classes, viz.: Air core or Tesla transformers; open iron core transformers, and closed iron core transformers.

24. The Induction Coil.—The induction coil is an open iron core transformer, in which the lines of force are caused to rise and fall by means of a vibrator.

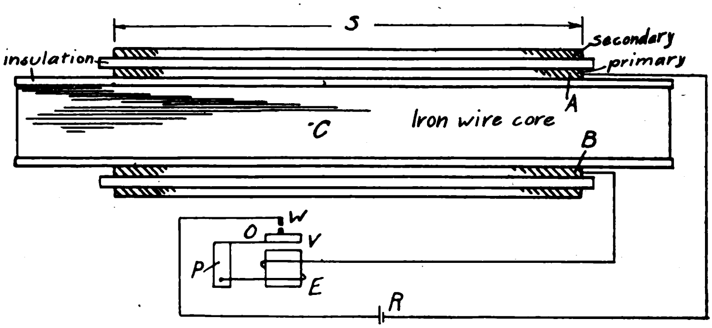


Fig. 74. Diagram of an induction coil.

Fig. 74 gives the connection to the vibrator. Many excellent works have been written on the construction and operation of induction coils, and the reader is referred to them for further information. Any of the transformer designs in this book can be altered to induction coils by using only one leg of the transformer. Wind the primary as directed in *Fig. 4*, insulate heavily with empire cloth and assemble the secondary over the primary. For wireless the core of the induction coil should be rather short and thick. The secondary should be wound in pies as directed in *Fig. 5*.

When constructed thus it is an open iron core transformer, that can be used the same as the other transformers, but it is very inefficient in its operation.

If a vibrator or Wehnelt interrupter is used and the direct current instead of the alternating, we have the induction coil. As the circuit is closed, the current builds up slowly and, consequently, the lines of force rise slowly. When these lines cut the secondary wires, they induce in them a current in the opposite direction, and these currents also set up lines of force which oppose those in the primary, as explained in *Fig. 65*. When the primary current is broken, however, the lines of force fall very rapidly, and, as they fall, they cut the secondary wires, setting up a current and pressure in the same direction as in the primary.

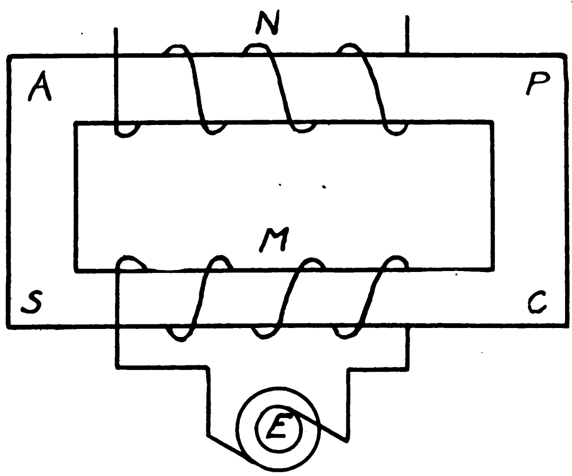


Fig. 75. Diagram of a transformer.
E, alternator; M, primary; N, secondary; APCS, closed iron circuit.

On account of the rapidity with which the lines cut the secondary wires, the voltage developed in the secondary is very high. The induction coil is a very inefficient transformer of energy and the vibrators are exceedingly troublesome, but where the alternating current cannot be obtained, its use is necessary.

25. Closed Iron Core.—The closed iron core transformer is shown in *Fig. 75*. *M* is the primary connected to the alternator *E*. *N* is the secondary and *APCS* is the iron core made up of laminated transformer iron.

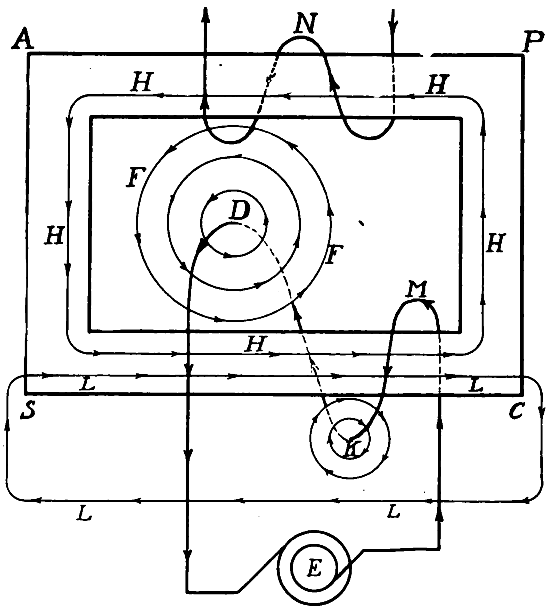


Fig. 76. Action of lines of force in a transformer with closed iron circuit.

E, alternator; M, primary; N, secondary; D, F, F, lines of force swelling out from primary; H, final path of lines of force in iron; L, leakage lines of force due to lines of force at K.

In *Fig. 76* let *E* be an alternator and let the current at any instant in the primary *M* be in the direction of the arrows. Then according to the right-hand rule the lines of force that rise from the primary wire at *D* will flow in the direction as indicated by the arrows at *F* and *K*. These lines of force form circles about the wire. The portions of the circles at *H*, near the iron, fall immediately into the iron leg *SC*. The portion of the circles designated *F*, swell outward from the wire and cannot reach the leg *SC*. Since the leg *AP* offers a path to these lines of force, they immediately collapse into the leg *AP* and then the line of force circulates around through the iron core in the direction of arrows, as shown at *H*. As these lines of force cut the secondary *N*, they set up a pressure and current in it in the opposite direction to the current in the primary *M*, as can be seen by applying the right-hand rule.

Iron is an excellent conductor of the lines of force and the air compared with iron is a very poor conductor of these lines. If the ends *AS* and *CP* were removed, the air gap at these points would offer great resistance to the passage of the lines and, consequently, many of the lines would rise up in the air, as shown at *K*, and circulate entirely through the air and the leg *SC*, as shown at *L* in the figure. The line *L* would not cut the secondary at all, and its energy would not be transformed. If the iron ends *PC* and *AC* are present, the line of force shown at *K*, instead of swelling out and following the path *L* through the air, roll over and fall into the leg *AP*, thus being compelled to cut the secondary. It does this because it finds less resistance to its flow through *AP* than it does through the air along *L*.

Not very much is to be gained by winding the primary on both legs and then putting the secondaries over the primaries. The difficulties of insulation are very much greater. The length of the leg *AS* and *PC* must be greater in order to separate the coils on each leg more fully. It requires much more wire in the secondary for the same voltage and this adds to the resistance of the secondary, which is a very important factor in wireless. For these reasons it is better to wind the primary on one leg and the secondary on the other leg.

Small commercial transformers range in efficiency from 90% to 95%, and large ones reach an efficiency of 98% to 99%. This is the case only when the resistance of the secondary is low. The resistance of the secondary in high potential transformers is large, and their efficiency falls as low as 80% to 85%.

If poor transformer iron is used, the efficiency falls as low as 50%, and in induction coils and open core transformers it falls very much lower. If the transformer is put up in a wax preparation, enameled wire can be used, thus putting on 60% more turns in the same space. The insulating property of the enamel is very high and its mechanical strength is great. The C. E. Cook Electric Company of this city handle this wire as well as transformer iron. The use of these materials will increase the efficiency of the transformer very much, on account of the lessened resistance for the same number of turns, and the decreased reluctance of good iron. The enamel stands a high degree of heat without injury. The transformation of energy is not due to the flow of the lines of force through the iron, as many suppose, but it is due to the lines of force being compelled to cut the wires of the secondary, on account of the fact that the iron offers an easy path to the lines, and they leave the air to reach the iron. In doing this they must cut the secondary wires. However, the iron offers an easy path to the lines and it does assist to that extent in the saving of energy and hence in its transformation.

26. Ratio of Turns.—The following proportions give the relations between the volts and amperes in the primary and secondary. The turns in the primary are to the turns in the secondary as the volts in the primary are to the volts in the secondary. The turns in the primary are to the turns in the secondary as the amperes in the secondary are to the amperes in the primary; or,

$$Tp : Ts :: Ep : Es, \text{ and } Tp : Ts :: Is : Ip,$$

where Tp is turns in the primary; Ts, turns in the secondary; Ip, amperes in the primary; and Is, amperes in the secondary.

The opposition that the iron offers to the flow of the lines of force is called reluctance. The reluctance increases as the length of the iron increases and it decreases as the area of the cross section of the iron increases. From this it follows that more iron must be used, if the iron is poor, like common sheet iron, in order to get a reasonably efficient transformation of energy. The iron should be greater in cross section and not in length.

27. Eddy Currents and Hysteresis.—The iron should be laminated in order to overcome the eddy currents. When a current of electricity circulates in the primary, it induces a current in the iron core parallel to it and in the opposite direction. These currents will heat the core and cause great loss of energy.

Each time the current reverses, the molecules of the iron turn end for end. In doing so they rub against one another and the friction causes heating. This is known as hysteresis. Further, the molecules do not come completely back to the neutral point and it requires expenditure of energy on the part of the lines of force to turn them back to the neutral point before turning them in the new direction. This, combined with the above, is known as hysteresis. The better the grade of iron, the more easily the molecules turn and hence the less the hysteresis loss.

28. The Air Core Transformer.—In the air core transformer the lines of force pass entirely through the air. On account of the reluctance of the air, the losses are large and the transformation of the energy is very inefficient, at ordinary frequencies. If the lines of force are caused to rise and fall with great speed, the efficiency of the transformation is thereby raised. This occurs in the case of high frequency currents. The presence of iron in high frequency current transformers cuts no figure, because the molecules of the iron do not have time to turn. Consequently the iron is like so much air or wood so far as the lines of force are concerned.

Ordinary iron becomes saturated when all the molecules are turned with their poles in the same direction. When this state is reached, it is a waste of energy to use more magnetizing current. Hence a transformer must have large enough cross section to carry the lines of force at low density.

The air core transformer does not transform the energy of the primary into an equivalent amount of energy in the secondary. A large part of it is transformed into waves in the ether. These waves are radiated and are a loss to the transformer. As the lines of force in the primary rise and fall the waves are produced.

In the case of the iron core transformer, the lines of force rise but do not fall back into the primary. They rise and rotate over into the iron through which they circulate. Thus the true oscillation is destroyed, and no waves are set up in the ether.

CHAPTER IX.

THEORY OF RADIOTELEGRAPHY.

1. The Current.—In the diagram shown in *Fig. 48*, *AKPR* is the primary circuit of the transformer, *A* is the alternator or source of alternating current, *K* is the sending key, and *R* is a water rheostat for regulating the flow of the current. The proper use of the regulating rheostat cannot be overestimated. The amateur and even the professional are very apt to assume that the distance they can send depends upon the amount of current that flows in the primary of the transformer. They think that a loud spark at S_1, and a noise that can be heard several blocks, mean powerful oscillations and great sending power. This is a great mistake.

The amount of current to allow in the primary depends entirely upon the inductance and capacity of the aerial; in fact, it is a matter of tuning. This can be determined readily by experiment. The primary turns *P* have a very low resistance, and, if it were not for the inductance of the coil *P*, which is very greatly increased by the presence of the iron core of the transformer, an immense current would flow, when the key *K* is closed and the water rheostat cut out. But owing to the presence of the iron, the reaction due to the inductance chokes back the current and but very little current flows as long as the secondary is open.

When the secondary is closed, however, a current flows; and the current that flows in the primary depends upon the resistances and reactances of the secondary. If the resistance of the secondary be low, an immense current flows in the primary, with a corresponding flow in the secondary and the transformer is burned out.

SC_1 is the secondary circuit in which C_1 is a condenser. The amount of current that flows in the secondary depends upon the capacity of this condenser. The secondary coils *S* have a high resistance, but there is a high voltage also developed in the secondary, and, if the secondary be shorted, a current flows that may prove dangerous to the transformer.

If this current is allowed to flow long, it is liable to burn out the transformer.

When the secondary is connected through *C1* it is not shorted. If *C1* is a small capacity, only a small current flows. The greater the resistance of *S*, the longer the time it takes to charge *C1*; and the greater the capacity of *C1*, the greater the rate of flow of the current. If the condenser is not put up in oil, the current oscillates back and forth through *C1* with a humming noise, with a frequency of 50 or 60 cycles per second.

The current pours into and accumulates in *C1* until its potential rises to that of the charging current. Suppose that in this case it is 10,000 volts. If *C1* is not in oil, a waste of energy occurs. The condenser fills and a spray discharges into the air all around the edges of the plates. This loss of energy can be stopped by putting the condenser in oil. The effect of this leakage is to increase the capacity of the condenser, but to its disadvantage.

If the plates of the condenser be too thin, the current also leaks through the plates, which injures the efficiency and operation of the transformer. To secure the best results, the plates should be made of heavy quartz glass and they should be immersed in oil. If the glass plates are thin, the high voltage may puncture them.

The greater the capacity of the condenser *C1*, the greater the current that flows in the secondary, and consequently in the primary. This causes the potential difference across the primary *P* to fall, and, if too large a current flows, arcing occurs in the spark gap *S1*.

C1S1C is the closed oscillation circuit, in which *S1* is the spark gap and *C* is the inductance or tuning coil.

When the condenser is charged, if *S1* is properly adjusted, a spark jumps across *S1* and oscillations take place in the closed oscillating circuit *C1S1C*.

The current rushes first into one side of the condenser and then into the other, gradually dying out. The frequency of these oscillations depends upon the relation between the capacity of the condenser and the inductance of the coil. It also depends upon the time that it takes to charge the condenser through the resistance of the secondary *S*. If this resistance be too large, no oscillations occur; hence, the lower the resistance in *S*, the better.

If too little condenser be used, no oscillations take place and an arc forms at *S1*. If too much condenser be used, the sparking distance is cut down. If too much current flows, the energy is wasted in two ways. First, an arc forms at *S1* and destroys the oscillations, and since oscillations are necessary to the formation of electromagnetic waves, this proves fatal.

This usually occurs when too little condenser is used and too much current is allowed to flow in the transformer. To remedy it, cut down the current and use more condenser. Second, if too much current is allowed to flow and enough condenser is used to handle it, the closed oscillation circuit is out of resonance with the open oscillation circuit of the aerial, and the result is poor. To remedy this, cut down the current and the condenser.

If this is not done, the spark *S1* is large and makes a great noise, but its energy is wasted in heat. The use of the right amount of current is one of the most difficult things for both the professional and amateur to learn.

In the manner here described, the amount of current used affects the tuning, and hence it becomes a factor in it. In *Fig. 48*, *IHDCEG* is called the open oscillating circuit. *G* is the ground, *H* is the anchor gap, *I* is the aerial, and *C* the tuning helix. For the complete tuning it is necessary to regulate the rheostat *R*, the capacity *C1*, the spark gap *S1* and the inductance *C*.

The frequency of the oscillations can be controlled largely by the spark gap. When the spark gap is wide open, the frequency is low, and when the gap is small, the frequency is high.

These various factors should be adjusted until the maximum result is obtained in the anchor gap *H*. The spark at *H* should be white, sharp and regular. The sound emitted by *S1* should be musical, neither ragged and harsh, nor hissing. If the spark *H* be too fat, and has too much energy in it, it is probably due to arcing and the oscillations are killed, no waves being set up in the ether under these conditions. Oscillations without arcing are necessary to the production of electromagnetic waves and anything that causes arcing prevents them. Furthermore, when arcing occurs, the system is out of tune.

The closed oscillation circuit is a persistent oscillator, but a poor radiator. The open oscillation circuit is a poor oscillator, but a good radiator of electromagnetic waves.

2. **Tuning.**—In order to produce good radiations in the open oscillating circuit, however, it is necessary for the closed oscillating circuit to be in tune with the open oscillating circuit; otherwise they interfere with one another.

The process of tuning consists in adjusting the capacity and inductance so that they offset one another. The current then flows according to Ohm's law. As has been before pointed out, the back E.M.F. of the capacity is 180 degrees from the back E.M.F. of the inductance, and hence if they are properly adjusted they offset one another. Furthermore, the condenser is charging and discharging. If everything is in resonance, the condenser discharges and charges so that the charging and discharging current act together. If the condenser attempts to charge while the oscillations are going on, the pressure of

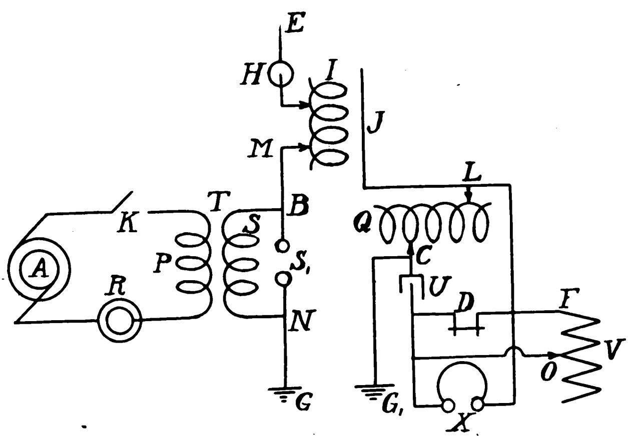


Fig. 77. Method of tuning open oscillation circuit to current used.

the charging current may be exerted against the pressure of the oscillations and the result is a decrease in both of them.

If, however, the charging current be always coming in one side of the condenser when the oscillating current is coming in, then they assist one another. This result can be brought about by adjusting the factors involved.

It is like a swing. If the swing be pushed as it is approaching, its motion is stopped, but if it be pushed just as it reaches the highest point of its swing, it is assisted instead of being retarded, and at each push it swings higher and higher.

3. Tuning the Open Oscillation Circuit.—The open oscillation circuit consists of the aerial *E*, *Fig. 77*, the anchor gap *H*, the tuning inductance *IM*, the spark gap *S1* and the ground *G*. The condenser in this system consists of the part of the system above *S1* for one plate, and the part *S1G* for the other plate, the air being the dielectric. If a transformer *T* be connected across the spark gap *S1*, the aerial and the ground charge the same as any condenser. If the spark gap *S1* is properly adjusted, a spark passes and oscillations take place in the aerial.

As the corpuscles rush back and forth, they set up waves in the ether, that radiate in all directions. In this case no condenser needs to be used in the closed oscillation circuit *SBS1N*.

The capacity of the aerial is small and an open circuit like this is not a persistent oscillator, but this arrangement can be used in order to tune the open oscillation circuit by adjusting the water rheostat *R* and the inductance *MI*, the capacity of the aerial being fixed, until a maximum result be obtained.

To the ordinary receiving set already described attach an aerial *J* long enough to be brought parallel to the inductance *IM*. Across the phones *X* shunt a potentiometer *FV*. This potentiometer should contain a slide wire resistance in series with the larger resistances of the phones. The current from the detector *D* divides between the phones and the potentiometer. If the sliding contact *O* be at *F*, the phones are shorted out and no sound is heard in them. If the point *O* be moved toward *V*, then more and more of the current is shunted through the phones.

In order to tune the open oscillating circuit, set the apparatus to going by closing the key *K*. Adjust S_1 until a spark passes. Adjust *R* until a maximum result is obtained in the phones *P*. When the sparks are passing at S_1, the aerial radiates waves. When these waves cut *J*, they set up a current in *J* which oscillates in the closed circuit *LCD*. If the point *O* be moved toward *F*, a point is reached where no sound is heard in the phones *X*. The stronger the oscillations are in *LCD*, the nearer *O* must be moved to *F* in order to have the phones *X* silent. Adjust the contacts *L* and *C* and the resistance *R* until *O* is the nearest possible to *F*. Then the maximum result is being obtained. By adjusting *R*, *L*, *C* and *O* until a maximum result is obtained, which will be when *O* is the nearest to *F*, the right current for the capacity of the aerial can be found. The right amount of current is then flowing for the capacity and inductance of the aerial.

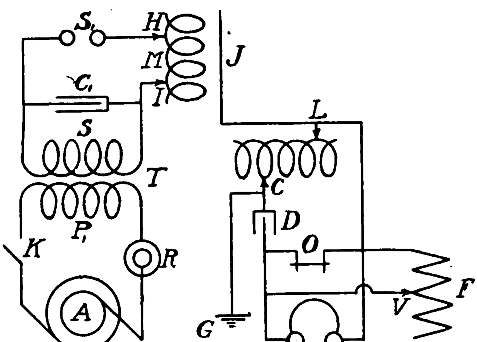


Fig. 78. Method of tuning closed oscillation circuit to open oscillation circuit.

If the oscillations be too strong and cannot be tuned out by shortening the telephones, move *J* farther and farther away from *I* until this can be accomplished. If the telephones prove to be too sensitive, replace them with a vacuum or a Crooke's tube.

These tubes can be obtained for fifty or seventy-five cents.

When everything is in resonance, the tube glows brightly. Adjust as described above until it glows its brightest.

When using the telephones it will be necessary to muffle the spark gap, or to make *JL* long enough to get farther away.

3. Tuning the Closed Oscillation Circuit.—The closed oscillation circuit can be tuned as shown in *Fig. 78*. Use the same sending helix *M1* as used in tuning the open circuit. Arrange the receiving set in the same manner as in *Fig. 77*. See that the aerial *J* is at the same distance from *M1* as in the previous experiment. Place the contacts *L* and *C* at the same point that they had in the previous circuit. Adjust *R*, *C1* and *S1* until a maximum result can be obtained in the phones as described in the previous experiment. When this result is reached, the closed circuit will have the same time period that the aerial circuit has. Couple them together as shown in *Fig. 48*, and they will work at their best, for they are in tune.

This method of tuning will not require a hot wire ammeter nor any other apparatus besides the apparatus used in sending and receiving. When this is done, the current that is running in the primary is the greatest that should be used with the aerial as tested. If it be desired to send further by using more energy, put more wire in the aerial by increasing its height or by putting up more wires in parallel.

If the tuning coil is calibrated, the wave length of the aerial can be found in this way. The calibration of the tuning coil will be described later.

The shunting of the potentiometer across the phones in order to determine the strength of the incoming signals was due to Capt. Wiseman of the U. S. Army. The relative strength of signals from different stations can be easily determined in this way. The point *O* is moved toward *F* until the phones are silent, and the nearer they can be moved the stronger the incoming signals.

4. Oscillations.—When oscillations are taking place in the aerial, corpuscles are rushing back and forth across the spark gap from the aerial to the ground, and back again from the ground to the aerial. The first discharge is strong, but each successive oscillation is weaker than the preceding, and they finally die out. These oscillations are called damped or unsustained oscillations.

Each discharge of the condenser sends out a damped oscillation. These follow one another at regular intervals. They are called a train of oscillations or jigs.

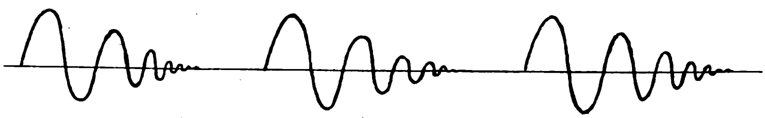


Fig. 79. Highly damped train of waves.

Fig. 79 shows a train. Each jig represents one condenser discharge. The higher the frequency, the nearer these jigs are together, and the more nearly the oscillations are like the sustained oscillations of the direct current, used in wireless telephony.

As the corpuscle rushes up the aerial it tangles with the ether in some way unknown and sets up a wave in it, which radiates out in all directions perpendicular to the direction of the movement of the corpuscle. Lines of force swell out around the conducting wire, and the corpuscles in giving motion to the ether lose motion in the exact proportion as they give it to the ether.

When they lose sufficient motion, they go back to the atoms from whence they came.

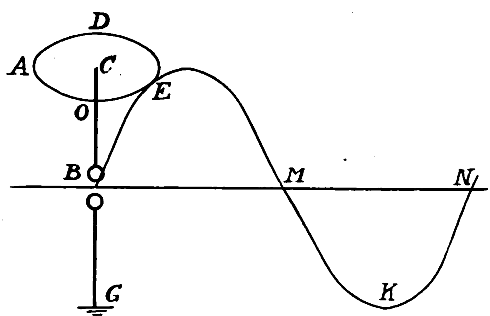


Fig. 80

5. Formation of a Wave.—The exact phenomena that takes place around an aerial is complicated. In *Fig. 80*, let *BC* be the aerial above the spark gap *B*, and *BG* the part below, the ground being a part of the aerial. When the corpuscle

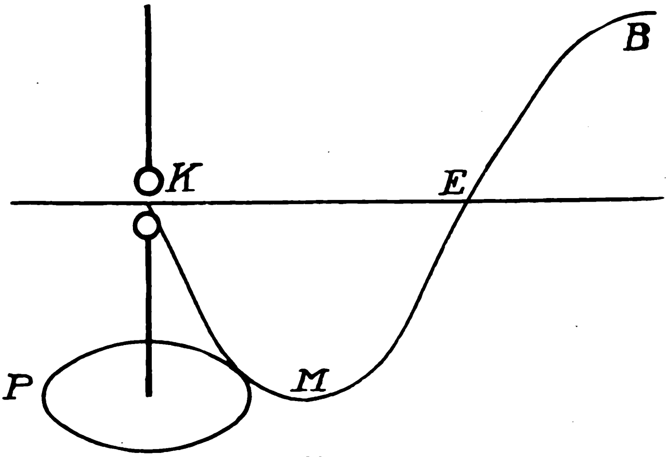


Fig. 81

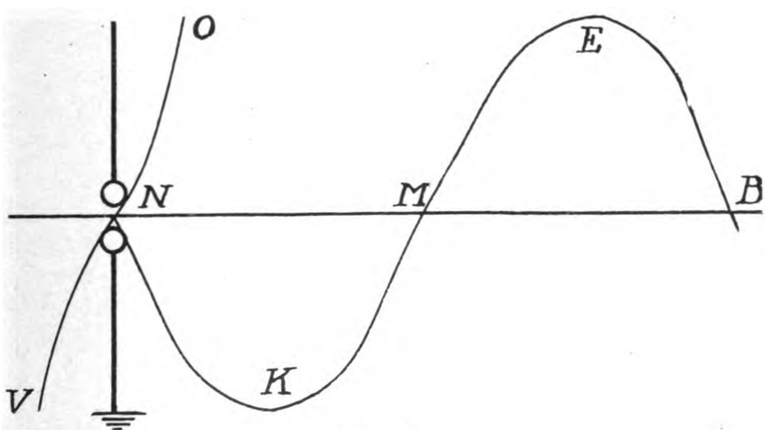


Fig. 82

rushes from *B* to *C*, it executes one-quarter of its swing, *C* being the top of the aerial. In passing from *B* to *C*, the line of force *ADE* swells out from the aerial wire as a center and the point *E* of the line of force traces the quarter wave *BE*.

Since *BC* is one-quarter of the swing of the corpuscle, it is easily seen why the aerial is one-quarter the wave length emitted by it. As the corpuscle swings back to *B*, the line of force *CDE* falls in upon the aerial, *BE* is pushed on to the position *EM*, and another quarter of the wave is formed at *BE*.

As the corpuscle rushes across the gap into the ground, the portion *MK* of the wave is formed and *BEM* is pushed on into the position *MEB*, shown in *Fig. 81*. As the corpuscle rushes back to the spark gap, the portion *KN* is formed, and in forming the portion, *KMEB* is pushed on into the position shown in *Fig. 82*, thus forming one wave.

The line of force *ADE* has its plane perpendicular to the aerial. The wave *BEMKN*, *Fig. 80*, has its plane perpendicular to *ADE*.

Thus one wave length after another is formed as the corpuscle rushes back and forth from the ground to the aerial and from the aerial to the ground.

A stationary wave *ONV* is also set upon the aerial, as shown *ONV*, *Fig. 82*.

The upper part of the wave *MEB*, *Fig. 82*, thus loops on the ground and runs along the ground. The ground is a conductor, and the free ends of a wave or a line of force always terminate upon a conducting surface. This is why the wave follows the curvature of the earth instead of rushing in a straight line off into space.

In the upper atmosphere the air is very thin. Very thin air is a good conductor of electricity and so is the ground. Many other waves are formed by the aerial and radiated in all directions. Many of them are formed like the stationary wave *ONV*, and the free ends of this wave are found in the conducting upper layer and the ground. They thus follow the curvature of the earth. Since the aerial and ground form a condenser, the rise and fall of the electrostatic lines around the spark gap *B*, as shown in *Fig. 83*, also set up trains of waves. The phenomena is very complicated.

Whenever lines of force or waves cut conductors perpendicularly, they set up currents in these conductors. The line

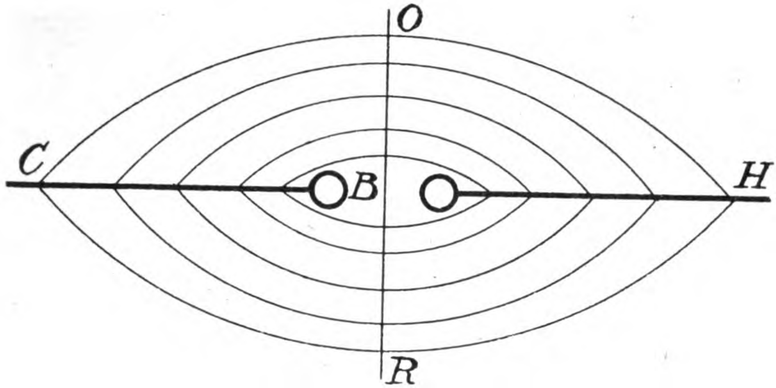


Fig. 83. Diagram of lines of stress around a spark gap.

of force or the waves are real, and, as they cut the wire, they tear loose the corpuscles from the atoms and set them to moving in the wire.

This current coming down the aerial through the detector to the ground oscillates back and forth between the aerial and the ground. This oscillation through the resistance, offered

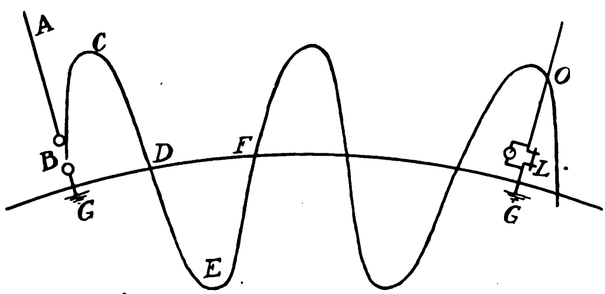


Fig. 84. Diagram of waves emitted by an aerial. BCD, the upper part of the wave only, is effective in producing current in L.

by the detector, shunts some of the current through the phones and consequently a noise is heard in the telephone.

Fig. 84 gives a graphic representation as to how the energy is transmitted from the transmitting station to the receiving station. The electricity oscillating in the receiving station is not the same electricity that oscillates in the sending station. If *B* be the spark gap of the transmitting station sending out the wave *BCDEF*, etc., and if *OLG* be the receiving aerial, then the wave cutting the receiving aerial at *O* tears loose the corpuscles at *O*, and presses them down the wire through the detector *L*, the free ends of the semi-waves looping in the ground.

6. Telegraphing to Mars.—It is very improbable that any electromagnetic waves set up by man ever get outside of our atmosphere. The conducting layer of the upper atmosphere absorbs their energy and thus prevents them from reaching any further. Whenever an electromagnetic wave cuts a conductor, it sets up a current in it, and the energy of the wave is absorbed. Its motion is given to the corpuscles of electricity, torn loose from the atoms, and in the proportion that the corpuscles are given motion, in that same proportion do the waves lose motion.

The upper layers of the atmosphere are very good conductors of electricity. The air here is in the condition of the air in a Crooke's tube. The powerful electromagnetic waves from the sun can penetrate this layer, as all of their motion is not absorbed, but the comparatively weak waves set up by man can not, and their motion is probably absorbed.

If this be true, communication by wireless with the inhabitants of Mars is impossible. Even if we were able to set up waves powerful enough to get through our atmosphere, these waves would have to meet the same conditions in the atmosphere of Mars, and, since the strength of the radiation decreases with the square of the distance, the waves would be very weak upon their arrival, and they would suffer absorption.

Referring again to *Fig. 84*, the only part of the wave *BCDF* that is effective in setting up current in *OLG* is the part *BCD*. The part *DEF* is absorbed by the ground. Since the ground is a conductor, the motion of the wave is changed into motion of corpuscles of electricity in the ground, and hence all of the wave below the ground is lost. If this wave could be rectified, it would result in a big saving; i.e., if *DEF* could be turned over and made to occupy the gap above it, it would result in all of the wave cutting *OLG* instead of only half of it.

It must be remembered that this wave shown in *Fig. 84* should be in the form of a train of jigs as shown in *Fig. 79*, the upper half of the jigs only being effective.

The wave shown in *Fig. 84* is a continuous undamped wave. This can be produced by causing the direct current to oscillate. It is then called an undamped wave.

Chapter X.

UNITS AND STATION CALCULATION.

1. **Force.**—Force is a pressure exerted by matter in motion. In many cases it is difficult to locate the motion that is the cause of the pressure, the force of gravitation being an instance.

2. **Dyne.**—The unit of force is the dyne. A force that can give a velocity of one centimeter per second to a mass of one gram is a dyne. This is a very minute force.

3. **Gram.**—The gram is the unit of mass. It is the mass of a cubic centimeter of pure water at zero degrees centigrade. A gram of force is equal to 980 dynes.

4. **Erg.**—The erg is the unit of work. It is the work done in overcoming a force of one dyne continuously through a distance of one centimeter.

5. **Watt.**—The watt is the unit of power or rate of doing work. It is equal to 10,000,000 ergs per second. Watts = volts $\times$ amperes.

6. **Current.**—The absolute unit of current, represented by i, is the current flowing through a wire one centimeter long, bent into an arc of one centimeter radius and exerting a force of one dyne upon a unit magnetic pole at the center. The ampere represented by I is $^1/_{10}$ the size of this absolute unit.

$$I = \frac{i}{10}$$

7. **Unit Pole.**—The unit magnetic pole is one that repels an exactly similar pole with a force of one dyne at a distance of one centimeter.

8. Voltage.—The absolute unit of pressure, represented by e, is the work in ergs necessary to carry one unit quantity of electricity from one point to another in a conductor against the resistances existing between the two points. The volt represented by E is 100,000,000 times as large. $E = 10^8 e$.

9. The Coulomb.—A unit quantity of electricity, represented by q, is a unit current flowing for one second. The practical unit is the Coulomb, represented by Q, which is equal to one ampere for one second. $Q = It$.

10. The Ohm.—The absolute unit of resistance, represented by r, is that resistance which will allow one absolute unit of current to flow under one absolute unit of pressure. The practical unit, the ohm, is represented by R. It is 1,000,000,000 times the absolute unit, or $R = 10^9 r$.

From the above definitions the current in amperes, represented by I, is equal to the voltage, represented by E, divided by the resistance represented by R. This is known as Ohm's law, and it applies to the direct current only or the alternating current when everything is in resonance. $I = \frac{E}{R}$

11. The Farad.—The farad is the unit of capacity. It is that capacity that one coulomb of electricity will charge to a pressure of one volt. The farad is very large and the microfarad is used. Capacity is usually represented by C. $Q = EC$.

12. The Henry.—The henry is the unit of inductance. A henry is the inductance that will set up a counter E.M.F. of one volt when the current varies at the rate of one ampere in one second.

13. Ohm's Law for the Alternating Current.—In the alternating current both capacity and inductance have an effect upon the current as well as the resistance and the voltage. In fact, the back or counter pressures due to these factors are really so much resistance. The following equation applies to the alternating current instead of Ohm's law.

(1) $$I = \frac{E}{\sqrt{R^2 + \left(2\pi nL - \frac{1}{2\pi nC}\right)^2}}$$

When $2\pi nL = \frac{1}{2\pi nC}$ we have resonance, and equation (1) reduces to $I = \frac{E}{R}$

$$\text{If } 2\pi nL = \frac{1}{2\pi nC} \text{ then}$$

$$4\pi^2 n^2 LC = 1 \text{ and}$$

$$n^2 = \frac{1}{4\pi^2 LC} \text{ or}$$

(2) $$n = \frac{1}{2\pi \sqrt{LC}}$$

Hence, when the capacity reactance equals the inductive reactance, there is resonance and equation (2) gives the frequency. In the above formulas, I stands for amperes, E for volts, R for resistance in ohms, n for frequency or cycles per second, L for inductance in henries, C for capacity in farads, and π for 3.1416, the ratio between the diameter and the circumference of a circle. The $\sqrt{LC}$ is called the oscillation constant.

The farad and the henry are very large units, and it is necessary to use smaller ones. The prefix micro is used, meaning one-millionth, and the prefix milli, meaning one-thousandth. Thus we have for practical units the microfarad and the microhenry.

14. Inductance.—The inductance of a wire increases directly as its length, and hence inductance can be expressed in centimeters. A straight wire 1,000 centimeters long has one microhenry of inductance, one 1,000,000 centimeters long has one millihenry of inductance, and one 1,000,000,000 centimeters long has one henry of inductance.

A current rising at the rate of one ampere per second will cause a back E.M.F. of one volt in a wire 1,000,000,000 centimeters long. This is equal to a wire equal in length to a quadrant of the earth's surface. 1,000 centimeters is equal to

10 meters, or about 33 feet. A wire 10 meters long will have one microhenry of inductance.

If these wires be curved into helices, their inductances are largely increased.

15. Station Calculation.—The capacity, inductance, frequency and oscillation constant of the closed oscillation circuit can be calculated roughly.

When the closed oscillation circuit is tuned to the open or radiating circuit, constituting the aerial, the oscillation constant of the two is the same, hence the radiated wave length can be calculated, if the constants of the closed circuit be known.

The following equation gives the relation between the velocity of a wave, v; its frequency, n; and the wave length, w.

(3) $$v = nw$$

Substitute the value of n in equation (2) in place of n in equation (3), then

$$v = \frac{w}{2\pi\sqrt{LC}} \quad \text{or}$$

(4) $$w = 2\pi v\sqrt{LC}$$

Since $v = 300{,}000{,}000$ meters per second, the velocity of all waves in the ether, w can be computed when L and C are known. 300,000,000 can be written 3×10^8, read 3 times 10 to the eighth power. 1 with 8 ciphers after it means 10 multiplied by itself 8 times. Remember that 10×10 is ten used twice and equals 10^2.

In equation (4), L is expressed in henries and C in farads. It is more convenient to express them in microfarads and microhenries or centimeters. 1,000,000 microfarads equals one farad, and 1,000,000 microhenries equals one henry.

If C represents farads and we call it microfarads, we have multiplied the number that C stands for by 1,000,000, and hence in equation (4) we must divide C by 1,000,000 in order to make it as it was before. The same observation applies to the inductance. Hence, (4a) $$w = 2\pi v \sqrt{\frac{L}{10^6} \times \frac{C}{10^6}}$$

where L and C are microhenries and microfarads; substituting 300,000,000 for v, the velocity of the electromagnetic wave in the ether, and taking 10^6 out from under the radicle, (4a) becomes:

$$w = \frac{2\pi \times 3 \times 10^8}{10^6} \sqrt{LC}$$
$$= 6\pi \times 10^2 \sqrt{LC}$$

It is convenient to have microhenries expressed in centimeters. If L is called centimeters in the above equation, it is equivalent to multiplying it by 1,000, and hence it must be divided by 1,000 to make it as it was before. Hence,

$$w = 6\pi \times 10^2 \sqrt{\frac{L}{10^3} C}$$
$$= \frac{6\pi \times 10^2}{31.62} \sqrt{LC}$$
$$= .596 \times 10^2 \sqrt{LC}$$
$$= 59.6 \sqrt{LC}$$

Hence,

(5) $$w = 59.6 \sqrt{LC} \text{ or } 60 \sqrt{LC}$$

where L is in centimeters and C is in microfarads.

Equation (2) can be reduced in the same way:

(2) $$n = \frac{1}{2\pi \sqrt{LC}} = \frac{1}{2\pi \sqrt{\frac{L}{10^6} \times \frac{C}{10^6}}}$$
$$= \frac{1}{\frac{2\pi}{10^6} \sqrt{LC}} = \frac{10^6}{2\pi \sqrt{LC}}$$

Where L is microhenries and C is microfarads,

$$n = \frac{10^6}{2\pi\sqrt{\frac{L}{10^3}C}} = \frac{10^6}{\frac{2\pi}{31.62}\sqrt{LC}}$$

(6) $$= \frac{5.033 \times 10^6}{\sqrt{LC}} \quad \text{or} \quad \frac{5 \times 10^6}{\sqrt{LC}}$$

where L is in centimeters and C is in microfarads. If L and C can be measured or calculated, then the frequency and wave length can be easily found.

The capacity can be roughly calculated from the following:

(7) $$C = \frac{KS}{36\pi d \times 10^5}$$

where C is the capacity in microfarads, K the dielectric constant of the insulating plates in the condenser. For air, K is 1, and for ordinary glass it is about 6. S is the area of the tin foil on the plates in square centimeters. d is the thickness of the glass in centimeters.

On account of the brush discharge in a condenser, its capacity for high frequency currents is from five to ten per cent higher than the calculated value. Hence, the value as calculated from the above formula is from five to ten per cent too small. The greater the thickness of the glass, the less accurate the formula also. This formula is for circular plates. This will introduce another error if the plates are square.

It can thus be seen that this calculation of capacity is only roughly correct.

If the diameter of the plates is 100 times the thickness of the glass, the calculated capacity is about 2½% less than the real capacity. This is owing to the leakage of the lines of force around the ends of the glass plates. Hence, in calculating capacity from this formula, from 10 to 15% must be added to make up for these errors.

Condenser plates in parallel are merely added together in order to determine their combined capacity. If the plates be in series, the following formula must be used to determine their combined capacity:

$$C = \frac{C_1 C_2}{C_1 + C_2} \text{ for 2 plates}$$

$$C = \frac{C_1 C_2 C_3}{C_1 C_2 + C_1 C_3 + C_2 C_3} \text{ for 3 plates}$$

$$C = \frac{C_1 C_2 C_3 C_4}{C_1 C_2 C_3 + C_1 C_2 C_4 + C_1 C_3 C_4 + C_2 C_3 C_4} \text{ for 4 plates}$$

In order to apply this formula, multiply all of the capacities together to form the numerator of the fraction. For the denominator form as many groups as there are capacities in the numerator, having one less capacity in each group than is found in the numerator, being careful not to repeat the groups. The groups of the denominator are added.

The groups in the denominator can be easily formed as follows: Cover one capacity of the numerator with the finger and multiply the rest of them together for the first group of the denominator. Cover the next capacity and multiply all the others together for another group, etc., until each capacity of the numerator has been covered.

The inductance in centimeters can be determined by measuring the length of the wire, if it be straight, and, if it be wound into a helix, the following formula can be used:

$$L = (\pi D N)^2 l$$

Where L is the inductance in centimeters, π is 3.1416; D is the diameter of the helix in centimeters; N is the number of turns per centimeter of length of the helix; l is the length of the helix in centimeters.

The value of L as found by this equation is always a little too large. If the length of the helix is 50 times its diameter, the value is correct to within 2% or 3%; if 100 times as long, it is correct to within 1% to 2%. The longer the helix and the less its diameter, the more nearly correct the value. In a short helix with a large diameter, the error is larger.

Since the calculated value of C is too small and that of L too large, they offset one another to a certain extent. In any case the calculated value is a rough one. If the plates of the condenser are put in oil, the brush discharge is stopped and the calculated value will then be very much more correct.

In order to give a concrete example, we shall proceed to calculate the frequency and wave length of the station located on the Los Angeles Polytechnic High School.

Formulae (5) (6) (7) and (8) are necessary for our purpose.

$$L = l(\pi DN)^2 \tag{8}$$

The helix has the following dimensions: The length l is 42.06 centimeters; the diameter D is 21.84 centimeters; total turns in the helix is 22; N, the number of turns per centimeter, is 22 divided by 42.06 = .523.

When in tune, there are 8 turns included within the closed oscillating circuit. Hence $8/22 \times 42.06$ is 15.2, the length l.

$$\begin{aligned} L &= 15.2(3.1416 \times 21.84 \times .523)^2 \\ &= 15.2(35.88) \\ &= 19{,}568.02 \text{ centimeters.} \end{aligned}$$

Since the helix is large in diameter compared with its length, we shall subtract at least 10% as a correction, giving 17,611.22 centimeters of inductance.

The condenser shown in *Fig. 16* had seven plates cut in when in resonance. Since the plates are in parallel, their capacity is their sum. If we take K as 6, and the thickness of the plates averages .32 centimeters as found by measurement, then,

$$\begin{aligned} C &= \frac{KS}{36\pi d \times 10^5} \\ &= \frac{6(20.32 \times 15.24)7}{36 \times 3.1416 \times .32 \times 10^5} \end{aligned} \tag{7}$$

where the tin foil on the plates measured 20.32 centimeters by 15.24 centimeters.

This gives a value of .00359 microfarads.

Since the condenser is not in oil, we shall add 12% for corrections. The corrected value is .003949 microfarads.

The oscillation constant is $\sqrt{CL}$ or

$$\sqrt{17{,}611.22 \times .003949}$$

$$= \sqrt{69.5467} = 8.34 \text{ or,}$$

$\sqrt{CL} = 8.34$, the oscillation constant of the closed oscillating circuit.

Since the closed oscillation circuit and the open oscillation circuit are in tune, they both have the same oscillation constant.

In order to compute the wave length, use formula

(5) $$w = 60\sqrt{CL}$$
$$= 60 \times 8.34$$
$$= 500 \text{ meters practically}$$

By formula

(6) $$n = \frac{5 \times 10^6}{\sqrt{CL}}$$
$$= \frac{5 \times 1{,}000{,}000}{8.34}$$
$$= 599{,}520 \text{ or practically } 600{,}000 \text{ cycles per second.}$$

CHAPTER XI.

CALCULATION OF TRANSFORMERS.

Transformers are calculated by the aid of the following formulae:

(9) $$\%\ \text{efficiency} = \frac{\text{watts output}}{\text{watts input}}$$

(10) $$\phi = AB$$

(11) $$Tp = \frac{E\,10^8}{4.44\phi n}$$

Where Tp = turns in the primary.
E = volts in the primary.
n = frequency.
ϕ = total lines of force.
A = area of the cross section of iron core.
B = lines of force per square inch.

Small transformers are lower in their efficiency than large ones. In order to secure the best efficiency the best kind of transformer iron should be secured.

The efficiencies range from 90% in small transformers to 99% in the largest ones. For our purpose we shall choose the kilowatt size. The first thing to determine is the input where we desire a kilowatt output. We shall assume an efficiency of 94%. Then,

(9) $$.94 = \frac{1{,}000}{\text{watts input}}$$

$$\text{and watts input} = \frac{1{,}000}{.94} = 1{,}063.83$$

The watts input then is 1,063.83, and the difference between this number and 1,000 watts gives us the watts loss, 63.83 watts.

This loss includes the total losses in the transformer. These losses are made up of core losses and I^2R losses. The I^2R losses are due to the heating effect of the current in both the primary and the secondary. The core losses include the losses occurring in the core due to hysteresis and eddy currents.

From experience the core losses are found to be about 47% of the total loss and the I^2R losses 53%.

To get core losses, take 47% of 63.83, the total losses.

$$.47 \times 63.83 = 29.986 \text{ watts core loss}$$

To get hysteresis loss, take 80% of the core losses, i.e., multiply 29.986 by .80, or calling 29.986, 30, since it is nearly so,

$$.80 \times 30 = 24 \text{ watts}$$

loss due to hysteresis.

The eddy current losses are due to the induced currents in the iron. The resistance of the iron core is small, and hence the currents running in the primary set up currents in the iron in the opposite direction, of low voltage and high amperage.

To prevent this, the iron is laminated, and, since the voltage of these eddy currents is low, the oxide that forms on the surface of the iron generally presents enough resistance to prevent their flow.

The hysteresis losses are due to the force necessary to turn the molecules of the iron first one way and then the other; as the lines of force flow first one way and then the other way, due to the alternations of the current.

It is with this hysteresis loss that we are particularly concerned in this calculation.

Table III gives the curve which shows the relation between watts loss per cubic inch for 50 cycles, for densities ranging 0 lines per square inch in iron to 40,000 lines per square inch.

The hysteresis losses increase with the density at which the iron is worked. The reluctance of the iron increases as the density at which the iron is worked increases, hence the greater the cross section of the iron, the better. Increased cross section means increased amount of copper wire, and increased losses due to its resistance. The cost of the wire also cuts a figure, so that it is necessary to choose a cross section that strikes a mean between all these factors.

For commercial transformers in which an all-day efficiency is required, the density should not run above 20,000 lines per square inch of cross section, but in transformers for wireless work an all-day efficiency is not required. 30,000 lines is about right for our purpose.

Look along the lower line in Table III for the number 30,000. This line is called the abscissa or the axis of *X*.

Having found this number, follow the perpendicular line drawn from this number upward until the curve is reached. From the point where this line cuts the curve, follow a line horizontally to the left, until it cuts the line of ordinates on the extreme left. Here the number .125 is found. This means that .125 watt loss occurs for each cubic inch of iron that there is in the core of the transformer, when it is worked at a density of 30,000 lines per cubic inch, and at a frequency of 50 cycles.

Since we are designing for 60 cycles, we must multiply this number by 60/50.

$$\frac{60}{50} \times .125 = .15 \text{ watts}$$

If one cubic inch suffers a loss of .15 watts, how many cubic inches will it require to handle a loss of 24 watts due to hysteresis?

$$\frac{24}{.15} = 160 \text{ cu. in. of iron.}$$

The dimensions to be given to the core containing 160 cubic inches is next to be determined. It will not do to give the core too small a cross section, as that would necessitate a core too long, which would require more turns in the primary in order to force the lines of force through the great reluctance. Experience indicates that the core should have a cross section of about four square inches. In order to make it convenient for winding, we will make the core square, thus making it 2 inches thick and 2 inches wide.

The other dimensions of the core depend upon the voltage desired in the secondary, and also upon the amount of money one can put into the transformer. The only way to do is to assume some values and try them; if they cannot be made to fit, try another set of values. For our purpose here we shall make the core longer than it is wide. If we divide 160 by 4, the area of the cross section, we have 40 inches for combined length of the ends and the sides. If we make the core 15 inches long and 8¼ inches wide, outside measure, it is about right. In order to arrive at this, assume various values for the length and the width. See whether the width and length will accommodate the windings. If not, try again. By referring to *Fig. 85*, we can determine whether this will suit our purpose. Compute the amount of iron with the assumed values.

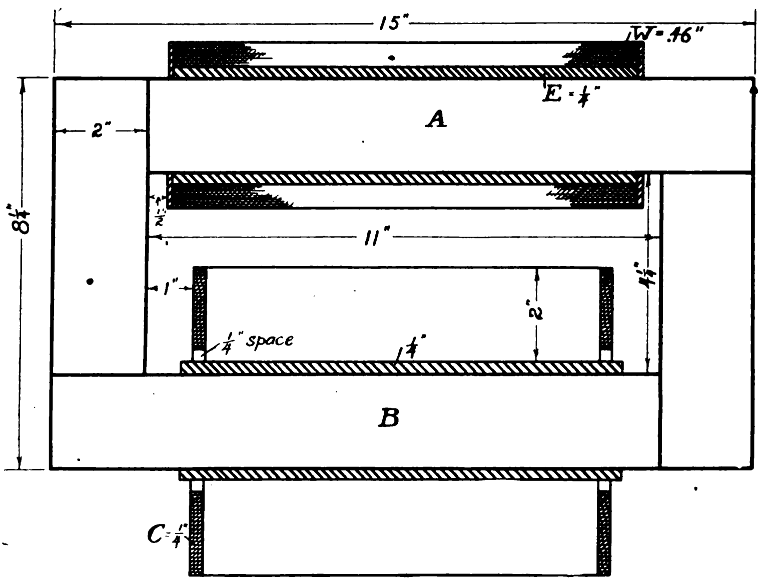


Fig. 85. Dimensions of kilowatt transformer.
A, primary leg; B, secondary leg; W, primary wire; C, secondary wire; E, empire cloth insulation.

Length around core = 15 + 15 + 4¼ + 4¼ = 38.5.
Width of core, 2 inches.
Thickness of core, 2 inches.
Hence, $2 \times 2 \times 38.5 = 154$ cubic inches.

This is close enough to 160 to do. It is now necessary to determine the total lines of force that will thread through this cross section at 30,000 lines to the square inch. Use formula

(10) $$\phi = AB$$
$$\phi = 2 \times 2 \times 30{,}000 = 120{,}000$$

for total lines of force.

Formula (11) is used for the purpose of determining the number of turns of wire in the primary necessary to set up a flux of 120,000 lines of force in the iron at a voltage of 110.

(11) $$Tp = \frac{110 \times 100{,}000{,}000}{4.44 \times 120{,}000 \times 60}$$
$$= 344 \text{ turns.}$$

Since the input in watts is 1,063.83 at 110 volts, the amperes to flow in the primary at full load is

(12) $$\text{Watts} = EI$$
$$1{,}063.83 = 110I$$
$$I = \frac{1{,}063.83}{110} = 9.67 \text{ amperes.}$$

Assuming 1,000 circular mils per ampere, the size of the wire necessary to carry 10 amperes can be obtained from Table IV. If we look in the column headed "Circular Mils," until we come to the number 10,381 circular mils, and divide this by 1,000 circular mils per ampere, we have the number 10. Looking under the column headed "Gauge Number," we find No. 10 wire. This means that No. 10 copper wire will carry 10 amperes without undue heating, allowing 1,000 circular mils per ampere.

If the numbers in the column headed "Circular Mils" be divided by 1,000, the resulting number is the number of amperes that the wire opposite it will safely carry.

Referring to table No. V, we find that No. 10 double cotton covered wire has 8.51 turns per inch of length of helix. Allowing ½ inch at each end in order to get the primary away from the iron at the ends of the core, we have 10 inches in which to place the primary winding. 8.51 turns to the inch gives

$$8.51 \times 10 = 85 \text{ turns}$$

per layer. Since there are to be 344 turns, it requires

$$344/85 = 4 \text{ layers.}$$

The depth of the winding is

$$4/8.51 \times 1 \text{ inch} = .47 \text{ inches.}$$

The empire cloth occupies about ¼ inch, and the total space occupied by the primary is

$$.25 + .47 = .72 \text{ inches,}$$

or practically ¾ inch. A tap should be brought out at the end of the second, third and fourth layer.

In order to calculate the amperes in the primary, apply the following formula:

$$\text{Watts input} = \text{amperes} \times \text{volts}$$
$$1{,}058.2 = 110I$$
$$I = 1{,}058.2/110 = 9.6 \text{ amperes.}$$

The amperes to flow in the primary of the transformers between 100 to 500 watts, inclusive, are calculated as follows: Take the 200-watt as an example. From the design the 200-watt transformer requires 1,200 turns.

$$200 = 110I \text{ and } I = 200/110 = 1.81 \text{ amperes.}$$

1,200 × 1.81 amperes gives 2,072 ampere turns necessary to drive the flux through the iron. Since we are going to use but 666 turns, the amperes necessary to get the same ampere turns is as follows:

$$2{,}072/666 = 3.1 \text{ amperes.}$$

This works the iron at a higher density and it really makes a 340-watt transformer of it, worked at a high density. Allowing 1,000 circular mils per ampere, the table shows us that it is necessary to use No. 15 wire for this transformer.

All other transformers in the table, following the 500-watt, are calculated in the same way as the 1,000-watt transformer here calculated.

In Table I, column 8 is taken directly from Table V. Column 11 is derived from *Fig. 85*, and column 12 is computed from columns 8 and 11. In the case of the 200-watt transformer,

$$14.68 \text{ turns per inch} \times 7\frac{1}{2} = 111.1 \text{ turns}$$

per layer. Column 9 is formed by dividing column 6 by column 12. Column 10 is computed by dividing column 9 by column 8.

Column 13 is formed by combining columns 2, 3 and 4 as in *Fig. 85*. Column 14 is found in the same way that it is found in designing the 1,000-watt transformer. It should be nearly the same as column 13.

Column 15 is found by multiplying column 13 by column 20. Column 16 is worked out from *Fig. 85*. Column 17 is found as follows: Take the 1,000-watt as an example. The iron is 2 inches on each side. To this add ½ inch for insulation, i.e., ¼ inch on each side. This gives 2.5 inches; 4 × 2.5 inches gives 10 inches as the distance around the insulated core. This then is the length of the turns first put on.

The winding has a depth of .47 inches. Take twice this or .94 and add it to the 2.5 inches in order to get the length of one side of the fourth layer. This gives 3.44 inches. Multiply this by 4 in order to get the length of an outside turn. It is 13.76 inches. Add 13.76 inches and 10 inches and divide by 2 in order to get the average turn. This gives 11.88 inches.

Multiply by the number of turns and divide by 12 to get the length of the wire in feet for the primary. It is 340 feet.

From Table IV obtain the pounds per foot of No. 10 wire. It is .0331. Multiply this by 344. It results in 10.7 pounds of No. 10 D.C.C. wire. This is given in column 18. Column 19 is assumed. Column 20 is taken from Table IV.

Table II gives the data for the secondary. From column 2 it is seen that we are to use No. 32 wire in the secondary. Column 3 shows the thickness of the pies or coils, and column 4 gives the diameter of the annular ring of the coils.

The free space between the primary and secondary is 4¼ inches (see *Fig. 85*). The primary occupies .72 inches. The secondary insulation occupies ¼ inch. Allow ¼ inch free space between the inside turns of the coil and the insulation on the iron. The coils are 2 inches in diameter across the windings. Adding all these gives, $.72 + .25 + .25 + 2.00 = 3.22$ inches occupied by the primary and secondary. Subtracting this from 4¼ inches leaves 1.03 inches between primary and secondary.

Allow ⅛ inch between each coil for insulation. Each coil then occupies ⅛ + ¼ inch or ⅜ inch.

Allow an inch between the ends of the iron core and the ends of the secondary coils. This leaves 9 inches of winding space. This gives $9 \times 8/3 = 24$ coils. Column 7 is found in this way.

The cross section of a coil is the product of columns 3 and 4. This is $\frac{1}{4} \times 2 = \frac{1}{2}$ square inches. From Table V, No. 32 D.C.C. is found to have 4,027 turns per square inch of cross section. $\frac{1}{2} \times 4{,}027 = 2{,}013$ turns in a coil, where the turns are put on carefully side by side. Since we are to wind on the turns rather rapidly in the lathe, $^1/_5$ must be subtracted for rapid winding. Divide 2,013 by 5. It gives 402. Subtract this from 2,013, and it leaves 1,611 turns in each coil of the secondary. This is found in column 6. Column 8 is taken from Table V.

Since there are to be 24 coils, $24 \times 1{,}611$ gives 38,664 as the number of turns in the secondary. From the formula $Tp : Ts :: Ep : Es$, the voltage in the secondary is computed. In this case

$$344 : 38{,}664 :: 110 : Es$$

and

$$Es = \frac{110 \times 38{,}664}{344} = 12{,}363$$

Column 10 is calculated in this manner. Columns 15, 16, 17, 18, 19 and 20 are calculated in the same manner, for the turns designated. If higher voltages are desired with all the turns in, the coils can be made larger in diameter, in which case the iron core must be made wider or the core can be made longer and more coils can be put on.

By cutting out turns in the primary, the voltage can be raised as shown in columns 15 to 20, already mentioned.

The transformer can be operated on all these taps, provided a water rheostat is used in the primary to cut back the current. Column 5 gives the size for the opening in the coil.

It is determined as follows: The iron is 2 inches on a side. Since the empire cloth is ¼ inch thick, it will add $2 \times ¼$ or ½ inch to the opening. This makes 2.5 inch opening.

To calculate the amount of wire, proceed as follows: 2.5 inches taken from column 5 multiplied by 4 gives 10 inches as the length of one turn next the core. Since the coil is 2 inches across, the outside dimension is 4 inches longer, hence $4 + 2.5$ gives 6.5 inches as the length of one side of the outside turns. This multiplied by 4 gives 26 inches as the length of the outside turn. Add 26 and 10 and divide by 2 for the average turn. This is 18 inches. Divide by 12 in order to express it in feet. It is 1.5 feet. Multiplying 1.5 by 38,664, gives 55,996 feet of wire in the secondary. This is found in column 11. Column 12 is found by multiplying the pounds per foot taken from Table IV by the number of feet.

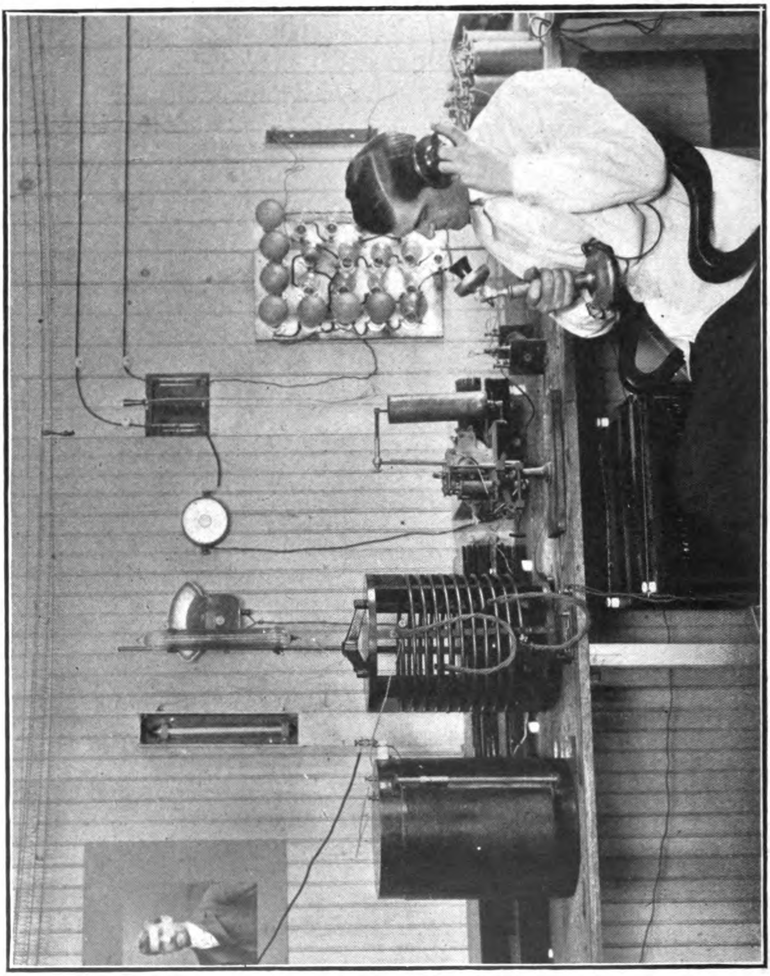


Plate I. A. Frederick Collins transmitting and receiving wireless telephone messages between Newark, N. J., and Philadelphia, September, 1908

WIRELESS TELEPHONY

by
William Dubilier
Chief Electrician of the Collins Wireless Telephone Company

INTRODUCTION

Up to the present time every known wireless telegraph system has been utilizing damped electric oscillations. It was not until lately that some of our greatest scientists and inventors have expressed their belief that by such means the greatest drawback that we have to contend with, that is, imperfect tuning, will never be eliminated and perfect tuning will only be possible by using undamped or persistent electric oscillations.

Since the possibility of the wireless telephone depends entirely upon the production of such oscillations and suitable means for varying them, we may predict that in the near future the wireless telephone will not only progress far ahead of the wireless telegraph, but take its place. For it can be used either for wireless telegraphy or wireless telephony. It also does away with the spark.

WM. DUBILIER.

There are a number of different ways of producing electric oscillations, the best known being an induction coil or transformer, and the one that is about the least known being an ordinary arc lamp, energized by a direct current. The difference between the two being that in the former they are damped and in the latter they are undamped or continuous.

Undamped or persistent oscillations are high frequency alternating currents, just as are the alternating currents used for electric lighting and the transmission of power, the only difference being that the frequency of one is anywhere from 1,000 to 100,000 times greater than the other.

There are several methods used for producing such currents. One is by the use of the high frequency alternator, the invention of which dates back to 1889, when arc lighting by alternating currents became popular, the sound of which they tried to eliminate by increasing the frequency.

Nikola Tesla constructed a machine which consisted of a fixed ring-shaped field magnet with magnetic poles inwards, and a rotating armature in the form of a fly wheel. The magnet had 400 radial poles in the circumference and 400 coils on the armature. When driven at a speed of 3,000 revolutions per minute or 50 per second, it produced an alternating current of 10,000 cycles. The output of this was limited to a small amount of energy, probably not more than ½ kilowatt. It was dangerous, however, to run such a machine.

The Westinghouse Co. has built for Mr. G. B. Famme an alternator having a 2-kilowatt capacity at a frequency of 10,000. It is of an induction type and has 200 polar projections.

In all these machines it is customary to make the field magnet the revolving part, the armature being stationary.

Duddell succeeded in building a machine of the induction type which, at a speed of 30,000 revolutions per minute, gave a current of one ampere and a frequency of 15,000 per second at 40 volts.

There is claimed to be built a machine possible to create an alternating current having a frequency of 100,000, when the disc is driven at a speed of 600 revolutions per second, the output being only 0.1 of an ampere at 2 volts.

R. A. Fessenden claims to have constructed a machine with a frequency of 60,000, with an output of not more than 200 watts, at a speed of 10,000 revolutions per minute. Although this machine was sufficient for experimental purposes, it was far from being practical for wireless, the output being too small and the machine being too dangerous to run.

It is said, on one occasion, while one of these machines was going at its normal speed, that a magnet flew from the field, clear through a two-foot brick wall and 250 feet out into the field. The efficiency being very low, the machine dangerous, and the output small, tend to make the high frequency alternator very impractical and useless at its present stage.

From the experience so far received by the scientific world, we may conclude: First, that an attempt to run alternators at high speeds, say above 5,000 revolutions per minute, involves the loss of considerable energy due to air friction and churning, hence it cannot have a high efficiency; second, that the size of the armature and its peripheral velocity has its practical limitations; third, in using an induction type of motor, it labors under the disadvantage that an attempt to take a current out of the machine generally results in a large drop in the terminal potential difference. It is, therefore, exceedingly hard to combine in one alternator the properties of high frequency, high power and a large power output. Such machines are not as yet commercial articles, hence the alternating method of producing undamped oscillations has up to the present only come into limited use, although there is a possibility of it being improved.

The Arc Method of Producing Undamped Oscillations

Up to the time Duddell described his singing arc, many inventors struggled to combine an arc lamp with a capacity and inductance for producing oscillations, but met with little success. As early back as 1840, Grove describes an arc lamp burning in hydrogen and its effects. In 1875 de La Rue and Hugo Miller used an arc in hydrogen in experimenting on some vacuum tubes, and in 1892 Elihu Thompson patented the following method for transforming an alternating current in an alternator:

In *Fig. 1*, *G* is a direct current generator in the same circuit with a very high inductance *R*, a spark gap, and two metal balls *S*. These balls are connected in another circuit, consisting of a condenser *C* and an inductance *L* in series. When the spark balls are brought in contact, a current is drawn through the inductance *L*. If the balls are separated, the condenser will become charged by the difference of potential created, and

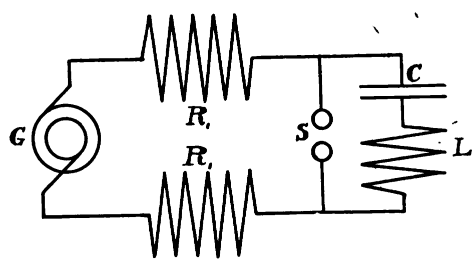


Fig. 1

G, D.C. generator; R, inductive resistance; S, arc gap; C, condenser; L, inductance.

when fully charged it discharges across the gap. Thompson claimed to obtain oscillations of 30,000 per second, but no proof was given in his specifications that these were not intermittant. Although this was quite theoretical, it shows that he was trying to find means for producing undamped oscillations.

About the same time. Firth and Rodgers gave out the statement that the current through an arc was oscillating and that they had succeeded in converting 3% of the continuous current into an oscillating one.

It was not until Duddell made his discovery in 1900 that the matter was seriously thought of. He described some of his observations made before the London Institute of Electric Engineers on the solid carbon arc lamp, having a capacity and inductance shunted across it, showing its oscillating nature. In his circuit he used a direct current generator of 3.5 amperes and a potential difference of 42 volts. Around the arc he shunted a capacity of about 3 microfarads in series with an inductance of 5 millihenries. Under such conditions the arc gave out a musical tone, the pitch of which depended upon the capacity and inductance. Since the musical tone is due to the rapid change in the arc, a very important factor arises which may open the way later for a new method of producing undamped oscillation, and the author, working on this theory, has been quite successful. An important factor must be taken into consideration in the Duddell arc. The inductance in the direct current circuit must have a high resistance and inductance as compared with the resistance or inductance in the oscillating circuit. If we draw the characteristic curve of a D.C. arc, we will find that it does not quite agree with Ohm's law; that is, it is not a straight line as the case would be with a metallic conducting circuit.

If we take observations with a voltmeter and ammeter on a solid carbon direct current arc, for various constants of the arc, using the potential difference in volts as the ordinate, and the current in amperes as abscissa, we will find a curve that is concave upward and as the current increases it slopes downward; it is therefore a curve that slopes in the opposite direction to the curves that obey Ohm's law. All this phenomena has been investigated by Messrs. Ayrton, Upson and others, and the conclusion is that in all cases, whether between carbon and carbon, or carbon and metal, or these with gases, the curves slope downward, showing that as we increase the current through the arc the potential difference decreases.

The action of the capacity and inductance on the arc may be as follows:

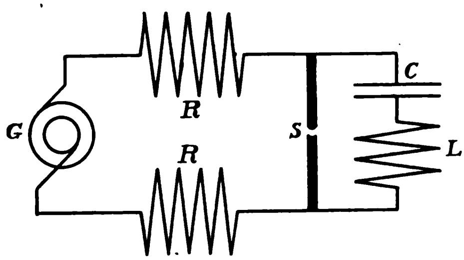


Fig. 2. Duddell's circuit.

G, D.C. generator; R, inductive resistance; S, arc gap; C, condenser; L, inductance.

In shunting the capacity *C* and inductance *L* across an arc (see *Fig. 2*) that is burning steadily, the capacity instantly takes upon itself a charge and the current through the arcs is at the same time diminished, the potential difference therefore increases across the arc and this tends further to charge the condenser. This reacts on the arc and still further increases its current, which in turn lowers the potential difference.

Since it discharges through an inductance *L*, it not only fully discharges but becomes charged in the opposite direction, just as a pendulum, when pulled to one side and let go, will not only go back to its original position, but go far beyond it in the opposite direction.

When in this condition, it is ready to repeat the operation with more vigor than before, and so, persistent and undamped oscillations are set up by the condenser charging and discharging.

Suppose in swinging the pendulum, we apply enough force on each swing to make up for the friction and other losses and make it come back to the same position all the time. This can be accomplished only when we apply the force just about the time it starts to swing in the opposite direction, since it has its own time period of oscillation, depending upon the length. Now if we should strike it before it starts to swing back, we will have two forces in the opposite direction applied to the same points and they will have a tendency to neutralize each other.

The same applies to the oscillating circuit. If the capacity and inductance, each having its own natural time period of oscillation (into which part of the direct current is converted), are not in resonance, that is, if the capacity does not fit the inductance, we will have very weak oscillations, one counteracting the other.

Poulson's Improvements

In 1903 the Danish physicist, Poulson, formed an arc between a water cooled metallic electrode *S* and a solid carbon *S1* (*Fig. 3*), the chief improvement being, however, the fact that he burned his arc in a medium of coal gas and later used alcohol. With this arrangement he succeeded in obtaining much more forceful oscillations than were heretofore known. The frequency varied from 500,000 to 1,000,000 cycles. When the machine was operated, a great amount of heat was evolved, and although the water cooled the copper rod to some extent,

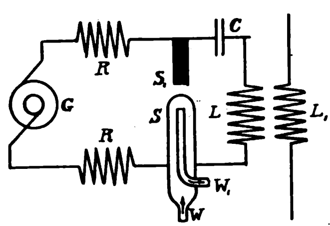


Fig. 3. Poulson's water-cooled arc.

G, D.C. generator; R, inductive resistance; S, arc gap; C, condenser; L, inductance.

S_1, carbon electrode; S, copper electrode; W_1, water pipe outlet; W, water pipe inlet; L, L_1, inductive coupling.

one may readily understand how inconvenient such an arrangement is. However, the advantages gained by the fact that undamped oscillations were obtained, which as stated in the beginning makes tuning possible, induced him to proceed at once and apply his machine to the practice of wireless telegraphy.

Now in summing up the work done with the arc, H. Simon and Fleming came to the conclusion, that in order to obtain strong undamped oscillations one must have an artificially cooled electrode for positive process, and this, I think, has been solved by Mr. A. Frederick Collins. Since 1900 he has been working on the combination of an arc lamp and transmitter for wireless telephonic work, thus being practically ahead of all other physicists.

At the time Duddell conceived of the musical arc, he had no idea of its being used in connection with a transmitter for wireless telephony. A description of this was given in the Scientific American of July 18, 1902, showing that he was the first scientist to apply an arc lamp for wireless telephony. The publication of Poulson's experiments, showing that the cooling of the arc lamp electrodes was the cause of powerful oscillations, led Mr. Collins to deeply investigate and evolve a perfect system of wireless telephony.

In the Poulson method of producing oscillations, if the arc was left burning for some time, the machine and its parts would gradually heat up, and the water in the tank would become warm. It was not safe to connect the water cooled electrode to a water pipe, since this would ground the machine and interfere with its operation. The question of cooling was therefore an important one, as pointed out before. Mr. Collins then produced his revolving arc lamp, in which the electrodes were revolved by a small motor or clockwork. This at once eliminated all troubles due to heating, also to getting rid of a large amount of energy dissipated as heat.

The first application of the direct current arc to wireless telephony was made by Collins in 1902, and since that time he has devised many a form of arc lamp for the production of sustained oscillations, one of which is shown photographically in *Fig. 4,* top view *Fig. 5* and in cross section in *Fig. 6.*

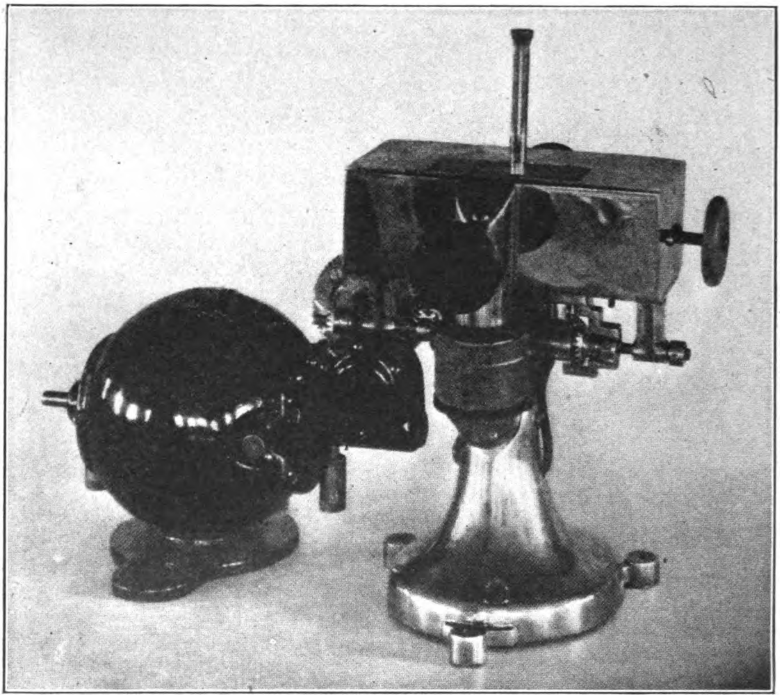


Fig. 4. The Collins rotating oscillation arc.

In 1903, when experimenting with the musical arc, Poulson found that more intense oscillations were obtained, if the arc is formed between a cool metallic electrode and a solid carbon.

Collins has ascertained that a greater percentage of direct current is converted into high frequency oscillations, providing carbons are used, and one or both are kept at a low temperature. In order to accomplish this in practice, he employs a pair of carbon or graphite disks as the anode and the cathode. These disks are mounted on parallel spindles so that they are in the same plane and are connected by means of beveled gears to an insulated shaft.

The disks are insulated from each other by fiber bushings inserted in the gearings, the casing forming one of the connections, while the insulated bearing in the bottom of the casing forms the other. The gearing is so arranged that carbon disks are rotated in opposite directions, the power being furnished by a 1/8 horse-power motor. One of the bearings in the shaft is mounted in a keyed sleeve which permits the spindle carrying one of the disks to be moved toward or away from the opposite disk so that the length of the arc can be varied while the lamp is in operation. The carbon electrodes are placed in a metal casing while the rotating mechanism is attached to the bottom casing.

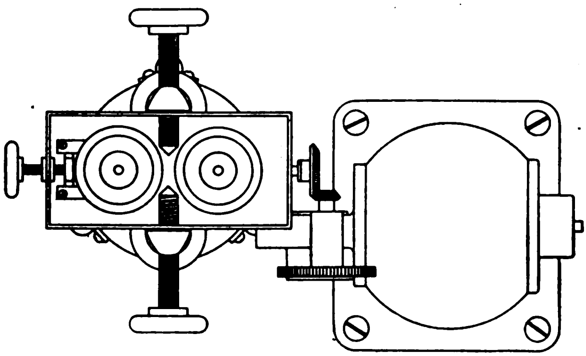


Fig. 5. Plan view of the Collins arc.

The casing is supported between the poles of an electromagnet, and through the ends of the poles and at right angles to them, are polar rods of soft iron which are threaded. These are screwed through the extremities of the magnet and at right angles to the arc. The ends terminating in the casing are pointed, while those projecting outside have disks of hard rubber so that they may be adjusted in positions to the arc. The magnet coils are placed in each of the leads of the supply circuit, and serve as well to choke back the oscillations from reaching the generator. The casing is supported between the poles of the magnet and the magnet in turn is held in position by an iron base.

The magnets provide a strong magnetic field in which the arc burns and so increases the resistance between the carbons and hence raises the voltage. The adjustable poles of the magnet are used primarily to blow back and keep the arc between the carbons where the distance is shortest. Were this not done, the arc would follow the revolving carbons until broken. The arc has been burned in different gases, under pressure and in vacuum.

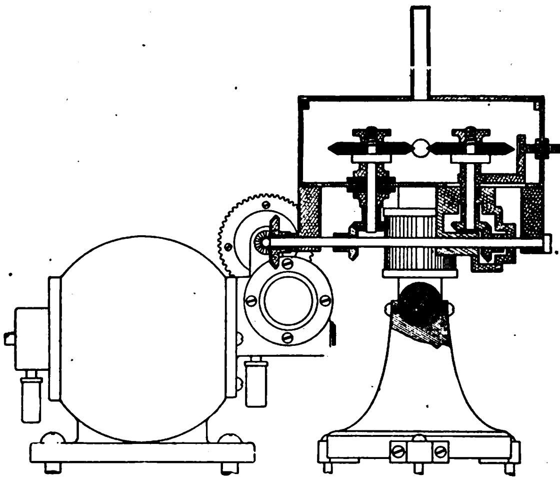


Fig. 6. Side elevation of the Collins arc.

In experimenting with this arc with different gases, the author has discovered that certain conditions existed in the arc chamber heretofore unknown, one being that certain gases under certain conditions do not burn continuously but explode with a very great rapidity. It was on one occasion when using this gas in connection with the arc that undamped oscillations were obtained in the aerial system which indicated two times as much current on a hot wire ammeter than was previously obtained.

Upon further investigation more detailed specifications will be made public in the near future.

The rotating oscillation arc eliminates the disadvantageous features of the stationary arc in that a constantly fresh and cool surface is presented to the arc, and in that it prevents the burning away of the electrodes which gives rise to untoward variations in the frequency of the oscillations, and finally in that the optumum length of the arc, namely, at the length when the frequency of the oscillations is the greatest, may be maintained for long periods of time, which is quite impossible when the carbons are stationary.

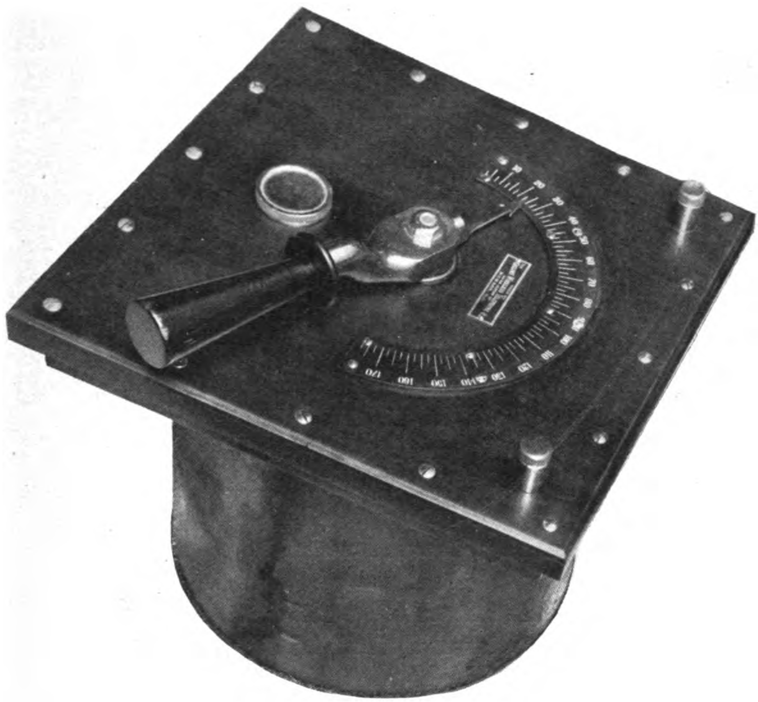


Fig. 7. Adjustable condenser.

Across this arc is connected an oscillation circuit having a variable condenser (see *Fig. 7*) consisting of metal plates placed above one another in a large tank of insulating white paraffine oil. One set of plates is fixed on a shaft so that it can be revolved and brought between the other set, so that any variation of capacity can be obtained. It is upon this condenser that free oscillations of considerable force, so to speak, depend. The variable inductance included in this circuit is a single helix of bare wire, which can also be varied so that any combination of inductance and capacity can be obtained. There is, however, one important point to bear in mind, and that is the capacity must be of a small value as compared with the inductance and adjusted so that a frequency may be obtained anywhere from 100,000 to 1,000,000 cycles per second.

In one test made by Mr. Collins between Newark and Philadelphia, a distance of ninety miles, described in the Scientific American of September 19, 1909, a revolving arc lamp energized by a current of 8 amperes at 500 volts was set in operation in connection with a resonance tube used for tuning. This consists of an exhausted glass tube 13 inches in length and 1¾ inches in diameter. Sealed in the ends are platinum wires $^1/_{16}$ inch in diameter, and these extend longitudinally through the center of the tube until the ends almost touch each other. The outside terminals are connected in shunt with the induction coil. Now, when the first feeble oscillations begin to surge in the closed circuit, one or the other will glow, or both of the free ends of the enclosed wires will glow, depending upon the oscillatory nature of the current. As the current strength of the oscillations increases, the glow light extends farther and farther toward the ends of the tube, always keeping close to the oppositely disposed wires.

The length of the glow on the wires is proportional to the current strength, and thus the tube may also be used as a measuring apparatus instead of the milliammeter usually employed. The characteristics of the oscillations can also be easily observed; for if they are positive the light will appear almost entirely on the end of one of the wires, and if the current is reversed, on the opposite end; while if the current is oscillating with equal electromotive forces, the light will have the same degree of intensity on both wires. By means of a revolving mirror the oscillations may be segregated, and it is then easy to see whether they are periodic or continuous, and if the latter, to analyze the wave form of the spoken words.

Upon the Land Title Building, Philadelphia, Pa., were raised three kites in tandem to which the aerial was connected. The aerial at Newark consisted of 1,500 feet of phosphor bronze wire. By means of a reel at Philadelphia, about the same length of aluminum wire was let out, which made the attuning of both instruments quite easy. *Plate I* shows Mr. Collins at the time talking to Philadelphia, where the speech was received quite audibly and clearly.

Although very good results were obtained by him a short time previous between his Newark laboratory and the Singer Building, New York, a distance of 9 miles, and between Newark and Rockland Lake, a distance of about 40 miles, the

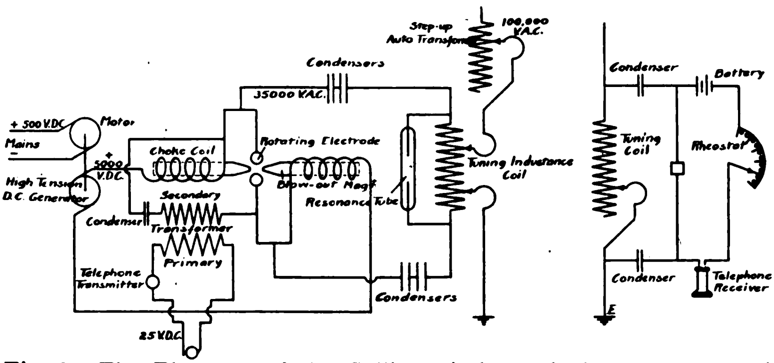


Fig. 8. The Elements of the Collins wireless telephone system and their electrical relation to one another.

Philadelphia test was the greatest distance ever made on this side of the Atlantic Ocean. *Fig. 8* shows a wiring diagram of the apparatus.

Controlling the Waves by Means of a Telephone Transmitter

Many different combinations and arrangements have been tried in connecting up the transmitter with the oscillating circuit, but in all my experiments with the wireless telephone, I have found it most practical, in fact the only possible way to get good results, to work the transmitter on an independent circuit of its own and connect that inductively to the arc, or superimpose it upon the direct current supplied to the arc.

Many experimenters claim results with the transmitter connected to the ground circuit. Upon experiment, this will be found to be almost impossible, as the high frequency oscillations of three or four amperes would arc the carbon and burn it out.

In the last distance tests made, the terminals of a small transformer coil were shunted across the arc, but a condenser of a large capacity is interposed to check the high voltage direct current from flowing through it. The primary of the transformer was connected in series with a 25-volt generator and a telephone transmitter, as shown in the wiring diagram. Now when the arc is set in operation, a slight change in its resistance would vary the oscillating circuit and hence change the amplitude of the waves sent out. Upon speaking into the transmitter, the current through the primary of the transformer produces an alternating current at the ends of the secondary circuit on the direct current of the arc, and changes its resistance, which in turn varies the oscillating circuit.

The amplitude of the electric waves changes in the same manner and is proportional to the change of air pressure against the diaphragm and the current through the transmitter. The transmitter may also be inductively connected to the inductance or to some plates of the condenser.

Marjorana's Liquid Transmitter

Marjorana has been using the intermittent discharge of a condenser by increasing its rapidity and he has produced discharges at the rate of 10,000 per second; these discharges in turn consist of a train of oscillations. This he has done by the use of a very short spark gap, a high inductance in series with the electromotive force and large impressed voltage. In his transmitter he utilizes the action of a liquid flowing from a tube, which is sensitive to sound vibrations.

A fine stream of liquid flows out at one end, and, when there is no sound, a straight and unbroken column of water passes between two conductors to which the instruments are connected. When a sound is made, the water column is found to contract in certain places which forms a wavy column.

Contact is made by the liquid between the two terminals, and when the liquid flows unevenly, we have a varying resistance between the two terminals.

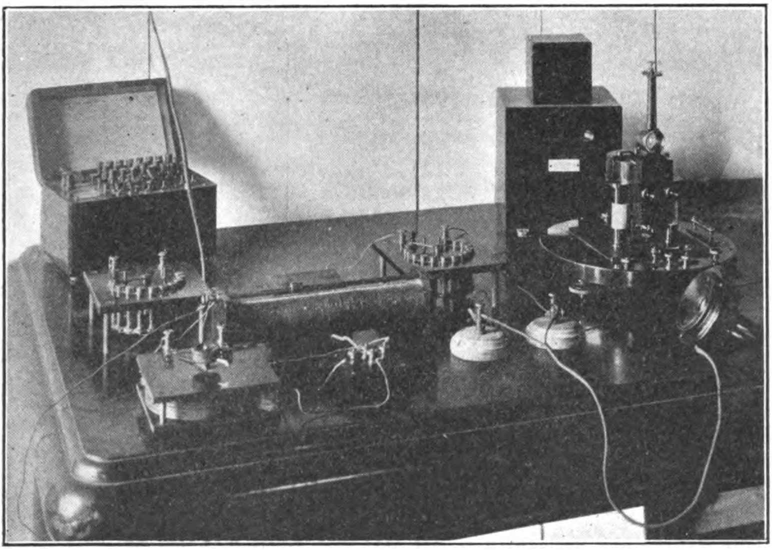


Fig. 9. Collins thermo-electric detector dissected.
Collins long distance wireless telephone receiver.

Receiving Instruments

The receiving instruments used for wireless telephony contain certain forms of detectors, as all wireless telegraph receivers are not suitable for wireless telephony. For example, detectors of the coherer or imperfect contact type will only detect oscillations, but do not indicate changes in their amplitude.

Three forms of detectors have been used with much success, viz.: The thermo-electric, electrolytic, and the ionized gas detector. Of these the first seemed to work about the best, as a form has been devised by Mr. Collins which eliminates all troubles of adjusting after once placed in position. It is different from all other detectors previously invented, and the principle upon which it works is as follows: Two exceeding fine wires of different metals, crossing at right angles, are made into a thermo-couple and so constructed that the conduction losses are far greater than the radiation losses. Another wire made of a very high special resistance material and which is heated by the received oscillation surging in it, is mounted on a movable block just underneath the couple and its distance from it can be regulated (see *Fig. 10*). When the received oscillations pass through this wire of a very high specific resistance, it heats up, which in turn acts upon the thermo-couple, the resulting electromotive force effecting a very sensitive receiver and producing the voice.

An improvement upon this detector was recently made by the author by making use of the wire which is heated up by oscillations, as one of the metals of the thermo-couple. This detector is shown in a photograph of the receiving set used by Mr. Collins in telephoning 81 miles between Newark and Philadelphia. *Fig. 9* is a photograph of the complete receiving outfit.

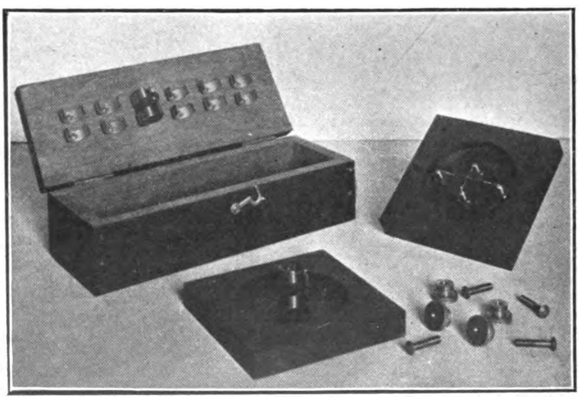


Fig. 10. Collins thermo-electric detector dissected.

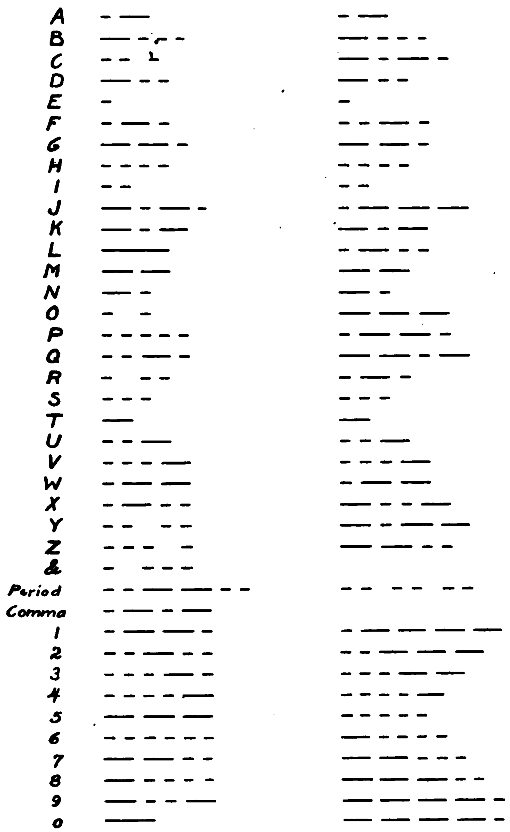

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TABLE I. DATA FOR PRIMARY.

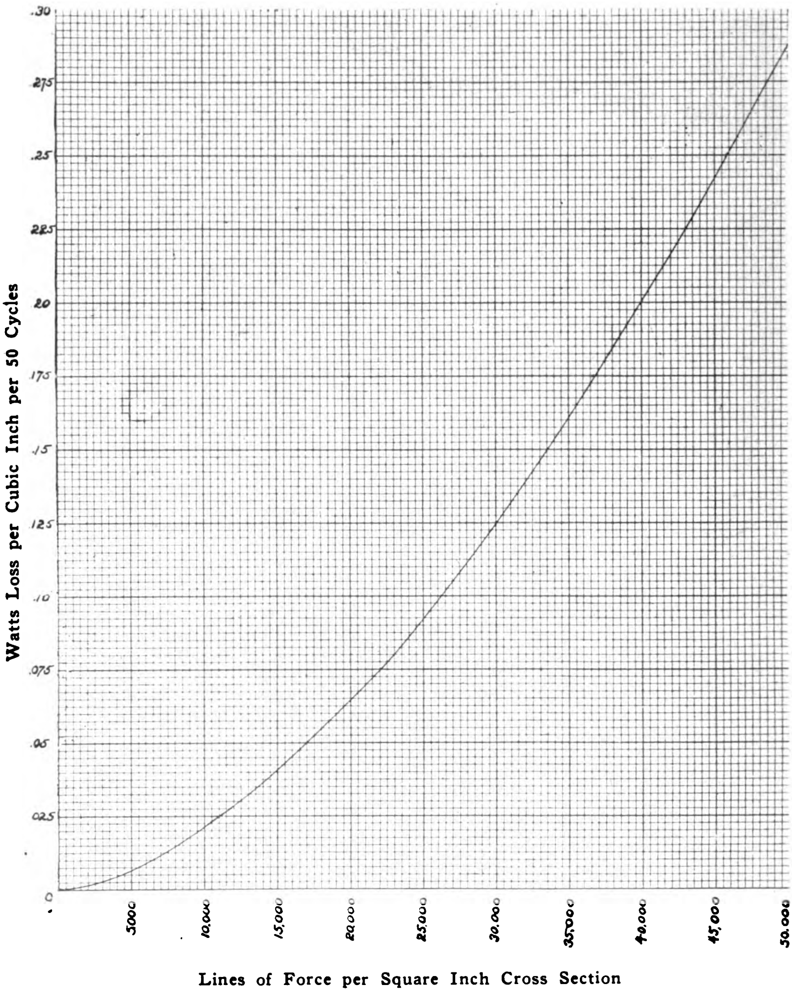
Capacity in Watts	Length in Inches of Iron	Breadth of Iron in Inches	Thickness and Width of Iron Core in Inches	No. of Wire B. & S. Gauge	Turns in the Primary	Amperes in the Primary at Full Load	Turns per Inch Double Cotton	Layers	Depth in Inches	Length of Winding in Inches	Turns per Layer	Cubic Inches of Iron	Cubic Inches of Designed Iron	Weight of Iron in Pounds	Distance between Primary and Secondary	Feet Wire in Primary	Pounds Wire in Primary	Per Cent Efficiency	Pounds per Foot D.C.C.	Pounds Wire in Primary D.C.C.
100	10	6	1.	15	700	3.	14.68	7	.47	7″	100	28	27	7.5	.9	460	4.5	90.	.0105	4.8
200	10½	6½	1.	15	660	3.6	14.68	6	.4	7½	111	30	32	8.	1.4	422	4.	94.	.0105	4.5
300	11	6½	1.2	15	666	3.8	14.68	6	.4	7.6	111	43	47	11½	1.07	461	4.5	94.	.0105	5.
400	12½	6¾	1.3	14	580	4.4	13.1	5	.38	8.9	116	56	63	15.	.71	421	5.3	94.	.0133	5.6
500	14	7	1.4	13	480	5.	11.88	4	.33	10.2	120	71	79	19.8	1.	357	5.6	94.	.0166	6.
600	14¼	7¼	1.6	13	476	5.46	11.88	4	.33	10.	108	94	96	25.	.64	385	6.	94.	.0166	6.4
700	15	7¾	1.7	12	448	6.37	10.62	4	.37	10.6	112	115	112	30.8	.88	384	7.6	94.	.0208	8.
800	15	7¾	1.8	12	440	7.28	10.62	4	.37	10.4	110	124	129	34.5	1.00	389	7.7	94.	.0208	8.1
900	15	8	1.9	11	390	8.2	9.58	4	.42	10.2	97.7	136	143	37.	1.00	366	9.2	94.	.0264	9.7
1000	15	8¼	2	10	344	9.6	8.51	4	.47	10.	85.1	154	160	41.	1.00	340	10.7	94.	.0331	11.3
2000	17½	8¾	2¼	8 or 2 No. 11	244	18.2	6.8	3	.44	12.	81.6	210	220	56.	.73	260	13.	95.7	.0518	13.5
3000	18	9½	2½	6 or 2 No. 9	196	27.3	5.44	3	.55	12.	65.28	273	274	75.	.60	232	19.	96.5	.0821	19.
4000	18	9¾	2¾	5 or 2 No. 8	166	36.4	4.83	3	.62	11.5	55.5	344	342	91.	.65	214	22.	96.7	.103	22.
5000	20	10½	3	4 or 2 No. 7	139	45.5	4.28	2½	.7	13.	55.6	427	424	118.	.94	195	25.	96.7	.13	25.4
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21

Note.—One cubic inch of transformer iron weighs .268 pounds.

TABLE II.

Capacity in Watts	No. D.C.C. Wire	Thickness of Pies in Inches	Width of Annular Ring of Coil	Size of Opening in Core	Turns per Coils	Number of Coils	Turns per sq. in. D.C.C. Accurate Winding	Total Turns Rapid Winding	Voltage with all Turns Cut in	Number of Feet of Wire in Transformer	Pounds Wire D.C.C.	Amperes in Secondary at Lowest Voltage	Winding Space in Inches	Voltage 100 Turns in Primary	Voltage 200 Turns in Primary	Voltage 300 Turns in Primary	Voltage 400 Turns in Primary	Voltage 500 Turns in Primary	Turns in Primary Voltage 600
100	34	1/4"	2"	1.5"	2092	16	5230	33476	5265	30686	3.7	.062	6.	36832	18416	12260	9208	7364	6136
200	34	1/4"	2"	1.5"	2092	17	5230	35564	5890	30686	3.7	.067	6.5	39120	19560	13040	9780	7624	6520
300	34	1/4"	2"	1.7"	2092	18	5230	37656	6220	46316	5.6	.067	6.6	41421	20710	13807	10355	8284	6903
400	34	1/4"	2"	1.8"	2092	21	5230	43932	8332	55354	6.7	.058	7.9	48325	24160	16108	12081	9665	.....
500	34	1/4"	2"	1.9"	2092	25	5230	52300	11908	67990	8.	.046	9.2	57530	28765	19176	14382	.....	.....
600	33	1/4"	2"	2.1"	1836	24	4594	44064	10183	52876	8.	.059	9.05	48470	24235	16156	12117	.....	.....
700	32	1/4"	2"	2.2"	1611	26	4027	41886	10285	51519	10.	.067	9.6	46074	23037	15358	11518	.....	.....
800	32	1/4"	2"	2.3"	1611	25	4027	40495	10123	51023	10.	.079	9.4	44544	22272	14848	11138	.....	.....
900	32	1/4"	2"	2.4"	1611	25	4027	40275	11359	58801	11.	.079	9.2	44302	22151	14764	11075	.....	.....
1000	32	1/4"	2"	2.5"	1611	24	4027	38664	12363	52996	10.	.086	9.	42530	21265	14176	.....	.....	.....
2000	28	1/4"	2"	2.75"	920	30	2300	27600	12440	43608	21.	.153	11.	30360	15180	.....	.....	.....	.....
3000	26	1/4"	2"	3"	708	30	1770	21240	11920	35258	27.	.252	11.	23364	11682	.....	.....	.....	.....
4000	26	1/4"	2"	3.25"	708	28	1770	19824	13136	34692	27.	.239	10.5	21806	10903	.....	.....	.....	.....
5000	25	1/4"	2"	3.5"	583	32	1456	18656	15478	34140	33.	.338	12.	20521	10260	.....	.....	.....	.....
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

TABLE III.



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50,000
Watts Loss per Cubic Inch per 50 Cycles
Lines of Force per Square Inch Cross Section

TABLE IV. DIMENSIONS AND RESISTANCES OF PURE COPPER WIRE.

Gauge No.	Diameter (Inches)				Area	Weight and Length sp. gr. = 8.89		Ohms per 1000 Feet			Feet per Ohm	Ohms per Lb.
	Bare	Single cotton covered	Double cotton covered	Triple cotton covered	Circular mils (d_2) 1 mil = .001 inch	Lbs. per 1000 ft.	Feet per lb.	@ 20° C.	@ 50° C.	@ 80° C.	@ 20° C.	@ 20° C.
0000	.460	....	....	.480	211600.00	640.5	1.561	.04893	.05467	.06058	20440.	0.00007639
000	.410	....	....	.430	167805.00	508.0	1.969	.06170	.06893	.07640	16210.	0.0001215
00	.365	....	....	.385	133079.40	402.8	2.482	.07780	.08692	.09633	12850.	0.0001931
0	.325	....	....	.343	105592.50	319.5	3.130	.09811	.1096	.1215	10190.	0.0003071
1	.289	....	.303	.307	83694.20	253.3	3.947	.1237	.1382	.1532	8083.	0.0004883
2	.258	....	.272	.276	66373.00	200.9	4.977	.1560	.1743	.1932	6410.	0.0007765
3	.229	....	.243	.247	52634.00	159.3	6.276	.1967	.2198	.2435	5084.	0.001235
4	.204	....	.216	.220	41742.00	126.4	7.914	.2480	.2771	.3071	4031.	0.001963
5	.182	....	.194	.198	33102.00	100.2	9.980	.3128	.3495	.3873	3197.	0.003122
6	.162	....	.174	.178	26250.50	79.46	12.58	.3944	.4406	.4883	2535.	0.004963
7	.144	....	.156	.160	20816.00	63.02	15.87	.4973	.5556	.6158	2011.	0.007892
8	.128	....	.140	.144	16509.00	49.98	20.01	.6271	.7007	.7765	1595.	0.01255
9	.114	....	.126	.130	13594.00	39.63	25.23	.7908	.8835	.9791	1265.	0.01995
10	.102	.108	.112	.116	10381.00	31.43	31.82	.9972	1.114	1.235	1003.	0.03173
11	.0907	.097	.101	.105	8234.00	24.93	40.12	1.257	1.405	1.557	795.3	0.05045
12	.0808	.087	.091	.095	6529.90	19.77	50.59	1.586	1.771	1.963	630.7	0.08022
13	.0720	.078	.082	.086	5178.40	15.68	63.79	1.999	2.234	2.476	500.1	0.1276
14	.0641	.071	.075	.079	4106.80	12.43	80.44	2.521	2.817	3.122	396.6	0.2028
15	.0571	.063	.067	.071	3256.7	9.858	101.4	3.179	3.552	3.936	314.5	0.3225
16	.0508	.055	.059	.063	2582.9	7.818	127.9	4.009	4.479	4.964	249.4	0.5128
17	.0453	.049	.053	.057	2048.2	6.200	161.3	5.055	5.648	6.259	197.8	0.8153
18	.0403	.044	.048	.052	1624.3	4.917	203.4	6.374	7.122	7.892	156.9	1.296
19	.0359	.039	.043	.047	1252.4	3.899	256.5	8.038	8.980	9.952	124.4	2.061
20	.0320	.036	.040	.044	1021.5	3.09	323.4	10.14	11.32	12.55	98.66	3.278
21	.0285	.032	.036	.040	810.10	2.45	407.8	12.78	14.28	15.83	78.24	5.212
22	.0253	.029	.033	.037	642.70	1.94	514.2	16.12	18.01	19.96	62.05	8.287
23	.0226	.027	.031	.035	509.45	1.54	648.4	20.32	22.71	25.16	49.21	13.18
24	.0201	.024	.028	.032	404.01	1.22	817.6	25.63	28.63	31.73	39.02	20.95
25	.0179	.022	.026	.030	320.40	.97	1031.	32.31	36.10	40.01	30.95	33.32
26	.0159	.020	.024	....	254.01	.77	1300.	40.75	45.52	50.45	24.54	52.97
27	.0142	.018	.022	....	201.50	.61	1639.	51.38	57.40	63.62	19.46	84.23
28	.0126	.017	.021	....	159.79	.48	2067.	64.79	72.39	80.22	15.43	133.9
29	.0118	.015	.019	....	126.72	.38	2607.	81.70	91.28	101.2	12.24	213.0
30	.0100	.014	.018	....	100.5	.30	3287.	103.0	115.1	127.6	9.707	338.6
31	.00893	.0125	....	....	79.71	.24	4145.	129.9	145.1	160.8	7.698	538.4
32	.00795	.0115	....	....	63.20	.19	5227.	163.8	183.0	202.8	6.105	856.2
33	.00708	.0105	....	....	50.13	.15	6591.	206.6	230.8	255.8	4.841	1361.
34	.00531	.0098	....	....	39.74	.12	8311.	260.5	291.0	322.5	3.839	2165.
35	.00562	.0086	....	....	31.52	.10	10480.	328.4	366.9	406.7	3.045	3441.
36	.00500	.0080	.011	....	25.00	.08	13210.	414.2	462.7	512.9	2.414	5473.

TABLE V.

Single Cotton Cover				Double Cotton Cover			
Max. Dia. in Mils	Turns per Linear Inch	Turns per Square Inch	No.	Max. Dia. in Mils	Turns per Linear Inch	Turns per Square Inch	No.
472.000	1.80	3.60	0000	478.00	1.70	3.21	0000
423.600	2.08	4.81	000	429.00	2.00	4.44	000
376.800	2.38	6.29	00	384.00	2.32	5.98	00
336.900	2.72	8.22	0	342.00	2.65	7.80	0
301.300	3.07	10.37	1	307.3	2.99	9.93	1
269.600	3.48	13.45	2	275.6	3.36	12.54	2
241.400	4.00	17.33	3	247.4	3.80	16.04	3
216.300	4.52	22.70	4	226.4	4.28	20.35	4
193.900	5.05	27.22	5	207.9	4.83	25.92	5
172.000	5.60	34.84	6	189.0	5.44	32.45	6
154.300	6.23	42.12	7	173.3	6.08	41.07	7
137.500	6.94	53.51	8	157.5	6.80	51.38	8
122.400	7.68	65.53	9	142.5	7.64	64.96	9
117.900	8.55	81.22	10	127.9	8.51	80.47	10
96.740	9.60	102.40	11	112.7	9.58	101.97	11
86.810	10.80	129.60	12	94.8	10.62	125.30	12
77.960	12.06	161.60	13	80.96	11.88	156.80	13
70.080	13.45	201.00	14	73 08	13.10	190.70	14
63.070	14.90	246.60	15	66.07	14.68	239.40	15
56.820	16.60	306.10	16	59.82	16.35	300.00	16
51.260	18.20	368.10	17	54.26	18.08	363.20	17
46.300	20.20	448.00	18	49.30	19.90	440.00	18
41.840	22.60	567.10	19	44.89	21.83	528.50	19
37.960	25.30	763.00	20	40.96	23.91	634.80	20
34.460	28.60	908.80	21	37.40	26.20	762.70	21
31.350	31.00	1065.00	22	29.12	28.58	907.00	22
28.570	34.30	1307.00	23	30.60	31.12	1075.00	23
26.100	37.70	1579.00	24	28.10	33.60	1254.00	24
23.900	41.50	1914.00	25	25.90	36.20	1456.00	25
21.940	45.30	2280.00	26	23.94	39.90	1770.00	26
20.200	49.40	2711.00	27	22.20	42.60	2016.00	27
18.640	54.00	3240.00	28	20.64	45.50	2300.00	28
17.260	58.80	3841.00	29	19.36	48.00	2560.00	29
16.030	64.40	4608.00	30	18.03	57.10	2901.00	30
14.930	69.00	5290.00	31	16.93	56.80	3585.00	31
13.950	75.00	6250.00	32	15.95	60.20	4027.00	32
13.080	81.00	7290.00	33	15.08	64.30	4594.00	33
12.310	87.60	8527.00	14	14.31	68.60	5230.00	34
11.620	94.20	9860.00	35	13.61	73.00	5921.00	35
11.000	101.00	11330.00	36	13.00	78.50	6847.00	36
10.450	108.50	12960.00	37	12.45	84.00	7392.00	37
9.965	115.00	13580.00	38	11.96	89.10	8821.00	38
9.531	122.50	16670.00	39	11.53	95.00	8805.00	39
9.145	130.00	18780.00	40	11.15	102.50	11650.00	40