NATIONAL RADIO INSTITUTE

Complete Course in PRACTICAL RADIO

NRI

Radio-Trician
(Trade Mark Registered U. S. Patent Office.)

LESSON TEXT No. 20

THE NEUTRODYNE RECEIVER

Originators of Radio Home Study Courses
••• Established 1914 •••
Washington, D. C.

TEMPERATURE AND LIGHT

A Personal Message from J. E. Smith

Everyone needs a suitable temperature. Most Americans keep rooms too warm in winter for the best mental activity. A temperature slightly under 70° Fahrenheit with a normal amount of moisture in the air, is most conducive to study.

Also, everyone needs proper light. Indirect lighting—that is, lighting reflected upon one's work from a ceiling or other surface, or direct diffused lighting is best. Glare on books and papers does not constitute good lighting.

The light, of course, should come from behind and somewhat above. If one is doing any writing in connection with his study, the light should fall across his left shoulder, unless he is left-handed, when it should fall across the right shoulder.

W75C4330

Printed in U. S. A.

Radio-Trician's

(Trade Mark Registered U. S. Patent Office.)

Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE WASHINGTON, D. C.

The Neutrodyne Circuit

One of the most popular Radio Receiving circuits ever designed is the Neutrodyne which employs a system of neutralizing oscillations in the radio-frequency amplifier developed by Prof. L. A. Hazeltine. This development was without doubt a distinct improvement in the art of radio reception in that it completely overcomes one of the most annoying causes of failure in tuned radio-frequency amplification, namely, it eliminates the tendency of tuned amplifiers to oscillate. In order to thoroughly appreciate and understand what the neutrodyne accomplishes, it is necessary to examine the conditions which led to its development.

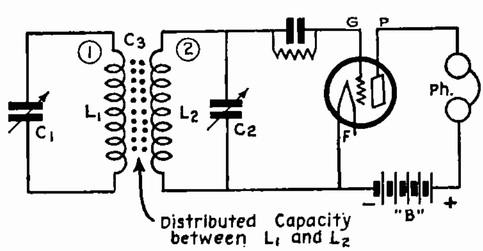

Fig. 1—Capacity Effect Between Inductively Coupled Coils.

One of the principal sources of trouble in radio-frequency circuits is the existence of small stray or distributed capacity between different parts of the circuits. Such small capacities are especially harmful at the low wave-lengths or high frequencies. For at the high frequencies the reactance of this small stray capacity becomes very small and so passes high-frequency currents when it is not intended that current should pass.

Thus suppose we have, as in Fig. 1, two radio-frequency circuits which are magnetically coupled to each other by the coils L_1 and L_2. Energy then passes from circuit ① to circuit ② by way of magnetic induction. But since both coils

L_1 and L_2 are conductors and are separated by an insulating medium they constitute a small condenser, or, in other words, there is distributed capacity between them. This distributed capacity behaves like any condenser and will therefore let radio-frequency currents flow through it. Thus high-frequency currents would flow from circuit ① to circuit ② by way of the small stray capacity rather than by way of the transformer coils and induction, thus defeating the purpose of the transformer. These capacity currents, called parastic currents, represent a loss of energy, and are, therefore, an undesirable feature of any circuit. Not only does this small stray capacity introduce harmful effects by by-passing from their legitimate paths currents to which the circuits are tuned, but it also creates trouble by introducing into the circuits undesirable, extraneous currents to which the circuits are not tuned.

Consider again Fig. 1, which represents two radio-frequency circuits inductively coupled, the secondary of which feeds the grid of a detector tube, and suppose C_3 represents the small distributed capacity existing between the two coils. Let us furthermore assume that the circuits represent the primary and secondary of a receiver which is designed to receive over a band of wave-lengths from 200 to 600 meters. In the first place, we would have present the harmful effects described above, namely, at the low wave-lengths around 200 meters, the distributed capacity will by-pass some of the received current, preventing the coupling coils from performing their proper function. In the second place, when reception is taking place at the higher wave-lengths, interference from low wave signals will be introduced by the distributed capacity. Any low wave signal which may get into the primary circuit in any way, as for example, via the aerial, will be transmitted to the secondary through the capacity which exists between primary and secondary, and thus will get on the grid of the detector tube and produce an interfering signal. This occurs irrespective of the tuning of the circuits, since capacity parastic currents do not depend on the tuning of circuits but simply flow through the capacity coupling.

When we consider the vacuum tube, we are again confronted with very small capacities which considerably influence the action of the tube. The plate and grid together form the two plates of a tiny condenser. In the average tube this capacity is of the order of 3 to 5 micro-microfarads. This is, of course, very minute but is capable of spoiling reception if not properly controlled.

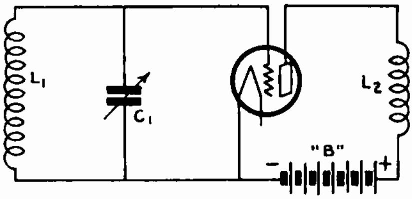

Fig. 2—Conventional Amplifier Circuit.

Figure 2 represents a conventional type of circuit frequently employed in radio reception, as for example one stage of a transformer, coupled R.F. amplifier with one tuned circuit. L_2 is not coupled to L_1, and it might therefore be thought that such an amplifier would be stable. This is not necessarily the case as will be seen when we simplify this circuit as in Fig. 3 where we have inserted CP in place of the tube. CP represents the capacity between plate and grid. This small capacity is in reality a coupling condenser, for one plate is in the grid or input circuit while the other is in the plate

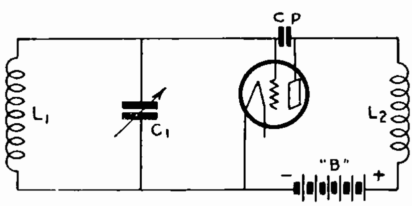

Fig. 3—Tube Capacity Effect in Circuit of Fig. 2.

or output circuit. As a result, even if there is zero coupling between coils L_1 and L_2, it will be seen that there is capacity coupling through CP between the output and input. Any current flowing in the plate circuit of the tube will therefore feed back into the input circuit, thus rendering the circuit unstable. This explains the reason for regeneration in circuits where there is no apparent feed-back coupling between input and output. The higher the frequency, the greater is this capacitive feed-back, for the reactance of the small coupling condenser decreases and makes feed-back all the easier.

It is for this reason that radio-frequency amplification at the low waves—600 meters and under—was very unsuccessful for a long time, for the capacity coupling and feed-back was so great that circuits were rendered unstable at the slightest provocation and would oscillate, thus ruining any amplification.

Methods of Neutralizing.

A number of methods have been advanced for overcoming this undesirable capacity effect, as for example, the well known device of a stabilizer potentiometer. This does not eliminate the regenerating effect of the tube capacity, but simply introduces such losses into the grid circuit that the amount of regeneration is reduced. One of the solutions to this problem of stable radio-frequency amplification was the development of the super-heterodyne receiver, which will be

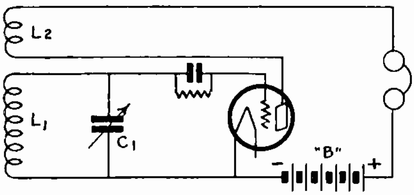

Fig. 4—Two Magnetically Coupled Circuits.

taken up in a later book. Another solution is the neutrodyne circuit as advanced by Prof. L. A. Hazeltine.

The principle on which the neutrodyne system is based is that of neutralizing the effect of one voltage by an equal and opposite voltage. In this particular case, neutralizing the capacity feed-back of the tube by an equal and opposite capacity feed-back introduced externally, the two feed-backs neutralize each other.

To understand the principle, let us consider the simple case of two magnetically coupled circuits which is more easily understood (see Fig. 4). Here we have inductive coupling and coil L_2 induces in coil L_1 a voltage which has a certain value and phase. Suppose that we are able to couple another coil L_3 to coil L_1, as shown in Fig. 5 and the direction of the coupling is such that the voltage induced in L_1 by L_3 is equal and opposite to the voltage induced in L_1 by L_2. Then these two voltages neutralize and balance each other in L_1, and no effect is produced by either.

This principle is applied in neutralizing the feed-back effect of tube *capacity*. Since the feed-back however is capaci-

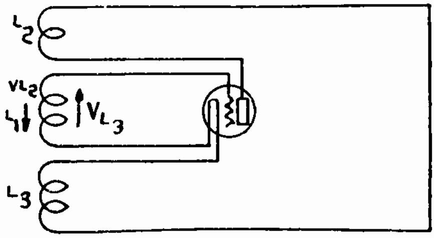

Fig. 5—Neutralized Inductive Coupling.

tive, it is necessary to employ a condenser to balance it. Furthermore, in order to obtain a voltage of opposite phase to an existing voltage it is necesary to employ two opposing coils as explained in the preceding paragraph. The neutrodyne method then is as follows:

Figure 6 represents one stage of a multi-stage radio-frequency amplifier in which the plate circuit is the tuned cir-

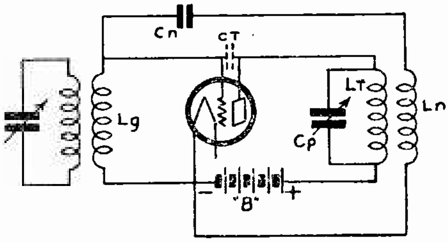

Fig. 6—One Stage of Tuned R. F. with Tuned Plate Circuit.

cuit. The dotted capacity CT represents the small but disturbing capacity which always exists between the plate and grid of the tube. L_g, LT and L_n represent inductance coils, of which L_n is the neutralizing inductance. C_n is a small fixed capacity external to the tube which is used as the neutralizing condenser. Assume for the moment that the neutralizing inductance L_n and the neutralizing capacity C_n are not present. When the amplified currents flow through the tuned plate circuit LT, C_p, a regenerative action is set up through the medium of the tube capacity CT and a feed-back current flows from the plate circuit through the capacity coupling CT and through L_g. This feed-back current flowing through L_g sets up a voltage across it which is applied to the grid and re-amplified by the tube, in this way producing the well-known regenerative effect as explained in a previous paragraph. To neutralize this effect, the coil L_n is coupled to LT; the voltage induced in it is opposite in phase to that in coil LT. This is obtained by using reverse coupling to that normally employed. In addition, the external neutralizing capacity C_n is adjustable and the current through it may be controlled. By adjusting the neutralizing condenser C_n, the current through it due to the reversed voltage of L_n may be brought to such

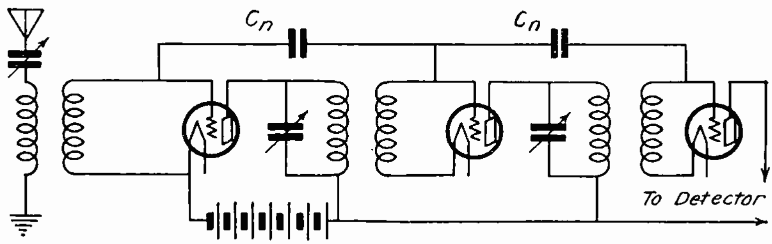

Fig. 7—Condenser Connections in Multi-Stage Neutrodyne Using Tuned Plate Circuits.

a value that it sets up a voltage in L_g equal to that set up by the feed-back current through CT. But since these voltages are opposite in phase, due to the reversed coupling of LT and L_n, they just neutralize each other and the regenerative effect is thus destroyed.

However, in coupling from the plate circuit of Fig. 6 to a succeeding tube, another coil is needed. If L_n is utilized solely as the neutralizing inductance, it will be seen that three coils will be required; one in the plate circuit of the tube, which acts as the primary of the radio-frequency transformer, a coil coupling this to the grid of the succeeding tube, *i. e.*, the secondary of the radio-frequency transformer, and thirdly a neutralizing coil. Such an arrangement is obviously cumbersome. As a result in commercial neutrodyne receivers, the neutralizing inductance acts also as the secondary of the radio-frequency interstage transformer.

The neutralizing coil and the plate inductance must be designed to behave efficiently as a radio-frequency transformer, and hence the ratio of the number of turns in each coil is limited. If the coils have the same number of turns, then the neutralizing condenser must equal the capacity of the tube CT. In practice this capacity is determined by trial and when the exact suitable value is found the capacity is fixed and sealed.

It will be apparent that the neutralizing condenser is extremely small, about a few micro-microfarads. In order to secure such small capacities which are adjustable, a small metal sleeve is used in some types about 2 inches long. This slides over the ends of two insulated wires as shown in Fig. 7-A. The capacity between the ends of these two wires is extremely small and varies with the extent to which they are

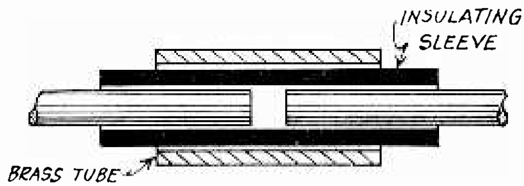

Fig. 7-A—Cross-Section of Early Neutralizing Condenser.

covered by the metal sleeve. The adjustment is made by moving the metal sleeve and when the proper conditions are obtained the sleeve is sealed in that position.

Figure 7 illustrates how the neutralizing condensers are connected in a multi-stage neutrodyne, namely, between the grids of succeeding tubes. Under ideal conditions, the neutralizing condenser should be constant at all wave-lengths. On account of leakage in the radio-frequency transformers this is not actually the case. Over a narrow band of wave-lengths, a fixed value of the neutralizing condenser is satisfactory. Even in cases where the neutralizing capacity is not exactly of the right value it effects a reduction in the feed-back coupling through the tube capacity and avoids oscillations due to regeneration. Figure 8 shows the complete wiring diagram of two R. F. stages and detector of a three tube neutrodyne set.

The .006 mfd. and .001 mfd. condensers are for by-passing the radio-frequency currents across battery and head-phones.

Figure 9 pictures the actual apparatus illustrated by the diagram in Fig. 8 and shows both the arrangement of the parts and how they are wired to one another.

Figure 10 shows a circuit of this type which is much used in commercial sets. The circuits shows two stages of radio-frequency amplification and detector. A complete commercial set would ordinarily require 5 tubes as it would contain in

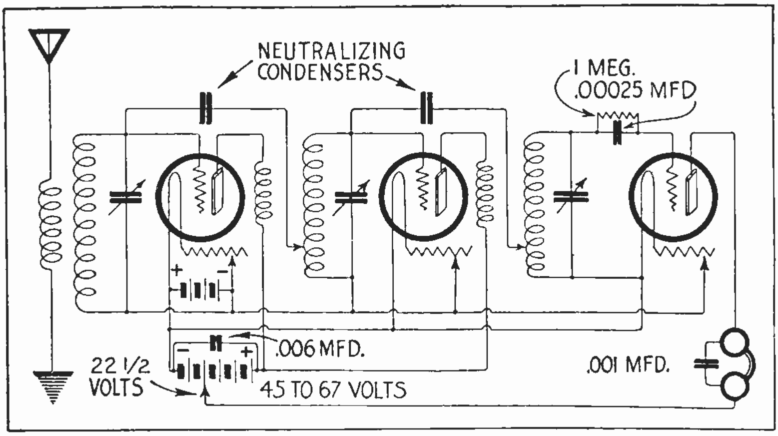

Fig. 8—Circuit Diagram of a Neutrodyne Receiver Using Two Stages of R. F. Amplification and Detector.

addition two stages of audio-frequency amplification. L_1 and L_2 constitute a radio-frequency transformer.

The neutralizing condensers CN are connected to the secondaries of the radio-frequency transformers (L_1, L_2) and

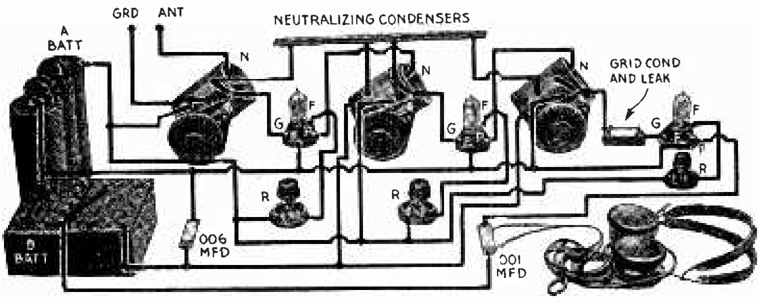

Fig. 9—Pictorial View of Hook-up Shown in Fig. 8.

(L_3, L_4) which are wound in such a direction that the radio-frequency voltage produced across CN will be 180 degrees out of phase with that of the radio-frequency voltage across the plate grid capacitance of the tube. The small neutralizing condensers the capacity of which is made variable so that when the correct capacity is obtained, the adjustment can be locked.

Two methods of adjusting C_N will be discussed here. An article by Professor Hazeltine on "Tuned Radio-Frequency Amplification with Neutralization of Capacity Coupling" states: "The adjustment of each neutralizing capacity is made experimentally by tuning in a strong signal and then turning out the filament of the tube whose capacity is to be adjusted, but leaving the tube in the socket. If the neutralizing capacity is not correct, the circuits on each side of the tube will have capacity coupling which will transmit the signal. The neutralizing capacity is then adjusted until the signal disappears."

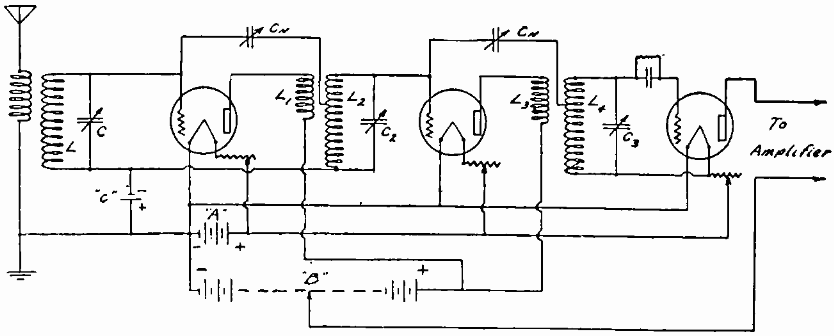

Fig. 10—Circuit Diagram of Neutrodyne Receiver.

This method of adjustment was developed by Mr. Harold A. Wheeler and will be carefully taken up later. It is quite evident that if a radio-frequency amplifier circuit is adjusted by this method, no regeneration exists, as variations of plate potential do not cause variations of grid potential to any appreciable degree, and thus, for all practical purposes there is no feed-back. If the capacitance of the condenser C_N is increased beyond the point necessary to completely eliminate the incoming signal, the voltage induced on the grid will tend to destroy any amplification resulting from the use of a tube.

It is not necessarily desirable to completely neutralize the effect of regeneration as has been described above. Stronger signals will be obtained with the same number of tubes if the capacitance of C_N is increased only to the point where the amplifier ceases to produce radio-frequency oscillations.

The regeneration remaining will also tend to increase the selectivity of the system. If too much regeneration remains, distortion may result from excessive selectivity or other reasons. We are not concerned with the debatable question as to whether or not the manufacture or sale of radio-frequency amplifiers in which the effects of regeneration are not completely eliminated is covered by patents which control regeneration, but only with questions as to the relative advantages of amplifiers in which regenerative effects are completely eliminated and those in which regenerative effects exist.

The statement has been made that it takes about one and one-half stages of non-regenerative radio-frequency amplification to deliver as strong a signal to a detector tube as can be obtained by the use of a regenerative detector circuit connected directly to the aerial. Such a statement is only a rough approximation, but expresses the fact that if non-regenerative radio-frequency amplication is used as a substitute for regeneration, more than one stage must be used if any increase in signal strength is to be expected. The results may not then be what the experimenter expects from the cost of the additional equipment necessary to add the radio-frequency amplification. If the radio-frequency circuits are carefully designed and the limitation of regeneration is carried only to the point where oscillations are not produced, there is no reason why a tube detector with one or two stages of radio-frequency amplification ahead of it should not deliver a much stronger audio-frequency signal than could be obtained by the use of only a regenerative tube detector circuit connected directly to the aerial.

Theoretically, after the neutralizing condensers are correctly adjusted for the prevention of oscillations for one adjustment of the tuning controls, this adjustment should be correct for all adjustments of the tuned circuits providing the tubes in the set are not changed. In general practice, this is not always the case and it may be found that when the neutralizing condensers are adjusted to the point where oscillations are prevented at a particular tuning adjustment, the set will begin to produce oscillations if the tuning adjustment is changed. It would seem, therefore, that the experimenter, thoroughly acquainted with the operation of his set, might obtain better results if the setting of the neutralizing condensers could be easily varied. The operator could then control the regeneration in the radio-frequency stages at will and operate the receiver at maximum selectivity and sensitivity at all wave-lengths. Manufactured sets are usually permanently adjusted at the factory in such a manner that in general radio-frequency oscillations will not be produced regardless of the wave-length to which the set is adjusted. This may mean that slightly better amplification is obtained at one wave-length than at others.

It will be seen by referring to Fig. 10 that a tuned radio-frequency amplifier having two stages of radio-frequency amplification has three tuned circuits and three tuning controls. For the reception of distant stations, all three of these circuits must be tuned to the wave-length to be received. Until the operator has made a chart showing the three settings which must be used to adjust the set for any particular station, the adjustment of the three circuits to the same wave-length is rather difficult. After such a chart has been made it is a simple matter to find any station by referring to the chart and adjusting the set accordingly.

Calibration of Set.

The original calibration of a three-dial set is best accomplished on a night when static or induction disturbances are fairly strong. When the dials are so adjusted that the noises resulting from static or induction are loudest, the three tuned circuits are adjusted to the same wave-length. By varying one of the dials a little at a time and then adjusting the other two until the noises again are at a maximum, the entire wave band covered by the receiver can be searched and all stations in operation giving a sufficiently loud signal to be heard can be logged for future reference.

It is common practice to use from 90 to 120 volts on the plates of both the audio and radio-frequency stages of a set using tuned radio-frequency such as is shown in Fig. 10. Unless a correct negative bias is used with amplifiers operating at such high plate voltages, heavy plate currents will flow and grid circuit losses will result due to the flow of current to the grids when they are positive with respect to the filament. The flow of grid current may not be important in the radio-frequency stages where the alternating currents and voltages are relatively small, but will cause distortion and loss of efficiency in the audio-frequency stages. Distortion will also result due to the fact that the tube is not operated on the central portion of the characteristic curve. We mention the fact as but few manufacturers and experimenters appear to recognize the importance of a correct negative bias when high plate voltages are used, and many sets do not provide for any negative voltage on the up-to-date grids of the amplifier tubes.

Figure 11 shows a very satisfactory comparatively simple three-tube receiving set using one stage of radio-frequency amplification, detector and one stage of audio-frequency amplification. If loud-speaker reproduction is desired, additional stages of audio-frequency amplification can be added. Certain features of this circuit are worthy of note. Only two tuning controls are used which make the set somewhat easier to tune than the one shown in Fig. 10. A negative bias is used on the radio-frequency amplifier tube for the reasons just brought out. The same "C" battery can be used for the audio and radio-frequency amplifier tubes if desired.

Instead of building a radio-frequency transformer using two closely coupled coils to provide a means of feeding back voltage to the grid which will limit regeneration, use is made of auto transformer action in a single coil. Exact physical dimensions of this coil L_2 will depend upon the wave-length band it is desired to cover. Approximately 60 turns on a 3-inch tube are suggested for use with the average condenser for broadcast waves. Approximately one-sixth the total number of turns should be included between the base of the coil and the "B" battery tap and another sixth between the "B" battery tap and the tap which goes to the plate of the radio-frequency amplifier tube. The neutralizing or regeneration limiting condenser C_N is connected to the base of this coil. It is necessary to connect the grid leak directly to the positive side of the detector tube filament. If it were across the grid condenser, as is common practice, the full voltage of the "B" battery would be applied to the grid of the detector. It is also necessary to use a grid condenser capable of standing this "B" battery voltage without leakage.

Regeneration is provided in the detector circuit by the insertion of the variometer V. A tickler coil in the plate circuit of the detector tube coupled to L_2 might be used in place of the variometer for the same purpose. Regeneration in the radio-frequency amplifier circuit can be controlled by varying the capacitance of the small condenser C_N. As has been explained, only a little of this adjustment is necessary beyond that originally made to prevent the production of oscillations or completely eliminate regeneration.

A valuable feature of a set which provides for regeneration in the detector circuit is the fact that regeneration can be carried to the point where oscillations are produced

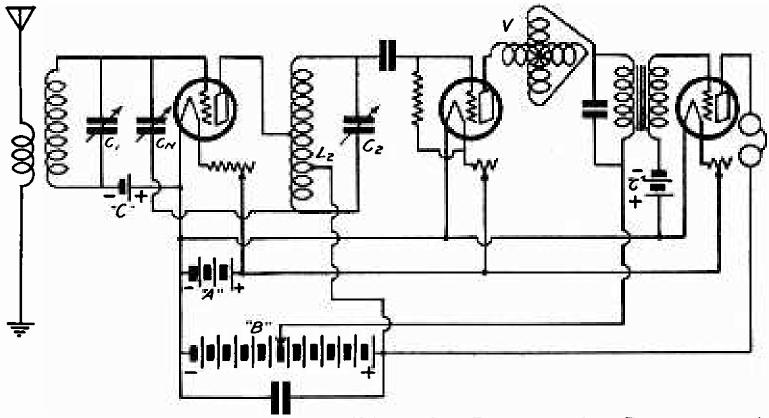

Fig. 11—One-Stage R. F. Amplifier with Regenerative Detector and One-Stage A. F. Amplifier.

and the beat note which results when the circuit L_2C_2 is tuned to a frequency near that of an incoming signal may be used as a means of tuning for weak signals. As the oscillations produced in the set are not produced in a circuit coupled to the antenna, the receiver does not radiate and thereby cause objectionable disturbance to nearby listeners. The setting of the dial controlling C_2 at which its circuit is tuned to various stations can be logged on a chart and this chart used for future reference. The variometer method of regeneration in the detector circuit is recommended because in general the effect of the variation of regeneration by this method on the tuning of the detector circuit will not be great. A circuit similar to the one just described has been used with very satisfactory results in sets designed for the United States Signal Corps by the Radio Laboratories at Camp Alfred Vail.

The conventional Neutrodyne receiver usually employs four or five tubes, two radio-frequency amplifiers, detector, and two audio-frequency amplifiers. The circuit of a five-tube receiver is illustrated in Figure 12. 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 receiver 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. 11 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. If the two coils are connected properly—that is, with the plate of one at the opposite polarity to the 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. 12, the neutralizing condenser C_{n-1} R. F. is connected from the grid of tube No. 1 to a tap on the secondary of the transformer unit B. The neutralizing condenser C_{n-2} for the second tube is connected in a similar manner from the grid of that tube to a tap on the secondary of the R. F. transformer 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 L_2 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 C_{n-1} 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 not provided with a proper panel shield, are very difficult to balance due to their inherent capacities. Referring again to Fig. 12, any capacity between adjacent grids tends to neutralize the tube capacity even more effectively than does capacity at C_{n-1}. This capacity will always be appreciable because the fixed plates of the variable condensers C_1, C_2, and C_3 are connected to the grids of the tubes and the variable plates grounded which present large surfaces thus introducing the capacity 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 to obtain a balance by a further addition of neutralizing capacity. This condition may be eliminated 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.

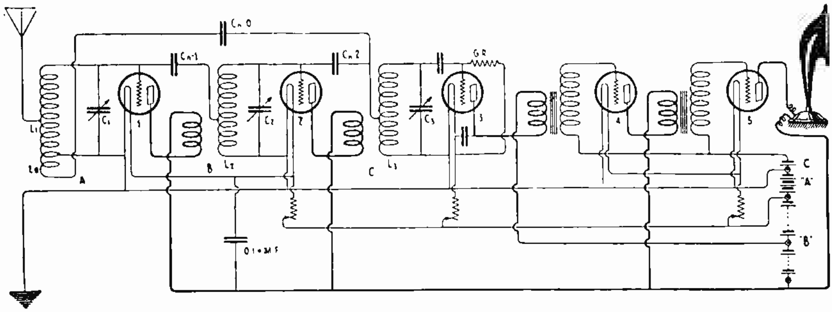

Fig. 12—Circuit of a Five-Tube Neutrodyne, Showing the Method of Neutralizing the Over-all Capacity.

Adjusting the Neutralizing Capacity.

The actual adjustment of the neutralizing condensers C_{n-1} and C_{n-2} is accomplished as follows: A strong signal either from a nearby broadcasting station or from a local oscillator is impressed on the antenna coil. The condensers C_1, C_2, and C_3 are then tuned to this signal with the filaments of 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 the capacity of the neutralizing condenser C_{n-1} is increased, the signal will grow weaker and weaker and finally will disappear entirely. If the capacity of C_{n-1} 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. 12, 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 C_{n-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.

The neutralizing condenser C_{n-2} is adjusted in a similar manner. For a final check repeat the process over again for both tubes.

BUZZER CIRCUIT FOR NEUTRALIZING.

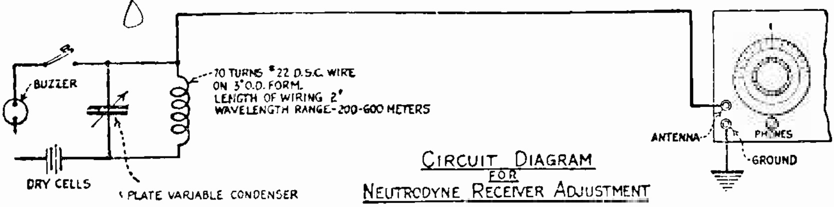

Fig. 13—Buzzer Circuit Attached to Receiver for Neutralizing Purposes.

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. 12 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 worthwhile 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.

The buzzer circuit, illustrated by Fig. 13, may be conveniently used when neutralizing a receiver. The buzzer is of the high-frequency type. The circuit may be tuned by the variable condenser to cover a wave-band between 200 and 600 meters. The method of attaching it to the receiver is clearly shown in Figure 13.

The use of a circuit of this type makes the operator independent of broadcast reception while neutralizing the set. The procedure for neutralizing is the same as already explained.

The final test to be applied to a receiving set is its actual operation. When the receiver is perfectly balanced out or neutralized, according to the Neutrodyne principle of circuit and tube capacity neutralization, as outlined, this adjustment will hold over its entire wave-length range. If this is not the case, the neutralizing condensers should be carefully readjusted.

Other Causes of Regeneration.

It is necessary in a Neutrodyne set to more than merely 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 undesirable couplings between circuits in a Neutrodyne set which should be eliminated are:*

(1) Inductive coupling between adjacent stages (coils L_1-L_2-L_2-L_3); (2) coupling 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.

Arrangement of Neutroformers.

The first of these, inductive coupling between coils of the different stages, may be eliminated by properly placing the coils. As is well-known, three coils may be placed mutually at right angles, making the magnetic flux of any one to have no resultant linkage with the turns of the others. A neater and more symmetrical arrangement was devised by Professor Hazeltine. He discovered mathematically that a number of coils might be placed on a common line of centers and if their axes were inclined at an angle of 54.57 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. 14 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 does not link with the turns at all. Other portions of this magnetic flux will link

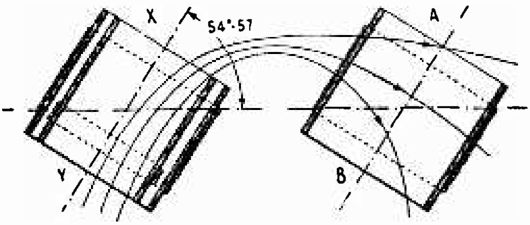

Fig. 14—How the Angles of the Coils Used in the Neutrodyne Receiver May be Used to Give Zero Magnetic Coupling.

with turns on AB. Some of it passes up and some down through the coil. There are flux linkage in both senses. It seems reasonable that if the coils are set at some such angles as these, 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 correct and the neutralizing condensers adjusted for a high broadcast frequency. The settings of the two neutralizing condensers C_{n-1} and C_{n-2}, Fig. 12, are then noted and the process repeated at a low broadcast frequency. In general the settings will be 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 neutralizing capacity. 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 from 54 to 58° by this method 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 objectionable 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. 15 by the impedance Z. Here the current of circuit C_1L_1 flows through the impedance Z which is common to circuit C_2L_2. 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. 15 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 electron current produced by tube No. 1. Starting at the plate the electrons pass 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. As it takes 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. The 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. 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 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 be done in the Neutrodyne circuit, 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. 15, a large radio-frequency current must pass through the "B" battery leads 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. 15.) 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 the grid-returns are usually connected directly to the negative filaments of the separate tubes as illustrated in Figure 12.

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 "A" or "B" 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

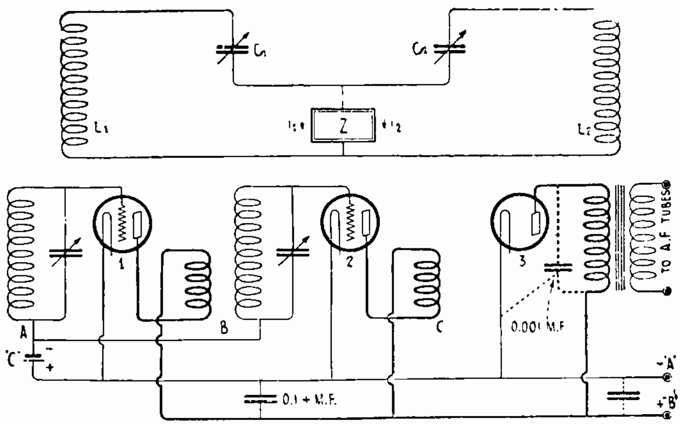

Fig. 15—How Coupling Other Than that Due to Tube Capacity May be Eliminated.

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. If the antenna is connected 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. 12 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. Another larger current flows through the third neutralizing condenser C_n-O. This current, in passing through the extra coil L_o which is coupled closely to L_1, produces a magnetic effect in circuit A exactly equal and opposite to that produced by the first current in flowing through L_1. 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 L_1, L_2, and L_3 are of 65 turns each. A tap on L_3 used for two neutralizing condensers is located 8 turns distant from the grounded side of that coil. L_o has but one turn. The neutralizing condenser C_n-O is of the usual form and when adjusted has a capacity of about 10 micro-microfarads.

The adjustment of the over-all C_{n-o} 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 C_n-O is increased until oscillation ceases. If increased too far, oscillation will again commence. The correct setting of this over-all 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, over-all 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.

Figure 16 shows the wiring diagram of a 5-tube Fada Neutrodyne receiver, employing two stages of radio-frequency

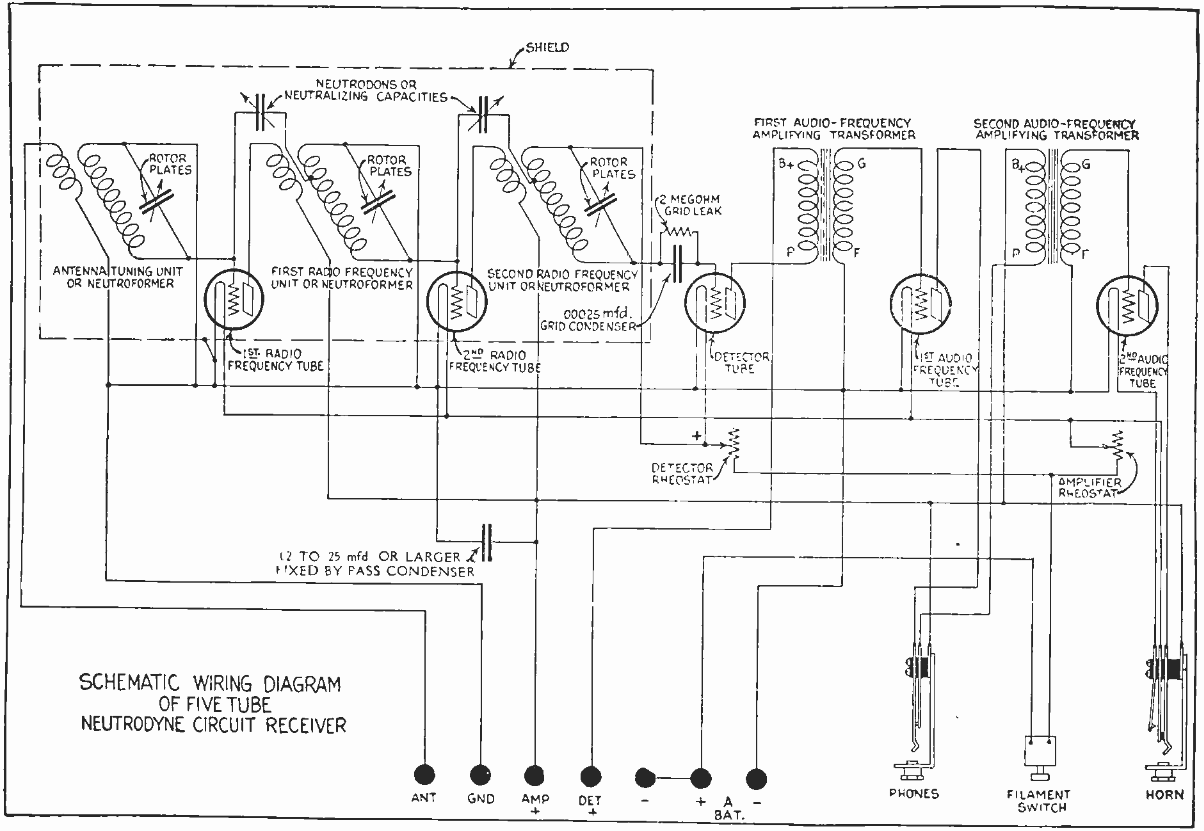

Fig. 16—Wiring Diagram of Fada Neutrodyne Receiver.

amplification, detector and two stages of audio-frequency amplification. This receiver is supplied with the necessary jacks, in order that either one or two stages of audio-frequency amplification may be used.

The transformers of Neutrodyne sets are of the air-core type, wound over a piece of tubing and mounted on the condenser as shown in Figure 17.

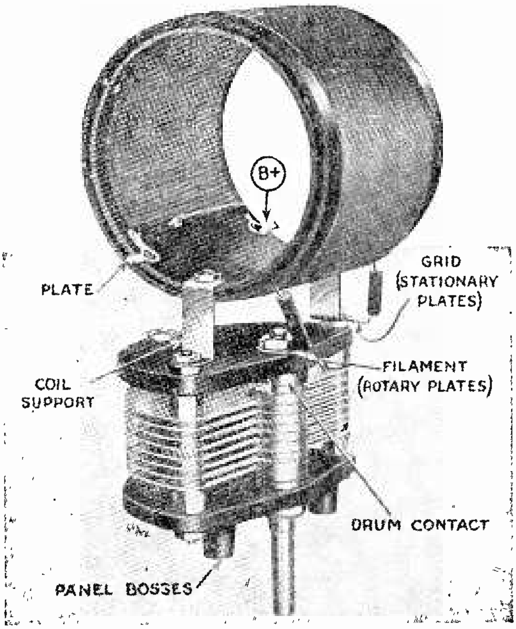

Fig. 17—A Neutroformer, Showing Construction and Terminals.

The Neutrodyne receiver employs an aperiodic, or untuned primary, for the coupling between the antenna and the first stage. The tuning is accomplished by means of the variable condenser only. The tuning of the secondary circuit by means of the condenser, affects the wave-length of the primary, due to the mutual induction of the two coils. The primary coil, being of only a small number of turns of wire, and having no variable contact in any way, means that the antenna system is used at approximately its fundamental wave-length.

This makes the apparatus of limited wave-length; such sets being usually designed for broadcast reception only. In tuning, it is usually found that the condenser dials will be at

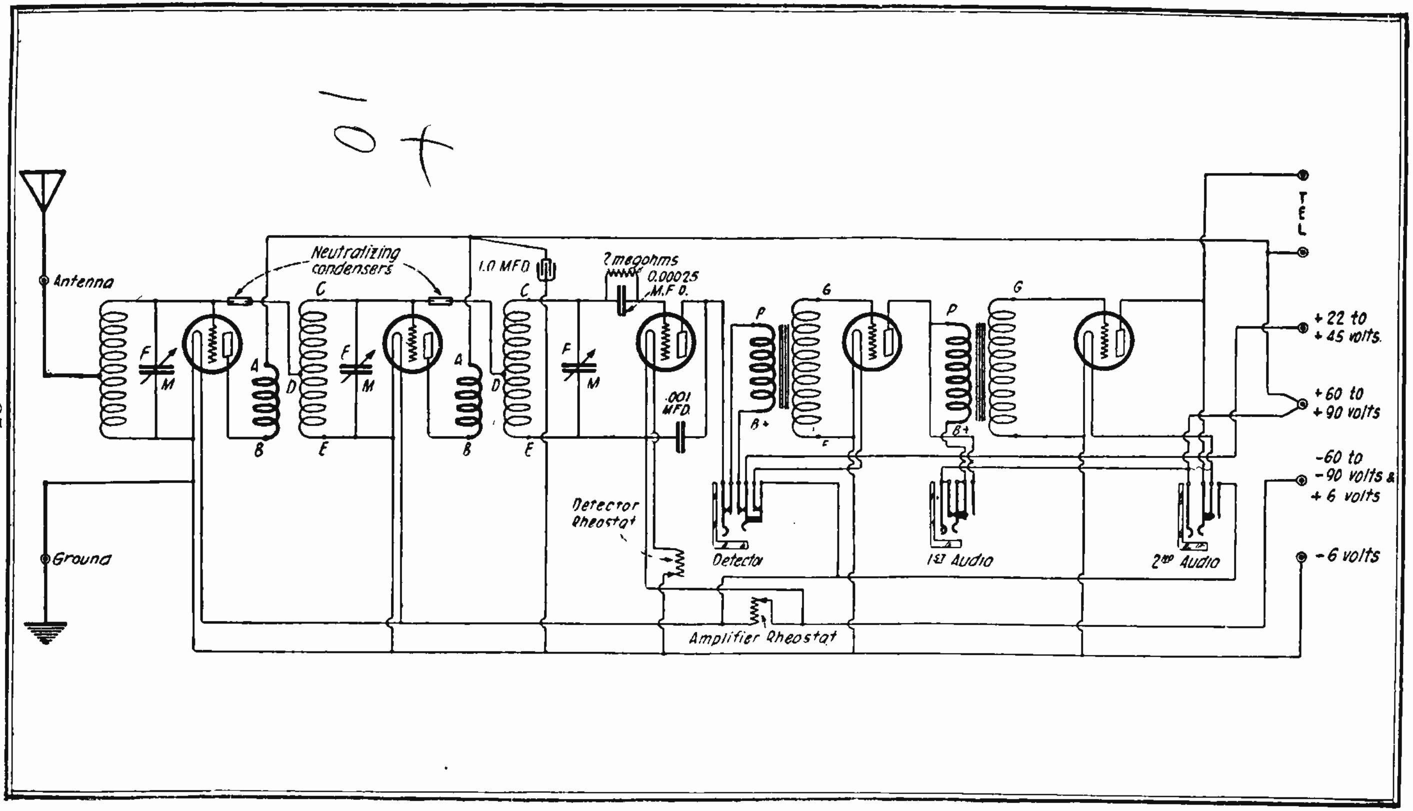

Fig. 18—The Freed-Eisemann 5-Tube Neutrodyne.

the same adjustment for all three neutroformers. In some cases, a geared control is employed, which turns the rotating plates of all three condensers at the same time. This is convenient for people who do not care to bother with much tuning. As it is difficult to obtain condensers and coils which have the exactly same characteristics, it is often found that they will not all be tuned in exactly the same manner to get the best results.

The coil in the antenna circuit frequently tunes a little differently from the others.

Figure 18 shows the circuit diagram of a Freed-Eisemann 5-tube Neutrodyne receiver. The neutroformers are represented by the inductance winding, AB, and CDE; the three variable condensers are represented by FM. The audio-frequency transformers are indicated by the windings, P, B plus and G, F. Otherwise, the diagram is self-explanatory.

Figure 19 shows the circuit diagram of the Fada 7 tube Neutrodyne receiver. This set employs four stages of radio-frequency amplification, detector and two stages of audio-frequency amplification. It can be operated either by the loop aerial or outside antenna. This receiver uses individual stage shielding on coils and condensers operated by dual control. The on and off switch and volume control are combined in one.

The circuit diagram of the Philco Electric Radio Receiver Model 87 is shown in Fig. 20. This receiver is of the Neutrodyne type, employing three stages of tuned radio-frequency amplification, detector, and two stages of transformer coupled audio-frequency amplification. The second audio-frequency stage is a push-pull arrangement. The plate supply is obtained from a full-wave rectifier tube.

Four variable condensers are used to tune the three radio-frequency circuits and detector circuit. To increase the selectivity, a small variable condenser is used with the tuning condenser in the grid circuit of the first radio-frequency tube.

The other three variable condensers each have a compensating condenser shunted across them. The capacity of the compensating condensers can be varied by adjusting with a wrench. This provides a method for equalizing or matching all the tuned circuits.

The push-pull amplifier uses two CX-345 or UX-245 power tubes to handle great volume of signals and fidelity of tone.

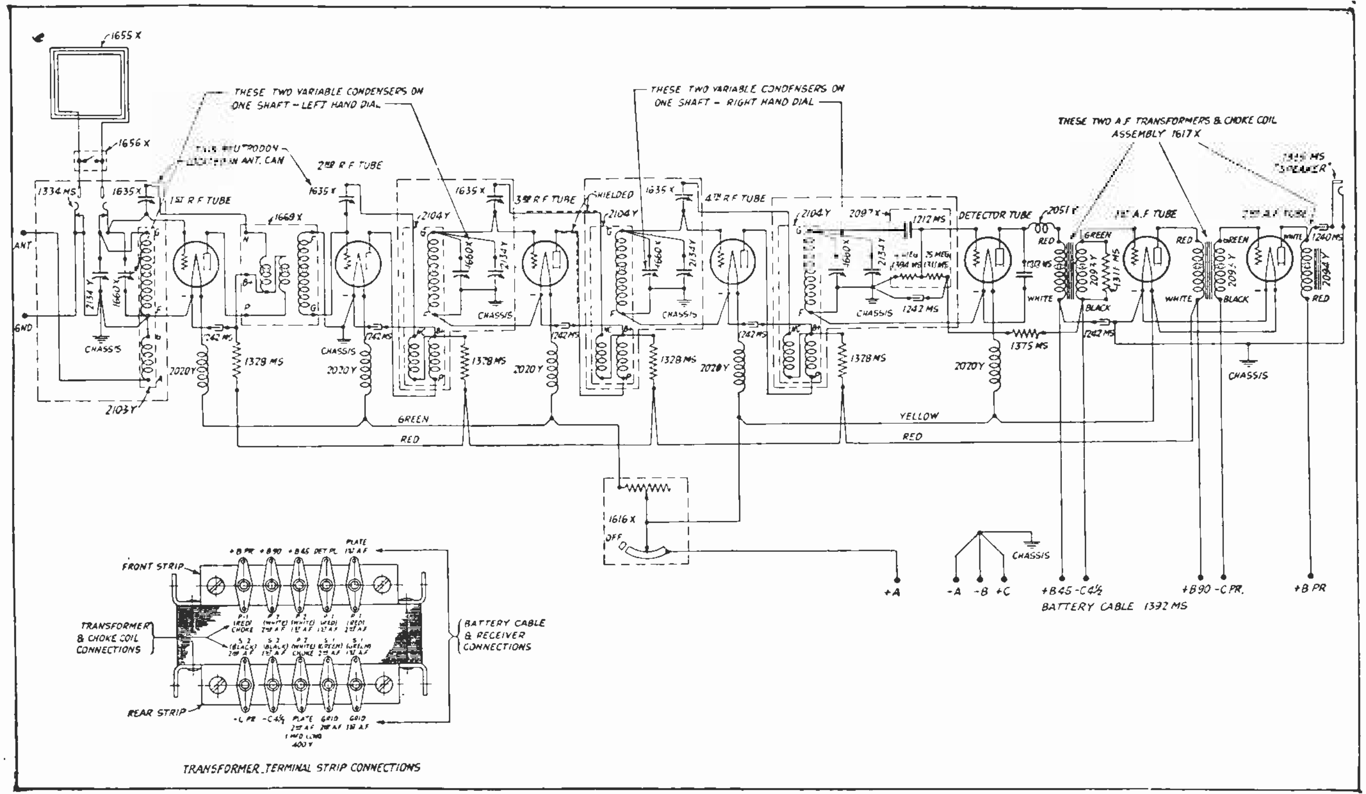

Fig. 19—Circuit Diagram for Fada 7-Tube Neutrodyne Receiver.

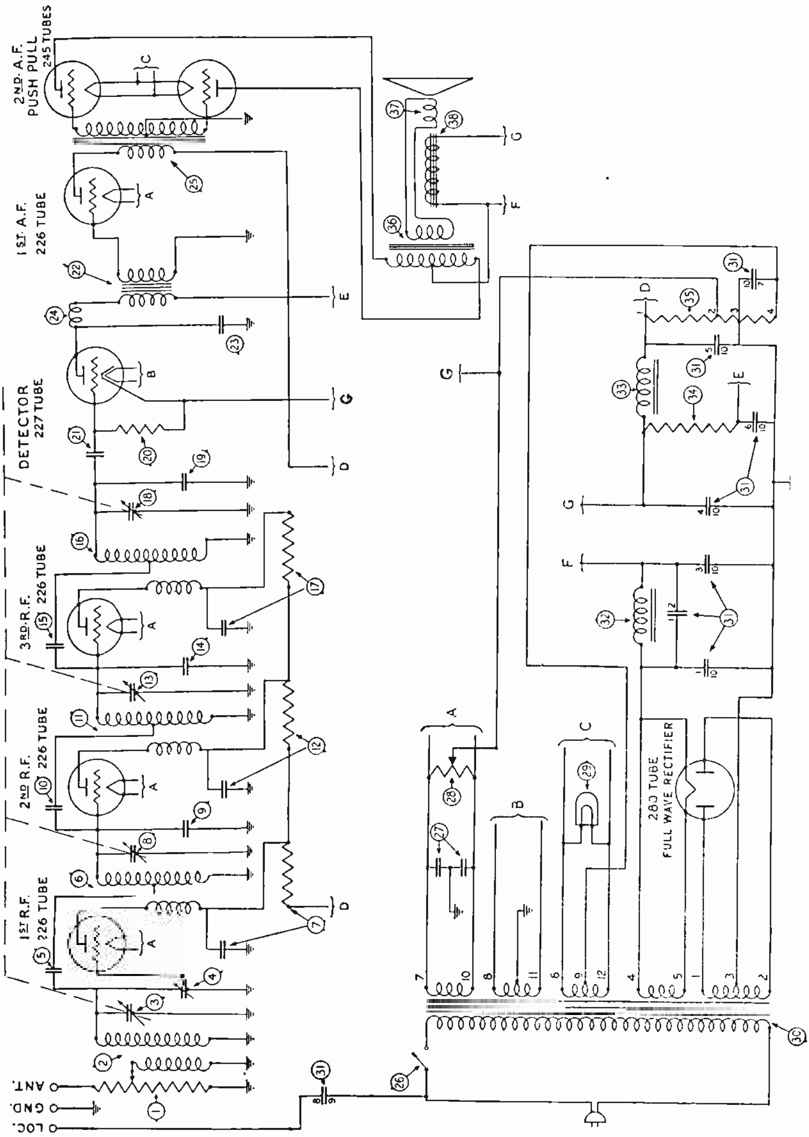

Fig. 20—Schematic Wiring Diagram of the Philco Electric Radio Set, Model 87.

The main volume control is a potentiometer resistance of 10,000 ohms connected from antenna to ground. The input to the set is connected to this resistance by means of a sliding contact, thereby allowing more or less of the signal strength to pass directly to the ground.

In the previous pages, the student has been given a complete explanation of the theory of the Neutrodyne set, the working principles of each part, with special methods for preventing oscillations. Various diagrams and essential features of different types of Neutrodyne circuits, along with the most important points of consideration which should be taken in the selection of a successful design, either for home-made receivers or factory built sets, have been presented.

A student should now have sufficient knowledge of the Neutrodyne receiving sets to proceed in a practical way in the construction, testing and operating of the various circuits involved in these receiving sets.

TEST QUESTIONS

Number your answer sheet 20 and add your **student number.**

1. What is the principal source of trouble in radio-frequency circuits?
2. How does the Neutrodyne system overcome these troubles?
3. Tell the difference between Figures 7 and 8.
4. Name several undesirable couplings between the circuits of a Neutrodyne receiver.
5. How is the over-all neutralization adjustment made for the third condenser C_n-O in Fig. 12?
6. What final test can be applied to the receiver to prove that the circuit is complete?
7. What precaution must be taken in placing the neutroformers on the panel?
8. Show by diagram how a buzzer circuit may be used for neutralization of the receiver.
9. How many rheostats are used in Fig. 12 and what tubes does each rheostat control?
10. Draw a diagram of a 5-tube Neutrodyne Circuit and mark the parts with the proper names.

RADIO BY MAIL
National Radio Institute
STUDENTS ALL OVER THE WORLD