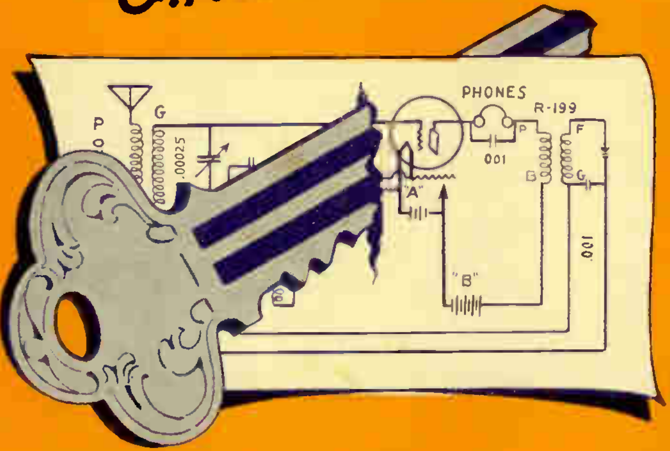
The Radio Key Book

E. N. Rauland



HOW TO HEAR FARTHER AND BETTER

Price 50 ¢

The Radio Key Book

How to Hear Farther and Better

Compiled by

E. N. RAULAND

Originator and Designer of the
"All-American" Radio Products

ACKNOWLEDGMENT

The Author wishes to acknowledge his indebtedness, for valuable suggestions and assistance, to Prof. G. M. Wilcox of the Department of Physics at Armour Institute of Technology, to Mr. Wm. J. Morey of the All-American Laboratories, and to Mr. H. K. Randall of the Technical Department, Thos. M. Bowers Agency.

THIRD EDITION

CHICAGO
Published by the Author
1925

Permission is hereby given to publishers to reproduce any portion of this book in a periodical if credit is given to "The All-American Radio Key Book."

Printed in the United States of America.

THE RADIO KEY BOOK

How to Hear Farther and Better

CONTENTS

See Alphabetical Index on Last Page

INTRODUCTION

"The Key to Range and Clearness"

"OF THE making of books there is no end"—and it is equally true that of the asking of questions about radio there is no end. To the initiated, who may seek an answer to some deep question of radio practice, the magazine editors are always ready and able to be of service.

We are aiming rather, in this little book, to be of service to the ordinary person who has heard much of hook-ups and "dynes" but "wishes somebody would tell the facts about radio without using so much jargon." This is, to be sure, not an easy undertaking, but the author has a sincere belief, founded on many years of experience as a "target" for radio questioners, that what is needed is not more reading matter on radio, but better selected, better arranged, and better systematized information, which keeps to the essentials in their proper order, without dwelling on unimportant matters.

Particularly in the matter of circuit diagrams, familiarly known as "Hook-Ups": we have made no particular effort to make this a "complete catalog" of circuits, since there is no limit to the variations that can be introduced into radio set wiring. What we have tried to do is rather to select the most practicable circuits for general use, and "pick them to pieces", showing the reader the units out of which they are built up, so that he can, at any time, read hook-up diagrams more quickly and intelligently than if he had to "spell out" separately each line and connection.

As regards technical radio terms, we have aimed to use them only where nothing else will convey the correct idea, and in each case we have endeavored to make the meaning of a term clear before venturing to use it. Most of our readers probably have some understanding of ordinary electrical terms such as resistance, potential, current strength, etc., and we have therefore not taken space to explain them. To anyone who wishes to refresh his memory on these matters we would recommend the following two pamphlets, which can be obtained by sending the amounts named (coins or money order) to the Superintendent of Documents, Government Printing Office, Washington, D. C.:

"Elementary Electricity", W. D. D. No. 1055 ....Price, 15c

"Elementary Principles of Radio Telegraphy and Telephony", W. D. D. No. 1064..Price, 10c

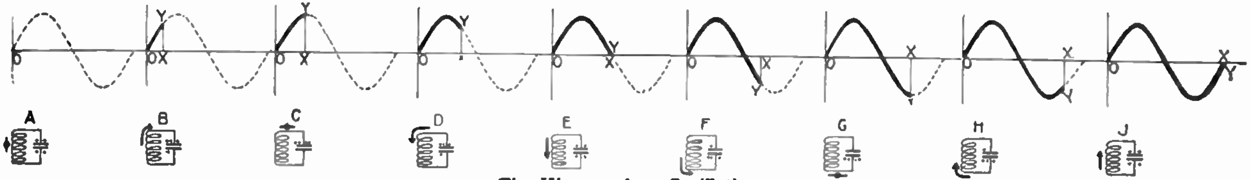
No apology will be necessary for having devoted such a large portion of the book to the subject of amplification—the increasing of distance and loudness of radio reception. Indeed, at the present time amplification methods make up nearly the whole of radio science, and in view of the fact that the author and his staff have been, for years past, engaged in an exhaustive study of just these problems, he feels that a simple and systematic account of his discoveries cannot fail to be of practical use to everyone desirous of "hearing farther and better".

The author is always glad to hear from experimenters who enounter difficulties or problems relating to amplification. If your question is of a more general nature, we suggest that you consult your local radio dealer, or, if necessary, write to any of the well-known radio magazines, all of which provide competent technical advice for their readers.

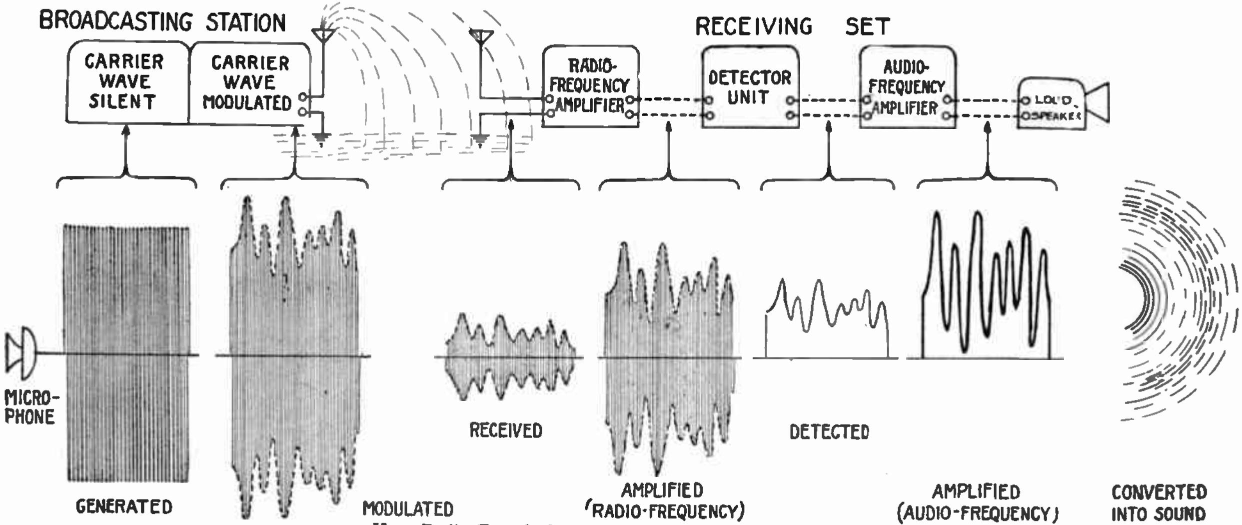
Many places will be found in the book where absolute technical accuracy has been sacrificed to clearness in presenting fundamentals. Such choice has been made deliberately, because this is in no sense an engineering textbook; it is rather a guide to better radio reception, and no pains have been spared to make it valuable as such. Suggestions as to improvement of future editions will be received with sincere thanks.

The beginner will probably find most valuable the chapters of this book on "Quick Hook-Up Reading" and "Practical Helps." The more advanced experimenter will, we hope, gain some worth-while information from the chapters on Audio and Radio Frequency and Power (Push-pull) Amplification and on the Super-Heterodyne. All fans alike will, we believe, be interested in the reliable, tested hook-ups we have given, and particularly in the unique form in which they are presented—each hook-up being, so far as possible, shown as a picture of the actual pieces of apparatus, connected together by lines representing the individual pieces of bus-wire required, and arranged so as to be readily understood by anyone who has read the earlier chapter on "Circuit Units." It is believed that a circuit presented in this way is so very much more "understandable" than those ordinarily seen, and that our artist's representation of the nature of radio waves and currents is so unusually clear, as to bear out in a unique sense the title of "The Radio Key Book."

Chicago. E. N. RAULAND.



The History of an Oscillation



How Radio Travels from the Radiocast Studio to the Ear

CHAPTER I

Oscillations

From the Studio to the Ear

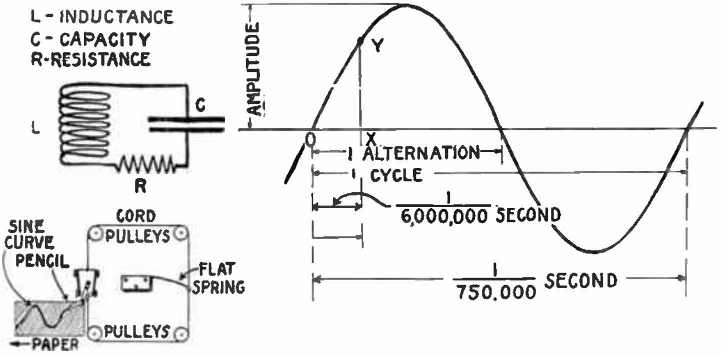
For a brief "bird's-eye view" of radio broadcasting and reception, we are going to start with the fundamental idea of an "oscillation," and try to make it plain just what is meant by that expression.

In order that an electric circuit may freely "oscillate", it must contain inductance and capacity; like all circuits, it will unavoidably contain resistance also. In the diagram below we have shown a separate resistance, but it is meant to indicate merely the resistance which is present in the inductance coil, the condenser, leads, etc.

The action of this fundamental oscillating circuit is very much like what would take place in the "mechanical oscillating circuit" sketched in below it. Here we have a rolling weight, such as a heavy toy railroad car, attached by two cords running around pulleys to a spring, which is fixed at the other end. If we give the car a few pushes with the hand, it will oscillate back and forth. The rapidity of these oscillations will depend on two things: the weight of the toy car and the elasticity of the spring. But the distance it will move each time it oscillates depends rather on the force of the pushes, and the friction of the roller and pulleys. In the electrical circuit above, we have an exactly similar electrical condition. The rapidity of the oscillations depends also on two things: the inductance of the coil and the capacity of the condenser; but the strength (amplitude) of the oscillations depends on the voltage applied and the total resistance. This assumes in each case, that the circuit has been "tuned" to the force applied, so that "every push helps." We could tune the mechanical device, or change the rapidity of its oscillations, by changing either (1) the weight of the roller, or (2) the elasticity of the spring. In the same way an electrical circuit can be tuned by varying either its inductance ("weight") or capacity ("springiness").

Now if, while our car oscillates back and forth, we were to have a pencil attached to it and draw a sheet of paper from left to right underneath it, the pencil would leave a curve, the shape of which becomes familiar to the eyes of a reader of radio literature. It is called, most briefly, a sine curve. What it really represents in radio may be seen in the curve below.

On our horizontal here we take a distance OX as representing the



To the Left, An Oscillating Electric Circuit, with an Oscillating Mechanical Circuit Drawn Underneath for Comparison. To the Right, an Electric Current Wave.

time elapsed since the oscillation started. Let us represent by XY the amount of electricity which has, by that time, traveled around to the upper plate of the condenser C.

On page 6 (above) we have illustrated the conditions at nine different points during the cycle. At A the circuit is dead; there is an equal charge on the upper and lower plates and no current is flowing. At B the current has commenced to flow upward, through the coil, in the direction of the arrow, and a charge is accumulating on the upper condenser plate, as indicated roughly by the plus marks. In position C the charge (represented by XY) has reached its maximum, and the current has stopped flowing, just as our toy car would stop at the end of its travel, before turning back. At D the current has reversed and is flowing back to the lower plate. This continues through E and F, until at G the charge has reached its maximum in the reverse direction, and again no current is flowing. At H the current has started flowing upwards again, and at J we are back to our starting point, ready to begin another complete oscillation or "cycle."

It is this process which occurs 750,000 times per second in a radio set which is receiving from a broadcasting station operating on 750 kilocycles—or, as we say more familiarly, on 400 meters wave length. Since all radio waves travel 300,000,000 meters per second, if there are 750,000 of them arriving each second we can find the length of the wave by dividing 300,000,000 by 750,000, the result being 400.

If the charges are flowing in and out of the condenser according to the sine-wave law as described above, then the variations of the electrical current as it flows up and down through our inductance will also be represented by a similar sine curve. And if we now imagine oscillations of this character steadily following each other out of a powerful electric generator at a broadcasting station, we have a good understanding of what is represented by the series of waves shown below on page 6. as "generated."

These generated waves, although powerful, could not be heard if passed through a telephone, for they are far too rapid. They represent, however, the output of a broadcasting station when no sound is being made before its microphone. When the announcer begins to speak, the sound waves from his voice are carried over the telephone wires to the radio transmitting station, where they are impressed upon the radio-frequency or "carrier-wave" as it is generated, so that its outline is no longer uniform, but is moulded to the shape of the waves from the speaker's voice. This "modulated" current is then forced into the broadcasting antenna, sending out electro-magnetic waves which have impressed upon them the "audio-frequency" vibrations of the speaker.

The current produced in the receiving antenna (shown as "Received") is of this same form, and if it is then passed through a Radio-Frequency Amplifier it is still of the same form, but stronger. This current then goes through the detector unit, after which it has approximately the form shown as "Detected." The original oscillations have disappeared, and we have instead a current flowing in one direction only, but varying in strength, or "pulsating," according to the shape of the sound waves. Passed through an "Audio-Frequency Amplifier," it becomes strong enough to energize the magnets in a loudspeaker, and cause the diaphragm to vibrate and send out waves in the air which reproduce, more or less faithfully, those originally created in the studio.

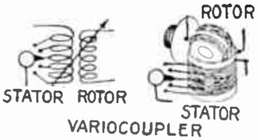
Thus is completed the process which, within a few months, transformed us into a nation of radio enthusiasts!

Symbols

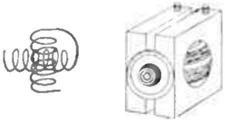
Commonly Used to Represent Radio Parts

ANTENNA

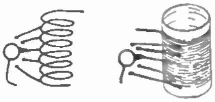
GROUND



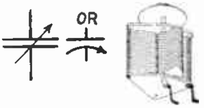
VARIOCOUPLER



VARIOMETER

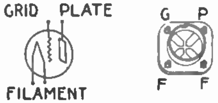


COIL



VARIABLE CONDENSER

FIXED CONDENSER



TUBE AND SOCKET

GRID LEAK

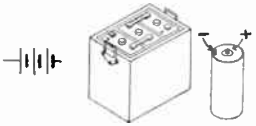
RHEOSTAT

In order to be able to read radio hook-ups it is desirable first of all to have some knowledge of the symbols used to represent the different pieces of apparatus. It is true that circuits can be drawn without the use of these symbols, as we have done in our chapter on "Hook - Ups," and such diagrams may have a much greater value for anyone wishing to build a set. At the same time it must be recognized that "conventional" diagrams can be drawn so as to give a clearer representation of the fundamental electrical relations, since they are not limited by the actual relative size and shape of the parts.

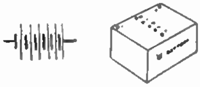
In the next chapter, where we want to explain the parts of a circuit in a fundamental way, we are therefore using conventional diagrams, and in order that they may be well understood we are giving, on this page, all the symbols commonly used, with pictures showing what they represent.

POTENTIOMETER

DOUBLE JACK

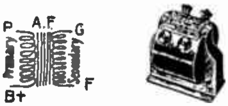


"A" BATTERY



"B" BATTERY

CRYSTAL DETECTOR



AUDIO TRANSFORMER

RADIO TRANSFORMER

UNJOINED WIRES

JOINED WIRES

CHAPTER II

Quick Hook-Up Reading

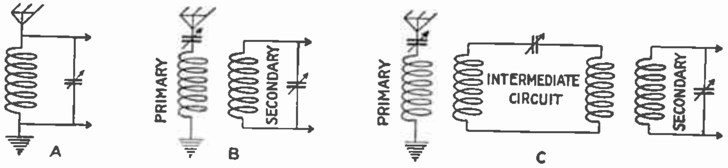
The Anatomy of Radio Circuits

Nearly all radio receiving circuits are made up of several parts which vary but little in themselves, and a "new hook-up" is usually only a very little different from the "old" ones. The difference may be in the tuner, or in the radio amplifier, etc., but if the reader looks all through the diagram and compares each line with some other he will waste a great deal of time in getting to the "point" of the new hook-up. The experienced eye becomes trained to recognize, instantly, all the familiar combinations that make up circuit diagrams, and can therefore pick out at a glance the special feature of any new hook-up, even if the diagram is badly drawn. If the beginner will spend a little time in acquainting himself with these familiar combinations, or "circuit units" as we have here called them, he can in a short time read and understand radio circuits like an "old hand.'

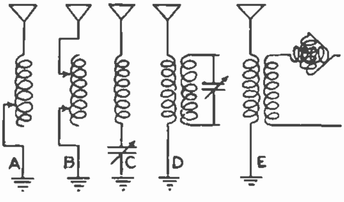
It must be thoroughly understood that this division of circuits into "units" is merely "on paper," for the purpose of understanding them better; do not assume that sets can actually be constructed to give good results by piecing together various separate "circuit units." This is explained more fully in the chapter on "Practical Helps."

The principal circuit units may be named as follows: Tuner Unit, Detector Unit, Battery Unit, Audio Amplifier Unit, Radio Amplifier Unit, and Phone Unit. The work done by most of these is indicated on page 6.

THE TUNER UNIT: The Tuner and Detector are frequently considered together as a single "unit," forming when properly combined, a "crystal set" or "single-tube set" as the case may be. It is helpful in classifying them, however, to consider the tuner and detector separately. In this sense, we may say that the tuner is that portion of the apparatus which picks the radiated waves directly out of the air and converts them into a very weak electric current, alternating at the same "radio frequency" as the waves which produced it. This is the action illustrated on page 6. The most familiar tuner is the aerial and ground, connected by a tuned circuit, as shown at A below. This "single-circuit tuner" is very cheap and simple, since there is only one circuit to be tuned, but it is not very selective; that is, even when tuned to the station we want to receive, it does not exclude others on near-by wave-lengths. For better selectivity we employ a "two-circuit tuner" (shown at B) where the energy is transferred from the primary to the secondary by electromagnetic induction, or inductive *coupling* as it is most commonly called in radio work. The principle of this is the same as that of the transformer, discussed at greater length in Chapter III. In a coupled tuner, it is necessary to tune each circuit separately, and



Fundamental Types of an Aerial-Ground Tuning Unit



Different Methods by Which a Coil can be Tuned

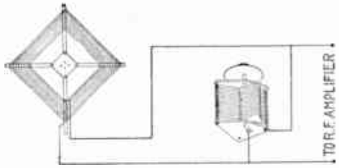
sometimes the amount of coupling is also varied, as by using a "vario coupler"; that is, the extent to which the two coils encircle the same magnetic flux is varied by rotating one of them. Still greater selectivity can be obtained by inserting a third or "intermediate circuit," as at C; a third tuning adjustment is here required.

By *tuning* a circuit we mean varying its natural vibration rate, as explained in the last chapter. We can vary a coil's inductance by tapping it so as to take some of its turns out of the current's path, either at one end as at A (page 11) or at both ends as at B. Or we can insert a condenser in series with it as at C, or in parallel with it as at D, or we can insert in series with it a variable inductance, such as the "variometer" shown at E. The latter is simply an inductance coil built in two parts, one rotating inside the other. They can be set so that their inductances combine either to strengthen each other or to oppose each other, or in any angular position between these, thus giving wide variation of inductance.

For the sake of variety, tuning methods A, B, and C are shown applied to a single circuit, or to a primary, while methods D and E are shown as applied to the secondary of a coupler; any of the tuning methods can of course be applied to either primary or secondary, though not always with practical success.

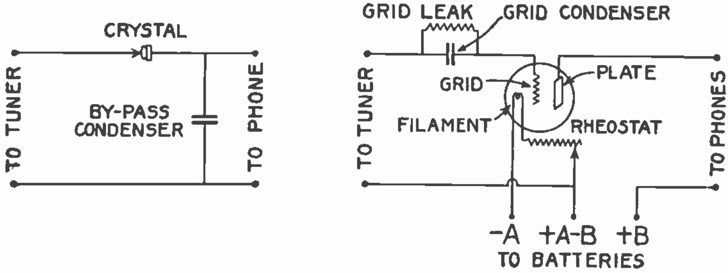
The most widely used tuners at present employ a principle known as "regeneration." This involves, when used, a change in both Tuner and Detector units, and is therefore explained more fully below, after the discussion of "Detectors."

An important class of tuners employs no aerial or ground connection whatever, but only an inductance coil of large diameter, known as a "Coil Antenna" or "Loop Antenna," and a variable condenser for tuning it (see illustration). These two pieces of apparatus form together a complete tuner, just as do the aerial, ground, and tuned inductances previously described. The difference is that the Loop type of tuner can deliver only a very weak current, ordinarily too weak to operate a detector directly, with any satisfaction. The "Loop Antenna" has the advantages, however, that it can be used almost anywhere, or carried around, and that it helps selectivity by its directional effect, in not picking up strongly any station unless it is "pointed toward" that station. When used with efficient radio-frequency amplifiers, it is therefore quite effective.



The Loop or Coil Antenna Tuner Unit

THE DETECTOR UNIT: A detector is simply a "rectifier," which allows current to pass in only one direction, stopping it off when the voltage tends to force any current in the other direction. There are two devices in common use for doing this in radio reception: the Crystal Detector and the Vacuum Tube. As we learned in the last chapter, it is necessary to "chop off" the lower half of the modulated wave as it comes out of the tuner, in order to get a current which will affect a telephone; this is only another way of describing the rectifying action of the detector.



Detector Units: Crystal and Vacuum Tube Types

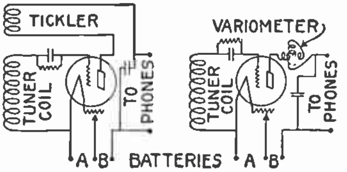
The reason why the crystal detector rectifies is not well understood, but these simple devices give very good results for short-distance reception, and have the great advantage that no battery is ordinarily required, thus eliminating "upkeep expense." Detection by vacuum tube is an intricate science, and no attempt will be made here to explain the theory of it; the reader not already familiar with it will enjoy an introduction through the government pamphlet already recommended. Originally the two electrode tube was used, just as in a battery-charging rectifier: the direction of "electron flow" (minus to plus) is always from the hot filament to the cold plate—never the other way. At the present time, the three-electrode or "Electron Tube" (audion) is used, because the addition of the third element or "grid" produces an amplifying as well as a rectifying action.

In order to make the tube rectify or "detect," we insert in the grid circuit, as shown in the diagram, a small fixed condenser, (usually .00025mfd.) with a "Grid Leak." The latter is usually a fixed high resistance of from ½ megohm (500,000 ohms) to 3 or 4 megohms. Most commonly the leak is in parallel with the grid condenser, but with some tuners it is found better to run the leak directly from the grid post of the tube socket to which the grid return runs from the tuner. (See Chapter VII, "Detectors.")

An essential part of the Detector Unit is a rheostat, which is always connected in series with the filament so that the amount of current which it takes can be accurately adjusted.

REGENERATIVE TUNER-DETECTOR UNITS: These are still the most widely used circuits, and in discussing them it is simpler to think of the tuner and detector as one "unit," since in all forms of regeneration it is the object to "feed back" some of the plate circuit energy to the tuner or grid circuit, thus strengthening the grid voltage so as to produce still stronger variations in the plate current. There are two principal schemes of connection to bring about this result. The first is to run the plate current through a coil known as the "tickler coil," which is coupled to the tuner coil in the grid circuits; the tuner coil here referred to may be either the single inductance used in a "single circuit" tuner, or the secondary of a "two-circuit" tuner. The second scheme of feed-back is to tune the plate circuit, usually by inserting a variometer in it. Both these schemes are shown in the diagram on this page; in the first the amount of regeneration is adjusted by varying the extent of coupling of the tickler with the tuner coil, usually by rotating the tickler coil within it. In the second type of regenerative circuit the amount of feed-back is regulated by the variometer in the plate circuit.

In the case of the tickler circuit, the principle of operation is not difficult to see: the plate current in the tickler coil, being coupled to the tuner coil, induces in it a voltage of the same radio frequency and of amplitude varying according to the sound, like the oscillations already present in it. The two effects may either add together or oppose each other; consequently it will be necessary to reverse the connections of the tickler if it is found to be weakening the reception instead of strengthening it.



Regenerative Tuner-Detector Units

The tuning of the plate circuit by inserting in it a variometer, and also a fixed condenser across the output of the detector unit, actually has an effect very similar to that of the tickler, though its cause is not so apparent to the beginner. The transfer of energy from the plate circuit back to the grid depends in this case on the fact that the two circuits are actually coupled through the capacity existing in the detector tube, its grid and plate acting as the two plates of a small condenser.

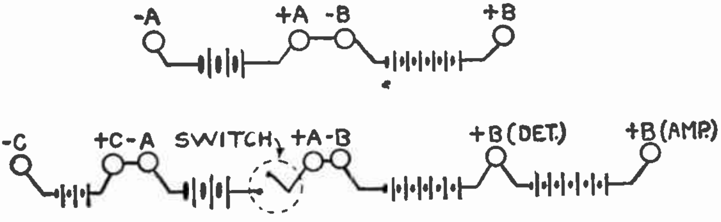
Various modifications of these feed-back schemes are in use, and working hook-ups of the principal ones will be found on pages 38 to 41.

In any method of regeneration, the feed-back action is practicable only up to the point where "self-oscillation" begins. If carried beyond the oscillation point, the effect is to cause the sound heard in the phones to lose their clearness and become "mushy." The amount of regeneration should always be kept under this point, as a self-oscillating tube, by producing beat notes heard as "squeals," (see Chap. VI) is likely to disturb all receivers in the neighborhood.

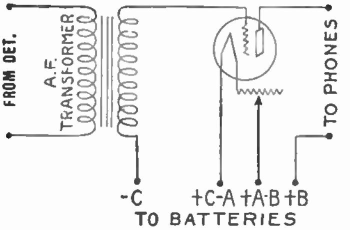
THE BATTERY UNIT: Much confusion exists in the minds of radio fans as to batteries, and it is believed that the classification of types and functions given here will be helpful alike to the novice and to many experienced set-builders.

The three elements of the common vacuum tube, filament, plate, and grid, are often designated respectively by the letters A, B, and C. The order in which the letters are assigned corresponds to the historical development of the tube: the heated filament is comparatively an old device, and the battery which lights it is known as the filament battery or "A" battery. The plate was the second element to be invented, and any battery used in the plate circuit is a "B" battery. The most recent of the three is the grid, and a battery in the grid circuit is termed a "C" battery.

The kind of "A" battery to be recommended depends on various factors, and suggestions are offered in Chapter VII. The "B" battery, connected in the plate circuit, maintains the plate at proper potential, and supplies the energy which operates the phones or loud speaker. The "C" battery provides



Battery Units: With and Without the Grid Battery what is called a "negative bias" on the grid. It is not always necessary, but its use reduces the drain on the "B" battery and frequently improves the volume and tone quality from an amplifier.



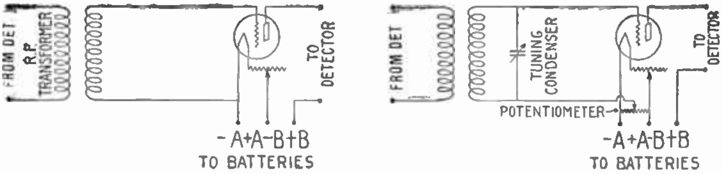
Audio Frequency Amplifier Units

AUDIO FREQUENCY AMPLIFIER UNIT: The wiring of the audio amplifier, as shown in the Circuit Unit Diagram, is subject to but little variation. Practically the only modifications commonly seen are in use or non-use of the "C" battery, unless the circuit is "reflexed," as described below, or unless the "Push-Pull' principle is utilized. Audio Frequency amplification is discussed at greater length in a succeeding chapter, as is also "Push-Pull" amplification.

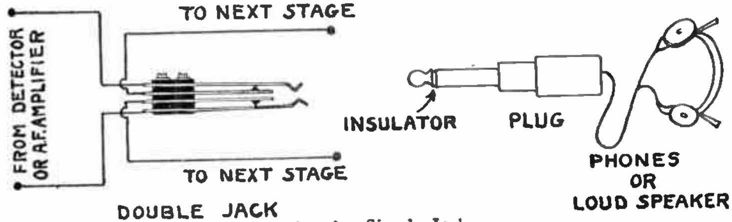
RADIO FREQUENCY AMPLIFIER UNIT: The amplification of signals before reaching the detector is a valuable aid in distance reception, and a number of interesting methods have been developed for overcoming the operating difficulties of such amplifiers; these are touched upon briefly in Chapter IV. At this point we are giving merely two typical circuit-unit diagrams of radio frequency amplifiers, for comparison with our other units.

THE PHONE OR LOUD SPEAKER CIRCUIT UNIT: under this head we may classify all devices for converting the audio-frequency current finally into actual sound waves. The principle of the telephone is so well known that we shall not attempt any explanation of it. In the ordinary headset the two phones are connected in series; where several sets are used they may be connected in various series-parallel combinations, with varying results; the best should be found by trial. A loud speaker is not different fundamentally from an ordinary phone, except that some types employ electro-magnets which require current supply from the storage battery. These are the only modifications commonly seen in this Circuit Unit, except that a "by-pass condenser" of about .005 capacity is sometimes connected across it, to shunt out any remaining radio-frequency oscillations.

JACKS FOR CONNECTING CIRCUIT UNITS: The common method for switching Circuit Units in and out—particularly audio amplifier stages and phones and loud speakers—is that of plugs and jacks. The two terminals of the phones or "speaker" are connected respectively to the "tip" and the "ring" of a plug which can be inserted into any standard jack, as shown in the "Simple Jacks" diagram. Besides completing the connection to the phones, the insertion of the plug in a jack ordinarily disconnects all following audio stages, these being then out of use. This disconnecting is accomplished by the use of the common "double jack" having three or four contact springs. (Jacks using three springs disconnect only one side of the following audio stage,



Radio Frequency Amplifier Units: Untuned and Tuned Types



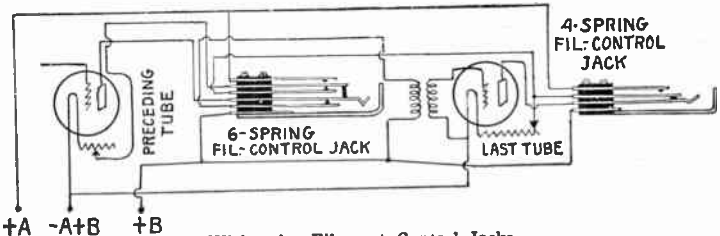
Wiring for Simple Jacks

which is sufficient to put it out of action.)

In addition to the above function, jacks are frequently built so as to switch on the filaments of all tubes in use, without lighting those in following stages, not in use. Such "filament control" jacks are convenient though they add complications to the wiring. The plug, on entering such a jack, works a spring connected to the preceding tube, as shown in the "Filament Control" diagram, connecting it then directly to the battery, and disconnecting it from the next following tube. When the plug is withdrawn, the battery connection is broken, and the connection to preceding tubes falls back into parallel with the following tube.

It is not practicable to switch radio-frequency amplifiers in and out by the use of jacks or any other rapid means, as the long wires required would interfere too seriously with the operation of the amplifier. Jacks have been employed for switching tuner units, disconnecting an aerial tuner and throwing in a loop tuner. This is bad practice, however; jacks should be used only in audio-frequency wiring.

REFLEX CIRCUITS: The idea of a radio hook-up as composed of various "Circuit Units" should be found very helpful in understanding any receiving circuit, whenever seen. Circuits are possible however in which the different units are combined and "mixed up" in various ways. The most important class of such hook-ups is the "Reflex," which depends on using the same tube at the same time for both radio and audio frequency amplification. Reflex circuits are of almost endless variety; the diagrams can usually be read and understood without difficulty if it is remembered that a radio frequency or "undetected" current flows with ease through a small condenser, but is effectually "choked off" by any heavy inductance; a detected or audio-frequency current, on the other hand, will not pass through a small condenser, but will go readily through a radio frequency transformer without any appreciable inductive effect on the secondary winding. With proper selection and arranging of parts, reflex circuits can be made to give wonderfully good reception at a low cost. Two good practical reflex hook-ups are given in Chapter VIII.



Wiring for Filament Control Jacks

CHAPTER III

Audio Frequency Amplification

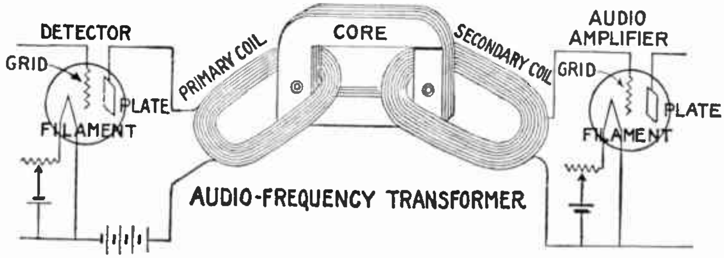
How a Whisper Grows to a Fortissimo

In Chapter II we outlined the ordinary "amplifier unit" very briefly, and we want to give to the reader in this chapter a clearer understanding of just how a weak sound-current, barely strong enough to be audible in the phones, can be strengthened so as to operate a loud speaker and be heard all over a room.

During the past few years vacuum tubes have practically displaced all other forms of audio-frequency amplifiers, because of the great volume and fidelity of reproduction obtainable with the tubes. Their use always requires some sort of coupling device, and the most effective is the transformer. An amplifier tube, together with the transformer which supplies the input current to its grid, make up what is called one *stage* of amplification, or one "Amplifier Unit," as we have seen in Chapter II.

We shall not attempt to describe in detail the amplifying action of the vacuum tube; we shall simply say that a vacuum tube of any of the common types, used without the grid condenser and leak, has primarily a "valve" action, by which we mean that an alternating voltage delivered to the grid of the tube "stops off" and "releases" the flow of plate current so as to mould it very closely to the wave form of the grid voltage itself. Hence the voltage we get from the detector tube need only be high enough to "work the valve" on the grid of the amplifier tube. However, we cannot connect the detector output directly to the amplifier grid, since we must have there only the *variations* of the plate voltage, and not the full continuous "plus" voltage necessary on the detector plate. So we use, as by far the best means of getting these variations of voltage delivered to the amplifier grid, an "audio-frequency transformer."

To the radio-wise, we could define a transformer as simply a very close inductive coupler—but for such readers no definition would be necessary at all. So instead, we have on this page a picture which symbolizes the parts of a transformer so that their functions can be better understood. Any iron-core transformer is, in its operation, simply a chain of three "links": two coils of wire, each interlinking with the iron core or "magnetic link." According to the principle of electromagnetic induction, when an alternating electric current is sent through one of the coils, it causes magnetism to appear in the iron core, and all changes and reversals of the current are accompanied by corresponding changes and reversals of magnetism. All the changes of magnetism are at the same time



Transformer Construction: The Electric and Magnetic Links

causing voltages in the other or secondary coil, proportional to the rapidity with which the magnetism is changing, and therefore proportional to the rapidity with which the primary coil current is changing.

Now, looking back on page 6, notice the kind of current which flows from the detector to the audio frequency amplifier; it is a "direct current," since it flows always in one direction, but it is a "pulsating direct current," because its strength is not uniform, but varies according to the form of the sound wave it is transmitting. This is the current which we send through the primary coil of our transformer, and variations in it cause continual variations in the magnetism of the core. Imagine one of these "peaks" of current coming from the detector; as the current grows, it causes a voltage to appear in the secondary. Then, as the primary current stops growing and reaches its maximum, the secondary voltage vanishes; as the primary voltage now begins to decrease, voltage appears again in the secondary but in the reverse direction.

All these changes of secondary voltage are transmitted to the grid of the amplifying tube, reflecting each little "kink" in the primary (detector) current. The *voltage* of this secondary current depends on the number of turns in the secondary coil as compared with the primary; thus, by winding five times as many turns on the secondary as on the primary, we have a "5 to 1 ratio" transformer, and can send out to the amplifier grid a voltage almost five times as high as we get from the detector plate. This "stepping up" of voltage increases the amplifying action.

The beginner should be careful, throughout this discussion, not to confuse the "kinks" in the audio frequency wave (due to overtones or partials in the sound wave) with the radio frequency oscillations. They are alike in that both are more rapid than the fundamental audio frequency, but the radio frequency is perhaps thirty or forty times as rapid, relatively, as we have been able to show it on page 6, while the overtone "kinks" are shown as they might actually appear in photographs of sound waves. The reader who is musically inclined will find a very interesting study of tone photos in "The Science of Musical Sounds," written by Prof. Dayton C. Miller, a pioneer in investigating the physical nature of music.

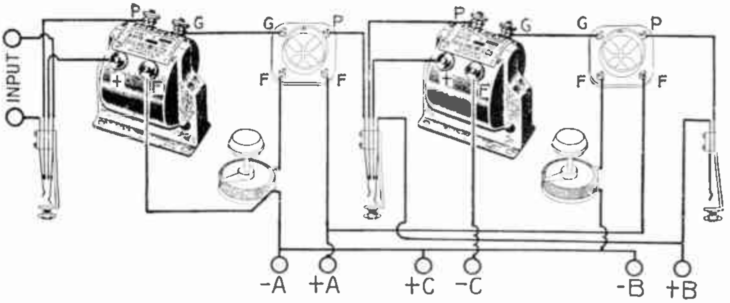
The above description of an Audio Amplifier Unit applies particularly to the "first stage;" the second stage, commonly used, is exactly like the first, except that it takes its grid supply from the first stage instead of from the detector directly. It is of course possible to connect three or more stages in the same way, but the truth is that, whatever transformers and tubes are used, a third stage of "straight audio" seldom satisfies the ear of a person of any musical taste. The controlling reasons for this fact are to be found to a large extent in the characteristics of the vacuum tubes themselves.

Since an audio transformer cannot well be "homemade," it is not surprising that there are a very large number of makes on the market. The beginner may be somewhat bewildered by the great variety in appearance of these instruments; some of this is due to legitimate difference of opinion among engineers, but much of it is merely "ornament." Nothing is gained in performance by the addition to an audio transformer of fancy miniature "panels" and cases of high-insulating materials.

The shielding of iron-core transformers is a much-mooted question. Careful tests sometimes seem to "prove" that a well-designed transformer requires no shield. Again, cases will appear in which certain noises seem to be traceable to magnetic leakage where the leakage should theoretically be negligible. Whatever interference may really be likely to take place between transformers placed close together, it can be prevented absolutely by proper shielding, and such leakage interference is thus removed from the list of possible causes of any fault in reception. It is for this reason that All-Americans are thoroughly shielded.

As has been explained in this chapter, the function of an audio transformer is to transmit accurately, and amplify uniformly, all voltages of audible frequencies impressed upon its primary. While this sounds like a simple requirement, there is no method by which the listener can measure the efficiency of any particular instrument, except by substituting it in place of another and comparing the sound produced. Few listeners are in a position to do this with all the widely-advertised makes of transformers. The "amplification characteristic" (see inside back cover) is a scientific method of stating the relative efficiency of an audio transformer, *when new*, but the amount of reliance which can be placed on a published amplification curves depends of course on the general reliability of the manufacturer. And the amplification curve shows nothing as to the likelihood of a transformer developing a "short circuit" after a few months of use, if the utmost precautions have not been taken in its manufacture. So in the last analysis the main reliance of the intelligent transformer buyer, in addition to his own experience and that of his friends, must be on the experience and standing of the maker, and his reputation for consistent and reliable workmanship over a period of years.

One of the main things which make the building of radio sets such an adventuresome occupation is the fact—well known to every old hand at the "game"—that two sets built with the same circuit exactly—perhaps even with the same make of parts and with the same panel drilling—may show very different results. There is always a reason for such occurrences, of course, though it may be difficult to find. Too often the reason has been, in the past, that parts which look exactly identical to the eye are far from identical inside. It has always been our view that the placing of such parts on the market is an injustice not only to the set builder himself, but to the whole science. Continued failure from a source not recognizable without laboratory instruments may disgust the newer experimenter entirely with radio-set building. Consequently, it has been our endeavor to make All-American transformers a model of uniformity in their construction, and we believe set builders who make a practice of using All-Americans in their various hook-ups will agree that whatever unaccountable freaks in performance they may experience are never traceable to any variation between one All-American transformer and another bearing the same name-plate.



A Complete Two Stage Audio Frequency Amplifier

CHAPTER IV

Radio Frequency Amplification

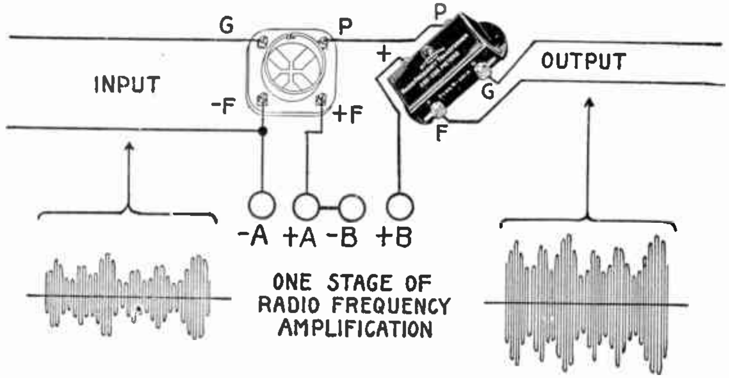
How a Distant Signal is Made Audible

In the last chapter we discussed the amplification of currents from which the radio frequency oscillations have been damped out or otherwise removed. Such amplification of "sound currents" presents difficulties due to the necessity for equally amplifying low musical notes and high overtones, if distortion of tone quality is to be avoided. In radio frequency amplification the problems are of a very different nature. The reason for employing it at all is not to strengthen a sound current, but to amplify the high-frequency oscillations as they are received in the tuner, giving them *sufficient strength* so that the *detector can convert them* into sound currents.

If all broadcasting was done on the same radio frequency, it would not be so difficult to amplify the oscillations, for we could then use a transformer designed especially for that frequency. However, since broadcasting stations use frequencies all the way from 550 to 1350 kilocycles, it is necessary either to use a transformer which will amplify satisfactorily oscillations of any frequency within this range, or else to substitute a new transformer when tuning to a new wave length, or to tune the circuit by the use of a variable condenser. The first method depends of course on having a transformer which will cover this wide range, and up to the present time such instruments have been hard to find. This second method—changing transformers—is cumbersome, and has therefore never been much used. The third method, under the name "tuned radio frequency" has therefore become quite popular.

The use of tuned circuits in amplifiers introduces, however, some new difficulties. There is in every electron tube a small but definite *capacity* between the grid and the plate, and with the grid circuit tuned almost to resonance with the plate circuit the two are coupled through this capacity, producing a tendency for the tube to oscillate just as it does in a regenerative circuit when there is too much feed-back. This is one difficulty which has prevented the general adoption of tuned transformer coupling.

Various methods have been employed, looking toward the correction of this tendency to oscillate. Among these are the



A Complete Stage of Radio Frequency Amplification, Showing the Effect on the Received Oscillations

Neutrodyne (page 42) and the Superdyne (page 43). In the former, the coupling within the tube is "neutralized" by the proper use of a small variable condenser. In this way the tendency to oscillate can be effectively overcome, but at the cost of reducing considerably the amount of amplification possible in each stage. In the Superdyne, the tendency to oscillate is overcome by the use of a reverse feed-back, which also, of course, cuts down the amplification per stage.

It has therefore become increasingly apparent that if it were possible to design a radio frequency transformer so as to amplify, with practically equal strength, waves of any length within the broadcasting range, *without the introduction of any such sharply tuned resonant circuits,* (and therefore without the necessity of introducing devices which cut down the amplification) *such a transformer would be of inestimable value* in distance reception. It is for this reason that All-American engineers have concentrated their energies on this problem during the past two years. The period (1922-1924) has seen the development of the above mentioned and various other devices for mitigating the difficulties of tuning a radio frequency amplifier, but progress has been slow toward a genuine solution of the problem by the actual construction of a transformer which would accomplish the results *without tuning.* The writer feels, therefore, that it is difficult to overestimate the importance of the increased distance range now possible with a simple untuned circuit, using the new All-American short-wave transformers.

It would seem that one reason why our researches have been more successful than others simultaneously conducted lies in the fact that we worked along different lines. Several months ago we became satisfied that the failure of many sincere efforts to reach a solution of the problem lay in the compromises of design which were necessary in order that the transformer might operate equally well on any of the standard tubes in use. Previously our own research staff had also attempted to make this compromise, but finding success no nearer than ever, we abandoned the effort, and started out on a new line of endeavor: namely, the development of a transformer which would amplify efficiently over the entire broadcasting range with *one definite type of electron tube.* The degree of success which has come to these efforts has surprised even the engineers who conducted the work. It might seem a simple thing to wind two different types of coil to fit the characteristics of the two leading amplifier types now in use—the 199 and 201-A types. But "the simplest discoveries are frequently the most far reaching," and we cannot but feel that such is the case with the new All-American Types R-199 and R-201A, recently announced as the culmination of what we believe is the most remarkable series of experiments ever carried out in radio frequency amplification.

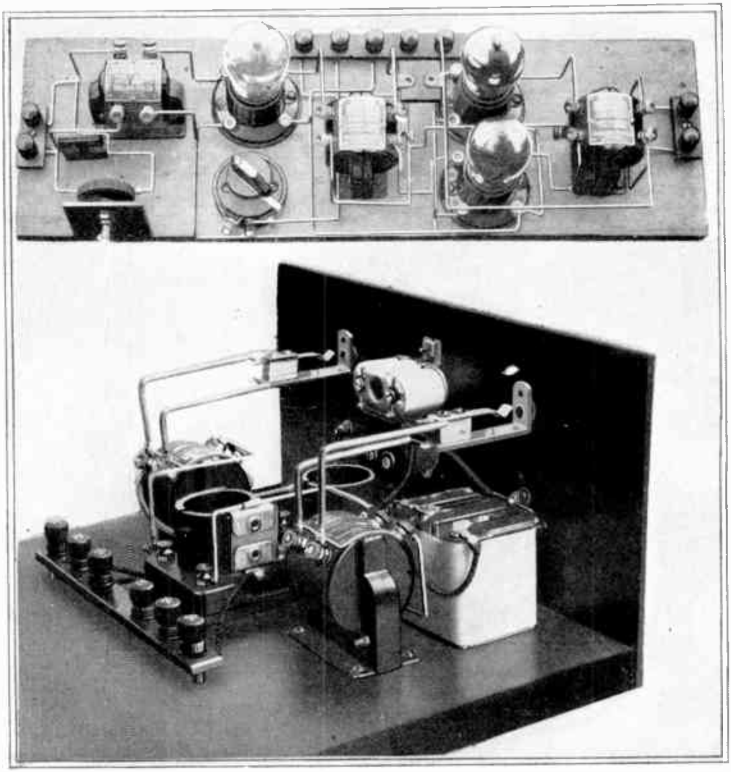
The New All-American Self-Tuned Radio Frequency Transformer

CHAPTER V

Power Amplification

The "Why" and "How" of the Push-Pull Circuit

In Chapter III it was pointed out that ordinarily more than two stages of straight audio frequency amplification do not give the best results. It is true that radio fans as well as manufacturers have made three-stage sets which perform very well, but these sets have been carefully designed in every detail, and usually require considerable experimentation before a three-stage amplifier is produced that will give uniform satisfaction. If



Upper Photo Courtesy of Radio in the Home. Lower Photo Courtesy of N. Y. Evening World

Two Very Good Arrangements of the Power Amplifier. Above We Have a Complete Audio Amplifier Consisting of One Ordinary Stage, Shown at the Left, Followed by a Second Stage of the Push-Pull Type. Below is Shown a Panel Mounting for the Power Amplifier as an Entirely Separate Unit: on the Panel are Mounted a Battery Switch, a Rheostat, and Two Jacks. On the Baseboard are the "C" Battery, the Input and Output Transformers, the Two Tube Sockets, One of Them Carrying the Fixed Condenser. Instead of Using Two Jacks, as Has Been Done in This Panel, it is Preferable in General to Connect the Input Leads to a Plug Which can be Inserted in Any of the Jacks of the Receiving Set

you desire more volume, particularly from distant stations, and at the same time clear, pure tone, then Power Amplification, of the well-known "Push-pull" type, will satisfy your most exacting requirements. In the following paragraphs we describe in some detail its advantages and operating theory.

The principal advantages of "Push-pull" amplification are as follows:

1—The signal current from the amplifier to which the "Push-pull" unit is attached is divided between two tubes. Thus, the tubes are not overloaded by strong signals from local stations.

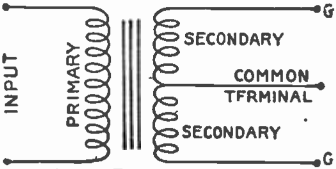
2—In ordinary transformers there is a magnetic flux at all times in one direction, due to the "steady plate current" from the tube. In the push-pull circuit the steady component is "balanced out", leaving no flux except that due to audio-frequency variations in plate current. This gives a very nearly ideal condition in the transformer core.

3—The fact that we have two tubes in parallel in "Push-pull" amplification enables us to use a specially designed transformer in the output circuit, having very low resistance. This results in a maximum of current delivered to the loud speaker.

4—The *characteristics of any amplifying tubes,* particularly at audio frequencies, always produce a certain amount of undesirable harmonics ("kinks") which may, or may not be, noticeable to the ear. In "Push-pull' amplication, these harmonics are balanced out, resulting in a decided improvement in tone quality.

There are other advantages of using "Push-pull" amplification in the last stage, but these additional points are somewhat too technical to discuss in a brief article of this kind. Having gained some knowledge of the principal advantages of "Push-pull" amplification, we shall now consider the operation of this unit.

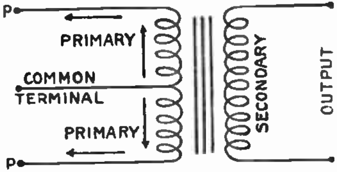
For a "Push-pull" circuit, the output of an ordinary one or two stage audio frequency amplifier is connected directly to the primary winding of a special input transformer, which has two windings on the *secondary,* as illustrated below:



Power Transformer: Input

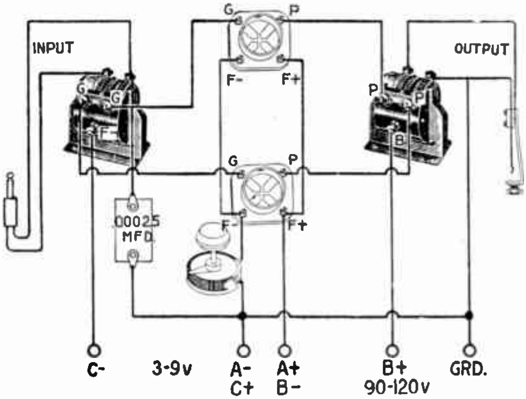
It will be observed that both of the secondary windings are connected to a common terminal. It is evident that if one of the "G" terminals is at any instant positive with respect to the center terminal, the other will at that instant be negative. Since the two "G" terminals of the double secondary winding are connected to the grid terminals of two tubes, a positive potential is impressed on the grid of one tube, while simultaneously a negative potential is impressed on the grid of the other tube. This means that we have *divided the secondary voltage* of the input transformer equally between the two tubes of our "Push-pull" unit. The result is a corresponding increase and decrease in the plate currents of these two tubes, since this plate current is governed by the potential of the grid.

Having followed the circuit from the input terminals of the power unit, through the input transformer, and thence to the grids of the two tubes, we will now consider the plate circuits of these two tubes and their relation to the output transformer. In the circuit diagram you will note that the plates of the tubes are connected to a special "output" transformer, which is similar to the "input" excepting that in this instance the transformer **has two *primary* windings, thus:**



Power Transformer: Output

In actual operation there is, at a moment of silence, a steady plate current flowing in both primary windings, but in opposite directions from the common terminal, as shown by the arrows. Since these currents oppose each other—one "pushing" and the other "pulling"—their magnetizing effect on the iron core of the transformer is neutralized, as stated above, and *there is no flux present.* But when a voltage appears on the grids, its effect is to *increase* one of these opposing plate currents and *decrease* the other, so that while one "increases its push," the other "relaxes its pull." Consequently, both windings *combine their effect* to produce a powerful sound current in the secondary. As a matter of fact, one stage of "Push-pull" amplification gives more volume than one stage of ordinary audio amplification, but somewhat less than two stages.



Complete Circuit Diagram for the Power Amplifying Stage

The principal value of "Push-pull" power amplification is its action in dividing the voltage delivered by the previous stage equally between the grids of the two tubes. From your studies of vacuum tubes you may remember that the output, that is to say the variations of plate current, is seldom, if ever, exactly in proportion to the signal impressed on the grid. This gives rise to "harmonics" which are balanced out in the "Push-pull" style of amplification, this being a further reason why we recommend a stage of "Push-pull" instead of a third stage of ordinary audio amplification. Experiment has abundantly proved that *no transformers now on the market can be made to give better results, on a third stage of ordinary "audio," than All-Americans.* However, all radio engineers recognize the fact that even though it were possible to produce a transformer ideally perfect in every detail, yet with plate currents as high as those in an ordinary third stage, the *tube characteristics* alone would result in introduction of undesirable harmonics, and consequently would impair tone quality. This is exactly what the "Push-pull" circuit avoids.

In the following paragraph we list a number of suggestions which the builder will be wise in following when constructing his "Push-pull" power unit. We want to emphasize particularly the point regarding use of tubes of the same type in the power stage. That is, the tubes in parallel between the input and output transformers should be of exactly the same type; for instance, *both* tubes should be UV-201A or similar type tubes such as C-301A, or else both should be of any other type which you find gives good results.

We wish to also mention the advisability of constructing your stage of "Push-pull" amplification as a separate unit electrically. It can, of course, be incorporated mechanically as a fixed part of your set, but when wired as a separate unit, with its own plug and jack, it can be plugged in on either the first or second stage of audio frequency amplification.

Suggestions

1. Follow layout of apparatus as shown in the diagram above. Make connections from transformers to circuit exactly as indicated on transformer plate. Grid and plate leads or wiring should be as *short as possible* to eliminate local feedback effects. These important leads may be shortened by raising the sockets an inch or two from the base board.

2. We recommend the use of UV-201-A or C-301-A tubes throughout the amplifier. *Be sure that you use tubes of like characteristics* in the power stage. *This is essential* to obtain the balancing effect; it is not so important in the other stages.

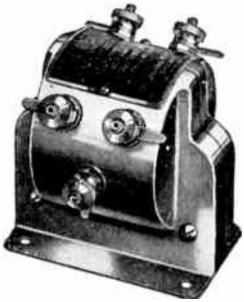
3. Ordinarily 90 volts will be found sufficient for the plate potential; however, when using power tubes, such as UV-202, greater voltages will be required, depending upon their specifications.

4. It is *essential* that the "C" or biasing battery be used. When using the 201-A type tubes, six volts will be sufficient; however, we suggest that you experiment with voltages ranging from three to nine and choose the value that gives the best tone. Ordinary flashlight cells will be found satisfactory, if cell-to-cell connections are well soldered.

5. We suggest the grounding of the transformer casings to the negative "A" battery or ground.

6. *Do not use soldering paste*—even so-called non-corrosive—in making joints in your wiring. Use only rosin-core solder.

7. Remember that a Push-pull amplifier depends absolutely, as does no other type, on perfect *balancing* of the two transformers; unless both are designed and made in a factory accustomed to *precision workmanship*, the neutralizing of distortion described above can by no means be depended on.



The All-American Power-Amplifying Transformers

CHAPTER VI

The Super-Heterodyne

Amplification at a Chosen Frequency

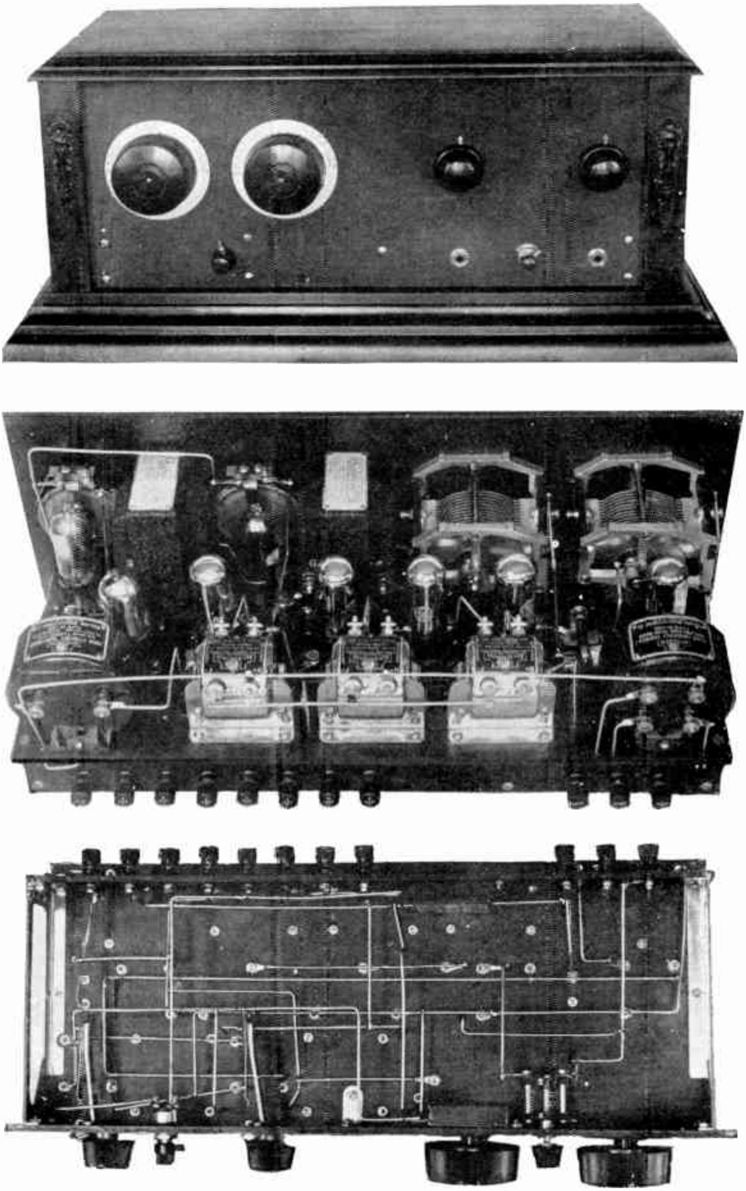
From the many superlatives that have been applied to the Super-Heterodyne Receiver, we may select a few which cannot be questioned by partisans of other modern circuits. The "Super-Het" is the most elaborate method of reception, and is the least subject to the various influences which limit the range, selectivity, and exactness of reproduction in other types of receivers. While it embodies principles entirely beyond those explained in Chapter II on Circuit Units, these fundamentals are readily made clear to anyone who understands the units of the ordinary radio receiving circuits.

It will be remembered from Chapter II that in order to strengthen the signals from far-distant stations so that they will operate a detector and become audible, we have to pass these weak signal currents through a radio frequency amplifier (unless the tuning is regenerative, which has a similar effect). So far as the circuit-unit diagram is concerned, a radio frequency amplifier (untuned) is practically identical with an audio frequency unit, but the important fact is that the radio frequencies most suitable for broadcasting (550 to 1360 kilocycles, according to U. S. Dept. of Commerce allocations of February, 1925) are too rapid for best amplification efficiency.

In the Super-Heterodyne, on the other hand, we make no attempt to amplify at these high frequencies, but instead we reduce them all alike to some lower radio frequency (still above the range of audible pitches) which has been decided upon as one for which an amplifier can best be designed. Then, with the reduced capacity effects we proceed to pass the signal current through as many stages of amplification at this "intermediate radio frequency" as may be considered necessary. Like "straight radio frequency" these intermediate frequency stages are relatively free from the fault of amplifying minute noises which may creep in at various points, since the transformers, if carefully designed, will not be sensitive to the audio frequency waves constituting the "noise" and will therefore tend to weed them out from the transmitted signal.

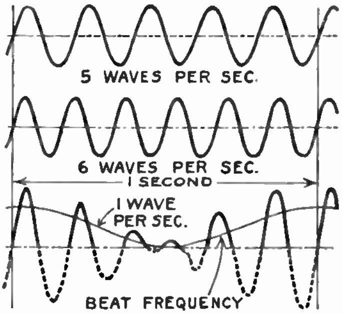
After the intermediate frequency current has been run through the desired number of amplifying tubes, it is rectified by a detector as usual, and may then be further amplified through one or more audio frequency stages.

The interesting thing about this circuit is of course the means employed for reducing the incoming signal current to the "intermediate" frequency. It is done by the simple method of "beats"—the same kind of beats which are heard when we strike a key on the piano, the two strings of which are not quite in tune with each other. If for example the note is the "A" which should vibrate exactly 435 times per second, but only one of the two strings is correct and the other is tuned to a pitch of 436, then, once every second, the faster string will "gain one" on the slower one; so that if at some particular instant the two strings are vibrating in phase, so as to "pull together," they will, just one second later, again come in phase with each other, and another "beat'" will be heard as the two strings reinforce each other. Half-way between the times when they are in phase, their effects oppose each other, so that the sound is greatly weakened. If the "sharp" string was still further "out of tune," and vibrated 437 to the correct string's 435, then there would be two beats



Views of a modern Super-Heterodyne Receiver using standard parts and 199 type tubes. The panel is only 7" x 18" and the receiver 7" deep. A RECEIVER of unique design capable of receiving over great distances.

per second, and so on. That is, by combining two frequencies nearly the same, we get a frequency equal to the *difference* between the two, which altho not the only one produced is the one in which we are interested.



How the Beat Frequency is Produced

The effect is shown also in the diagram, where, for the sake of simplicity, we have represented a frequency of 5 per second, and another of 6 per second, and have shown how, when the effects of the two are added together, the result is the appearance of a new frequency equal to their difference. This wave looks "broken up" by the kinks due to the original frequencies, but only because of the small numbers used.

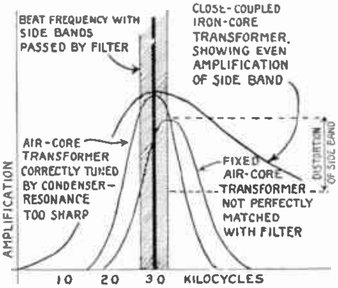
In the best Super-Heterodyne practice we use ordinarily a beat-frequency around 30,000 cycles per second (10,000 meters wave length), so that in order to bring down to it a 750 kilocycle signal we would have to combine with it a series of oscillations at a rate of either 780 or 720 kilocycles per second. This new wave must of course be adjustable, so that we can tune it to just 30 kilocycles above or below whatever station we want to receive.

To produce this auxiliary wave we use a Heterodyne, or Oscillator, which is simply an electron tube connected to a tuned circuit so that its plate current pulsates steadily at the natural frequency determined by the tuning of the circuit. This pulsating current is run through a coil coupled to another coil which in turn is connected into the tuning unit of the set, so that its output contains a beat frequency equal to the difference between the incoming frequency and the oscillator frequency. The resulting current might be represented in much the same manner as the "Received" current on page 6, but when it is rectified and the high-frequency oscillations damped out (or shunted out through a condenser), just as in the figure on page 6, the result is not an audio frequency, but is instead the desired "intermediate-frequency current.' The rectification is done in this case by the "First Detector Tube," and the damping-out by the filter shown as "R-120" in the hook-up on page 47, instead of by an audio frequency transformer.

It must be remembered that the intermediate frequency current still carries, moulded into the outline of its waves, the voice frequencies originating in the microphone of the broadcaster. After the intermediate frequency current has been sufficiently amplified, all we have to do is to repeat the detecting process, exactly as represented on page 6 this time, using what is called the Second Detector Tube, and we have our current ready for the "speaker".

Let us now consider how the remarkable selectivity of the Super-Heterodyne is obtained. A little figuring will show that a very slight change in the tuning of our oscillator, say from 720 kilocycles to 727½ kilocycles—a change of only about 1%—will change our beat frequency from 30 kilocycles to 22½ kilocycles—a change of 25%. Looking at it another way, if there should be another station "interfering" with our 750 kilocycle station, by transmitting on 742½ kilocycles, (404 meters as compared with 400 meters) then the resulting beat frequency would be in reality 25% different from the one to which our filter coils are tuned, and hence would not interfere any more than a 500 meter station would under ordinary methods of tuning. The selectivity of the "Super-Het" is thus almost unbounded; it is limited in practical design by the fact that when a 400-meter station is transmitting waves modulated at voice frequencies up to say 4000 (or 4 kilocycles), there are in effect "side bands" present at the same time, which vary between 746 and 754 kilocycles. The presence of the "side bands" will be understood by a reversal of the explanation of the "beat frequency" formation; instead of combining waves at 750 to 720 kilocycles to get one at 30 kilocycles, we have here a radio frequency of 750 kilocycles and an audio frequency of say 4 kilocycles, and again the two together are capable of acting on a tuned circuit like a third frequency—in this case 746 cycles.

As suggested above, it is the function of the filter coupler to *select* the signals of the desired beat frequency, and eliminate all others; the tuning of the filter should therefore be as sharp as possible, without weakening the "side bands." For this reason the filter coupler should always have an air core, and be loosely coupled. The inter-stage transformers, on the other hand, receive the signal already filtered, and should therefore be broad enough in their tuning so that there will be no uncertainty about their transmitting faithfully the actual frequency of the filter. For example: the filter may have been intended to operate at 30,000 cycles (10,000 meters), but owing to variations in manufacture it may respond instead to 32,000 cycles (9,375 meters). If then the interstage transformers are properly designed, we need only tune our oscillator to produce the required 32,000 cycle beat frequency, and reception will be exactly as good as with a true 30,000 cycle filter. But if instead we are using, with the 32,000 cycle filter, air-core transformers accurately designed for 30,000 cycles, then the set will not work properly. Since accurate matching is hard to obtain in manufacture, it is difficult to find on the market a number of air-core transformers which exactly match the filter.



How Various Types of Intermediate-Frequency Transformers Function

Because of this, "tuned air-core transformers" are sometimes used, each one being tuned independently, by a variable condenser. This of course permits perfect resonance with the filter, but introduces a number of extra parts and wires, together with the possibility that one or more of the transformers may tune too sharply and distort the side bands, causing poor tone quality; also it does not correct the tendency of loose-coupled transformers to interfere with each other by magnetic leakage. Consequently, it can hardly be recommended except as a makeshift in the absence of well-made iron-core transformers, broad tuned and close-coupled so as to transmit quietly and efficiently the output of any good filter coupler.

There are, of course, many other modifications of the Super-Heterodyne circuit, as for example in the method of the first rectification. In the Ultradyne circuit it is accomplished by the rectifying action in the plate circuit of the modulator tube, this tube having no steady plate potential. In the original Armstrong Super-Heterodyne the ordinary grid condenser and leak are used, while in still other circuits a suitable "C" battery, in connection with the tube characteristic, is the rectifying device. In any case, the result is as described above.

CHAPTER VII

Practical Helps in Constructing Sets, with Notes on Sources of Trouble

The Aerial and Ground Circuit

AERIAL: Use No. 14 or No. 16 solid or stranded copper wire in the aerial. Copper ribbon can also be used and is very good. Do not use iron or steel wire, except the copper clad types.

An aerial about 50 to 75 feet long usually gives the best results—the combination of good reception with maximum selectivity. If it is much longer than this the set will not be so selective. If tapped in the center — the preferable method — it should be 60 to 75 feet long. If tapped at one end it should be 50 to 60 feet long. In case the supports on which your aerial is fastened are a greater distance than 60 feet apart, place insulators on the wires supporting the aerial in such a way that the aerial itself is only 60 feet long. If you have not space to erect an aerial 60 feet long, use a somewhat shorter one of several wires, keeping the wires at least 3 feet apart. They should be parallel and should all be soldered or firmly clasped together at both ends. Very good results are obtained by continuing all of the aerial wires down to the set as a lead-in.

Connect the lead-in either in the exact middle of the aerial or at the extreme end. Do not tap part way in at either end, as the short part between the lead-in and the end hinders the reception more than it helps.

Keep the aerial as high above the roof as possible—not less than 4 to 5 feet. Keep it far away also from gutters, cornices, wires, trees and so forth, as they all tend to absorb energy and weaken the signals.

Do not run wires close to, and especially not parallel to, telephone wires, electric light wires, or other aerials, as the light and 'phone wires cause a hum in the set and the other aerials cause weak signals, howls, and whistles. DO NOT CROSS OVER OR UNDER LIGHT WIRES, TELEPHONE WIRES, OR HIGH TENSION WIRES, AS IT IS VERY DANGEROUS. EITHER THE AERIAL OR THE LIGHT WIRE MAY FALL AND CAUSE A SERIOUS ACCIDENT.

INSULATORS: Insulators on your aerial are very important and should be used wherever necessary. Glazed porcelain makes about the best insulators; for receiving aerials, the ordinary glazed porcelain cleats are very good. Where an aerial lead-in goes over the edge of the roof, fasten an insulator on the end of a stick about 2 feet long, nailed to the window sill. With a stick over the cornice and one at the window sill, the lead-in will be kept about 2 feet from the building.

Where the lead-in enters the house, it may be insulated by using a porcelain insulator tube, or it can be brought directly through the pane of glass in the window by using a bolt fastened through the window pane with rubber washers on each side. The aerial lead-in is then fastened to the outside of the bolt and a connection taken off the bolt on the inside.

LEAD-IN: Where the lead-in is tapped off to go into the house, use a good lightning arrester, running the ground wire direct from the lightning arrester to the ground. If you cannot put in a ground rod, connect to the closest water pipe in the basement. The lightning arrester will serve two good purposes, in that it protects the set from harm due to static discharges from the aerial, and during thunder storms will conduct the static electricity from the air surrounding the aerial so that it will be less likely to be struck by lightning. (A building with an aerial using a good lightning arrester is considerably safer than a building without an aerial.)

LOCATING RECEIVER: The receiving set should be located near the point where the aerial lead-in enters the house. Do not run the aerial lead-in around a picture moulding or base board into another room, as this causes the loss of considerable energy.

GROUND: The ground is also very important. The best connection is made by soldering a wire to the water pipe where it enters the house. If this is not possible the next best plan is to make a good connection, anywhere, to the nearest water pipe. Another type of ground is a connection to the radiator, although this is not as good as either of the above. Do not run the ground wire along close to the aerial wire, but keep it as far away as possible.

In general it is a good thing to avoid turns, bends, and points of support in both the lead-in and the ground wire. Every point of support means a decrease in both volume and selectivity.

TROUBLE SOURCES: If the signals are weak, check through your aerial and ground installations to see whether they agree with the methods outlined above. If not, try improving them by adopting the suggestions given.

If whistles, howls, or hums are heard, see if your aerial is near other wires or near the aerials of neighbors who have regenerative sets.

Tuning Apparatus

INSULATING MATERIAL: Use a good insulating material for supporting the parts of your set. The panel should be of hard rubber, bakelite, formica or some other good insulating material. If wood or poor material is used there will be considerable leakage and you will get poor results.

The best material for tubes on which to wind the tuning coils is cardboard, thoroughly dried and painted with collodion. Do not use shellac anywhere on your tubes or windings, as it will tend to introduce distributed capacity.

Use double-cotton-covered wire —or better, double silk-covered— for the coils. It is very good practice to space wires on coils about one-half the diameter of the wire apart to help insulate the turns from each other and also to reduce the distributed capacity. Spacing the turns will aid sharpness in tuning.

Do not use any insulating covering on the connecting wires in a set except where absolutely necessary, as it adds distributed capacity and so weakens the tuning.

Some results, and even good results, may be obtained without paying any particular attention to the above notes; but for the experimenter who desires the best reception possible, they will be found a great help.

WINDINGS: For primary circuits, the best size is about No. 20, although any size from No. 16 to No. 22 will prove satisfactory. For the secondary use No. 20 to No. 26. In the plate circuit the wire can be the same as that used for the grid circuit. Where coils are tapped, use only as many taps as are really necessary. The connecting wires to the taps should be small, and not covered unless absolutely necessary to prevent short circuit.

In tuning units such as varicouplers and variometers, do not have the rotors connected to the circuit by a wiping contact on the shaft. Use instead a pigtail soldered to the shaft and to the connection post. A wiping contact adds resistance to the circuit and causes scratching sounds when tuning.

CONDENSERS: The fixed condensers in a set should have a mica dielectric for best results. Do not use condensers in which the dielectric is paraffined paper. For the best operation of your set, it is important to use the condenser of the proper capacity for the part of the circuit it is in.

For a variable condenser the best type is that having movable plates and air dielectric. Select one that has as small a quantity of insulating material in the field of the condenser as possible. Also see that the connection to the rotary plates is made by a pigtail or by a very good wiping contact; otherwise the set will scratch when tuning. Variable condensers are made in value from .00025 or less up to .001 mfd. Use the value specified in the diagram or plan you are following. A well-made 43 plate condenser usually has a maximum capacity of about .001 mfd., a 23 plate .0005 mfd., and an 11-plate .00025 mfd.

Keep the condenser away from coils, and never place one inside of a coil to save space, as it will hinder the coil from functioning as it should.

In using variable condensers connect the movable plates to the ground side of the circuit as this will reduce body capacity effects.

MOUNTING AND WIRING THE SET: In mounting the apparatus keep all the units as far apart as possible, (without using unduly long wires, particularly in radio frequency stages); otherwise they will interfere with each other and will cause weak signals, poor selectivity, howling and a very unstable set.

Avoid freak or special apparatus as much as possible. Where jacks are used, put in the simplest type that will accomplish the purpose in view. Do not try to make a set that can be converted from one circuit to another by throwing switches, as it will not work satisfactorily. Decide on one circuit and build your whole set for that circuit only.

In wiring use No. 14 or No. 16 tinned copper wire, which is much easier to solder than the plain copper wire. Do not use a covering on the wire except where necessary.

Arrange your wiring so that no two wires are close together or parallel. This is especially true in that the plate wires should never be near or parallel to the grid wires. If they are near, the signals will be "mushy," or the set may howl. The "A" battery leads to the filaments may be run close together without any harm. Where wires come so close together as to allow a possibility of short circuit, they should be protected with a piece of "spaghetti' slipped over each wire.

The lead from the *tuning coil* to the filament of the tube should go direct to the tube and should not be connected to a common ground wire. Do not for instance connect the two "-F" posts on the transformers together with a common wire that is grounded and then connect the lead from the tuning coil to this wire, at a point which may be remote from the filament itself. Neglect of this precaution is liable to cause "mushy signals" or howling.

Short straight connections are better than sharp cornered bends, even though the sharp corners make a neater appearance.

In making connections under screws and washers, be sure the wires are scraped very clean before fastening. Scrape or file all connections very clean, and with a well-tinned soldering copper it is quite easy to solder. It may take a little care and a few minutes longer may be needed to make a good joint with rosin, but it will save many hours of "grief" later.

In soldering connections *do not use any kind of soldering paste, flux,"* or *acid.* Even if such substance is not strictly a conductor there is danger that it may form a leak of low enough resistance to keep the circuits from working properly. *Use only Rosin when soldering.* Many sets that are soldered with flux do not show trouble until after two to four weeks of use. The flux gradually spreads until the parts and set are spoiled.

ADJUSTING THE TUNING APPARATUS: Before starting to tune in, first set all tuning devices at their "true zero point," then loosen their dials and set these at O; then tighten up.

The "true zero point" of a variable condenser is the point in its rotation where the rotor plates are furthest away from the stator plates. For a variometer, the "true zero point" is where the direction of the rotor current around the "air core" is *directly opposite* to that of the stator current.

Start tuning by turning up the detector tube until a hissing sound is heard. Then move controls *very slowly* from minimum toward maximum until a signal is heard. Move the dial *slowly* back and forth to find the best place; then adjust the detector tube. Move the other control until the signal is as good as possible.

With a regenerative set, leave the regeneration dial at zero until a station is heard, then turn up gradually until the signal becomes rough. While adding regeneration it is necessary to readjust the detector and other dials. Do not adjust your set so that it oscillates or whistles.

When a station is heard, make a note of all dial settings. Then the same station can be received again later by setting dials near the points recorded.

SOURCES OF TROUBLE: If your completed set does not tune in sharply, or if the signals are weak, check through all of the suggestions.

If the set worked well at first but gets poor later, it may be because you have used some paste for soldering; or some wiping connection on the variometer or variocoupler may not be making a good contact.

If the set howls when on detector only, it may be caused by the wiring being too long, or not connected the best way, or by a poor detector tube.

With a tuned-plate-circuit regenerative set the by-pass condenser may not be good, or it may not be of the right value. (This is not likely in a factory-made set.) In the same way, the neutralizing condensers in a home-made Neutrodyne may be adjusted to get better results.

Detectors

CRYSTAL DETECTORS: A crystal detector of Galena requires a light fine contact, Silicon a heavy contact, and some crystals such as carborundum require a battery for best operation. Most of the patented crystals on the market require a light-contact cat-whisker. Connect a .001 mfd. condenser across the phones when using a crystal detector. See circuit diagram, page 35.

Do not touch the crystal with your fingers, as the oil from the skin will spoil the crystal. The crystal can be cleaned by washing it with alcohol, kerosene, or carbon tetrachloride. If washing does not restore the sensitivity of the crystal, it is no longer useable and it will be necessary to buy a new one.

VACUUM TUBE DETECTORS are much more sensitive and stable in operation that crystal detectors. There are several types of detector tubes on the market; whichever type is used should be provided with proper batteries, as described below.

With tubes of the UV-199 and the 201-A types, the grid return should be connected to the positive side of the filament. For the WD-11 and WD-12 types, the grid return is connected to the negative side of the filament.

When using tubes do not light the filament any brighter than necessary, as a bright light runs down the batteries and wears out the filament. Do not use more "B" battery voltage than necessary as the tube works best on only one voltage. When using a tube for the first time if it is desired to find exactly the best plate voltage, use a tapped "B" battery, and connect more cells in as required.

Always use a vernier or fine-adjustment rheostat for a "soft" detector tube. It is not necessary for amplifier tubes.

DETECTOR TROUBLE SOURCES: If you do not get good results, examine the prongs on the tube and the springs on the socket, to see that they are making good contact; also see that the slider of the rheostat makes good contact on the wire. If these contacts are not good the set will be noisy when making adjustments with the rheostat, and will be erratic in operation.

Weak signals from a tube detector suggest that all batteries should be tested with a voltmeter to see if they are O. K.

When your crystal set gives weak signals, adjust the catwhisker wire to different points on the crystal until you get best results. All the points are not equally sensitive, so you will have to try till you find a good "spot."

Batteries

If dry cells are used for the "A" battery, it is necessary to buy new ones whenever the old ones get too weak for further use. When using a storage battery, see that there is sufficient water in each cell; also test with a hydrometer. Recharge the cells often enough to keep the specific gravity of the electrolyte in each cell always above the minimum prescribed by the battery manufacturer.

The decision as to which kind of "A" battery should be used depends of course on the voltage for which the filament of the tube was proportioned, and on the relative importance of first cost and hourly cost—also on the availability of facilities for recharging. The UV-200 and C-300 tubes require a 6-volt storage battery, and the UV-201-A and C-301-A are also intended for storage battery use, though a single such tube can be lighted by four dry cells in series, if necessary. The UV-199 and C-299 tubes operate very nicely on a battery of three common dry cells, or can also be used with the storage battery if proper rheostats are provided, such as a 60-ohm for each "99" tube. The low-voltage tubes (WD-11, WD-12, C-11, C-12) operate nicely from one dry cell for each tube; it is better economy however to use two dry cells in parallel for each tube, or to use a single 2 volt storage cell.

"B" batteries are ordinarily built in blocks of 15 small dry cells, supplying 22½ volts when new. One of these blocks is ample for a detector tube, until the voltage falls below about 18 volts. On amplifier tubes, voltages from 16 up to about 100 volts can be used; the recommendation of the designer of the circuit should be followed.

For the "C" battery, 3 to 9 volts (2 to 6 dry cells) are used, depending roughly on the plate voltage; the higher the plate potential, the more grid bias is required.

It is good practice to connect the minus end of the "B" battery to the plus side of the "A" battery, and bring these out to a common binding post. Similarly, the plus side of the "C" battery may be connected directly to the minus terminal of the "A" battery; this brings all batteries together in a single series, forming a self-contained "battery unit." It is, however, preferable to locate the "C" battery so as to shorten the path from tuner to grid, the connections remaining fundamentally the same.

It is convenient in any tube set to connect a switch directly in series with the "A" battery, so that opening the switch stops current flow from all batteries, without changing the tuning of the set. The "A" battery switch is necessary where a potentiometer is used, to prevent a continuous waste of current.

Amplifiers

TRANSFORMERS: Good amplification depends upon good transformers. They must be able to amplify all of the audible frequencies equally, otherwise they will not reproduce the voice and music faithfully.

In one-stage amplifiers and in one-tube reflex sets the standard All-American 10-to-1 ratio **trans-**

former will work satisfactorily. In two-stage amplifiers two 5-to-1 or 3-to-1 All-Americans are recommended. If more volume is desired, add a stage of "push-pull" amplification to the two-stage outfit.

See that all transformers are properly connected, as shown in the Hook-up diagram. To test for open winding, connect phones in series with battery and a dry cell or two. If click is heard, windings are not broken. A better test is to substitute transformers in a circuit that is working O. K.

Do not tamper with the transformer in any way as it is a delicate piece of mechanism and easily damaged.

Do not solder to transformer terminals or other binding posts, but use the thumbnuts to fasten wire, or to fasten terminals soldered to ends of wire.

WIRING: Keep the wiring of the second stage away from the detector and first stage circuit; otherwise there will be a feedback of energy and the set will howl.

For best results use a separate rheostat for each tube, although one rheostat may be used for all of the amplifier tubes if they are of the same type.

Mount transformers close to tubes, so that the lead from the "G" terminal of the transformer to the grid of the tube is very short—not more than 2" to 3" at the most.

BY-PASS CONDENSERS: Do not connect a by-pass condenser across the primary or secondary of Audio transformers, except across the primary of the first stage for a regenerative set, and across the transformers in reflex sets wherever it is necessary to by-pass the radio frequency currents. The condensers decrease the efficiency of properly designed transformers.

GRID BIAS BATTERY: The use of a "C" battery is recommended, as it will save the "B" battery by cutting down the plate current, without decreasing the signal strength. It also improves the tone and clears up the signals. Adjust it till best reception is obtained.

The "-F" posts of the two transformers can be connected together and connected through the "C" battery to the filament. It is better, however, to use a "C" battery in each stage.

AMPLIFIER TROUBLE SOURCES: If you are not getting good results, test out the tubes by trying them in another set. Also test out the transformers in the same manner by substituting in a set that is working. Check up on your "A" and "B" batteries with a voltmeter.

Phones and Loudspeaker

Be sure to use high-quality phones or a good loudspeaker, to be certain of reproducing faithfully the audio-frequency currents in your amplifier.

Do not drop or jar the phones as it weakens and sometimes spoils them altogether. Do not tamper with them or take them apart, except as may be necessary in replacing worn-out cords.

The loudspeaker will not ordinarily work on a simple detector set, but will require a stage or two of amplification. Occasionally a loudspeaker can be operated on detector only, where the receiving set is close to a powerful broadcasting station, or when an especially powerful hook-up is used, like the one on page 44.

When receiving do not force the phones or loudspeaker too much. It is better to get signals clearly than to get tremendous volume.

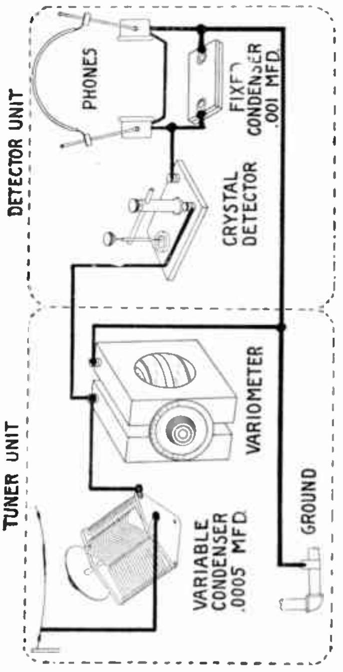
CHAPTER VIII

All-American "OK" Circuits

The Hook-Ups You Can Rely On

In this chapter we are giving a small but representative assortment of the best-known radio receiving circuits; anyone who is familiar with them may certainly feel assured that he has a good working knowledge of receiving circuits. With one or two exceptions, each circuit is presented in two ways: first, a picture-diagram showing the actual appearance of the parts and the pieces of wire and how they are attached or soldered, and second, a simplified diagram in conventional symbols, following naturally upon the "circuit unit" methods of Chapter II. The latter should be useful in making the principle clear to the beginner, and equally valuable as showing at a glance, to the more advanced experimenter, in just what form the circuit is being recommended. All of the hook-ups given have been thoroughly tested in the All-American Laboratories, and have given excellent results.

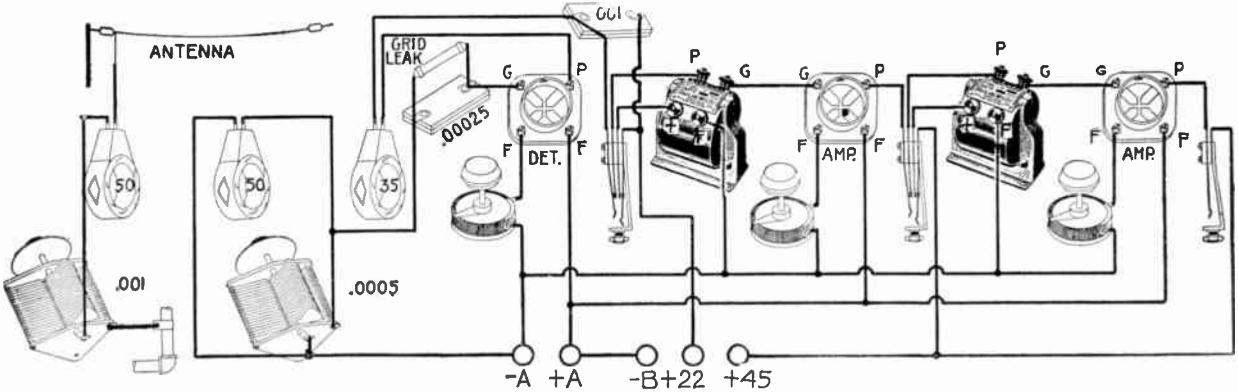
CRYSTAL SET

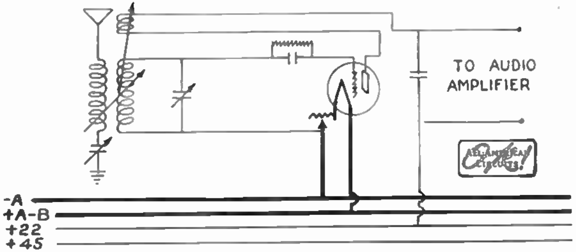


The crystal receiving set, as is well known, has only a short distance range, but it requires no batteries and gives a very good quality of tone. Ordinarily it will not operate a loud speaker, unless very close to a powerful broadcasting station, but its output can always be amplified if desired. This is done by simply removing the phones and the by-pass condenser, and connecting in the input leads of a good audio amplifier, such as shown on page 23.

The tuning arrangement shown here has been chosen because, though not complicated or expensive, it gives good audibility over the entire broadcasting wave-length range, and has fair selectivity.

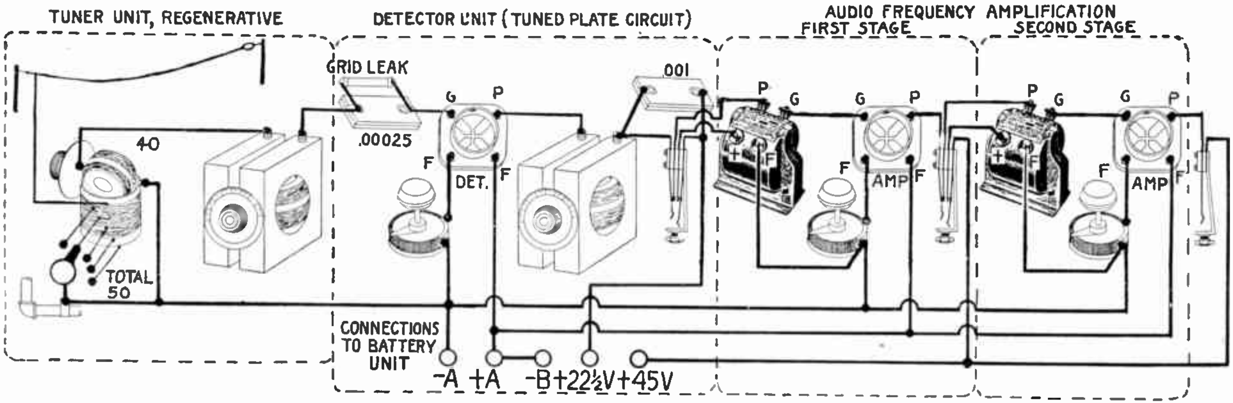
TWO-CIRCUIT TICKLER REGENERATIVE

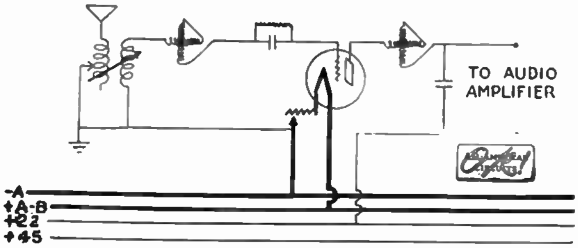




This circuit is quite popular, and splendid results can be obtained with it. Due to the two-circuit or inductive coupling, selectivity is quite high, and with the proper number of turns on the tickler, a very smooth control of regeneration can be secured. As in other regenerative circuits, it is important to have a by-pass condenser across the detector output, and using a larger condenser will increase the amount of feed-back.

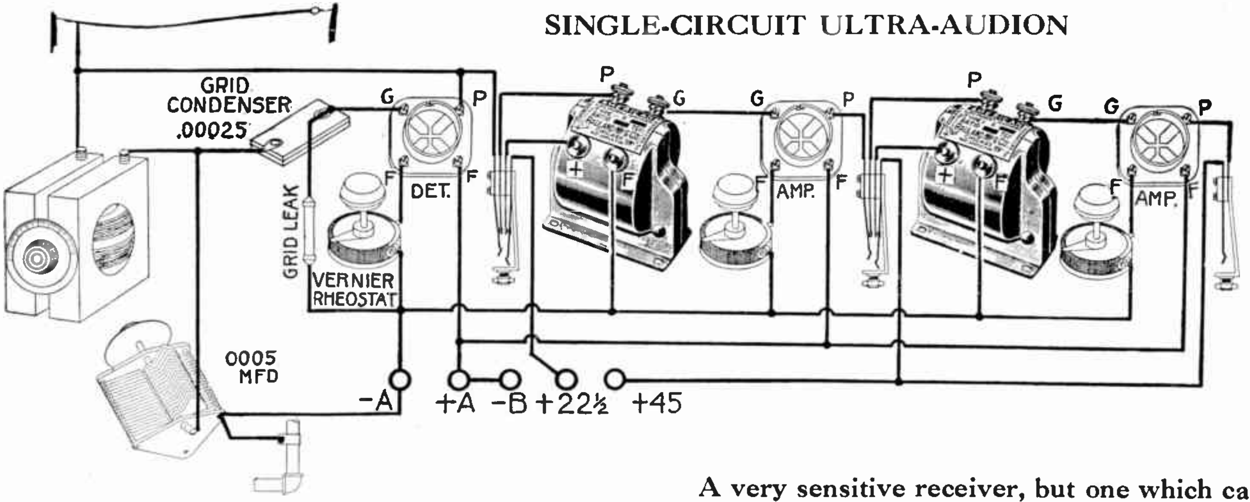
TUNED-PLATE REGENERATIVE

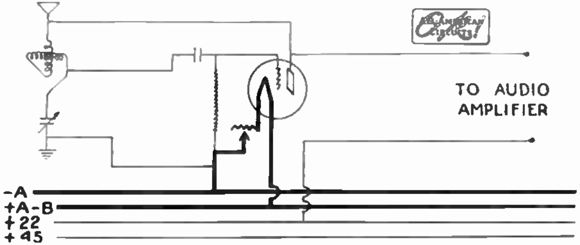




This is one of the "old original" regenerative circuits. The variometer in the plate circuit enables it to be tuned to the proper relation to the grid circuit so that regeneration will take place. The second variometer, in the grid circuit, tunes this circuit to the received signal. Selectivity is fairly good, as a rule. This circuit can be used with a loop antenna for local stations.

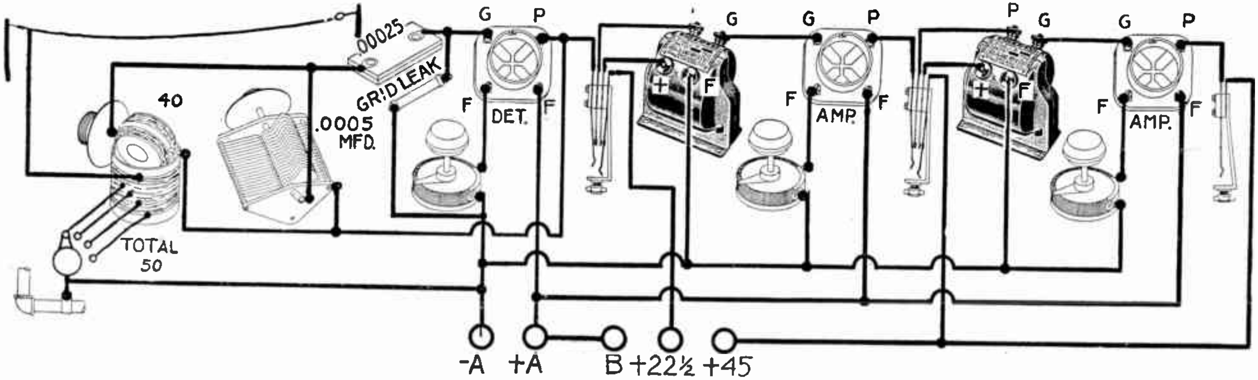
SINGLE-CIRCUIT ULTRA-AUDION

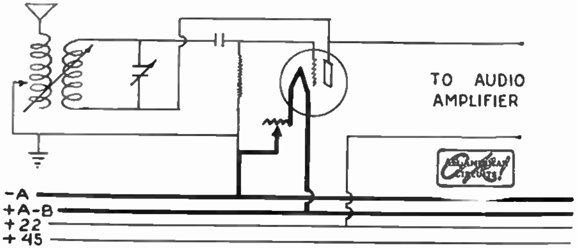




A very sensitive receiver, but one which cannot be recommended except for use in very isolated neighborhoods, as its generating action is likely to cause exasperating interference (hisses and "squeals") with any other listener in the vicinity, or even several miles away. Selectivity is not very good. It is important to use a vernier rheostat on the detector, as this provides practically the only control of regeneration.

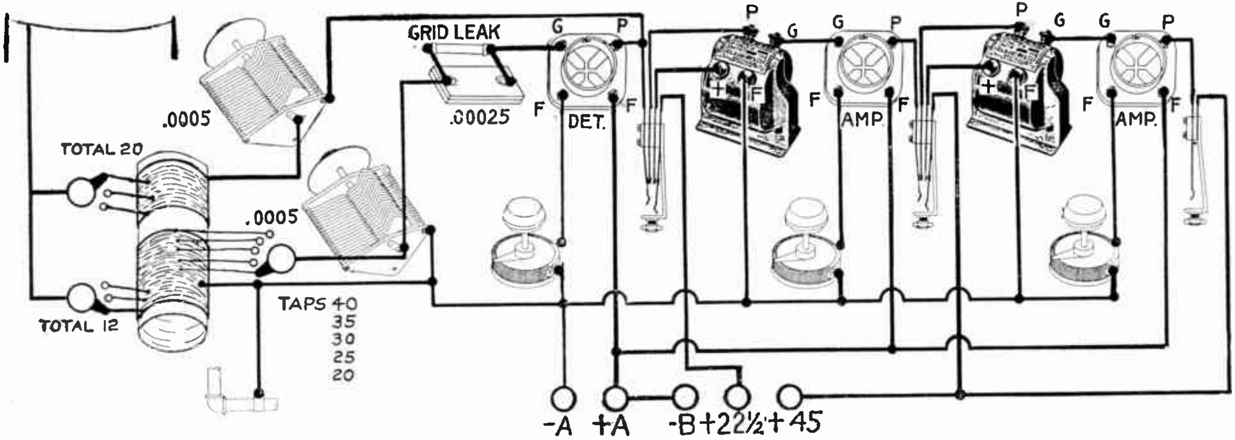
TWO-CIRCUIT ULTRA-AUDION

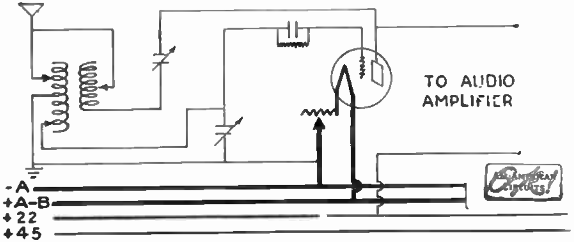




Here also we have a very sensitive hook-up, and one which is not expensive to build. Selectivity is naturally better than with the single-circuit, since but little energy is transmitted by inductive coupling except when the circuits are tuned to resonance. The interfering action, due to action of the tube as a generator, is not so bad as with the single-circuit, but requires very careful watching, and it is better to avoid the ultra-audion entirely in a crowded neighborhood.

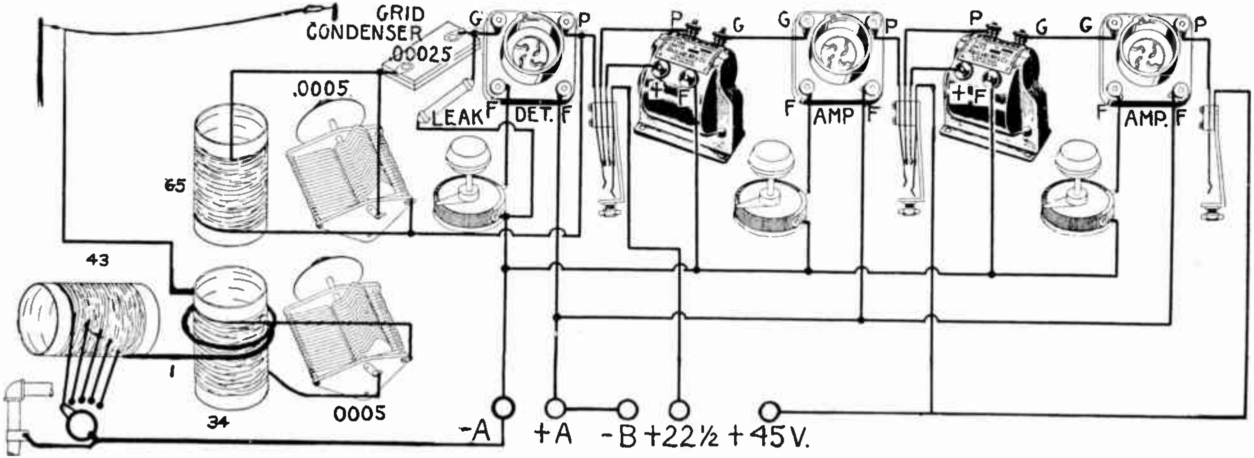
REINARTZ CIRCUIT

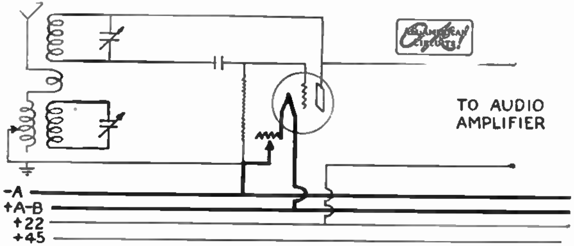




This is a very sensitive hook-up. Selectivity is fair, and smooth control of regeneration can be obtained. The Reinartz cannot be said to be "trouble-proof", but it has many faithful "boosters". If trouble is experienced in getting regenerative action over the entire range of wave-lengths, it may frequently be remedied by using a small choke coil between the plate and the first audio-frequency transformer.

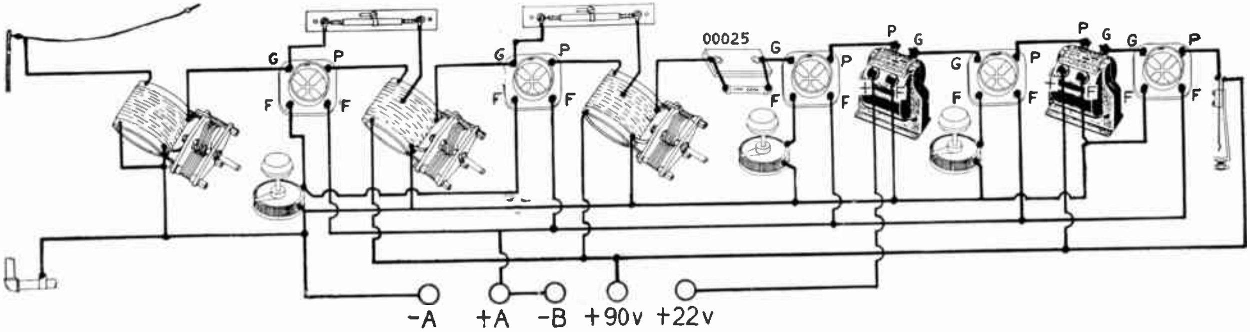
COCKADAY CIRCUIT

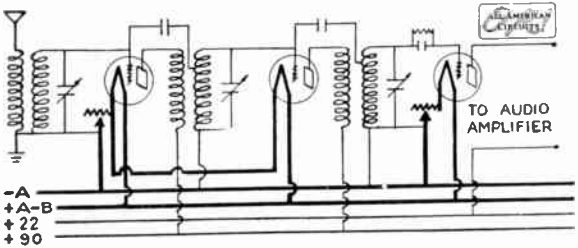




Introduced by the designer as a "four-circuit tuner", this peculiar hook-up possesses a very high selectivity. It is, however, likely to be found very critical in its adjustments, and difficult to operate as a practical receiver. A single turn in the antenna circuit acts as the primary of the coupler. The "idle" resonant circuit to which it is coupled seems to act as a trap or absorbing circuit, reducing interference.

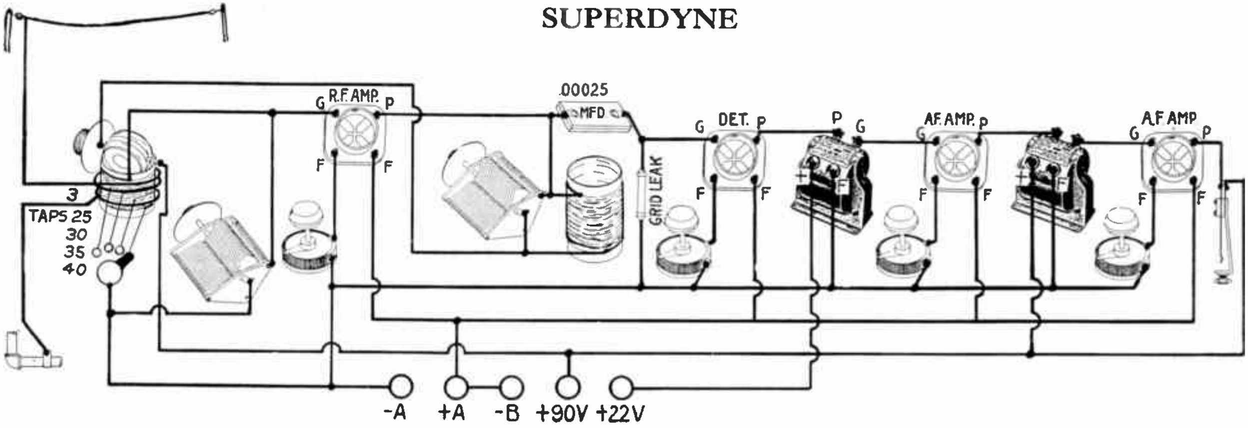
FIVE-TUBE NEUTRODYNE

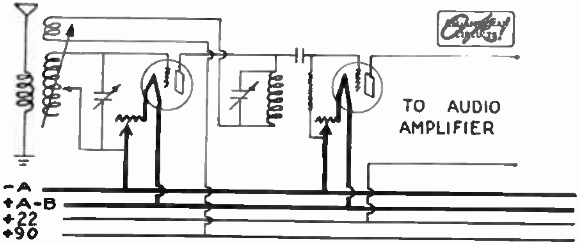




The Neutrodyne has been popular in many quarters on account of its freedom from oscillation (which however depends on exact neutralization for the tubes being used) and on account of its dependability when properly made. It is doubtful, however, whether a Neutrodyne will equal even in these respects the radio frequency hook-up shown on page 46. In distance range, the latter is certainly far superior, particularly when using the loop antenna, for which the Neutrodyne is not very well adapted.

SUPERDYNE

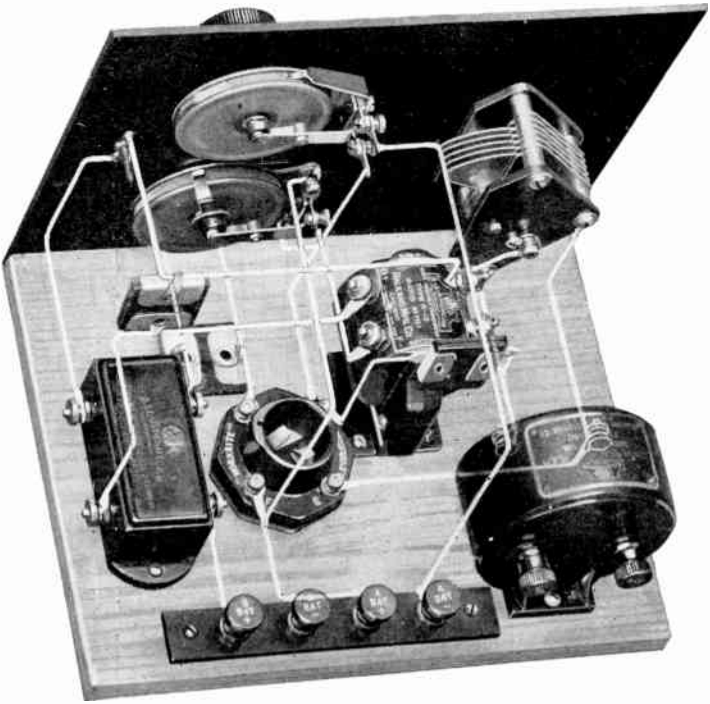


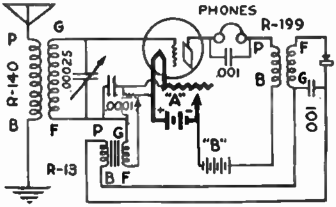


The Superdyne is designed to overcome the tendency of a tuned radio frequency circuit to oscillate whenever the tuning approaches resonance, thus drowning out the signals. This is effected by introducing a tickler coil in the plate circuit of the radio frequency tube, with its connections reversed, forming a "reversed feed back" which permits tuning to resonance without oscillation. Be very careful to use proper fixed condensers and inductances. The circuit gives good results on an indoor antenna.

All-Amax Junior

ALL-AMERICAN CIRCUITS



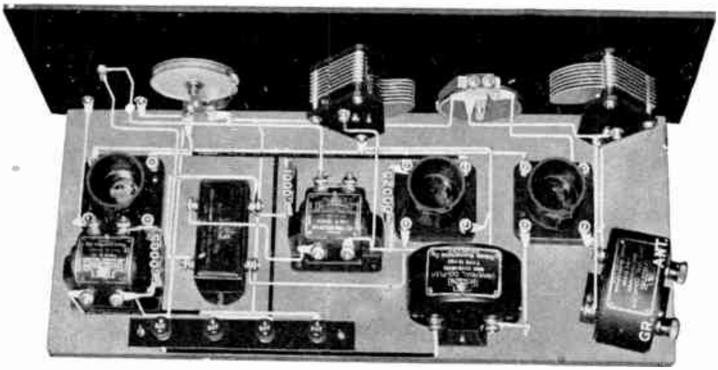


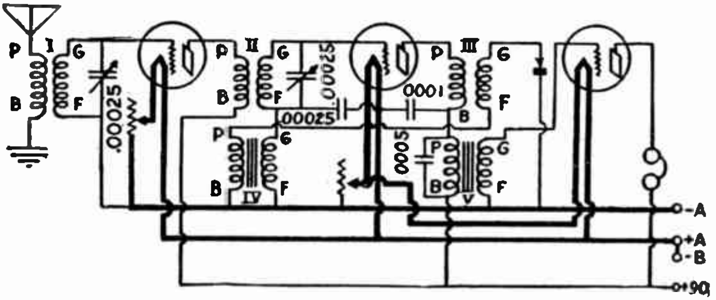
All-Amax Junior is undoubtedly the most powerful one-tube set ever built. The crystal detector insures good tone quality, and the All-American Self-Tuned Transformer makes possible a degree of efficiency which has never before been approached in Reflex hook-ups.

All-Amax Junior (non-radiating) gets its unusual selectivity through the use of the All-American Type R-140 Universal Coupler. Using only one tube of the "199" type, which operates a long time on three dry cells, the Junior is a real long-distance receiver. Local stations come in with good volume on the loudspeaker.

In spite of its superior performance, All-Amax Junior is not an expensive hook-up; whether built from the separate parts or purchased complete in "Semi-Finished" form, it is obtainable at very moderate cost. As compared with any other low-cost radio set, of the Reflex or any other type, All-Amax Junior is decidedly the best buy for the money.

All-Amax Senior





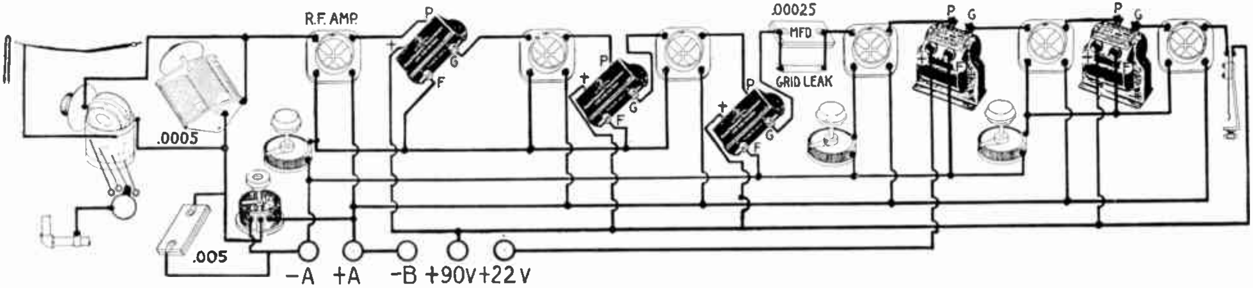
All-Amax Senior represents the culmination of several years of study in the All-American laboratories, undertaken in the belief that with proper development of suitable parts it would be possible to design a set embodying to the fullest extent the advantages of both the tuned radio frequency and reflex principles. This has, in fact, been accomplished, without introducing troublesome controls, and the set is not only highly sensitive and exceedingly sharp in its tuning, but is very simple and easy to wire.

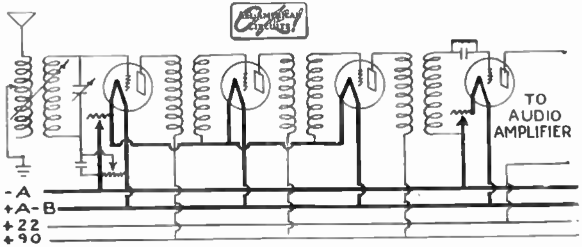
These advantages come largely through the use of the All-American Type R-140 Universal Coupler, in the antenna circuit and also in the tuned r. f. stage. An additional stage of reflexed r. f. provides additional distance range without necessitating a third tuning dial, and a final stage of straight audio amplification provides sufficient volume to tax the capacity of the best loudspeaker.

Tests of the Senior have shown a consistent ability to tune in stations on both coasts, even through local interference. Moreover, the tone quality is unsurpassed, due to the high-grade parts used.

All-Amax Senior is readily assembled from the parts illustrated, or can be had completely mounted, all ready to attach the wires, with full photographic instructions for this work, which can be readily done in one evening.

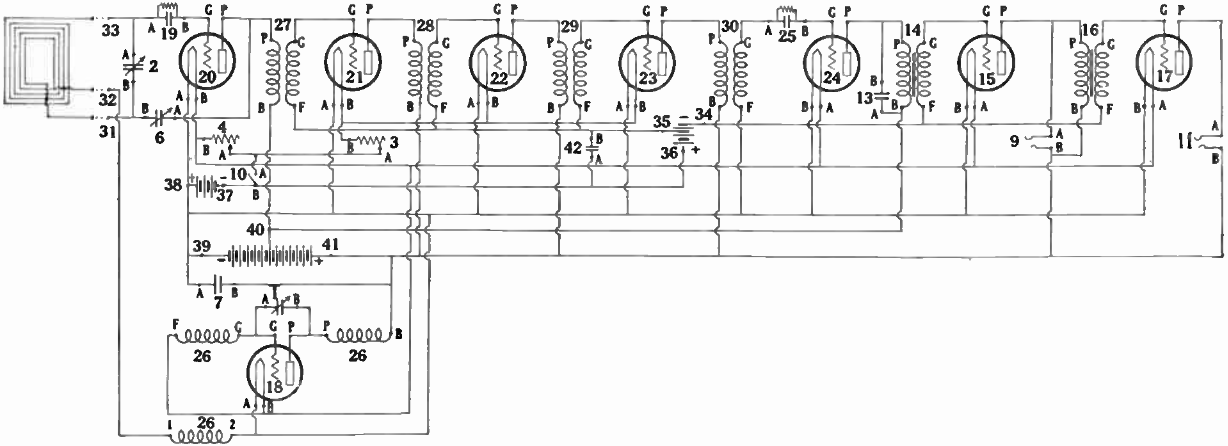
THREE STAGE RADIO FREQUENCY





Here we have a powerful, highly sensitive, long-distance set, with good selectivity and only two controls, one of which need seldom be used. The use of this type of circuit has been limited in the past by the difficulty of finding transformers which will actually cover the broadcasting wave-length range. With the development of the All-American Types R-199 and R-201 A, each designed especially to fit the characteristics of a definite type of tube, these limitations disappear. Where the extreme selectivity of the Super-Heterodyne is not required, this hook-up is indeed "hard to beat". Splendid results are obtained with loop antenna.

THIRTY KILOCYCLE EIGHT TUBE SUPER-HETERODYNE



The Superheterodyne is the most selective and sensitive receiver so far developed. It assures consistent long distance reception through a multitude of powerful local broadcasters. The above circuit probably represents the nearest to the ideal in this type of a receiver. High grade component parts are now available on the market and the uninitiated can easily build this highly efficient receiver.

INDEX