

RADIO RECEIVING EQUIPMENT*

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This paper is intended to discuss questions of design of those types of receiving apparatus which are adapted for reception over a limited range of wave length, and which depend for their operation on such manipulation as can be successfully carried out by persons entirely unfamiliar with the technique of radio apparatus. Their principal field of application is the reception of broadcast radio telephone signals.

Among the many requirements which an ideal receiver of this class should fulfil are that:

(1) It should tune in the wave length desired with only simple adjustments, which should not interact on each other. With a signal of normal audibility from a desired station, the signal strength from another equal or possibly more powerful station, separated by ten thousand cycles, should be below audibility.

(2) Its sensitivity should be such that its range will be limited by static interferences, fading, and so on, rather than by actual lack of response. Any local sources of power necessary for its operation should require infrequent attention.

The first-mentioned requirement, which may be termed selectivity, is more or less fulfilled by giving the receiver a characteristic in which its impedance to the desired band of wave length is very low in comparison with its impedance to the wave length above and below this band.

The curve in figure 1 shows the relation of admittance to wave length in a simple oscillating circuit which has the constants of the antenna ordinarily used and which is tuned to a definite wave length by the addition of a variable inductance.

An examination of this curve shows that, altho the maximum signal is obtained for the wave length to which the circuit is tuned, appreciable response is given to wave lengths differing considerably from those for which it is in resonance.

*Received by the Editor, September 24, 1922. Presented before THE INSTITUTE OF RADIO ENGINEERS, New York, October 4th, 1922.

In order to obtain the desired selectivity, it is necessary considerably to increase the time constant of this circuit. This result can be accomplished in one or both of two ways: namely, by increasing the inductance element with a corresponding reduction, of capacity or by decreasing the effective resistance by regeneration.

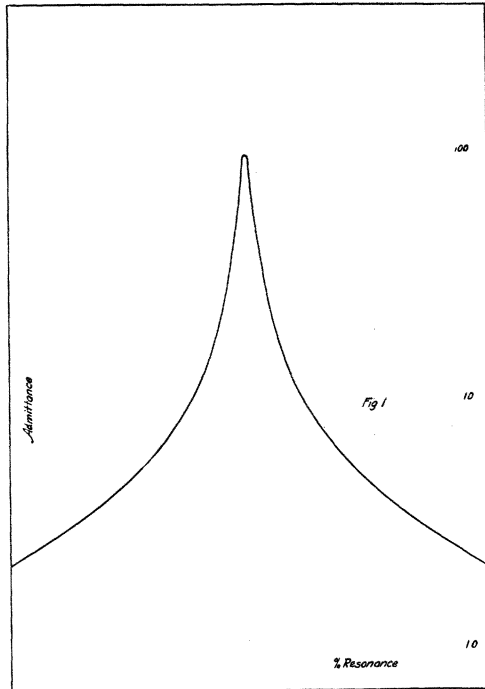


FIGURE 1

The curve in Figure 2 shows the effect of placing an additional capacity of 25 micro-microfarads in series with the circuit with a corresponding increase in inductance to bring the circuit in resonance with the same wave length as under the first condition. It will be noted that the selectivity is very considerably improved.

In the case of a vacuum tube detector, which is nominally a voltage-operated device, the large inductance implies a correspondingly large voltage available for operation of the detector, with the resultant increase in signal strength. In the case of the crystal detector, the maximum signal strength is obtained when the effective resistance due to the detector is equal to that of the balance of the antenna circuit. It therefore should be connected

across such part of the inductance as will give the best compromise between selectivity and sensitivity.

The use of the regenerative vacuum tube offers the further possibility of increase of selectivity with the additional advantage of a very marked increase in sensitivity.

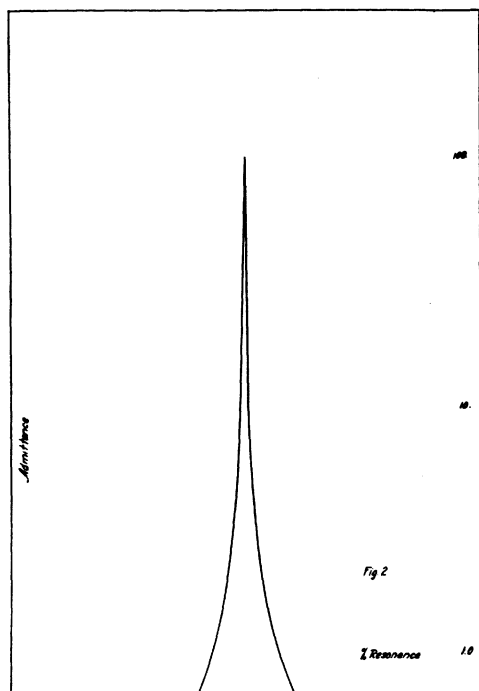


FIGURE 2

The curve, Figure 3, shows the relation of admittance to wave length of the same circuit as that for Curve 2, with the exception that the resistance element is assumed to be one percent of that in Figure 2. This is an amount of regeneration which can readily be obtained. The ordinates of this curve are drawn to a scale one hundred times that of Figure 1 and 2, and it might be assumed that the signal strength would be one hundred times that which would be obtained from the circuit of Figure 2. This condition does not necessarily follow, owing to the fact that there is a definite limit to the component of antenna current which is proportional to the incoming signal.

This condition may be illustrated by the diagram, Figure 4. In this diagram, *O E* represents the incoming signal field affecting

the receiving antenna. Should the impedance of the receiving antenna circuit be infinite, the voltage induced in this circuit will be in the phase OC . For finite values of resistance impedance in this circuit, the current will be bounded by the circle OBA . Thus, for a given value of resistance impedance, the current will be represented by the line OB . The field surround-

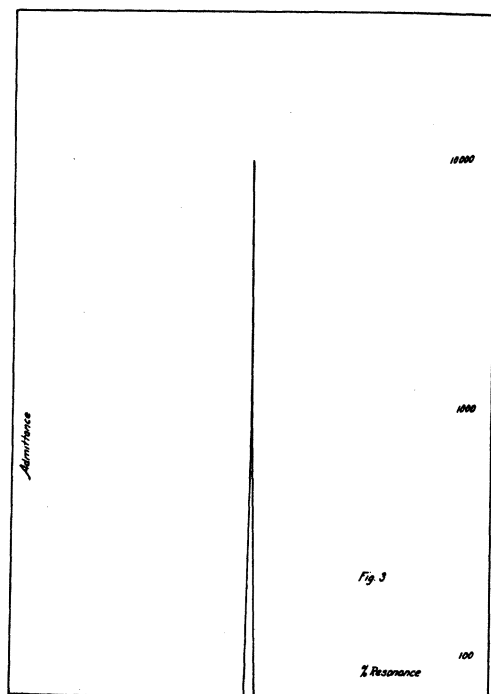


FIGURE 3

ing the antenna due to this current will have the same phase and relative length, and the total effective field will be the sum of OE and OB , or OD . For zero resistance the current will have the phase and relative length OA , with a zero resultant field. Further consideration will show that this ultimate received antenna current is independent of the height of the antenna, provided all sections of its length are affected by the same field intensity, it being dependent only upon the field per unit length.

The antenna therefore may be considered as a constant voltage generator, having a definite internal impedance, which is proportional to antenna height. This generator supplies a load circuit having the constants of the oscillating circuit.

In the case of a regenerative system in which the regeneration is carried out to such an extent as to produce oscillations, the current due to the incoming signal will be super-imposed on the local current, and have a value dependent entirely upon the effective resistance but independent of any local oscillating current.

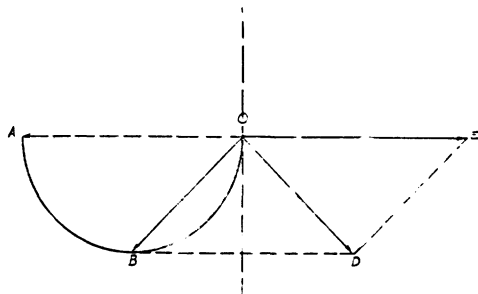


FIGURE 4

Figure 5 shows the conditions determining the resistance of the antenna circuit under the oscillating condition. In this curve the line G shows the relation of voltage impressed on grid terminals to the oscillating component of plate circuit. Curve P shows the oscillating component of plate circuit set up by this impressed grid voltage. From this curve it will be seen that, once the oscillations are started, they will increase to a point where the curve P intersects the line G . The effective resistance of the antenna circuit is determined by the relation of the angle of this intersection to the angle of G with the base. In actual practice, it is possible to reduce the angle of intersection at this point to such a value that the antenna current due to incoming signal will closely approach the ultimate value. Any possible increase of the sensitivity is therefore limited to an increase of the inductance across which the detecting circuit is connected. The extent to which this increase can be carried out is largely a matter of design.

The limitation of sensitivity due to ultimate antenna current also imposes an apparent reduction in selectivity and is a feature which usually is not considered in the discussion of the oscillating circuit.

Referring to the curves, Figures 2 and 3, these show the characteristic of simple circuits made up of capacity, inductance

and resistance. In the case of an actual antenna circuit, it has been shown that there is, in addition, a limiting impedance which is proportional to the height. In the consideration of the sharpness of tuning of the antenna circuit, it is necessary to consider this limiting impedance in addition to the actual impedance of the oscillating circuit. Therefore, the actual increase of sharpness of tuning which can be obtained by regeneration is largely determined by this limiting impedance, or, in other words, by the antenna height.

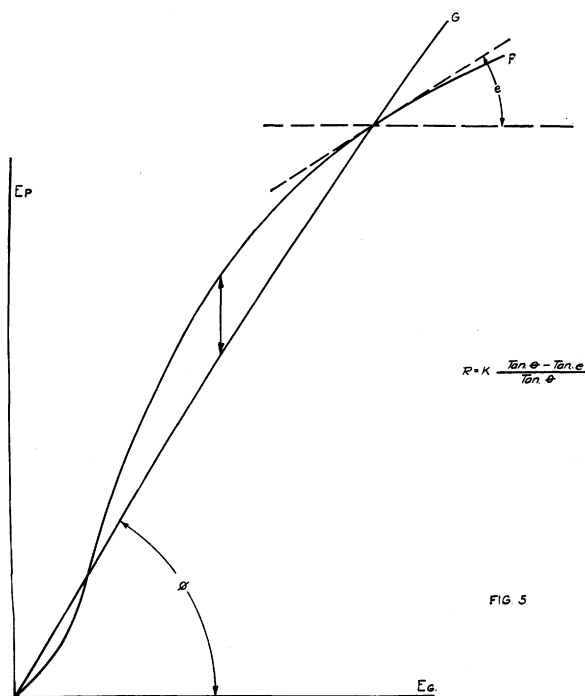


FIGURE 5

In Figure 6 are shown two curves taken with similar receiving sets, but on antennas of different heights. The left-hand curve is from a single-wire, inverted-L antenna, having a height of 35 feet (10.6 m.) above ground, and a length of horizontal portion of 75 feet (23 m.). The right-hand curve was taken from an antenna having a height above ground of 15 feet (4.6 m.), the length of horizontal portion being the same. The same receiver was used in each case.

These two curves show the very great increase of selectivity to be obtained by the use of the low antenna. In fact, the in-

crease is considerably greater than would be expected from consideration of the comparative heights of the two antennas. It is probably accounted for by the condition that the effective height of the lower antenna is a considerably smaller percentage of its actual height than in the case of the higher antenna, owing to the indefinite height of the ground connection which was made to the hot water heating system, thus giving an effect equivalent to raising the height of the actual ground.

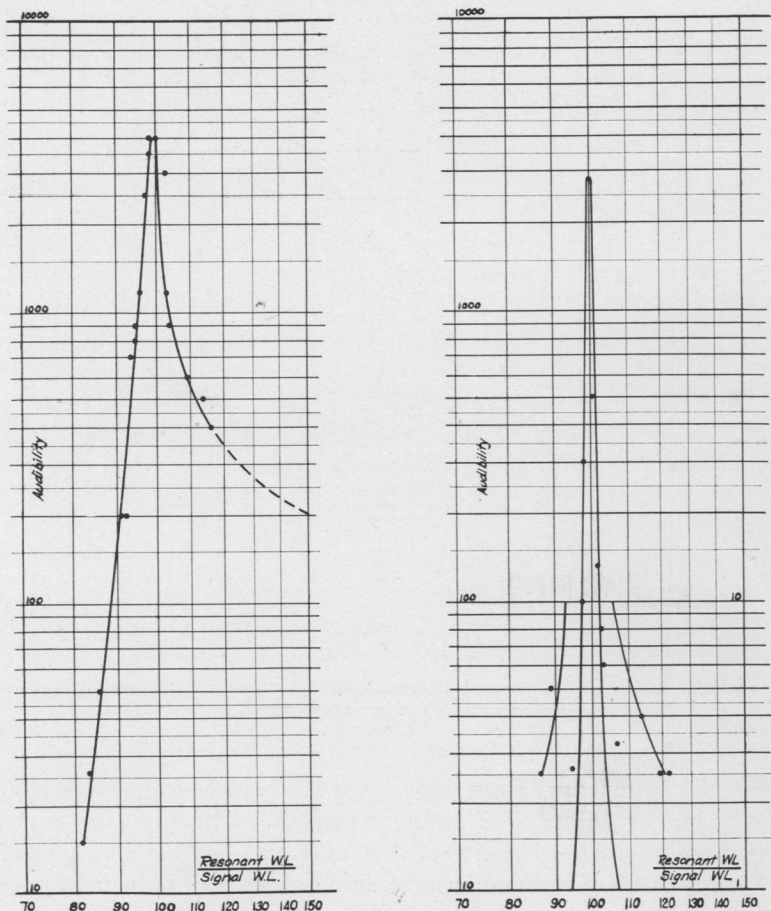


FIGURE 6

Due to the absorption by objects on or near the ground, it is usually impossible to realize completely the condition of equal signal strength with low as with high antenna, and of course the

possibilities in this direction depend on the surroundings of the antenna in question.

Under conditions in which the reduction of signal strength with height is due, as is often the case in thickly built-up districts, to the appreciable absorption near the ground, it is possible to improve the selectivity of the antenna by the use of a coupled secondary circuit in the receiving set. If another resonance circuit of the same constants were connected to the output circuit of a vacuum tube amplifier connected to a resonance circuit having the constants corresponding to that of Figure 2, the characteristic of this double circuit would be proportional to the product of the characteristic curves, which, it is evident, would give a very greatly increased selectivity.

This arrangement constitutes the ideal method of improving the selectivity of a receiver. If, in place of the relay coupling between the oscillating circuits, a direct coupling were used, the relation of the secondary to primary would, in a sense, be a duplicate of that existing between primary and the transmitter, with the equivalent antenna height of secondary corresponding to the looseness of coupling, thus permitting the possibility of a receiver connected to a high antenna and with the selectivity of a low one. However, the extent to which this can be carried out is limited by the fact that, as the apparent secondary antenna height is reduced by reduction of coupling, the reduction of primary resistance by regeneration is also reduced, with a corresponding limitation of ultimate secondary signal current and its attendant reduction of selectivity.

Owing to the difficulty of carrying out the necessary interacting adjustments, the use of a coupled circuit receiver is justified only under those particular conditions in which it is not possible to take advantage of the selectivity of the low antenna.

A further possibility towards the solution of the receiver problem for congested districts is the use of a closed coil or loop in place of an open antenna. The loop receiver will have the advantage that, similar to the short antenna, it embraces a limited field area, and at the same time can usually be placed sufficiently above ground level to be in a somewhat denser field than would be the case with a corresponding short, open antenna. The limiting impedance of the loop is comparatively low, but as the induced signal voltages are also low, it is necessary that a regenerative system be used in order to obtain the benefit of selectivity. It, of course, has certain possibilities of eliminating interference, due to its directional properties. In general, the

loop receiver under its best conditions, will give results which are practically identical with those obtained from a receiver connected to a properly proportioned, open antenna, barring, of course, the possibility that the relative position of the interfering station may be such as to permit of advantage being taken of the directional effect. It has the advantage of convenience of installation and of not being restricted to location as regards height where the field density may be low. However, the first cost and maintenance expense of such a receiver are far greater than those of the equivalent regenerative set on an open antenna, and for these reasons, cannot, at the present time, be considered as a real competitor of the open antenna receiver.

The foregoing conclusions in regard to the conditions effecting selectivity are based on the premises that the receiver is used for the reception of modulated continuous wave signals and that the interferences to be dealt with are those set up by similar transmitters.

In the case of interference resulting from atmospherics, or static, the particular precautions which would minimize interference from other transmitters would have insignificant effect, and at the present time there is no practical scheme which gives any appreciable reduction of interference from static.

In the case of interference from damped wave transmitters, the effects will lie between the conditions of a modulated continuous wave signal and static, the similarity to one or the other being determined by the decrement of the interfering signal.

In the case of the usual amateur spark transmitter, which is the one most likely to set up the interference, the conditions will be not far removed from those governing the effects of static, owing to the usual high decrement of these transmitters.

The solution of the problem of interference from this source should be in the direction of elimination of the spark transmitter by the substitution of continuous wave sets, rather than by any receiver development, owing to the actual great width of wave band covered by even the best type of spark transmitter.

The one serious defect of the regenerative receiver is the interference it can produce on other receivers due to radiation when regeneration is carried to the oscillating point. The intensity of this radiation can be controlled to a certain extent by the antenna circuit constants and the constancy of regeneration of the receiving set with various wave length adjustments.

With increase of the inductance element in the antenna circuit, the antenna current for a given voltage applied to a receiving

tube is correspondingly reduced, with attendant reduction of interference; and, with constancy of regeneration with varying wave length adjustment, the possibility of the set producing strong oscillations during the tuning operation will be reduced. This latter feature has considerable bearing on the system of regeneration which it is advisable to employ.

The mechanism of regeneration implies a coupling between anode circuit of tube and oscillating circuit, such that any fluctuations in anode current sets up corresponding oscillations in the oscillating circuit, and of such phase relation as to reinforce the original oscillations which had acted on the grid of the tube. This coupling may be electro-magnetic or electro-static.

In the electro-magnetic coupling a coil which is in series with the anode circuit is so disposed that its field embraces more or less of the inductance in the oscillating circuit.

With the electro-static coupling, advantage is usually taken of the capacity between grid and anode elements of the tube and its connections. When the impedance of the anode circuit is altered by a varying grid potential, corresponding potentials are induced on the grid element thru the capacity of tube and connections. When the grid is connected to a resonant circuit and the impedance in the anode circuit is principally a resistance, the phase relation of induced potential on grid thru anode is 90 degrees displaced from the original controlling potential of the grid. An inductive reactance in the anode circuit so shifts the induced potentials that it assists or adds to the grid controlling potential. A capacitive reactance so shifts the phase relation that the induced charge on the grid subtracts from the original controlling potential. Therefore, by incorporating a variable inductance in the anode circuit, the amount of regeneration can be controlled at will.

The inductive coupling method of regeneration possesses the advantage that when the anode coil is coupled to the variable inductance which controls the wave length of the oscillating circuit, the amount of regeneration remains practically constant over an extended wave length band. In the case of the capacitive coupling, both the effect of capacity between anode and grid circuits and the effect of inductance in the plate circuit vary with change of wave length. The regeneration, therefore, requires readjustment with each readjustment of wave length of the set. For this reason the operation of tuning-in a signal is more complicated. The inductive coupling method, however, requires proper proportioning of the relation between coupling

coil and tuning inductance, while the capacitive coupling merely requires the insertion of a variable inductance in the anode circuit and the necessary by-pass condensers to shunt the radio frequency fluctuations in this circuit around inter-tube transformers or telephone receivers. For this reason, this arrangement has been a great favorite with radio experimenters as well as manufacturers of receiving apparatus, who have merely assembled conventional parts in a containing case.

From the standpoint of interference produced by the receiver, therefore, the inductive coupling method is considerably superior to the capacitive coupling, owing to the fact that the coupling can be set at some value below the oscillating condition, which it will maintain thruout the whole range of wave length adjustment. The degree of regeneration which can be obtained over the whole range without oscillations occurring at any point is, of course, dependent upon the excellence of design of the set. In case of the capacitive coupling, as the degree of regeneration increases at a very rapid rate with decrease of wave length setting, it is necessary, in order to obtain any appreciable regenerative effect, that simultaneous adjustment of anode inductance be made with adjustment of wave length.

The design of the oscillating circuit tuning elements of a receiver is largely determined by the range of wave length desired and in the regenerative scheme employed, if any. The inductance or capacity elements alone may be variable, or, to obtain a greater range of wave length adjustment, they may both be variable.

When the inductive coupling for regeneration is employed, it is usually desirable that at least the inductance element in the oscillating circuit be varied for adjustment of resonant wave length, as by this means the proper coupling between the resonant circuit inductance and the feed-back coupling coil for constant regeneration at various wave lengths can be obtained.

In Figure 7 is shown the interior of a typical regenerative receiver, using inductive coupling for regeneration, and simultaneous variation of both inductance and capacity for wave length adjustment. This receiver covers a comparatively long range of wave length with one continuous adjustment, and in order to compensate for the comparatively small angle of adjusting of the knob which will carry a heterodyne note thru the audibility range, it is fitted with a so-called "vernier" condenser, consisting of a small single plate variable condenser in parallel with the

main tuning condenser. The total range of this condenser is made equivalent in wave length change to a few divisions of the main tuning dial. This receiver is normally intended to be used as a single circuit set. However, for conditions surrounding the antenna under which it is not possible to realize the necessary selectivity, it can be used as a tuned coupled circuit set by using a separate primary tuner, as shown in Figure 8 the secondary tuner being merely short circuited on itself.

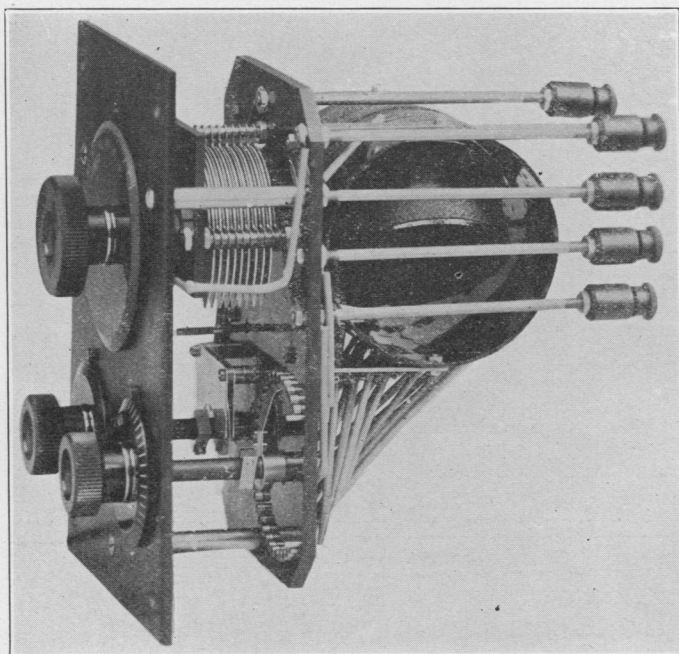


FIGURE 7

When the boxes containing the two elements are placed side by side, they give about the proper coupling for usual operating conditions. As the coupling is between the variable inductances, these can be proportioned so that they maintain the proper coupling value over the whole range.

In Figure 9 is shown a single-circuit regenerative receiver in which the inductance element alone is varied for the purposes of tuning, a fixed capacity being used in series with the antenna circuit for the purpose of increasing the selectivity. However, this fixed capacity is made in two steps, thus permitting two separate wave length ranges. The regenerative coupling coil

and the main tuning inductance are so inter-related as to give practically constant regeneration over the whole range of possible wave length adjustment, when the set is connected to the average antenna.

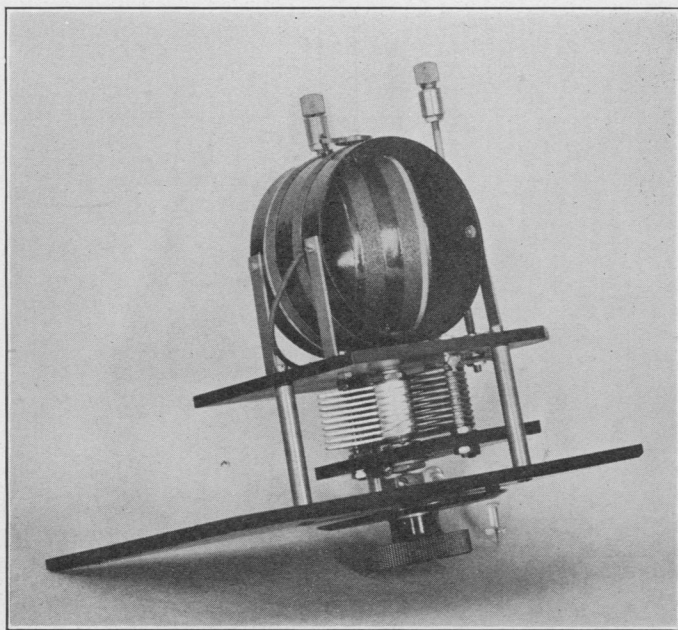


FIGURE 8

The foregoing remarks mainly cover questions of design affecting the tuning elements of the receiver, and on the general assumption that a three-element vacuum tube receiving system of the requisite sensitivity is employed.

The problems which may be presented for future development will be influenced largely by the condition imposed on the operation of the transmitting stations. With the transmitters grouped in one band of wave length, the possibilities of improvement are very remote. With the separation of transmitting waves, the ease of solution of the interference problem increases with the extent of this separation. The logical solution would appear to be a separation which would correspond to the possibilities of available receiving apparatus, and it is probable that, as the number of transmitters continues to increase, with a corresponding reduction of wave separation, the development of

receiving apparatus will keep pace with the increasing exactitude of requirements.

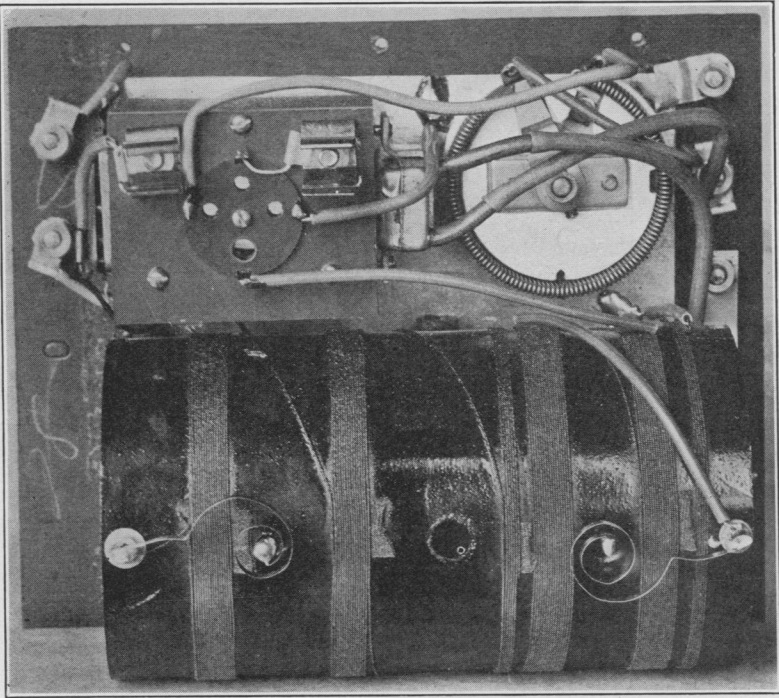


FIGURE 9

SUMMARY: The requirements and possibilities of a receiver for radio-telephone broadcast signals and the importance of considering the antenna in the design of this receiver are discussed. It is brought out that the increase of signal strength which is obtainable by regeneration is limited to a definite value, which is determined by the strength of the incoming field, and it is shown by curves that this maximum signal strength is independent of antenna height. Some of the possibilities in the direction of eliminating interference by various circuit arrangements are discussed.