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Solving the Problems of the Neutrodyne

One of Professor Hazeltine's Aides Discusses the Set—How to Neutralize Stray and Over-All Capacity in Two- and Three-Stage Radio-Frequency Sets—A Radio Club of America Paper

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A YEAR ago Professor Hazeltine described before the Radio Club of America his method of tuned radio-frequency amplification. The objectionable and uncontrollable regeneration caused by the capacity which couples the grid and plate circuits of the vacuum tubes had previously stood in the way of a successful amplifier of this type. The receiver employing this method, which he called the Neutrodyne, removed this obstacle by neutralizing the objectionable coupling due to this capacity. Since that time the Neutrodyne receiver has become very popular; and many amateurs have constructed their own receivers, though often with much difficulty in completely attaining the results of which a factory built Neutrodyne is capable. It is the purpose of the writer to describe the different problems which have presented themselves and to explain how these problems were solved.

In order to form a basis for further discussion, it is necessary again to explain the fundamental theory of capacity coupling neutralization. Fig. 1 illustrates a vacuum-tube amplifier whose grid and plate circuits are both tuned to the desired frequency. A passing radio wave causes a minute current to flow through the grid circuit C1L1. This circuit being tuned to the wave frequency, and thus having a high impedance, builds up an appreciable voltage which is impressed on the grid of the vacuum tube. By the relay action of the tube a similar current flows in the plate circuit. As this circuit is also tuned to the wave frequency, it builds up a still higher voltage which is passed on to the next tube. Without neutralization, regeneration takes place due to the capacity coupling the grid and plate circuits. That is, the voltage built up in the plate circuit of the tube causes a current to flow through this capacity C^1, which reinforces that already present in the grid circuit due to the passing wave. This may be sufficient to cause self-sustained oscillations which, unless very carefully controlled, completely destroy the value of this form of amplification.

HOW THE HAZELTINE PRINCIPLE IS APPLIED

THE Hazeltine circuit as embodied in the Neutrodyne receiver eliminates this effect in the following way: A third coil, L3 is coupled closely to L2 as shown, so that one end (the other end being grounded) varies in potential in exactly opposite phase to that of the plate end of L2. A small condenser, Cn is then connected between this end of L3 and the grid of the tube. If C^1, Cn, L2, and L3 are properly related, the following action occurs: a current still flows through the plate-grid capacity, C^1 due to the voltage built up in L2, but this current no longer enters the circuit C1L1 for the reason that the combination CnL3 demands exactly the same current. This current therefore, instead of flowing down through C1L1 passes back harmlessly through CnL3 to its source at the plate of the tube.

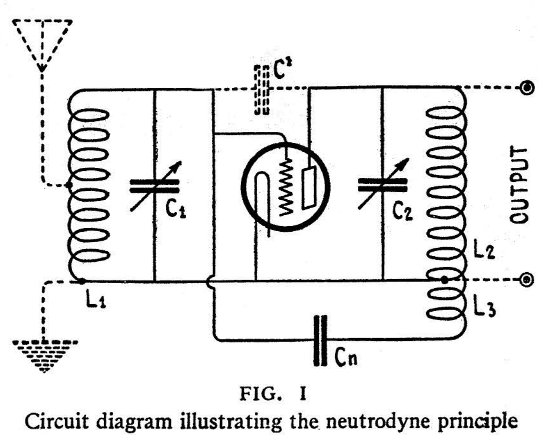

FIG. 1
Circuit diagram illustrating the neutrodyne principle

The conventional Neutrodyne receiver employs this circuit in a slightly modified form. There are usually four or five tubes employed, two radio-frequency amplifiers, detector, and two audio-frequency amplifiers. Or perhaps one audio tube is omitted and a radio tube used in place of it by the usual reflex method. The circuit of a five-tube receiver is illustrated in Fig. 2. Three separate rheostats are provided, one for controlling the filament temperature of the radio-frequency tubes, one for the detector and one for the audio frequency. The radio-frequency rheostat provides a volume control for cutting down the strength of the signal, which is advisable when the user is located near one of the more powerful broadcasting stations. The other two rheostats are used in the ordinary way.

The two radio-frequency amplifiers (employing the Neutrodyne principle) are different from the one illustrated in Fig. 1 in that instead of tuning the plate circuit, a secondary coil closely coupled to the primary or plate coil is tuned. This allows a step-up ratio to be employed which gives greater amplification and selectivity. Also if the two coils are connected properly—that is, with plate of one at the opposite polarity to grid of the succeeding tube, then a portion of the secondary coil may be used in place of a third or neutralizing coil. Referring to Fig. 2, the neutralizing condenser Cn is connected from the grid of tube No. 1 to a tap on the secondary of the transformer unit B. The neutralizing condenser for the second tube is connected in a similar manner from the grid of that tube to a tap on the secondary of the unit C. The correct location of these taps depends on the value and range of the neutralizing condensers used—that is, if the tap on coil B is moved up so as to include twice as many turns between it and the ground potential end of the secondary coil, then the capacity required at Cn will be only one half (approximately) as large as before. In this connection it should be pointed out that many receivers constructed from parts but which are not provided with a proper panel shield are very difficult to balance due to their inherent capacities. Referring again to Fig. 2, any capacity between adjacent grids tends to neutralize the tube capacity even more effectively than does capacity at Cn. This capacity will always be appreciable because the fixed plates of the variable condensers C1, C2, and C3 are connected directly to the grids of the tubes and therefore present large surfaces which act as the electrodes of condensers connected between them. As mentioned above, it is possible for these capacities to more than neutralize the tube capacities. If this is so, it is impossible, of course, to obtain a balance by a further addition of capacity at Cn. This condition may be eliminated by adding capacity at C^1 or better still by minimizing the inherent capacities by shielding. A grounded metal shield properly mounted on the panel cuts down the external field of the condensers sufficiently to make a balance possible.

ADJUSTING THE NEUTRALIZING CAPACITY

THE actual adjustment of the capacity Cn is accomplished as follows: A strong signal either from a near-by broadcasting station or from a local oscillator is impressed on the antenna coil. The condensers C1, C2, and C3 are then tuned to this signal with the filaments of

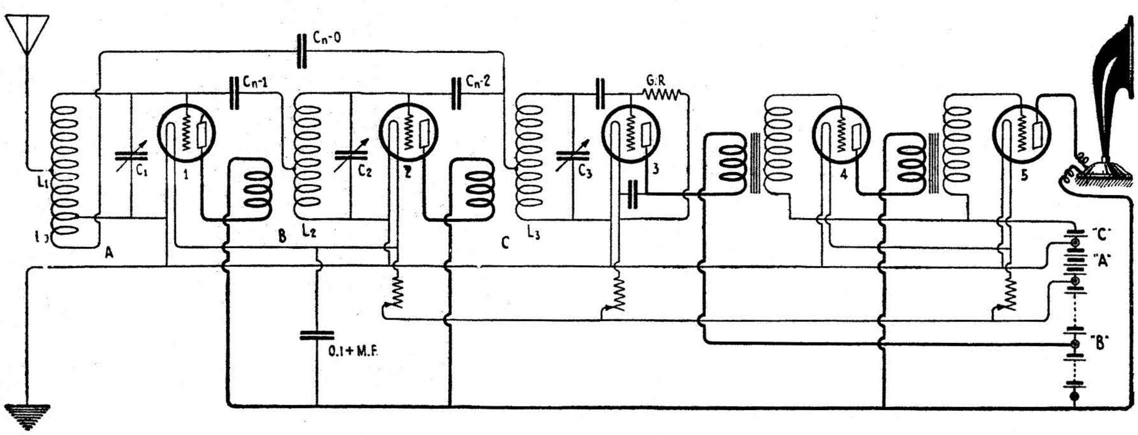

FIG. 2

Circuit of a five-tube Neutrodyne, showing the method of neutralizing the over-all capacity all tubes lighted. At this time the receiver will probably oscillate. The filament of tube No. 1 is then extinguished, usually by placing a piece of paper under one of the filament prongs. The dials can then be retuned for maximum signal. This signal is present only because of the coupling between circuits A and B introduced by the grid-plate capacity in the tubes. If now the neutralizing condenser Cn is increased, the signal will grow weaker and weaker and finally will disappear entirely. If the capacity is still further increased, the signal will again become stronger. The circuit is then said to be over-neutralized. An over-neutralized receiver will oscillate when all tubes are operating.

If the tube capacity is exactly balanced while the filament is not lighted and still cold, no signal will be transmitted through the succeeding tubes. The explanation of this is as follows: Referring to Fig. 2, the voltage present in circuit A causes a current to flow through the grid-plate capacity of tube No. 1, but at the same time another current flows through the neutralizing condenser Cn-1. These currents in passing through the primary and tapped portion of the secondary of circuit B, respectively, produce equal and opposite magnetic fields in circuit B which cancel out and produce no resultant voltage.

A third neutralizing condenser is sometimes used for the purpose of neutralizing the very small capacity existing between circuits A and C. This will be discussed in detail later. It should be noted in Fig. 2 that primaries of the audio-frequency transformers are reversed relative to the secondaries in a manner similar to that employed in the radio-frequency circuits. This very often prevents "singing or howling" at audio frequency. It might even be worth while for the purpose of improving the quality of reproduction to completely neutralize the audio-frequency tube capacities. This could be done by the introduction of very small capacities between adjacent grids.

For Those Who Have Built Their Own and for Those Who Haven't

This paper on the Neutrodyne receiver will have an appeal. As Mr. Dreyer, who is an assistant to Professor Hazeltine, the inventor of the Neutrodyne, says, "In one short year the Neutrodyne has sprung into very great general popularity." The many owners and operators of Neutrodyne sets should read this with great interest because it treats of kinks of operation and experiment with this type of receiver which have not appeared anywhere else. Those who have heard a great deal about the receiver and are a bit hazy on just how it works can easily bolster up their weak technical points by reading this paper.—THE EDITOR

HOW TO PREVENT REGENERATION

IT IS necessary in a Neutrodyne more than merely to neutralize the tube capacities. In the conventional type which employs three sharply tuned circuits it is necessary to remove all couplings that may exist between these circuits except mutually conductive or one-way coupling of the tubes. In fact if in any way radio-frequency energy may be transferred from one circuit to a preceding one, regeneration will usually occur. This is always undesirable since it has the effect of sharpening the tuning to too great an extent and thus ruining the quality of reproduction. The capacity couplings due to the tubes may be neutralized by the method already described. The other couplings which should be eliminated are:

(1) inductive coupling between adjacent stages (coils L1-L2, L2-L3); (2) couplings from the second to the first stage due to the impedance of the leads to the B battery; (3) coupling from the third to the first and second stages due to improper connection of the telephone condenser; (4) coupling introduced by a common C battery or due to improper connection of grid returns; (5) coupling between stages introduced by inductive loops in the wiring; (6) coupling between first and last stages due to inherent capacity between high-potential surfaces of these stages.

The first of these, inductive coupling between coils of the different stages, may be eliminated by properly placing the coils. As is well

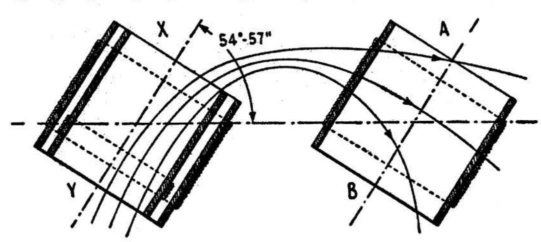

FIG. 3
How the angles of the coils used in the Neutrodyne receiver may be used to give zero magnetic coupling

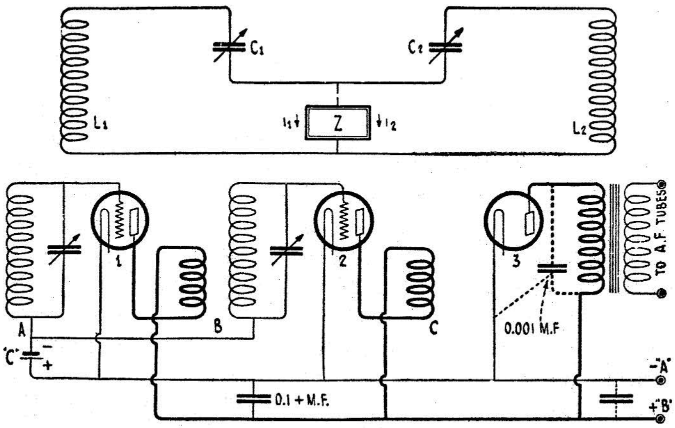

FIG. 4
How coupling other than that due to tube capacity may be eliminated

known, three coils may be placed mutually at right angles, so that the magnetic flux of any one has no resultant linkage with the turns of the others. A neater and more symmetrical arrangement was devised by Professor Hazeltine. He discovered mathematically that any number of coils might be placed on a common line of centers and if their axes were inclined at an angle of 54.7 degrees to this line of centers, no magnetic coupling would exist. That this is physically possible is rather hard to visualize at first. In Fig. 3 two coils are shown inclined at the theoretically correct angle. Magnetic flux of coil XY will pass through coil AB roughly as shown. Some of this flux, as represented by the middle line, passes through coil AB in a direction perpendicular to the axis of that coil and therefore does not link with the turns at all. Other portions of this magnetic flux will link with turns on AB. Some of it passes up and some down through the coil. There are, therefore, flux linkage in both senses. It seems reasonable that if the coils are set at some such angle as this, zero coupling may be obtained. This is true, but the angle varies slightly from the theoretically correct one, due to conditions not being ideal. The most conspicuous reason for variation is the fact that the leads which carry the coil current to the condenser form a single turn in an entirely different plane from the turns on the coil itself. The exact angle may be determined in any given receiver whose coils are first set approximately correctly as follows: the neutralizing condensers are first adjusted for a high broadcast frequency in the manner previously described. The settings of the two neutralizing condensers Cn-1 and Cn-2, Fig. 2, are then noted and the process repeated at a low broadcast frequency. The settings will be in general different. This is due to the fact that, if inductive coupling is present between adjacent coils, the neutralizing condenser counteracts this as well as the coupling due to the tube capacities. This neutralization will be exact for only one frequency, because with varying frequency the coupling effect due to the mutual inductance between coils varies at a different rate than the negative coupling effect due to the capacity Cn. If the settings are different, the coil angles are shifted a slight amount and the process repeated. When the neutralization is correct at both high and low frequency ends of the scale, the coil angle is correct. It has been found to vary by this method from 54 to 58° in different receivers.

INTER-CIRCUIT COUPLING IS OBJECTIONABLE

OBJECTIONABLE coupling between circuits due to the use of a common C battery has proven very troublesome, but not unavoidable if proper precautions are taken. The coupling introduced by the battery is analogous to that introduced in the theoretical circuit shown at the top of Fig. 4 by the impedance Z. Here the current of circuit CL1 flows through the impedance Z which is common to circuit C2L2. It is evident that the current of one circuit will induce a voltage in the other, or it may be stated that if any portion of the current of one circuit flows through an impedance in common with any portion of the current of another, then these circuits will be coupled. The lower portion of Fig. 4 illustrates several ways in which this sort of coupling may be introduced (batteries, rheostats, and non-essential wiring are omitted to avoid confusing the figure) The plate circuits of tubes 1 and 2 carry radio-frequency currents which, like all other electric currents, must flow in closed paths. Let us trace the probable path of the radio-frequency current produced by tube No. 1. Starting at the plate it passes through the primary of unit B and thence to the B battery, through the battery, and back to the filament, where the electron stream completes the circuit to the plate. If it does take this path, the batteries and, more important, the leads to the batteries, form an impedance through which a similar current from tube No. 2 must also flow. This common impedance introduces coupling. A large condenser placed as shown between the + B and the — A leads has the effect of by-passing these currents and preventing their passage along common leads. To be effective, this condenser should be of at least 0.1 microfarad capacity. Also it should be carefully placed at the point which provides the minimum of common wiring for the currents in the separate circuits. It would be less effective if placed at the right, as shown by the dotted connections.

The detector plate circuit also carries radio-frequency current for which a reasonably low impedance path must be provided. If this path is not provided the signal will be considerably weakened. In regenerative circuits it is common practice to shunt the high impedances of the telephones or audio-frequency transformers by a condenser of about 0.001 microfarad capacity. This must also be done in the Neutrodyne, but care must be taken to connect this condenser from the plate of the detector *directly to its filament*. Otherwise if connected as shown alternatively in Fig. 4, a large radio-frequency current must pass through the B battery in order to complete its circuit. This might readily cause trouble.

PREVENTING COUPLING PREVENTS OSCILLATION

COUPLING sufficient to cause oscillation has been found when either a C battery or a common filament rheostat has been used to introduce a negative bias on the grids of the radio-frequency tubes. (See Fig. 4.) This is analogous to the coupling introduced by the common B battery, since the currents which pass through the grid filament capacities for the first two tubes must return to their starting points by way of this rheostat or C battery. If such a device is used, it should be by-passed with a large condenser which is located in the most desirable place, namely the one which provides the least common wiring for the different currents. It has not been found necessary to use a bias on the radio-frequency tubes and therefore the grid returns are usually connected directly to the negative filaments of the separate tubes as illustrated in Fig. 2.

Inductive loops in the low potential wiring cause a great deal of trouble and are present in a great many "home-made" receivers. If, for instance, the negative and positive battery leads are far apart, a loop closed at the ends by the filaments of the tubes is formed. This loop has mutual inductance to all coils in the receiver and provides a path for the feed-back of energy which is often sufficient to cause oscillation. The remedy for this is obvious and simple. All wires which carry the B or A battery currents should be bunched together and thus minimize the area of possible loops.

It was found in certain receivers that after all other possible sources of coupling had been eliminated that energy was fed back through the extremely small capacity usually present between circuits C and A. This capacity may be eliminated by shielding, but because this is expensive, several types of receivers have been equipped with a third arrangement which serves to neutralize this last form of coupling. The effect of this coupling capacity is only noticeable in receivers having very low resistance circuits and having therefore very high amplification. It is accentuated by the presence in the neighborhood of the receiver of a piece of ungrounded metal such as a long piano hinge on the cabinet. Also, if the antenna is connected

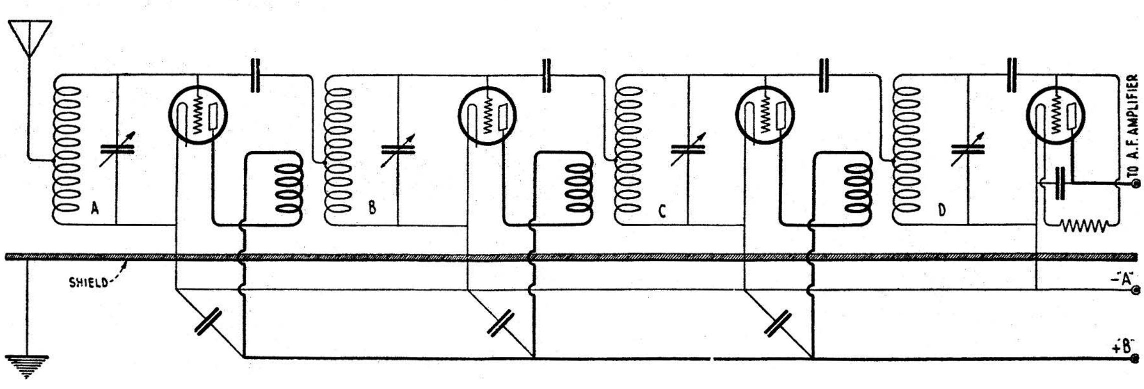

FIG. 5
How the "segregated shielding" is used in a three-stage (radio-frequency) Neutrodyne

in such a way that it passes behind the receiver close to the last circuit, the effective capacity between the first and last circuits is increased. The antenna lead may be shielded with a grounded metal tube or Belden braid, and the metal hinge may also be grounded. If these precautions fail to remove the trouble, complete shielding or neutralization must be resorted to. Neutralization of over-all capacity may be accomplished with the arrangement of Fig. 2 already referred to. When adjusted, the action is as follows: a very small current passes through the space from the high potential parts of circuit C to circuit A. However, another larger current flows through the third neutralizing condenser Cn-O. This current, in passing through the extra coil Lo which is coupled closely to L1, produces a magnetic effect in circuit A exactly equal and opposite to that produced by the first current flowing through L1. The net regenerative effect is then zero. It is interesting to note the relative size of the coils and capacities involved in this action. In a certain receiver L1, L2, and L3 are of 65 turns each. A tap on L3 used for two neutralizing condensers is located 8 turns distant from the grounded side of that coil. Lo has but one turn. The neutralizing condenser Cn-O is of the usual form and when adjusted has a capacity of about 10 micro-microfarads.

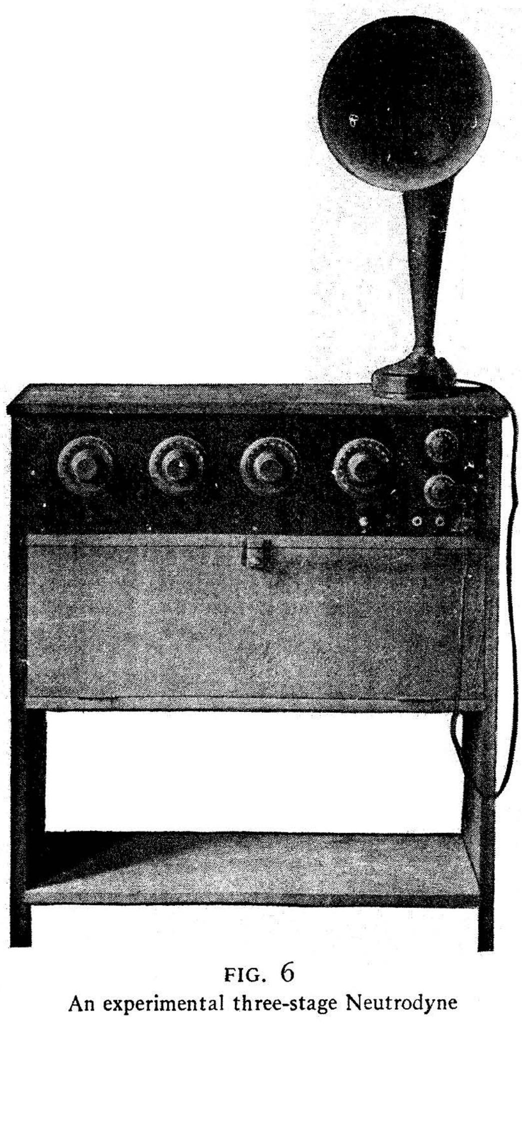

FIG. 6
An experimental three-stage Neutrodyne

The adjustment of this third neutralizing condenser is accomplished by first encouraging the receiver to oscillate. This is done by tuning the circuits to the highest possible frequency and by adjusting the plate and filament voltages to produce the greatest amplification. If the receiver oscillates under these conditions, the condenser Cn-O is increased until oscillation ceases. If increased too far oscillation will again commence. The correct setting of this overall condenser is, of course, at the center of the range of non-oscillation. If no oscillation or regeneration is noticeable when these steps are taken, overall neutralization is unnecessary and may be omitted.

Another cause of unsatisfactory operation on the part of Neutrodyne receivers is that introduced by local conditions. High impedance ground leads may be the cause of oscillation for reasons which are not very clear. The trouble may usually be eliminated by replacing the long lead with a short one to the nearest piping system, such as the radiator or water pipe. If the A battery is located at some distance from the receiver and is wired to it with long leads, trouble again may occur. This form of oscillation trouble usually appears over only a limited frequency range and is probably due to an action which occurs at the natural period of the ground or battery system.

THREE-STAGE NEUTRODYNE RECEIVERS AND THEIR PROBLEMS

SO FAR, all discussion has been limited to the two-stage receiver. Successful three-stage Neutrodyne receivers have been constructed and when finally adjusted give very great amplification and selectivity. One of these constructed by H. W. Dreyer and the writer and used with a ten-foot indoor antenna compared favorably with the performance of a good two-stage receiver when used with an outdoor antenna 75 feet long.

The problems which arose in the construction of this receiver were of the same nature as those previously discussed. They are, however, more difficult to solve, and the stray coupling had to be eliminated to an even greater degree than was necessary with the two-stage. Fig. 5 illustrates schematically some of these problems.

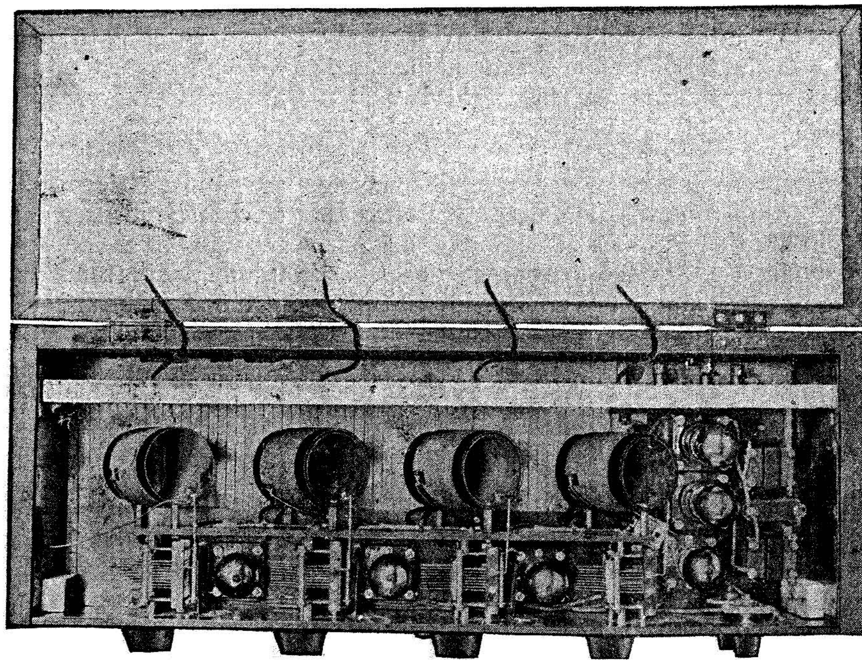

FIG. 7
Top view of a three-stage (radio-frequency) Neutrodyne. Note the wire shielding in the bottom of the cabinet

It should be noted that three separate by-pass condensers are used to prevent B battery coupling. The most troublesome coupling, however, was found to be that due to over-all capacity. This becomes of more and more importance as the amplification increases. When four tuned circuits are used, it becomes too cumbersome to effect a neutralization of all capacity couplings between circuits. Since to eliminate them would require six adjustments, it was decided to shield out as much as possible of these capacities and neutralize the remaining tube capacity by the Hazeltine method. The shielding of a copper lined cabinet proved ineffective, due probably to eddy currents set up in the shield. These currents caused coupling between first and last stages in a manner similar to that caused by inductive loops in the wiring.

Shielding in the form of a cabinet lined with copper wire grids did prove effective. Care was taken to see that no closed loops were formed in this shielding. Also it was necessary to segregate it into four insulated portions adjacent to the four coil systems. These four sections were grounded at the low-potential points of the individual coil systems. Of course, no attempt was made to shield the magnetic fields, but these are not harmful if the coils are at the proper angle.

In the short year that the Neutrodyne circuit has been before the public it has met with very great popular approval. In the coming year improvements will undoubtedly be made, but probably not of a radical nature. Greater amplification may be expected by more careful construction and by the use of more shielding.