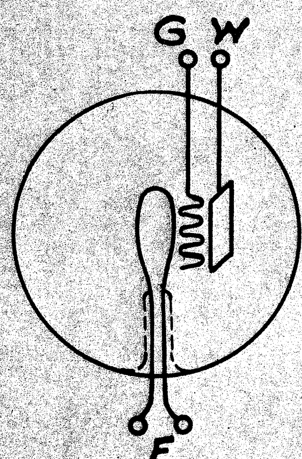
Applications of the Audion

By Paul F. Godley

THE popularity of the **audion** as a detector and amplifier is unquestioned. Yet there seems to be a general lack of familiarity among a great many amateurs with the audion and its operation, to say nothing of misunderstandings concerning its value as a detector. The misunderstandings are due in the majority of cases to lack of knowledge and to the attempts on the part of manufacturers of other detect-

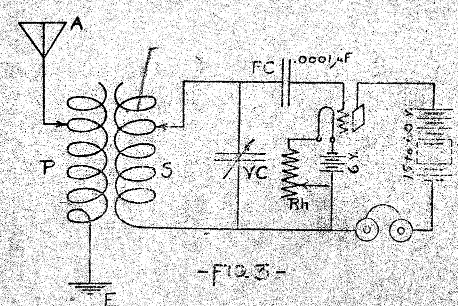
on the market, unfortunately, poor audions just as there are poor crystals of galena or silicon, but, notwithstanding, due to its inherent properties, the audion is, and probably will remain, the detector superior.



-FIG. 2-

The audion consists of a filament, a "grid," and a plate or "wing" enclosed in a bulb from which to a degree the air has been exhausted. (Figure 2) Figure 3 shows the simple audion circuit, and we have here the **combined action of rectification** and **amplification**, and it is because of this relay action that a properly constructed audion must of necessity excel any simple rectifier.

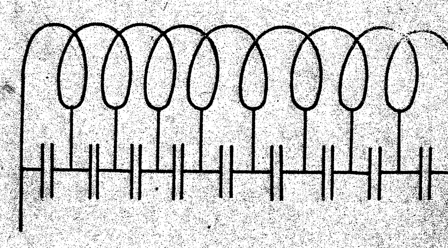
The audion is a voltage operated device. That is, the greater the potential of the charges applied to the grid, the greater will be the corresponding change in the wing circuit, or telephone currents, so that the first thing which concerns us in the selection of apparatus suitable for application in conjunction with the audion is how we



-FIG. 3-

may insure at all times under given conditions maximums of potential at the grid. In this connection it will be well to look for a moment at a certain relationship existing between the electromotive force and capacity in any oscillatory circuit.

Every electrical conductor has a certain capacity depending upon its size, its shape, and surrounding conductors. The larger this conductor, the greater the charge required to bring it to a certain potential. Hence the potential is directly proportional to the charge and inversely proportional to the capacity, or $E=Q/C$ where E is the E. M. F., Q the quantity, and C the capacity. Therefore if we have a closed oscillatory circuit in resonance with an exciting circuit and we decrease the amount of variable capacity, in order to maintain resonance we may increase the amount of in-



-FIG. 4-

ductance and by so doing we increase the E. M. F. Inasmuch as all coils have more or less distributed capacity it would be ad-

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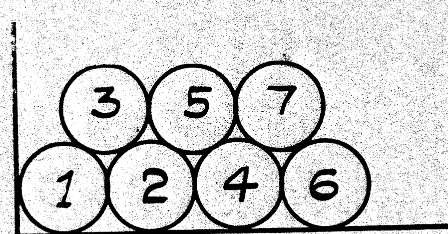
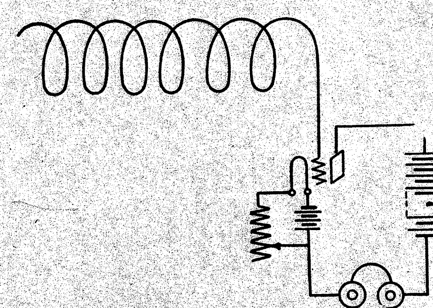
vantageous to eliminate entirely the variable capacity providing we could adopt some suitable means of continuously varying the inductance. The distributed capacity of any coil may be considered as in Figure 4. It will be noticed that the capacities between turns appear as in series with each other as far as the coil as a whole is concerned and it is therefore apparent that, providing the coil consists of sufficient turns, the value of the capacity as compared to the inductance will have fallen to a relatively small value. Mr. H. E. Hallborg, in the Proceedings of The Institute of Radio Engineers (Vol. 1, Part 2), in discussing the paper read before that body by Mr. F. A. Kolster on "The Effects of Distributed Capacity of Coils used in Radio-telegraphic Circuits" says, "The distributed capacity of two similar coils is half that of one, obeying the same law as condensers in series; and when connected in parallel, double." The exact value varies with the degree of coupling, as Mr. Kolster has stated. Hence, with a straight coil of considerable length, the distributed capacity of the coil as a whole falls off in definite proportion to the increase in coil length or number of turns." With reference to Figure 4 we see therefore that the shorter the length of the wave to be received the more important becomes the consideration of distributed capacity because of the few number of turns in the inductance. Dis-



-FIG. 5-

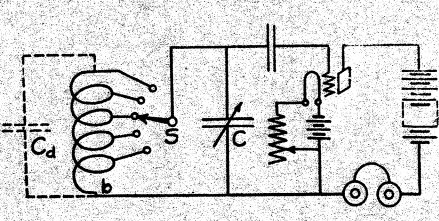
tributed capacity effects may depend upon **the cross-section of the wire used, the specific inductive capacity and thickness of the insulation, the diameter of the coil, length of tap leads, or the design and disposition of switch points.** In this connection the following will be of interest. A coil 3¼" in diameter consisting of 167 turns of No. 26 D.C.C. magnet wire had a natural wave length of 148 meters. After being shellaced, its natural wave length was found to be 186 meters. Twelve taps were taken off to switch points, and the natural wave length was found to be 222 meters. The coil was mounted as the secondary of a tuning transformer, the carrying rods being used to bring out connections, and the natural wave length had increased to 268 meters. It is quite apparent that better signals would have been obtained with this



-FIG. 6-

coil in conjunction with the audion had the coil been taken in its original form and sufficient winding added if necessary to bring its natural wave length up to the desired value. By the addition of this disadvantageous capacity the natural wave length of this coil has been raised to the point where other serious losses begin to occur when this coil is used in the reception of wave lengths in the neighborhood of the final natural wave length of the coil. These losses are known as end-turn losses and will be referred to later.

Again referring to coil design, the following may also be of interest. 118 feet of No. 28 D.C.C. magnet wire were wound on a tube 3 1-16" in diameter, and had a natural wave length of 148 meters. The same wire wound on a tube 5½" in diameter was found to have a natural wave length



-FIG. 7-

of 180 meters, and when this same wire was wound on a tube 9" in diameter it was found to have a natural wave length of 244 meters.

	Diameter in inches	Length in inches	Number of turns	Measured Natural Wave Length in Meters	Calculated Inductance in Microhenries	Calculated Capacity in Microfarads
(1)	3 1-16	3.13	150	148	1520	.00000406
(2)	5½	1.67	80	180	1850	.00000493
(3)	9	1.08	50	244	1675	.00000997

No. 28 D.C.C. Magnet Wire — 48 turns per inch

$$L = \frac{2\pi^2 A^2 N^2}{BK}$$

A = Radius
N = Number of turns
B = Length
K = A Constant

Values of K
Coil (1) 711
Coil (2) 414
Coil (3) 230

It might be well to add that multilayer coils, that is, coils of more than one layer of wire, are entirely out of the question for short wave work, and usually should not be used in any case unless some special means is taken to reduce the capacity effects encountered. Figure 5 shows a method sometimes employed when multilayer coils are desired for their economy of space.

In general, for the best results it is far better to use separate pieces of apparatus than to attempt the assembly of a complete receiver in a small cabinet. Such a compact arrangement usually entails a maze of connections, braces of conducting material, various complicated mechanisms, etc., etc., all of which tend to decrease the efficiency due to counter inductive effects, resistance losses at various switch points, and above all losses resulting from undesirable capacity, for even the mere presence of conducting bodies in proximity to the audion circuits may result in a surprisingly great decrease in signal strength.

It is readily seen that the more sensitive the detector, the more apparent becomes a given percentage of lost energy and the more apt is the presence of lost energy to become noticeable. Using an audion it is a very easy matter to show the marked presence of high frequency resistance losses, leakage due to poor insulation, and above all, end turn losses in about 99% of the radio apparatus manufactured, and especially that on the market for amateur use. In many cases those losses aggregate apparently as high as 80% on certain wave lengths, and on wave lengths usually used for amateur communication, 50% loss appears to be quite the rule. Inasmuch as the restrictions to which amateurs are subject in the operation of transmitting apparatus limit to a very great degree the range to be covered with a given power, the importance of loss elimination in the receiver can not be overestimated. The radio frequency dealt with on a wave length of 200 meters is 1,500,000 cycles per second. Ten meters of No. 22 copper wire has a resistance of .431 ohms for direct current, but for an oscillatory current of a frequency of 1,500,000 cycles the resistance of this same length of wire has increased approximately ten times due to the fact that the "skin effect" which takes place in the wire allows the passage of the high frequency current on, or very near, the surface of the wire only. The high frequency resistance of a wire may be decreased by increasing the amount of surface, and this may be done without necessarily increasing the diameter by the use of a stranded wire, or a strand of wires wherein each wire is insulated from its neighbors. Such a conductor consisting of fine enamelled wires is known as "Litzendraht" and may be used to advantage on waves above 700 or 800 meters but recent developments tend to show that stranded conductors are of questionable advantage in connection with the higher frequencies. "Litzendraht" may be purchased on the market, or those to whom the price seems prohibitive may do well to purchase D.C.C. magnet wire, say No. 36 or No. 38, and braid or twist it themselves. This may be done quite conveniently by stretching 30 or 40 wires between two supports, and twisting them by the use of an eye-bolt secured in the chuck of a small hand drill.

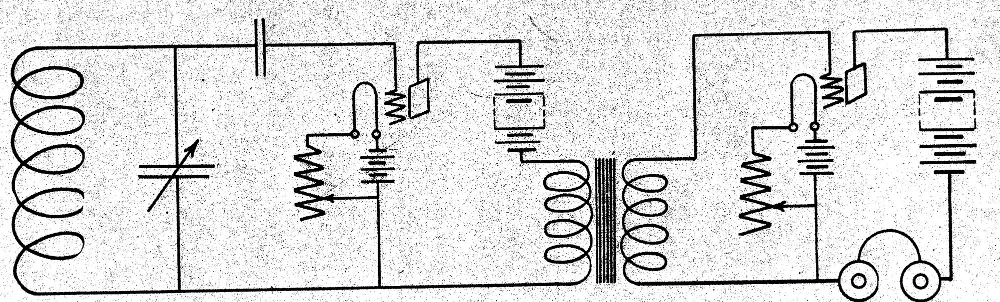
Resistance leakages are encountered in coils used for receivers due to the coloring matter used in insulations or to the presence of moisture in the insulation. Wire having colored insulation may be avoided to distinct advantages and every effort should be made to exclude all moisture from windings and their supports. When paper or cardboard tubes are used in the construction of inductances, they should be thoroughly dried out by placing them in a warm, dry room for several days or, baked in an oven at not too high a temperature. The tube should then be well shellaced. It is advisable to purchase shellac in bulk and mix with 95% alcohol as the lower grades of alcohol contain a great percentage of water. After the tube is thoroughly dried and wound, care should be taken that all the moisture which may possibly be in the insulation of the wire is expelled, after which the whole coil is covered with a thin coat of shellac; a second coat being added later if desired.

The natural wave length of any coil of wire may be determined by connecting as in Figure 6 and exciting the coil with a wave meter. It will be found that the wave length at which the greatest response is obtained is quite sharply defined. Due to the distributed capacity of the coil it is in itself an oscillatory circuit and acts as such immediately upon its excitation by a circuit with which it is in resonance.

Take the coil mentioned in connection with the discussion of distributed capacity and utilize it in a receiver, as in Figure 7. It is desired to tune to an incoming signal at a wave length of 275 meters. It is possible to use less than half of the coil for this purpose and, as a result, two oscillatory circuits exist—the circuit comprised by the inductance b to s and the condenser C responding to 275 meters, and the circuit comprised by the entire inductance and the capacity Cd (distributed capacity) responding to 268 meters. Due to the slight difference between their periods of vibration a division of the energy between the two circuits is unavoidable, the energy loss to the detector being governed by the percentage of difference between the periods of the two circuits. It will also be quite apparent that, since circuits having two distinct periods of freedom are here dealt with, the damping of the receiver at will result. Short circuiting is however detrimental under certain conditions and for the best work should not be depended upon. In case it is desirable to utilize this method means should be provided for shortcircuiting the overhanging turns when their number is great, the "short" to be lifted as soon as their number falls below say one quarter of the total turns in the coil.

The simplest method of eliminating this "end-loss effect" is to short circuit the unused portions of the receiving coils. A marked improvement of signals in the neighborhood of the affected wave lengths certain wave lengths will be extremely great and hence, the selectivity of the system as a whole quite materially lessened.

A second method of eliminating the end-turn losses lies in the provision of means for a division of the coil into sections and a switching device so arranged as to connect or disconnect the sections automatically as required. (See Figure 4, page 160, July 1916 Number of "QST"). It should be remembered that the arrangement of these sections must be such that the natural periods of vibration of the coil or coils present are at all times well removed from the wave length being received regardless of the value of such wave length. In the construction of a receiving tuner of sufficient size to properly cover wave lengths between say 200 and 3000 meters, it is hardly practicable to divide the coils into small sections such that the natural wave length of each section is well below 200 meters. It is possible however to cut the number of divisions down to five or six with careful study and painstaking experimental work with the wave meter. It might be well to call attention to the fact that end-losses may occur in both the primary and secondary coils of the receiving tuner and that, where a series condenser is used in the primary circuit, it should always be placed between the antenna and the receiving transformer since otherwise the natural wave length of the primary inductance in conjunction with the antenna may easily exceed the safe limit.



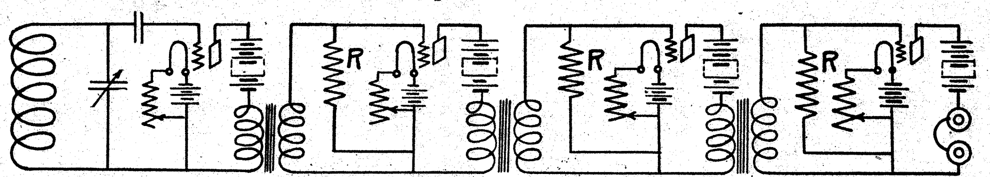
-FIG. 9-

A very simple method of preventing end-turn losses is one wherein separate inductances are employed for different ranges of wave length. The proper size of these coils may be very easily determined by means of a wave meter.

These inductances may take the form of variometers and to a decided advantage for, in this form, no necessity is found for tap off connections and since a continuously variable inductance is had the variable capacity element may also be eliminated from the circuit. For short wave reception the variometer, once used, will be found to be indispensible, inasmuch as capacity loss due to decreased voltage and end-turn losses have been eliminated as far as it is possible to do so in a practicable manner.

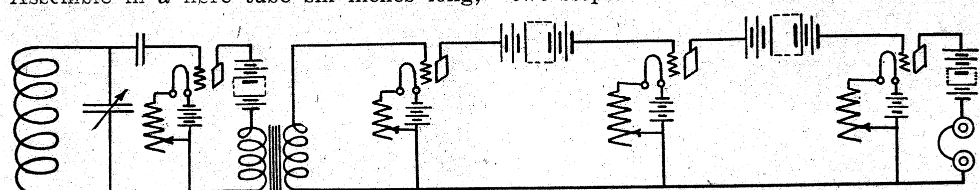
One very interesting application of the audion is found in the form of the Audion Amplifier (Figure 9) wherein the audion is used as a relay. A step-up transformer is provided, the primary of which is substituted for the telephones in the circuit of the first detector, the outside end of the secondary being connected directly to the grid of the amplifier audion. The filament of this audion is then connected to the primary of the transformer, or if two audions are being used and both lighted from the same battery, no connection at all need be provided at this point. It is possible to go further and use a second and third step (Figure 10) in the process of amplification. It will be found disadvantageous however to go further than a third step because of the interactions between the amplifier circuits resulting in a continuous whistling sound in the telephones. Resistances marked R in Figure 10 may consist of a few lead pencil marks on pieces of paper, the weight of the marks being varied as desired. This high resistance leak tends to prevent the whistling sound mentioned above.

The construction of a very good step-up transformer for this purpose is described by Stanley and Camp in the 1916 Year Book of The Radio Club of America as follows. "Assemble in a fibre tube six inches long, one inch outside diameter and seven-eighths of an inch inside diameter, a bundle of number 22 or smaller, double annealed iron wire. If the wires are all cut the length of the fibre tube and packed in as tightly as possible a good core will be had upon which should be pressed two fibre heads, each 3¾" square and ½" thick. These heads must be so placed that there will remain a clear winding space of 4¾". In this space is wound a primary which will consist of 36 layers of No. 34 S.S.C. magnet wire, each layer being separated from the next by a layer of paper .005" thick. On top of the primary wind sufficient good quality paper to form a layer .025" thick. The secondary should consist of 50 layers of No. 38 S.S.C. magnet wire, each layer having the same separating paper as the primary layers. It is important that the leads from the two windings be brought out at the proper places. Care should be taken to connect the coil in properly as the primary of the coil can not be used as the secondary with any degree of success."



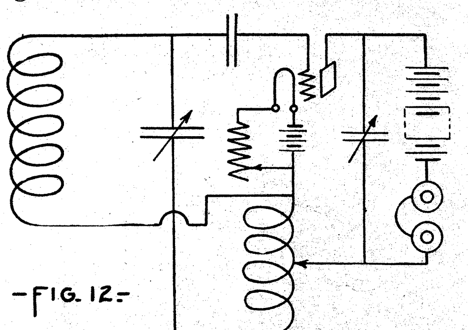
-FIG. 10-

Figure 11 shows an arrangement of audion detectors originated by Professor G. W. Pierce of Harvard University. An audion amplifying transformer as described above is used between the detector and the first amplifier audion. The battery current in the wing circuits of the remaining audions is increased until ionization of the gases in the bulbs occurs, i.e., until the blue glow appears. A very careful adjustment of this arrangement will give wonderful amplification, probably somewhere in the neighborhood of 1,000 times. This adjustment is difficult however and the critical condition of the audions comparatively hard to maintain especially, when less than three steps are employed, although the writer has occasionally secured excellent results with but two steps.



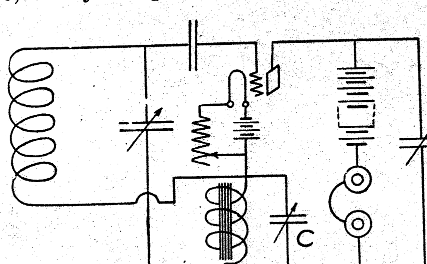
-FIG. 11-

If the wing circuit of an audion is sufficiently coupled either electro-magnetically or electro-statically to the grid, or closed oscillatory circuit of the audion, and if a charge is placed on the grid thereby interrupting the existing flow between the filament and the plate, the resulting pulse of current in the wing circuit will be repeated by means of the coupling back into the grid circuit. The grid condenser will then again receive a charge, which it delivers to the grid and the phenomenon again takes place, and will, providing the adjustments are proper, continue to do so indefinitely, and at a frequency usually dependent upon the time period of the closed oscillatory circuit. If the closed oscillatory circuit is tuned to an antenna, and this system placed in resonance with an incoming wave, it is readily seen that, inasmuch as the resultant pulse of current in the wing circuit is many times greater than the initial charge thrown on the grid, and since the wing circuit current may be repeated back into the grid circuit in exact phase with the incoming oscillations, a reinforcement or amplification of the received signal may result, the degree of amplification depending upon the radio frequency of the received wave. In this condition the audion is oscillating or generating a continuous oscillation.



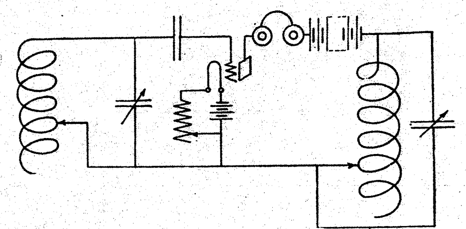
-FIG. 12-

It is impossible to receive a continuous oscillation with a plain rectifier due to the fact that the received currents are of such frequency as to be inaudible to the human ear. However, inasmuch as a generator of continuous oscillations is had at the receiving station advantage may be taken of the "heterodyne" method of reception for undamped waves. Reception by this method is accomplished by the production of beats at an audible frequency between the wave being received and the wave generated at the receiving station. For example, assume that an incoming wave has a frequency of 200,000 cycles per second. Now there is



-FIG. 13-

produced in the receiving circuit an alternating current with a frequency of, say, 199,000 cycles. The result is a "beat" frequency, dependent upon the difference between the two frequencies present, which in this case is 1,000 cycles per second, an audible note. Since the audion then acts as a generator, rectifier, and amplifier, by

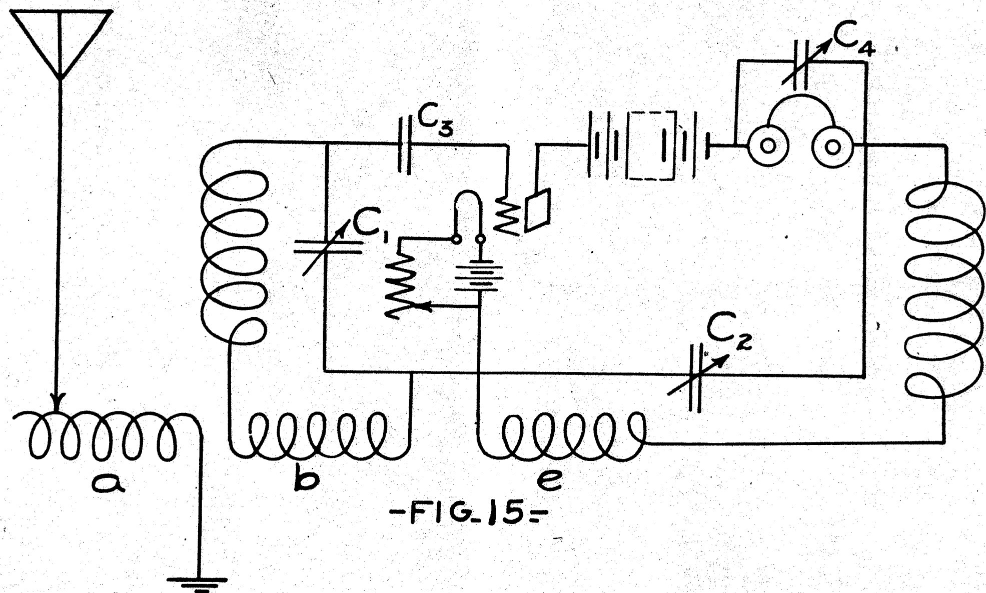


-FIG. 14-

its use, either damped or undamped waves may be received and amplified.

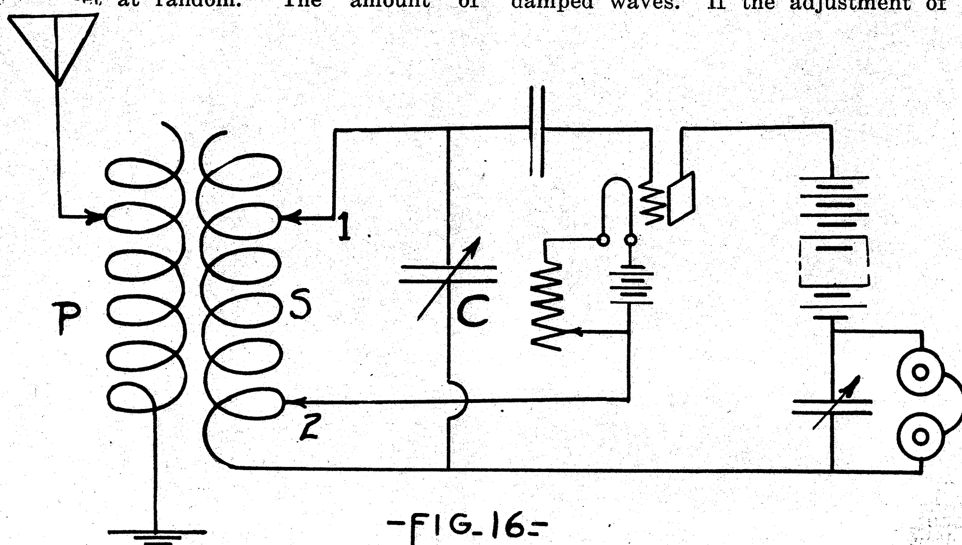
Figures 12 and 13, respectively, show electro-magnetic and electro-static coupling between the grid and wing circuits. In Figure 12 the coupling consists of an auto-transformer. It may consist of an **inductively** coupled transformer and, as is apparent, the proper degree of coupling between the two circuits may be obtained by variation. In Figure 13 the coupling consists of the condenser **C**, shunted by an iron core choke coil, which permits the passage of direct current only. This is the so-called "ultraudion." Figure 14 shows an oscillating system wherein no coupling is provided other than the small amount offered by the audion itself. Here the wing circuit is tuned to resonance with the grid circuit, the energy being transferred as above suggested through the coupling provided by the audion. This elimination of external coupling however often renders the circuit difficult of operation especially on the longer wave lengths. The writer prefers the method as shown in Figure 15. Coils **a**, **b**, and **e** are so arranged that **e** slides into **b**, and **b** into **a**. Their length may be of the order of 8" and their diameter about 4" or 5". They should be wound with No. 28 S.S.C. magnet wire. Taps are provided about every ¾" and a loading coil and suitable variometer should be used in conjunction with coil **a** for tuning the antenna. The loading coil (not shown) should consist of a tube 6" in diameter and 14" in length wound with No. 28 D.S.C. magnet wire. The condensers C1, C2, and C4 should have a capacity of about .001 microfarads. C3 is comparatively very small, its maximum capacity being that of C1 with pointer on 10° scale mark.

A simple and very good method is shown in Figure 16. Here **S** may be a tube 7" in diameter and 14" in length wound with No. 28 D. S. C. magnet wire. **P** may be a coil 6" in diameter and 8" in length wound with No. 24 D.S.C. magnet wire. On coil S taps should be taken off every ¾" to accommodate switch No. 1, and about every ¼" for a distance of 3" from the lower end of the coil for the accommodation of switch No. 2. The range of this system will lie between approximately 2,000 and 15,000 meters where the capacity of C is of a maximum value of .001 microfarads.



-FIG.15-

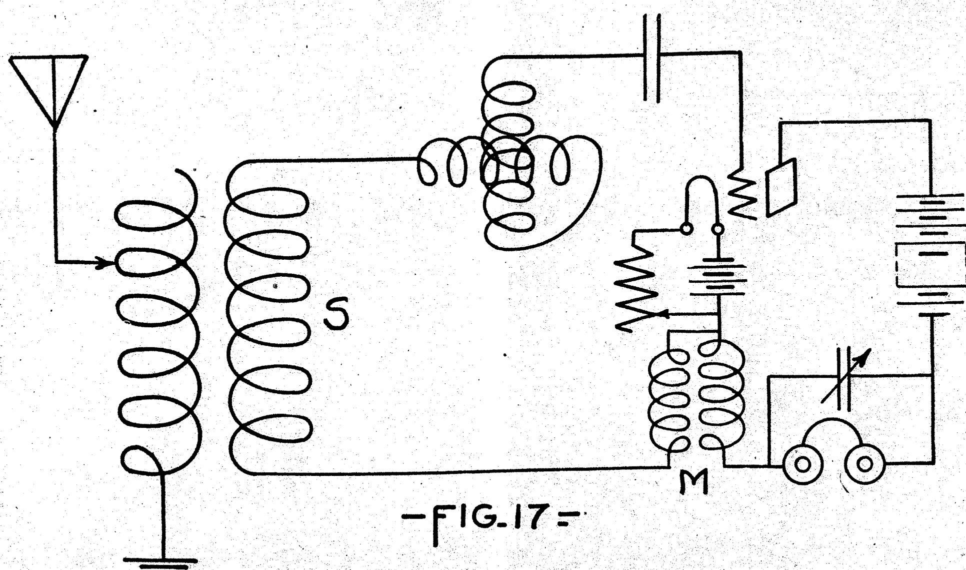
Inasmuch as the peculiarities of operation of these arrangements are the same throughout, an outline of the procedure with reference to Figure 16 will suffice for all. The value of inductance and capacity in the grid or closed oscillatory circuit of Figure 16 is set at random. The amount of inductance common to both the wing and grid circuits is increased at switch No. 2 until a howling noise is heard in the telephones. This sound may be quite loud and disagreeable. The common inductance should then be decreased until this sound ceases, at which time the audion should be oscillating. By adjusting the antenna inductances, a point will be found where a hiss is heard and reaches a maximum. At this point the entire system is in resonance. This hissing sound is due to the shock excitation of the system by infinitesimally small atmospheric disturbances or stray damped waves. If the adjustment of the secondary tuning condenser now be varied, it will be found that the oscillations of the audion may be stopped or started at will



-FIG.16-

and that their stoppage is accompanied by a rather muffled click in the telephones. The system as a whole may be gradually swung from 2,000 to 15,000 meters and kept at all times in resonance. Hence, any stations which happen to be working within range may be logged for future reference. Both damped and undamped waves may be received on these systems. The damped (spark) waves however, will come in with a hiss, that is, their natural spark tune will not be apparent. By decreasing the amount of wire common to the wing and grid circuits, a point will be reached where the audion ceases to generate, and at this point the natural spark tone of the station will be apparent. However, in this condition the audion still continues the repeating action and amplification results. Close adjustment of grid-wing circuit coupling is necessary for the best results.

Figure 17 shows a circuit applicable to the shorter wave lengths, that is, below 2,000 meters. It will here be noticed that the secondary tuning condenser has been dispensed with, all the tuning of the secondary or closed oscillatory circuit being accomplished by the variometer. It will be necessary to provide at least three variometers, each wound with different sizes of wire, to cover the range from 200 to 2,000 meters. The secondary circuit is coupled to the antenna circuit by means of the coil which may consist of 50 turns of No. 22 magnet wire wound on a tube 4″ in diameter. The two coils comprising the coupler M, for coupling the wing and grid circuits, may also be approximately this size, except that one should slide within the other. Direct coupling may be used at this point, but with a smaller measure of success due to the impossibility of getting as close an adjustment of the coupling, and it may also be found advantageous at certain wave lengths to resort to tuning the wing circuit by the insertion of variometers. Great pains should be taken in the assembly of apparatus for the reception of shorter wave lengths by these methods and care should be taken to eliminate all end-turn and similar effects, inasmuch as the presence of additional frequencies due to overhanging ends or nearby oscillators may make these circuits at the higher frequencies absolutely inoperative.



-FIG. 17-

The Possibilities of A Spark Coil

By M. A. Herzog

The article on the "spark coil amateur" by Mr. Felix which appeared in the July issue of "QST" was interesting, and the writer heartily agrees with him that some space should be given in the magazine to assist those who use them.

Since the advent of the transformer the spark coil has been regarded by many amateurs as a toy incapable of serious work. This is a mistaken impression. The induction coil, while rather inefficient as an electrical instrument, is remarkably efficient in radio work, since greater distances per watt input can be covered with an induction coil, than with a transformer. Some personal experiences in this line may be of