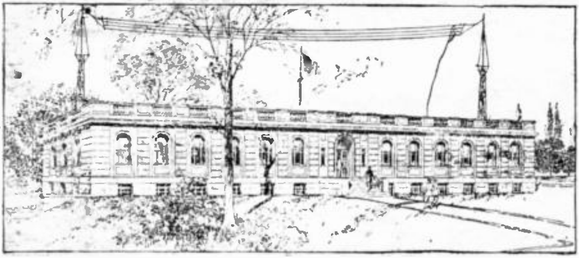
Lefax Radio Handbook

W4CW

THE REAL AUTHORITY ON ALL RADIO SUBJECTS—IN EVERYDAY LANGUAGE—BY THE HIGHEST GOVERNMENT EXPERTS—NOT OPINIONS—NOT HEARSAY—BUT TRIED AND TESTED FACTS



RADIO LABORATORY OF THE U. S. BUREAU OF STANDARDS

By

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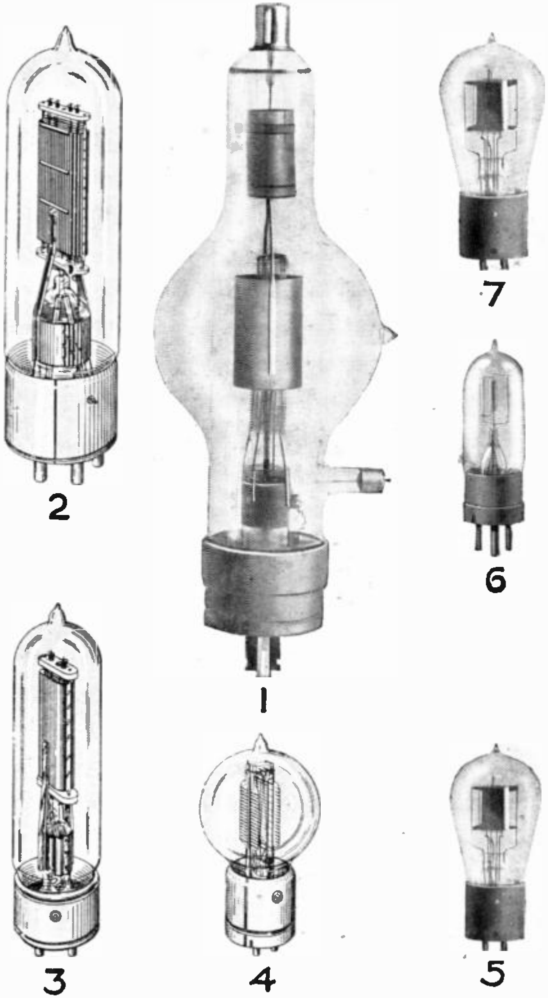

Electron Tubes
The Heart of Modern Radio

No. 1—1000-Watt Transmitting Tube.
No. 2—250-Watt Transmitting Tube.
No. 3—50-Watt Transmitting Tube.
Nos. 4 and 7—5-Watt Transmitting Tubes, (also used as power amplifiers)
No. 5—Detector and Amplifier (storage battery).
No. 6—Detector and Amplifier (dry battery).

1933

Preface

Radio has taken its place in modern life alongside the telephone, the phonograph, and the automobile. Civilization is communication, and radio is the unique supplement of all other means of communication. With its novelty and mystery, radio has an appeal to everyone, but it has also rapidly increasing real utility.

The life of the sailor in mid-ocean depends upon it. It is of routine commercial value to the business man and it is a great force for the education and entertainment of the whole population. One who is new to the subject wants to know what radio really does and can do; what is needed to receive or use radio; and how it works. This handbook aims to give just that information without too much technical explanation. Practical information on the use of receiving apparatus is given in Chapter 2, explanations of how it all works being left to later chapters.

In the apparatus section the reader will find illustrations and detailed description of the various pieces of equipment that enter into a modern radiophone receiving set. An effort has been made to make this section as complete as the limited space assigned it will allow. It will often facilitate understanding of the text matter to turn to this section and see an illustration of the apparatus discussed. The reader is urged to use the apparatus section for this purpose.

Radio is bound to seem mysterious at first. It is invisible; it cannot be sensed directly, like sound or light. It does not stay on a track or wire but penetrates everywhere. It is a most willing servant of mankind, carrying all manner of signals, sounds, electric currents, and messages.

The authors and publishers will be glad to hear from holders of the book telling of any errors or of important points not fully covered.

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DEPENDABLE CIRCUITS OF REAL MERIT

It is the policy of Lefax to keep *Radiofax*, like the Radio Handbook, free from circuits of doubtful value and of a freakish nature. Too often the radio fan is led by fabulous claims for a new hook-up to dismantle an entirely satisfactory set in the expectation that he will attain far superior results with the later arrangement, and it is needless to say that in most cases it is a waste of time. It is usually far better to give a careful study to the possibilities for improvements in the set in use. Suggestions along this line are published in *Radiofax* from time to time.

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CHAPTER ONE

WHAT RADIO DOES

The word radio comes from "radiate." Radio is an electrical action which is radiated out in all directions through the air. Just as there is one kind of electrical action known as the electric current which goes along wires and turns machinery and lights our homes, so radio is another form of electricity. Instead of going along wires it radiates out in all directions from the place where it is started. Because radio thus produces an electrical effect at a distance without connecting wires, it was formerly called wireless. Radio has possibilities that are not found in the ordinary electric current, just as an automobile is free from some limitations of a trolley car confined to tracks.

Since radio spreads out in all directions from the place where it is started, its effect can be picked up at an unlimited number of places simultaneously. It may thus be spoken of as a highly democratic, even communistic, kind of communication, being available to everyone. It is very similar to sound waves. Sound similarly spreads out in all directions through the air and can be heard by many people simultaneously. Radio is not sound, however, because it is electrical in its nature. Radio is in fact very much like light—except that instead of using our eyes to detect it, we use special receiving instruments. Radio is practically instantaneous. It spreads out with the same speed as light, 186,000 miles per second.

As will be explained in chapter 4, radio consists of electric waves radiated out from a special kind of outfit called a radio transmitting station. It will also be shown how these electric waves are produced by the action of the electric current in the transmitting station. As soon as the reader realizes, however vaguely, this fundamental fact that radio consists of electric waves proceeding out from the transmitting station, he is well started on the road toward understanding what radio can and cannot do. The form of the waves is determined by the nature and variations of the electric current at the transmitting station. This current can be varied in accordance with the dots and dashes of ordinary telegraphic signalling or can be the kind of current flowing in an ordinary telephone line. Further consideration of how the radio wave can thus carry any form of signal or even speech or music may very well be deferred until chapter 4.

In the use of the ordinary wire telephone, the sound produced at the transmitting end is converted into a varying electric current which flows along the wires, this current being changed back again into sound in the telephone receiver at the other end. Radio-telephony is similar except that there are no connecting wires. There must be arrangements at the transmitting end for converting the speech into an electric wave and at the receiving end arrangements for converting the received electric wave into sound. The great difference between the two is that the electric action has been carried by means of electric waves passing through the air instead of by means of electric current passing along a wire. Consequently it is possible to transmit and receive by radio anything that could be transmitted and received by the wire telephone, radio having the great additional feature (advantage in many respects and disadvantage in some) that it can be received by anyone in any direction from the transmitting station. This book will deal primarily with radio-telephony, as this is of most interest. There is little difference in the receiving of telephonic or telegraphic signals.

Uses of Radio.—Radio has taken its place as one of the great means of communication comparable with the ordinary telephone and the newspaper. In the communication business proper it is recognized as an agency of communication comparable with the wire lines and the cables. It is particularly useful in marine and aerial transportation, both in furnishing special aids to navigation and in carrying on of communication, especially distress signals. It is perhaps most similar to the newspaper in the work of broadcasting news, entertainment, etc. The following are the principal uses of radio:*

1. Broadcasting.
2. Communication with moving ships, aircraft, etc.
3. Transoceanic communication.
4. Communication between two points on land.
5. Non-communication uses.

Radio broadcasting is the most recent but the most important use of radio. It is now possible in any section of the United States, by means of suitable receiving apparatus which anyone can learn to operate, and which may be easily installed in any private home or office, to pick up valuable and interesting news, information, and music, broadcast on regular schedules by various radio-telephone transmitting stations. By the use of amplifiers and loud-speaking horns, the speech or music received may be reproduced as loud as

*Information regarding licenses for radio transmitting stations and operators may be obtained from a pamphlet, "Radio Communication Laws of the United States," which may be purchased for 15 cents from the Superintendent of Documents, Government Printing Office, Washington, D. C.

desired, and thus be made available to large gatherings of people without the necessity of separate head receivers for each listener. The value of the radiophone broadcasting service is rapidly being increased by the construction of additional transmitting stations in various sections not now reached with regularity. The services of existing stations are being extended; many stations are sending out regularly such items as weather forecasts, market prices and data, stock market reports, the latest news, standard time signals, church services, theatrical entertainments, speeches, lectures, and music of all kinds. Broadcasting is discussed in later sections of this chapter.

The use of radio at sea was the first practical application of radio and still continues one of its most important services. Besides regular messages between ships and land, reports of ships' positions are made by radio, and ships receive from shore stations weather warnings and general and hydrographic news. So important is the use of radio on ships that the use of radio on shipboard is compulsory, and no vessel carrying over 50 persons can leave a United States port without a certificate from a U. S. radio supervisor that its radio equipment is in working condition. Coast radio transmitting stations are required to have an operator listening for distress calls which may be sent by ships and to stop operating their stations if such calls are heard.

The use of radio on commercial aircraft is practically universal. In foggy weather, the use of radio on an airplane is as necessary as on a ship at sea. It is now technically possible to connect the ordinary wire telephone lines to the radio apparatus so that conversation can be carried on from the ordinary house telephone with a distant ship or airplane which is equipped with radio apparatus. It is only a question of time till the telephone companies furnish such service regularly.

Radio is an alternative to the submarine cable for transoceanic communication. Commercial radio service across the oceans has been maintained for several years in competition with the cables. It has the great additional advantage that persons on two different continents can speak to one another directly instead of through code telegraphy, an advantage not possible with the cable. Such radio-telephony, however, is not yet a regular service. To cover these great distances very high power radio stations are used. All of the large nations are now extending their high power radio systems, their great usefulness to business being evident. For this kind of service, the fact that radio can be picked up in many places in all directions from the transmitting station is a disadvantage and indicates that for transoceanic communication radio can never entirely replace the cable.

For reasons which will be explained later, radio messages more or less interfere with one another. Consequently it is necessary that communication which can quite readily be carried on by other means than radio should utilize such other means. Radio is, therefore, not used much for communication between two points on land, inasmuch as wire telephony or other means of communication could be used. There are, of course, exceptions in the case of deserts, mountain regions, remote forest regions, etc. One kind of communication between two points on land where radio may be suitable is communication with moving trains and other vehicles. This has been done but not actually developed to any considerable extent. It is in fact likely that means will be found to utilize electric currents guided along the rails or nearby wires for railway communication so that radio will not be needed for this purpose. The only extensive use of point-to-point radio communication on land is the radio work of amateurs. In the relaying of messages across the country an extensive communication system has been built up by the United States amateurs.

A large number of uses of radio which are not communication have already been developed. Among these are various aids to navigation. A radio station automatically sending out signals acts as a radio beacon. These signals can be received by ships or aircraft, and by means of them the vessel can navigate just as by the aid of beams from a lighthouse. The United States Bureau of Lighthouses is installing a number of such radio beacons. Various radio navigational aids for aviation are being worked out. One that has been developed is the use of radio signals at a landing field to facilitate airplane landing. Another non-communication use of radio is the transmission of time signals giving standard time twice daily in the United States. By means of radio, distant control of any desired machinery or motion is possible. The radio signals can operate a relay which will throw into or out of service any desired machinery. In this way aircraft and ships are started and operated without any persons on board. Methods have been worked out for transmission of photographs, thumbprints, and writing by radio. This is still in the experimental stage, but handwriting has been reproduced across the Atlantic by radio.

Broadcasting.—It was only when radio began to be used for broadcasting that it attracted the widespread interest of the general public. Broadcasting is transmission to an unlimited number of receiving stations without charge at the receiving end. Since radio spreads out in all directions and can be received by an unlimited number of persons, it is obviously of most use when the material transmitted is of interest to a large number of people. Weather and other news of interest to ships has been broadcast by radio-telegraphy (code) for many years. The year 1921, however, saw the real beginning of broadcast radio service. A number of electric companies, newspapers, etc., then began sending out music and lectures by radio-telephone. Since only relatively simple and cheap receiving apparatus was required to hear all of this material, the popular interest in radio grew rapidly.

Radio broadcasting is an established and valued supplement to the newspaper, the theater, and the phonograph, and excels each of these in some respects. The proper development of such service has received the attention and guidance of the Government, and all sorts of organizations, newspapers, communication companies, schools, churches, and other Government and commercial concerns have provided radio broadcasting service.

An interesting illustration of the value of broadcast news is the utilization of such service by exploring expeditions. Arctic exploration parties carry radio transmitting and receiving apparatus, and both receive the daily news and entertainment from high power broadcasting stations and send out stories of their adventures.

The waves which constitute radio are all in the same air and so are capable of interfering with each other. The thing that makes it possible to use radio at all is that it is possible to "tune" radio receiving apparatus so as to receive waves of a particular frequency (or wave length) and not receive those of other frequencies. "Tuning" will be explained later. Practically its effect is that turning to different points on the dial on the receiving set makes the set pick up waves of different frequencies or wave lengths.

The general idea of frequency is explained in chapter 4, page 8. It can be readily understood by comparison with sound waves. A sound wave of higher frequency has a shorter wave length than a sound wave of lower frequency. The same thing is true of radio waves. The frequency or wave length is determined by what takes place in the transmitting antenna. Any particular transmitting antenna sends out a radio wave of some particular frequency or wave length, just as a piano string when sounded sends out a sound wave of some particular frequency or wave length.

The frequency of the electric current in a radio transmitting or receiving antenna is designated in kilocycles. A kilocycle is 1000 cycles or complete alternations of the direction of the current. The frequencies used in radio communication range from 12 to 3000 kilocycles. The wave length is the distance from one wave crest (or maximum) to the next. Radio wave lengths range from 25,000 to 100 meters. The meter is about 39⅜ inches, and is the unit of length used all over the world except in the United States and the British Empire. Wave length has nothing directly to do with the distance to which a radio wave spreads out. Similarly, a sound wave or a water wave may have a wave length of one foot, but such a wave could travel a distance of very many feet.

Broadcasting stations are divided into the following classes:

Class A stations—that is, stations equipped to use power not exceeding 500 watts or not complying with certain requirements as to quality of program and service. In this class the Department of Commerce assigns distinctive wave lengths to each station in a given locality so far as is possible between 1350 to 1000 kilocycles (222 to 300 meters).

Class B stations—that is, stations equipped to use from 500 to 1000 watts and meeting certain requirements as to quality of program and service. These stations are licensed on frequencies from 1000 to 870 kilocycles and from 800 to 550 kilocycles (300 to 345 meters and 375 to 545 meters). There are forty distinct frequencies available in this range, 10 kilocycles apart. Each is assigned to a certain locality, there being no duplications except for a few cases of stations on opposite coasts. Where more than one Class B stations operate in the same locality, they must operate on the same frequency and avoid interference by operating at different hours.

Class C stations—comprising all stations originally licensed for 360 meters (833 kilocycles). No new licenses or renewals are issued for stations on 360 meters.

Broadcasting Development Class—To encourage scientific development of broadcasting and the apparatus used for this purpose, licenses in this class are issued to such stations as are used for the development and improvement of broadcasting and which have adequate laboratory and manufacturing facilities and personnel, with sufficient skill, training and experience to insure progress in development work and the best obtainable quality of broadcasting.

The complete schedule of frequencies for all classes of radio communication is given below. A list of all broadcasting stations in this country and Canada will be found in the Appendix.

The radio conference held in Washington, March, 1923, recommended that wave frequency expressed in kilocycles be used primarily, wave length in meters being given in parenthesis when desired. The reader is urged to familiarize himself with and think in terms of kilocycles as soon as possible, inasmuch as waves are now assigned in even values in kilocycles, the wave

FREQUENCY ALLOCATIONS

Frequency, Kilocycles per Second	Wave Length, Meters	Class of Service
Above 2300	Below 130	Reserved. (See Note 1.)
2300	130	Government, CW, exclusive.
2300 2100	130 143	Reserved. (See Note 1.)
2100	143	Government, CW, exclusive.
2100 2000	143 150	Reserved. (See Note 1.)
2000 1700	150 176	Amateur, CW, ICW, Phone, exclusive.
1700 1500	176 200	Amateur, CW, ICW, Phone, Spk, exclusive.
1500 1350	200 222	Special amateur, and technical and training schools, CW, exclusive.
1350 1300	222 231	Aircraft, CW, ICW, Phone, non-exclusive.
1350 1000	222 300	**Class A broadcasting, Phone, non-exclusive.**
1000	300	Marine, CW, ICW, Spk, non-exclusive.(Note 2.)
1000 870	300 345	**Class B broadcasting, Phone, exclusive.**
835	360	**Class C broadcasting, Phone, exclusive.**
800 667	375 450	**Class B broadcasting, Phone, exclusive.**
667	450	Marine, CW, ICW, Spk, exclusive. (See Note 3.)
667 550	450 545	**Class B broadcasting, Phone, exclusive.**
550 500	545 600	Marine and aircraft, CW, ICW, Spk, exclusive.
500	600	Marine and aircraft, CW, ICW, Spk, excl.(Note 2.)
500 445	600 674	Marine and aircraft, CW, ICW, Spk, exclusive.
445	674	Government, CW, non-exclusive.
445 375	674 800	Marine and aircraft, CW, ICW, Spk, exclusive.
375	800	Radio compass, CW, ICW, Spk, exclusive.
375 315	800 952	Marine, Phone, exclusive.
315	952	Government, CW, ICW, Spk, exclusive.
315 300	952 1000	Reserved.
300	1000	Radio beacons, CW, ICW, Spk, exclusive.
300 285	1000 1053	Reserved.
285 275	1053 1091	Marine, Phone, exclusive.
275	1091	Government, CW, ICW, non-exclusive.
275 250	1091 1200	Marine, Phone, exclusive.
250	1200	Government, CW, ICW, non-exclusive.
250 235	1200 1277	Marine, Phone, exclusive.
235 230	1277 1304	University, college, and experimental, CW, ICW, exclusive.
230 190	1304 1579	Government, CW, ICW, Spk, exclusive.
190 120	1579 2500	Marine and point-to-point, non-government, CW, ICW, Spk, exclusive.
120 95	2500 3158	Government, CW, ICW, Spk, exclusive.

Note 1.—Available for special licensing by the Department of Commerce.

Note 2.—The 1000 and 500 kc. (300 and 600 meter) waves are for calling and distress purposes, with a minimum of traffic.

Note 3.—Mobile service on the 667 kc. (450 meter) wave is to be stopped between 7 and 11 p. m. local standard time, and to be transferred in so far and as soon as practicable to wave frequencies below 500 kc. (above 600 meters).

length in meters being calculated therefrom. It is expected that the use of the term "wave length" in radio will gradually disappear.

Regulation of Frequencies.—Not only in broadcasting but in all uses of radio, the whole success of the communication depends on proper use of the frequencies. Certain specific frequencies are assigned for certain purposes by international and national laws, and technical requirements determine the use of some others. The lower frequencies are more suitable for longer distances, because waves of high frequency are very much more absorbed or impeded by the surface of the earth over which they travel. Thus frequencies from 37.5 to 12.5 kilocycles (wave lengths from 8,000 to 24,000 meters) are used in transoceanic communication. Very short waves carry especially well at night. Amateurs (who work mostly at night) use frequencies above 1500 kilocycles (wave lengths less than 200 meters). The various other uses of radio are on frequencies intermediate between these extremes.

Every transmitting station in operation makes it more difficult for receiving stations to hear other transmitting stations without interference. Therefore, no business which can be transacted by using other methods of communication should be conducted by radio. The number of frequencies available for the use of radio stations is limited, and in densely populated regions and in all important seaports the problem of radio interference is an extremely serious one.

Time Signals by Radio.—The system of transmission of time signals is as follows: Beginning 5 minutes before the hour on which the time signals close, the transmission of a series of dots is commenced. One dot is sent at the beginning of each second of time; the 29th second of each minute is omitted, and the last five seconds of each minute are omitted for the purpose of enabling the one who counts the signals to make preliminary observations before the closing signal. At the close of the final minute, the last 10 seconds are omitted. Then at the exact hour a long dash is transmitted, whose beginning marks the hour.

Factors Affecting Distance Range.—The distance over which radio can be picked up varies with time of year, day and night, and other factors. It is sometimes possible to hear a station 1000 miles away at night, while 200 miles would be the greatest distance covered in the day. An explanation of this, and of the fluctuations of signals that sometimes occur at night and other variations, has been published by the authors in Bureau of Standards Scientific Paper No. 476, "A Study of Radio Signal Fading." The tests described in this paper indicate that the sources or causes of fading are intimately associated with the conditions of the Heaviside surface, which is a conducting surface about sixty miles above the earth. Daytime transmission is largely carried on by means of waves moving along the ground, while night transmission, especially for great distances and at high frequencies, is by means of waves transmitted along the Heaviside surface. Waves at night are thus free from the absorption encountered in the daytime but are subject to great variations caused by irregularities of the ionized air at or near the Heaviside surface.

On account of disturbances of the electrical condition of the atmosphere during midsummer, radio reception during daylight hours may be occasionally interrupted. At times, during the summer months, the strays may completely drown out the radio signals picked up by the receiving set. The idea that the addition of sensitive amplifiers to the receiving set will relieve the situation is erroneous. The amplifier amplifies the strays along with the incoming signal, so the amplified signal is often less intelligible than the signal received on a simple detector.

During severe electrical storms sometimes it is not only impossible to receive any messages, but it may be unwise, especially if the storm is accompanied by lightning discharges. At such times the antenna should be grounded to protect the apparatus and no attempt made to receive radio messages. While it is possible during the winter to receive from any one of a large number of broadcasting stations, the summer decrease in transmission range means a decrease in the number of stations between whose service one can choose.

Radio receiving sets until recently required heavy storage batteries, difficult to move from indoors to outdoors to meet summer time conditions. For many purposes a portable radio set is as desirable as a small, portable phonograph, and the advent of the dry battery tubes has made such sets possible. Thus it is possible with small, portable receiving sets, which can be purchased or which can be fairly easily assembled, to receive radio broadcasting while out camping or boating or making automobile tours. Also, the ease with which wires can be strung to enable the removal of the loud speaker to the porch, the lawn, or the garden without disturbing the receiving set should tend to convert radio into a thoroughly satisfactory outdoor amusement. This will open up a wide field for inventive genius in thinking up unique locations. A number of ways to erect small antennas are suggested in chapter 3.

Limitations of Radio.—A word is desirable as to its shortcomings, so loudly are its advantages heralded. While the spreading out in all directions is an advantage for broadcasting and some other uses, it is a disadvantage in other ways. Radio lacks the secrecy or individual character of communication by wire, and cannot take its place..

While for many years it has been the dream of scientists and engineers that some time it might be possible to transmit power over long distances by radio, the day is not yet here when this can be accomplished.

The energy which leaves the antenna during a given interval of time is instantaneously distributed over an extremely large area. A receiving station only 100 miles away receives but an extremely minute fraction of the power originally transmitted. It can be seen, therefore, that if it were desired to light an electric light or run an electric motor by power transmitted entirely by radio, it would be necessary to broadcast a stupendous amount of power from the transmitting station in order to produce a sufficient amount at a given distant receiving station.

The actual transmission of power by radio and the use of this received power to turn machines or light lamps at a receiving station should not be confused with the use of ordinary received radio signals to operate a local relay and set in motion machinery which is supplied with power by local batteries or generators. In the latter case the radio receiving set serves as a sort of trigger which is pulled or set off by the very feeble received signal. It is in fact by an action of this sort that we are able to hear such loud signals through the telephone receivers and loud speakers.

A serious and regrettable kind of misinformation to which the public is subject is the claim that, by some mysterious method of using radio, an individual is able to diagnose physical or psychological conditions and make discoveries regarding the characteristics of individuals at a distance while this same information cannot be obtained even by individual examination of the patient.

This must not be confused with the use of radio as a means of communication of regular telegraphic messages from one station to another. Radio communication has made it possible for physicians to transmit to otherwise isolated points messages giving advice and thereby assist in relieving sickness when no physician is at hand for consultation. The operators on many ships at sea have, in case of need, communicated by radio with another ship or with a shore station to which they reported the symptoms and conditions of a patient and from which in turn they secured advice and information regarding his treatment. A fine example of a radio station which gives important service of this kind is that maintained by the Seaman's Church Institute in New York City. This service is now furnished free to ships through the co-operation of the U. S. Public Health Service and the Radio Corporation of America and the United Fruit Co.

CHAPTER TWO

HOW TO RECEIVE RADIO

This chapter gives practical information on the handling of radio receiving sets. Part A gives the information desired by the man who simply wants to be able to operate a receiving set, while Part B tells how to construct or assemble various types of sets. Additional data and details are given in Part C.

PART A

There are receiving sets of many kinds. They differ in respect to the range of frequencies or wave lengths they are good for, the distance from which they receive, and in many other respects. The simpler and cheaper sets which can be purchased for broadcast reception receive satisfactorily the music, etc., that is broadcast by medium power stations over an area the size of a large city. Anticipating the explanations below of the various parts of a receiving set, these very simple sets include a crystal detector and head phones, and cost $5 to $25. To receive over about 50 miles reliably, a set with an electron tube detector is required, which costs from $25 up. For greater distances, receiving sets with more electron tubes are necessary; some sets have as many as 10 tubes; the advantages, however, do not increase proportionally with the number of tubes used.

A loud speaker may be used instead of head-phones with any receiving set, even the simplest. This requires replacing the head phones by a two-tube amplifier and a loud speaker, adding about $50 to the cost. It is then possible to fill the room with the sound received.

Receiving sets differ greatly in their ability to tune in a particular station without perceptible interference from other stations that are broadcasting at the same time. The ability to do this is called "selectivity," and is one of the most important characteristics to be sought in a receiving set. Information on this is given in "Manipulation of Receiving Sets" and "Wave Traps," below.

The most satisfactory day-after-day reception of broadcasting is from local stations, that is, stations within one hundred miles of the receiving station. Reception over greater distances, especially up to five hundred miles or more, is less regular and the signals received vary greatly in loudness. The long distance records of reception over distances of several thousand miles are comparatively infrequent and are almost always made by operators who are very experienced in the manipulation of their apparatus. A receiving set which accomplishes these results usually employs two or three stages of radio-frequency amplification, a detector, and two stages of audio-frequency amplification.

It is, however, entirely practical to secure regular broadcast service at a distance of one hundred miles from the broadcasting station. Loud-speaker reception with the production of sound which can be heard through an entire house is possible with a receiving set employing several electron tubes. For example, a regenerative receiving set with electron-tube detector, and two or three stages of audio-frequency amplification. The loud-speaking reproducer will usually accomplish this if the broadcasting station is one of the higher power stations. Such a station would, for example, be a Class B station putting 500 watts in the antenna. The most satisfactory loud-speaker reception is secured when the audio-frequency amplifier and the loud-speaking reproducer are designed and built to work with one another.

Loud-speaker reception of moderate intensity which can be heard satisfactorily through a single room can be secured with slightly less equipment than that indicated above. A regenerative receiving set with electron-tube detector and one or two stages of audio-frequency amplification will usually be sufficient for this purpose. A loud speaker can sometimes be made satisfactorily by using a single telephone receiver attached to a simple horn or fastened by a suitable attachment device to the horn of a phonograph. Instead of using a regenerative set it is possible to secure signals of practically the same intensity by the use of two stages of radio-frequency amplification between the receiving tuner and the detector tube.

If one is content to secure signals which can be heard only if the telephone receivers are worn on the head of the operator, it is possible to use equipment which is quite a little simpler than that suggested above. A one-tube regenerative set is very satisfactory in this case.

With each of the combinations suggested above it is possible on many occasions to receive signals over greater distances, though these times are not regular in occurrence and are less frequent in the summer than in the winter. The increasing number of the better broadcasting stations and the improving quality of the service which they transmit make it apparent that the dependence of the public will be placed upon the local stations, and that reception from distant stations, once in a while will serve to give added interest to the reception of regular local service.

If one expects to make the fullest use of his radio set he must plan to install one which will be sure to receive regularly the service which he desires. He will then receive as extra service the more distant stations which may be heard when transmission conditions are favorable. It must also be emphasized that radio carries much farther at night than in the daytime. This is especially noticeable at a distance of fifty miles or more from the transmitting station. For reliable radio service in the daytime one must, therefore, have much better radio receiving apparatus than is necessary for reliable service at night. While very much depends upon the design of the particular type of receiving set which is used, it is believed that the following table may be used as a guide in determining the general type of receiving set which should be purchased in order to get reliable service from certain distances in the daytime.

Table 1.—Showing approximate distances in miles for reliable daytime radio telephone receiving

Intensity of Signals	From Transmitting Station having 50 watts in antenna			From Transmitting Station having 500 watts in antenna		
	Crystal Detector	Regenerative receiving set and electron tube detector	Regenerative receiving set with 2-stage amplifier	Crystal Detector	Regenerative receiving set and electron tube detector	Regenerative receiving set with 2-stage amplifier
Readable signals in telephone receivers..	8	20	40	35	65	100
Loud signals in telephone receivers.....	1	8	20	5	35	65

It will be noted that one of the important factors affecting the receiving range is the power used at the transmitter. For this reason we have incorporated these values in the broadcasting station list in the Appendix.

Connection of Parts of a Receiving Station.—The connections between the essential parts of the simplest type of receiving station are shown in Fig. 1. The principal apparatus is the "receiving set." Its main

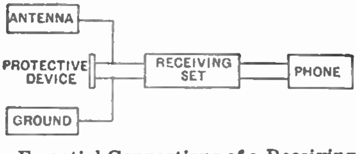


Fig. 1—Essential Connections of a Receiving Station.

connections are to the "antenna" and to the "ground" (or, in the case of sensitive sets, to the terminals of a coil antenna). The received signals come into the receiving set through these connections. In the receiving set they are converted into an electric current which

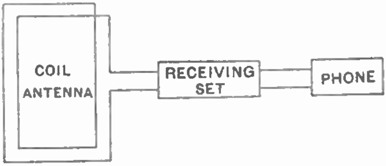


Fig. 1-A—Essential Connections with a Different Kind of Antenna.

produces the sound in the "phone." The phone is either a pair of telephone receivers worn on the head of the listener or else a loud-speaking telephone receiver which can be heard all over the room. The received signals will not be powerful enough to operate a loud-speaking telephone receiver with the simpler types of sets unless the signals come from a powerful transmitting station not more than a few miles away

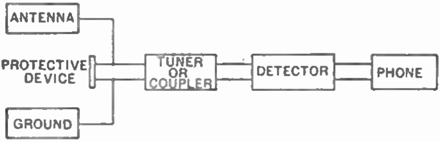


Fig. 2—More Detailed Connections of a Simple Type of Receiving Station.

The "receiving set" is subdivided into "tuner" and "detector," as shown in Fig. 2. Further details of connections of parts of various types of receiving sets are shown in Figs. 3 to 7.

Manipulation of Receiving Sets.—In view of the differences of manipulation of the various types and makes of radio receiving sets, it is impossible to give a single general outline of procedure which can be followed with all sets, but a few suggestions will be given for the handling of three specific types: (1) the single-circuit; (2) the two-circuit; (3) the three-circuit receiving set. This classification is based on the number of elements of the receiving set that have to be adjusted to respond to the wave frequency that is received. For each tuning element there are one or more dials that must be tuned.

Generally speaking, a radio transmitting station cannot be heard unless the tuning dials are properly set to tune to that station. The tuning dials perform the

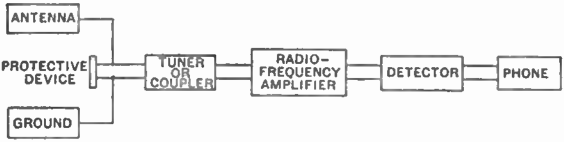


Fig. 3—Essential Connections of Receiving Station with Radio-Frequency Amplifier.

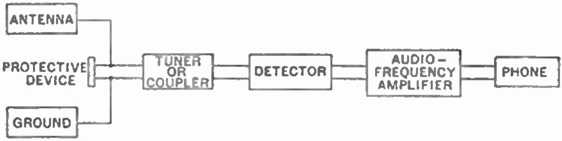


Fig. 4—Essential Connections of Receiving Station with Audio-Frequency Amplifier.

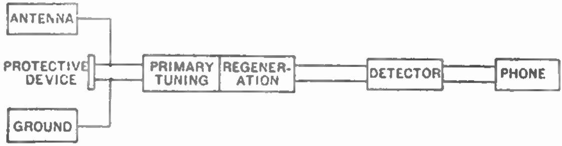


Fig. 5—Essential Connections and Controls of Receiving Station with Single-Circuit Regenerative Receiving Set.

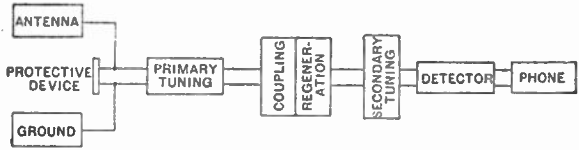


Fig. 6—Essential Connections and Controls of Receiving Station with Two-Circuit Regenerative Receiving Set.

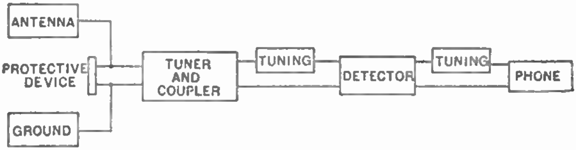


Fig. 7—Essential Connections and Controls of Receiving Station with Three-Circuit Regenerative Receiving Set.

double service of permitting the signals from the desired station to be received and excluding other signals. The importance of this latter service is appreciated as soon as one begins to use a receiving set, because there are so many radio stations transmitting at once.

The parts of a single-circuit receiving set are shown diagrammatically in Fig. 5. It may be seen here that there is but a single tuning element, though adjustments of other parts of the set must be made.

The two-circuit receiving set is shown in Fig. 6 and the three-circuit receiving set in Fig. 7. The diagrams show how the several tuning elements are associated with the other parts of the set.

Preliminary Adjustments.—It is first necessary to make sure that the antenna is properly connected to the receiving set and that the ground connection is thoroughly made (see chapter 3). If an antenna switch is used, this should be thrown to the receiving position. Next the detector must be adjusted to a sensitive condition. In a crystal detector this involves adjusting the contact of the fine wire or "cat whisker" until it touches a sensitive spot on the surface of the crystal. This can be determined by noting when the loudest sound is heard in the telephone receivers when the test buzzer is operated. If such a test buzzer is not included in the receiving set, a simple one can be connected as shown in Fig. 11.

If the detector is an electron tube it is necessary to light the filament by closing the filament switch. In some receiving sets this is done by the mere insertion of the telephone plug. The filament rheostat knob is then turned in the direction which increased the brilliancy of the filament until the signal is loud enough or until a slight hissing sound is heard in the telephone receivers; then the rheostat handle is turned back very slightly to the point where this hissing is no longer heard. If an electron-tube amplifier is used, a slight adjustment of the current through the filaments of the amplifier tubes is also necessary. Filaments should be burned at as low a heat as possible, and always turned off when not in use.

Tuning of Single-Circuit Set.—Some single-circuit receiving sets have but a single tuning control in the form of a knob which is marked with a scale for reading its position. Other types of single-circuit tuners have in addition a switch which can be turned to any one of several contact points. In either case the usual procedure is to carefully turn one or both knobs until a position is found where the desired signals are heard. On account of the sharp tuning of the radio-telephone signals from distant stations it usually requires much more careful adjustment of the receiving circuits to receive speech or music than is required to receive signals from radio-telegraph stations using spark transmitting sets. It is therefore desirable to move the continuously variable control knob rather slowly and listen carefully for a desired radio-telephone station. In some receiving sets there is provided an extra dial for a so-called "vernier" condenser, which is used for the clearest final adjustment of the tuner.

A "tickler" or regenerative control, if present, is operated as described below under "Adjustment of Regeneration."

Tuning of Two-Circuit Set.—The ordinary "coupled-circuit" or "two-circuit" tuner has three knobs or control handles. These are the primary circuit tuning control, the secondary circuit tuning control, and the coupling control. In the first tuning of a receiving station it is advisable to turn the coupling control knob to a point near the position marked "maximum." Then an approximate adjustment may be made of the primary circuit, after which the secondary control is moved gradually over its entire range. If no signal is heard at any point, the primary control is moved slightly and the secondary control is again turned over its range. By repeating this process, a point on both primary and secondary controls will be found where the desired signal is heard most clearly. Then the coupling knob is turned slightly in the direction toward "minimum" and the primary and secondary controls readjusted slightly in order to secure a louder signal. It will be found that the farther the coupling knob can be turned in the minimum direction the less will undesired stations be heard. It will also be found possible to hear radio-telephone signals with a much smaller or looser coupling than spark signals from stations of equal power. It will make the tuning of a coupled-circuit receiving set much easier if one has a chart or table giving the frequency or wave length to which the secondary circuit is tuned at each position of the secondary control knob. It will then be possible to set this knob at the position corresponding to the wave length of the desired station, and further adjustment of the primary circuit to this same wave length can be made much more quickly. A chart giving this wave length calibration of the secondary circuit can be made when the receiving set is manufactured. A similar chart cannot be made for the primary circuit until after the receiving set is installed and connected to the antenna with which it is to be used, since the wave lengths corresponding to the various positions of the primary control knob depend to a great extent upon the size of the antenna employed.

If there is an additional control knob marked "tickler" or "regeneration" it should be kept in the minimum position until the tuning just described has been accomplished. It can then be adjusted as explained in the section on "Adjustment of Regeneration."

Operation of Amplifiers.—The amplifier is a device employing one or more electron tubes in order to make the received radio signals louder than they would be without it. Many amplifiers have two or three electron tubes and are called "audio-frequency" amplifiers. The "audio-frequency" currents which are thus amplified are those which pulsate at a frequency which can be heard by the human ear, *i. e.*, ordinarily between 16 and 10,000 cycles per second. They correspond to the frequencies of sound waves produced by the voice and by musical instruments. They are connected between the detector and telephone receivers or loud speaker. Radio-frequency amplifiers serve to amplify the currents of the tuner before they are connected to the detector. This type of amplifier is very similar in outward appearance to the audio-frequency amplifier. Since amplifiers employ electron tubes, it is necessary to use batteries to light the filaments of these tubes as in the case of the detector tube referred to above. It is also necessary to use the small blocks of dry batteries in the plate circuits of these tubes. The connections of the amplifier and detector are ordinarily arranged to make possible the use of a single battery for lighting the filaments of all of the tubes and a single "B" battery for connection to the plate circuits of all of the tubes of a single receiving set. The voltage of the "B" battery may be anything between 40 and 100 volts. Somewhat louder signals are secured by using the higher voltages suggested. The detector tube, however, rarely requires a voltage over 22½.

The adjustment of the potentiometer rheostat found on many radio-frequency amplifiers is similar to the regenerative adjustment described below.

Most receiving sets now utilize electron tubes requiring a comparatively small current to light the filaments. These tubes can be operated from dry batteries, unless there are several tubes in the same receiving set. In the latter case the total current required is great enough to make storage batteries more economical. Receiving sets have been developed in which the filaments of the tubes are lighted from the commercial lighting circuit, but no one should attempt to improvise such a connection without expert advice. Until further improvements are effected, the battery will remain the most satisfactory means of operating the vacuum tubes.

Adjustment of Regeneration.—In some receiving sets there is provided a control handle which is marked "regeneration" or "tickler." After the receiving set has been tuned to the desired signal, the sound can usually be increased by turning the tickler knob from its minimum position until the speech or music begins to be distorted or until a whistling or sizzling sound is heard. The tickler control should then be turned back just below this critical point. In order to economize in the use of the storage battery for lighting the filaments of the detector and amplifier tubes, the filament brilliancy may then be slightly reduced while the tickler or regeneration control is gradually turned toward the maximum position. Since the loudness of the received signals increases greatly as the tickler or grid and plate variometer controls are brought close to the position which gives the hissing sound, it is desirable that these adjustments be made very accurately in order that the loudest sound possible may be obtained without the undesirable noise. It should also be remembered that when the tickler adjustment is turned beyond the hissing or whistling point, the receiving set is usually acting as a weak transmitting set and will cause interference for other receiving sets nearby. This condition should therefore be avoided. By the proper use of a radio-frequency amplifier this undesirable feature of regenerative sets may be kept from causing trouble.

Time spent in indiscriminate tuning and manipulation of the various controls will not produce nearly as satisfactory results as equal time spent in systematically making the tuning, coupling, and regenerative adjustments outlined above. The controls described are the principal ones, though some additional controls, such as vernier condenser, are provided on certain receiving sets for use in obtaining closer tuning adjustment. Such additional adjustments need not be made until the signals from the station desired have first been tuned in.

Tuning of Three-Circuit Receiving Set.—The tuning of a three-circuit receiving set is somewhat more complicated than that outlined above for single-circuit and two-circuit receiving sets. In all there are five separate adjustments to be made. Adjustments of these must be changed in turn until the desired signals are received with the greatest intensity. These controls are as follows:

1. Primary circuit (marked on some sets "antenna inductance" or "antenna condenser").
2. Secondary circuit (sometimes marked "grid variometer").
3. Coupling.
4. Plate circuit (sometimes marked "plate variometer").
5. Detector (this is the same adjustment as the filament of the detector tube described under "Preliminary Adjustments").

In tuning this receiving set the coupling control should be turned to approximately the middle point. A first approximate adjustment should then be made of the antenna inductance or antenna condenser control, setting them somewhat above the middle of the scale if the recommended antenna length of 75 to 100 feet is used. Using both hands, rotate the grid variometer and plate variometer dials over their entire scales. These controls should be turned, one following the other, in such a way as to just keep the set from causing a slight hissing sound in the telephone receivers. When, by successive adjustments of the primary control, the desired signal has been located at a given position of the grid variometer and plate variometer controls, the coupling knob should be turned toward the minimum position until the signal is just barely audible. The primary antenna inductance or antenna condenser control should then be turned to a point which just causes the cessation of the hissing sound in the telephone receivers. The final adjustment to give the loudest signals should be made on the coupling knob.

Operation of Neutrodyne Set.—The manipulation of the tuning controls of the neutrodyne is similar to that described under the "two-circuit" set. above, the procedure being extended to the three controls which are usually employed. The relative settings of the three dials ordinarily remain nearly the same throughout the tuning range of the set, so that after the proper settings for a single station have been determined, the set may be tuned to higher or lower frequencies by turning the dials approximately an equal number of scale divisions in the same direction.

About Batteries.—Dry batteries used for lighting the filaments of tubes gradually deteriorate during use until they are unable to supply the required current. The "B" batteries also become exhausted in the course of use. Exhausted dry batteries cannot be recharged and new ones must be secured to replace them.

A storage battery can be used with a radio receiving set for only a limited time without recharging. In order to recharge the battery and put it in condition to supply further current to the receiving apparatus, it is necessary to connect it through special apparatus with the power or lighting circuit or send it to an electrical shop to be charged. A number of devices are made for use in charging a small storage battery from the house-lighting circuit. Some of these can be connected to an ordinary electric light socket and require very little attention. One must be sure to know by inquiring of his electric light company whether the lighting power is alternating or direct current. This makes an important difference in the type of battery charger which is suitable. When the battery is connected to the electric light circuit through the charger and the necessary initial adjustment of the charging current is made, it can ordinarily be left in this condition, that is, "on charge," for a number of hours without attention. The time of charge depends upon the capacity of the battery and the amount which it has been used since it was last charged. It is advisable to use a hydrometer as a tester in order to determine whether the battery needs recharging. It is not desirable to permit the battery to become so greatly discharged as to fail to light the filaments of the electron tubes to their normal brilliancy. Storage batteries need to have distilled water added to them at intervals. This can be secured at any automobile or battery service station. Detailed instructions for care and operation are furnished with each battery by the manufacturer. Information on battery chargers is given in Part C, below.

Telephone Receivers.—Telephone receivers are mounted either singly or in pairs and are usually provided with a head band to hold them in place against the operator's ears. Telephone receivers designed for use with radio receiving sets usually have much more wire wound upon the magnets in order that a small current through the receiver may produce a louder sound from the diaphragm. As an indication of the amount of wire used in winding the telephone receiver magnets, the receivers are ordinarily rated by the resistance of this winding. Thus some receivers are 1000 ohms and others 2000 or 3000 ohms. It is impossible, however, to judge the performance of a telephone receiver by resistance alone, since many other factors enter into the determination of its efficiency. The two receivers of the head set are usually connected in series.

Two or three pairs of telephone receivers may be connected to a single receiving set by connecting them all in parallel or all in series. Telephone plugs may be purchased which are so constructed as to accommodate several pairs of telephone receiver terminals.

Loud Speakers.—Loud-speaking reproducers are on the market which can be substituted for the telephone receivers in any receiving set which employs an amplifier. The use of this loud speaker makes it possible to hear the radio signals throughout an ordinary room, though the volume of this sound varies with different types of reproducers.

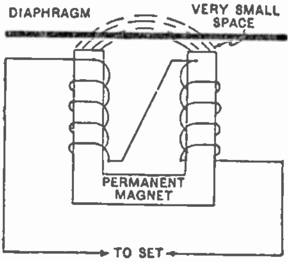


Fig. 7-A

The most common type of loud-speaking reproducer is that operated on the **electro-magnetic** principle, in which a metallic diaphragm is placed over the poles of a permanent magnet. Two coils of very fine wire are arranged on the pole pieces of the magnet and are connected to the receiving set. (Fig. 7-A.)

The magnet in this reproducer is very strong, as can be seen by trying to lift the diaphragm from the pole pieces. The diaphragm is under a constant strain or tension, due to this magnetic pull. When electrical energy from the receiving set passes through the coils on the pole pieces, the magnetic pull on the diaphragm is varied in accordance with the strength of received signals. It is this diaphragm movement that causes sound waves to be set up, thus reproducing the sounds coming through the receiving set.

Sound reproducers constructed on the **electro-dynamic** principle are capable of operating efficiently over a very wide range of electrical energy received. In this type of loud speaker there is no strain or tension on the diaphragm when no electrical energy is received from the plate circuit of the receiving set. Instead of a permanent magnet, an electro-magnet is used whose field coil is connected to a 6-volt battery which supplies a current of about 1 ampere for this electro-magnetic field. An armature, which is a small coil of wire the shape of a ring, attached to the metal diaphragm, moves up and down in the ring air gap of the electro-magnet, which is cylindrical in shape. Fig. 7-B illustrates this type of reproducer.

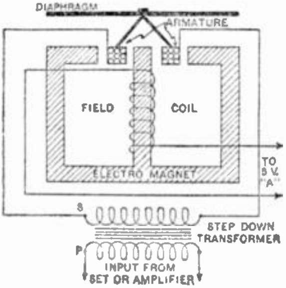


Fig. 7-B

Another type of efficient loud-speaking reproducer is that operated on what is known as the **balanced armature** principle. In this type the diaphragm and moving parts of the receiver unit respond to all frequencies in the broadcasting range without appreciable distortion. The better type of loud speakers on this principle have receivers sensitive to very weak currents and capable of carrying comparatively heavy currents without the armature chattering against the pole pieces.

Still another type of loud speaker is one recently developed and known as the **"relay type."** Its construction is similar to that of a polarized telegraph relay. Four pole pieces, each carrying a coil, are grouped about a thin iron armature. The pole pieces receive their magnetism from a magnet.

How to Remedy Receiving Circuit Troubles.—Receiving sets, like other electrical apparatus, may suffer from short circuits or open circuits. An open circuit often makes itself known by a low-pitched hum in the telephone receivers. A simple way of testing for this trouble is by the use of a telephone receiver and dry cell. If no signals are received, either the filament or "B" battery may be wrongly connected. Try reversing one or both. On account of the small space which is allowed between the fixed and moving plates of the variable condensers it is possible for these condensers to become short circuited at certain positions on the scale. The telephone receiver and battery may also be used for locating this trouble. It may be remedied by giving the bent plate a slight push with a screw-driver while care is taken to avoid bending the adjacent condenser plates. In some condensers the position of the shaft carrying the movable plates is adjustable and may be changed by means of nuts located on the base of the condenser. Sometimes the telephone receiver cord becomes defective. This is noted by a rasping or scratching sound or a click when the telephone cord is moved. A new telephone cord can be obtained for a small sum from any radio supply store. In a regenerative receiving set if the adjustment of the grid and plate variometers or the tickler coil fails to produce regeneration, the filament current and plate voltage should be changed. If the filament of an electron tube fails to light or flickers, the tube should be removed from its socket and the ends of its four contact prongs should be cleaned with sandpaper or a fine file. It should be made certain that the spring connections in the tube socket make good contact with the prongs on the tube. It is desirable to try various combinations of the tubes used as detector and amplifier tubes, since tubes as sold are not entirely uniform and it is possible to find a best arrangement of these tubes in the various parts of the circuit. When the filament of an electron tube is burned out there is no remedy other than to replace the tube by a new one. Repaired tubes are not likely to be satisfactory unless as great care is taken with the repairing as in the original manufacturing. It is especially difficult to be sure that the vacuum will hold.

Grinding noises which persist when the antenna and ground wires are disconnected from the receiving set are not caused by atmospherics or "static" but may usually be remedied by tightening the connections to the binding posts at various parts of the circuit, by cleaning the contacts of the tubes, or by replacing old "B" batteries by new ones. Sometimes an electron tube is found which has a poor connection between the filament itself and the lead wire, which connects the filament with the prong on the base. Such a tube should be removed from the circuit and replaced by a new one.

If the signals which are usually loud from a certain station suddenly become weak, the trouble may be any of the following:

(*a*) The transmitting station may have reduced its power.

(*b*) If a crystal detector is used, the crystal may be out of adjustment or dirty. If dirty, the surface should be washed with soap and water, thoroughly rinsed and allowed to dry completely before using. The surface of the crystal should not be touched with the fingers. It may be worth while to file the metal point which touches the crystal.

(*c*) The receiving antenna or ground wire may have become disconnected. For further information on ground connections, see chapter 3.

(*d*) If an electron tube set, the plate or filament battery may be exhausted.

(*e*) The telephone plug may not be making good contact, or some other poor contact may have developed in the set wiring.

In case of difficulty in tuning out one broadcasting station in order to listen to another, it is often well worth while to utilize a wave trap. The use of this device and other details of the operation of receiving apparatus are given in Part C of this chapter.

Atmospheric Interference.—Irregular interfering noises heard in the telephone receivers are often caused by atmospheric electricity. These disturbances are variously called "strays," "static," "atmospheric," "atmospheric disturbances," and other names. There are probably many causes for these stray waves, but their sources have never been completely explained. They are more troublesome in the summer time than in the winter and are also more serious in tropical latitudes than in northern regions. The most satisfactory methods of reducing this atmospheric interference are the use of small antennas with very sensitive amplifiers and the use of very loosely coupled circuits. Radio-telephony has an advantage over radio-telegraphy when it is necessary to receive through this type of interference, since speech can often be understood by context even though some parts of it are lost. Some sources of interference which produce sounds very similar to atmospherics are the leaking of electric currents over the surface of faulty insulators of power lines, the sparking at commutators of electric motors, sparking at the contact of trolley wheels with the trolley wires, the irregular operation of arc lights and the operation of X-ray machines. In some cases a continuous hum is heard on account of the antenna or ground wire being run parallel to an electric light or power circuit. This can be reduced by moving the antenna to a position at right angles to the power line. When it is desired to use a receiving station for continuous reliable reception of any radio service, it is advisable to investigate the possibility of such causes of interference in the immediate neighborhood as have just been mentioned. Interference from undesired radio stations or from atmospheric electricity is obtained only when the antenna and ground wires are connected to the receiving set. The interference from spark stations can be recognized by the long and short buzzing sounds constituting the dots and dashes of the radio-telegraph code. Such stations may be either commercial radio stations, such as operate between ship and shore, or may be amateur spark stations. Such interference can be minimized by reducing or loosening the coupling between the primary and secondary circuits or by reducing the tickler or regenerating action of the receiving set. Interference from continuous wave transmitting stations or from nearby receiving stations which are so adjusted as to act as weak transmitters is recognized by a whistling sound or continuous musical note. If it is found that the pitch of this musical note changes as the receiving set is detuned, this is an indication that the receiving set at hand is also generating and acting as a feeble transmitter. The tickler or regenerating action should therefore be reduced. When the adjustment passes this generating point a click will be heard in the telephone receivers.

Sometimes it is noticed that the strength of the signals received from distant stations varies rapidly for no apparent cause. This is particularly true at night, when the signals may fade in and out regularly or irregularly. While it is advisable to make sure that the connections to the receiving antenna are not loose, this difficulty is usually caused by changes in the condition of the space through which the radio waves travel between the transmitting and receiving stations. This difficulty is therefore obviously entirely out of the control of the receiving set manufacturer or user.

Interference from Electric Power Lines.—One of the best ways to reduce interference caused by alternating-current power lines, generators or motors having badly sparking commutators, arc lights, leaky insulators, sparking contacts at circuit breakers or on trolleys, etc., is the use of a small antenna. If the ordinary open type of antenna is used, its height and length may be reduced and the loss in signal strength recovered by employing a more sensitive receiving set. In case a coil antenna (see chapter 3) is used there is also some loss in signal intensity, but there is an added gain in freedom from interference on account of the directional characteristics of the coil. One of the simplest things to try, then, is the use of a coil antenna turned in such a direction as to reduce the interference to a minimum.

If an open antenna is used it is often helpful to turn it in a direction at right angles to that of power lines which may be passing near the house, or the antenna may be laid along the ground; in this case it should be covered with insulation or should be held a few inches above the ground with suitable insulators.

It is sometimes possible to balance out induction from neighboring power lines by using an auxiliary antenna which extends in a direction opposite to the antenna used with the receiving set. This auxiliary antenna can be connected through an inductance to

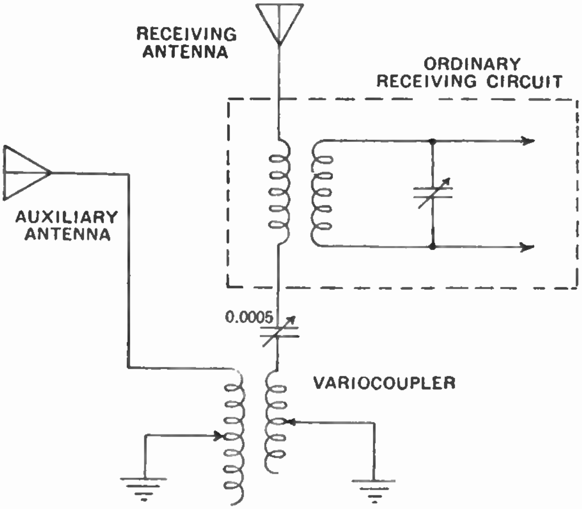


Fig. 8—Connections for Auxiliary Antenna

the ground. The inductance should be coupled with a similar inductance in the regular antenna. The coupling must be in the proper direction to oppose rather than aid the two interfering effects in the antenna. A diagram illustrating this is given in Fig. 8. Sometimes merely using a counterpoise turned in the proper direction will accomplish the desired result without any special means of coupling.

If the antenna has been arranged to pick up a minimum of interference, it is worth while to use various means to improve the sharpness of tuning of the receiving set; then such interference as is picked up by the antenna will to some extent be filtered out before it reaches the telephone receivers. The receiving set itself should be thoroughly shielded to prevent the tuning coils and transformer windings from direct induction from the source of trouble. Inductively coupled receiving sets are preferable to single-circuit sets under these conditions. Radio-frequency amplification with sharply tuned amplifier transformers are also helpful. A well-designed regenerative set is also very selective. The coils, condensers and other parts forming the circuit should be designed to have minimum resistance. If the receiving set is one which has a series condenser in the antenna circuit, it is sometimes helpful to shunt the set with a high resistance (several thousand ohms) connected between the antenna and ground terminals.

PART B

Assembly of Receiving Sets

Radio is unique in offering as much fascination in the construction or assembly of the apparatus as in its use. The construction of a receiving set is a little education in electricity. Most of the parts are inexpensive. For short distances a very simple set can be used.

It is assumed that the reader of this book does not wish to do more than purchase the separate parts of a receiving set and put them together. The person who wishes to go still farther back and actually construct the parts of the very simplest receiving sets is referred to an authoritative series of brief pamphlets issued by the U. S. Bureau of Standards. (See footnote.)

The following circuit diagrams show the connections which should be made in order to assemble several typical receiving sets. The actual value of many of the coils or condensers required in the various circuits depends upon the frequency or wave length of the stations which it is desired to hear. The values given on the diagrams are correct for wave lengths of about 200 to 600 meters. The numbers shown on the condensers are maximum capacity in microfarads.

Single-Circuit Set.—Fig. 9 shows a single-circuit receiving set using a crystal detector. Only one tuning adjustment is required with this set. This can be in the form of a switch or sliding contact for making connection at the desired point on the inductance coil, or may be a variable inductor (also called "variometer"). This type of receiving set is extremely simple to construct and operate, and is useful and serviceable to an extent far out of proportion to its cost. For receiving from broadcasting stations located within fifteen or even twenty-five miles when only telephone receiver reception is desired, this circuit is most satisfactory.

Circular 120.—Construction and Operation of a Simple Homemade Radio Receiving Outfit..............5 cents
Circular 121.—Construction and Operation of a Two-Circuit Radio Receiving Equipment with Crystal Detector. 5 cents
Circular 133.—Description and Operation of an Electron Tube Detector Unit for Simple Radio Receiving Outfits. . 10 cents
Circular 137.—Auxiliary Condensers and Loading Coil Used with Simple Homemade Radio Receiving Outfits. . 10 cents
Circular 141.—Description and Operation of an Audio-Frequency Amplifier Unit for Simple Radio Receiving Outfits...10 cents

These circulars may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. (Stamps are not accepted—send cash or money order.) The issuance of radio publications of the Bureau of Standards is announced in the Radio Service Bulletin, a monthly publication of the Dept. of Commerce, a year's subscription to which may be obtained by sending 25 cents to the Supt. of Documents at above address. This bulletin contains, each month, radio news from other Government departments.

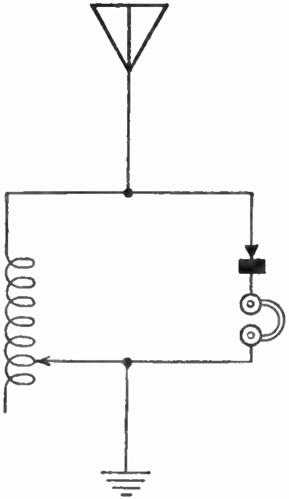


Fig. 9—Diagram of Single-Circuit Receiving Set using Crystal Detector.

It has the additional advantage that one who is interested in adding improvements, such as audio-frequency amplifiers, radio-frequency amplifiers and wave traps, may do so while making full use of the apparatus originally employed.

Two-Circuit Set.—Fig. 10 shows a two-circuit receiving set with crystal detector. The inductance coils L_1 and L_2 constitute the two coils of a coupler. There is no metallic connection between them. There are several forms of coupler: the "slide coupler," sometimes called a loose coupler, in which the coils are two cylinders wound with wire, one sliding within the other; the "variocoupler," in which one coil may be rotated within the other, and the "hinge coupler," in which the two coils are pivoted together like the two parts of a hinge.

The use of two circuits, both tuned, coupled to one another in this way increases the selectivity or sharpness of tuning of the set and thus makes it possible to hear one station to the exclusion of others under conditions when this would be impossible with a single-circuit set.

The variable condenser C_1 is used for fine adjustment of the tuning of the secondary circuit. It is also convenient for tuning the circuit to different wave lengths. The longer the wave to which it is desired to tune, the higher up one must go on the condenser scale, unless he simultaneously increases the number of turns of the inductance coil which are included in the circuit. It is usually best to use as much of the coil as possible in tuning to a given wave length, and do the close tuning with the condenser near the lower end of its scale, *i. e.*, with the plates only slightly enmeshed.

Where a variable condenser (see symbols on page 00) is shown on these diagrams, a condenser having a larger maximum capacity than indicated can be used, and when used with a given coil, makes it possible to tune the circuit to a wider range of wave lengths.

The condenser C_2 is connected in series with the ground connection of the receiving set in case the antenna is somewhat longer than the ideal length for tuning to a given wave length. When connected in this way the condenser practically shortens the effective length of the antenna. The lower parts on its scale tunes the circuit to shorter waves, and when its capacity is made zero it corresponds to disconnecting the receiving set entirely from the ground.

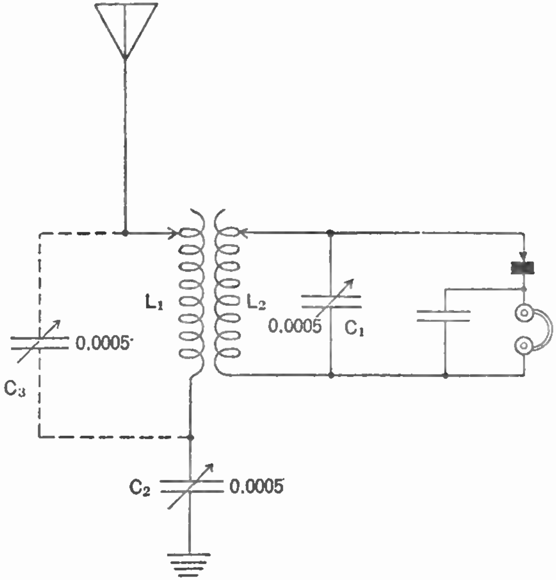


Fig. 10—Diagram of Two-Circuit Receiving Set using Crystal Detector.

In the case of a short antenna which it is desired to use in receiving from a longer-wave station, the primary tuning condenser should be connected across the terminals of the inductance coil as shown by the dotted lines in Fig. 10, instead of in series with the coil. The end of the coil which is not connected to the antenna should then be connected directly to the ground. This parallel condenser gives the effect of lengthening the antenna so far as tuning is concerned and is also useful in making the final, clcse tuning adjustment.

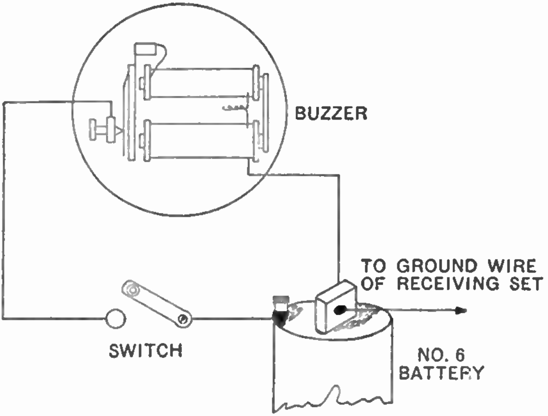


Fig. 11—Test Buzzer Circuit.

The fixed condenser connected across the telephone receivers is called a "telephone condenser." Its size is not ordinarily of much importance. Its effectiveness may depend upon the make of telephone receivers used, and in some cases the use of such a condenser decreases rather than increases the strength of the received signals. Where it is useful at all, a condenser of about 0.002 microfarad will usually be found quite satisfactory. It may be particularly effective in the case of reception from spark transmitting stations having low spark notes. Its utility can only be determined by trial.

The "vernier" condenser, used for securing very fine adjustment of the tuning of a circuit, is a very small variable condenser connected across the terminals of a larger condenser so that a substantial change in the position of the control knob causes only a small change in the condenser capacity.

In order to determine when the crystal detector is adjusted to a sensitive position it is desirable to use a test buzzer. The position of the contact point on the crystal should be adjusted until the loudest sound of the buzzer is heard in the telephone receivers. The circuit for connecting this buzzer with a battery and by a single wire to the ground connection of the receiving set is shown in Fig. 11.

Audio-Frequency Amplifiers.—When it is desired to operate a loud speaker on a crystal set, it is necessary to use an amplifier to increase the current delivered by the crystal detector to a strength sufficient for its operation. The amplifier is connected to the receiving set in place of the telephone receivers, and to the amplifier in turn is connected the loud speaker or telephone receivers. Fig. 12 shows an amplifier thus connected to the two-circuit set of Fig. 10. The amplifier shown is said to have two "stages," *i. e.*, two electron tubes, each with a transformer and other accessories. Information on electron tubes is given in chapter 5. Either storage-battery tubes or dry-cell tubes can be used. Greater volume of sound is obtained when storage-battery tubes are used, but great volume of sound can also be obtained from dry-cell tubes by using several of them in parallel in the last stage of the amplifier.

The special type of transformer used is called an "amplifier transformer" or an "audio-frequency transformer." The voltage ratio (ratio of secondary to primary voltage) of such transformers is usually between 5 to 1 and 10 to 1.

Unless very special precautions are taken to shield the transformers and the connecting wires of the amplifier, it is amost impossible to employ more than three amplifier tubes connected after the detector tube without causing a howling sound in the telephone receiver which makes the reception of signals impossible. In general, by placing the transformers as far as six inches apart, and placing the cores of the transformers at right angles, the trouble will be minimized. The connecting of a condenser across the terminals of the primary winding of the first transformer of an audio-frequency amplifier will sometimes increase the strength of received signals as well as reduce the likelihood of the occurrence of this "howling." A condenser having a capacity of 0.005 microfarad is suitable for this purpose.

Amplifier tubes should be used in such a way that the magnitude of the output voltage is strictly proportional to the magnitude of the input voltage, otherwise the quality of speech or music received may be distorted. In order to secure maximum amplification with a minimum of speech distortion it is usually desirable to use, with amplifier tubes, a "B" battery of 45 volts or higher. An adjustable grid voltage is also of value for this purpose and may be obtained by using a "stabilizer" or potentiometer resistance connected across the terminals of the filament battery. The sliding contact is connected to the part of the circuit which would otherwise connect the grid to the filament or "A" battery. Such a "stabilizer" rheostat is shown at R_1 in Fig. 26. If the input voltage to an amplifier is so great that the output voltage would be

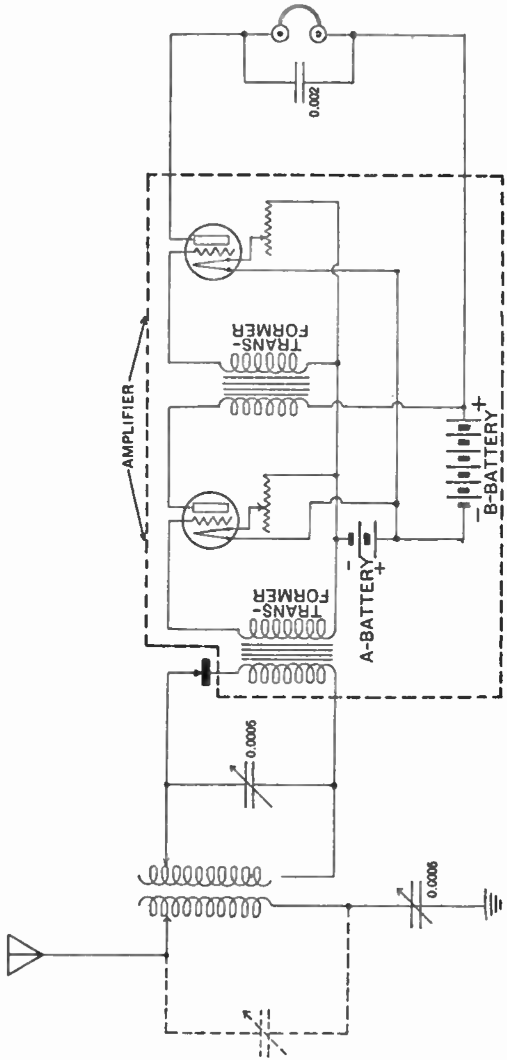


Fig. 12—Diagram of Crystal-Detector Receiving Set with Two-Stage Audio-Frequency Amplifier.

more than the maximum which the tube could carry and still maintain proportionality, distortion is bound to result. A "potentiometer" resistance or "stabilizer"

Capacity of a Long Wire Parallel to the Ground.—For a length greater than four times the height,

$$C = \frac{0.614\,l}{(x_1 - k_1)} \times 10^{-6}\ \mu f. \qquad (4)$$

For a length less than four times the height,

$$C = \frac{0.614\,l}{x_2 - k_2} \times 10^{-6}\ \mu f. \qquad (4a)$$

Values of the constants are given in the following table; h/l, l/h, l/d, and h/d are ratios between the length of the wire, the height above the ground, and the diameter of the wire. The tables are good for lengths up to about 100 feet and for wire sizes Nos. 10, 12 and 14. The values in the table below for x_1, x_2, k_1, k_2, have been computed from the expressions

$$x_1 = \log_{10}\frac{4h}{d} \qquad k_1 = \log_{10}\left[\frac{1+\sqrt{1+\left(\frac{4h}{l}\right)^2}}{2}\right]$$

$$x_2 = \log_{10}\frac{2l}{d} \qquad k_2 = \log_{10}\left[\frac{l}{4h} + \sqrt{1+\left(\frac{l}{4h}\right)^2}\right]$$

h/l	k_1	h/d	x_1	h/l	k_2	l/d	x_2
0.9	.444	1,600	3.806	9	.673	12,000	4.380
.8	.453	1,400	3.748	8	.627	10,000	4.301
.7	.531	1,200	3.681	7	.576	8,000	4.204
.6	.620	1,000	3.602	6	.518	6,000	4.079
.5	.656	800	3.505	5	.455	4,000	3.903
.4	.740	600	3.380	4	.382	2,000	3.602
.3	.851	400	3.204	3	.301	1,000	3.301
.2	1.02	200	2.903	2	.209	800	3.204
.1	1.31	100	2.602	1	.107	600	3.079

All measurements should be made in inches.

Capacity of a Vertical Wire.—The formula given above for the capacity of a single horizontal wire whose length is less than four times its height, omitting the k_2 in the denominator, is sometimes used to calculate the capacity of a vertical wire. It applies accurately only when h is large compared with l, and gives very rough values for a vertical single-wire antenna, the lower end of which is connected to apparatus at least several yards above the ground.

Capacity of Various Types of Antennas.—The theoretical formulas that have been evolved for the capacity of types of antenna other than the single-wire are very involved and difficult to handle. A formula has recently been derived empirically which gives the capacity of antennas of all shapes not too elongated or having the wire too widely spaced.

$$C = \left[1.22\sqrt{a} + 0.27\frac{a}{h}\right] \times 10^{-5}\ \mu f, \qquad (5)$$

in which a is the area of the top of the antenna in sq. ft. and h is the actual mean height above the ground in ft.

For a very long antenna having a length greater than eight times its breadth, the above formula must be multiplied by the **elongation factor** $(1+0.01 / b)$, (6) where b is the breadth of the antenna in feet. This equation is accurate to about 10% for antenna tops. The capacity of the lead-ins, etc., must be estimated. The poorest agreement between the calculated and experimental values is in the case of umbrella antennas. The quantity a is the area enclosed by the bounding wires of the antenna.

The estimation of the capacity of the lead-in wires from an antenna is a very difficult matter, due to the fact that very often we do not know the length and other characteristics of the ground lead. If the apparatus happens to be located in an upper story of a building or residence and the set grounded through the water system, it can be seen what an impossible problem we have at hand. Accurate calculation of the antenna constants is possible only when a special ground lead to a pipe or plate buried in the ground is used. In this case the capacities of the antenna top and lead-in wire are calculated separately and combined by the formula for condensers in parallel, viz.,

$$C = C_h + C_v,$$

in which C_h is the capacity of the horizontal or top portion and C_v is the capacity of the vertical portion or lead-in.

The **mutual capacity** of two parallel wires is the capacity of these two wires, regarded as a single system, with respect to the earth as the other plate of the condenser. The mutual capacity is not the same as the capacity of the two wires regarded as the two plates of a condenser, and the capacity of the two-wire system is not twice the capacity of each wire by itself with respect to the earth. As a matter of fact, it is less. The normal electric field of one of the wires overlaps the normal electric field of the other. The total capacity of these two wires to earth is diminished to some extent by this overlapping.

The capacity of a two-wire antenna with respect to the earth is twice the capacity to earth of one of the wires, less the mutual capacity of the two wires. In general, although each added wire adds something to the total capacity, it adds much less than the capacity it would have alone in the same position.

The use of all these formulas will give only an approximate idea of the capacity of an antenna, as, even in the simplest cases, the presence of houses, trees and other neighboring objects, and the difficulty of allowing for the lead-in wire, makes any precise calculation impossible.

Self-Inductance of Single-Layer Coils.—Nagaoka's formula for computing the self-inductance of single layer coils is:

The transformer which is connected to the grid and filament of the first tube is an ordinary audio-frequency amplifier transformer. The other two transformers shown in this circuit should preferably be special transformers having connections brought out from the center point of one of the windings, as shown; that is, the transformer connected between the two stages has a "split" secondary, while the transformer between the last stage and the loud speaker has a "split" primary.

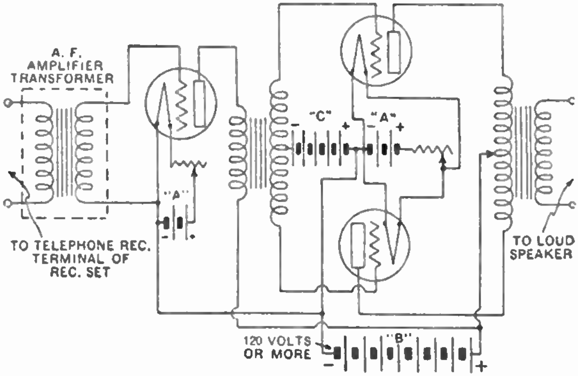


Fig. 12-C—Push-Pull Amplifier.

In principle, this push-pull circuit uses one tube during one-half of the cycle and the other tube during the other half of the cycle. Each tube is effective while the terminal of the secondary transformer winding to which its grid is connected is at a positive potential with respect to the middle of the winding. During the other half of the cycle, when this terminal is negative with respect to the center tap, this tube is not operating, but use is made of the other tube whose grid is connected to the transformer terminal, which is momentarily at a positive potential.

Ordinary amplifier receiving tubes can be used in this circuit, although louder signals can be secured if 5-watt power tubes or special tubes having a high amplification coefficient are used.

Transformers built especially for use in the push-pull amplifier are not generally available, although several have been advertised. Ordinary audio-frequency transformers may be used, however, as indicated in Fig. 12-D.

Two transformers are used in series for the input, and two more arranged similarly for the output. Any of the good transformers on the market may be used. The important thing is that the two transformers in each pair must be identical.

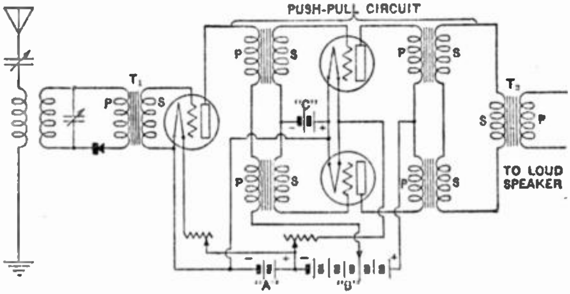


Fig. 12-D—Push-Pull Amplifier using Ordinary Transformer.

In Fig. 12-D it will be noted that an audio-frequency transformer T_2 is connected between the push-pull circuit and the loud speaker. This transformer is used inverted, that is, the current is put into the high resistance winding (generally marked secondary) and taken out of the low resistance winding (marked primary). In other words, it is used as a step-down transformer. The use of this transformer in some cases increases the volume output of the loud speaker or phones several times. The reason for this is as follows: It is generally known that the efficiency and consequently the output of any system comprising a generator and a receiver of energy is greatest when the impedances of the generator and receiver of energy are equal. The impedance of the loud speaker (or receiver of energy) is generally low compared with that of the secondaries (in series) of the output transformers of the push-pull amplifier. By introducing this step-down transformer, the high impedance secondaries in series feed into the high impedance winding of the added transformer, and the low impedance winding of this latter feeds into the low impedance of the loud speaker. Where special tapped transformers are used, this additional step-down device is not required.

Simple Electron Tube Set.—An electron tube may be used as a detector in place of the crystal detector in either the single-circuit set (Fig. 9) or two-circuit set (Fig. 10). The way in which the electron tube is connected into the circuit, with its associated batteries and rheostat and grid leak, is shown for the two-circuit set in Fig. 13. In the various circuits which follow, any type of receiving tube may be used. Filament and plate batteries must, of course, be of the proper voltage to suit the tube used. A table of data on the different types of electron tubes is given in chapter 5. It is desirable to employ a plate battery which is adjustable by means of taps which are brought out from a number of cells which form the complete battery. The rheostat in the filament battery circuit is used for adjusting the filament temperature to the best value.

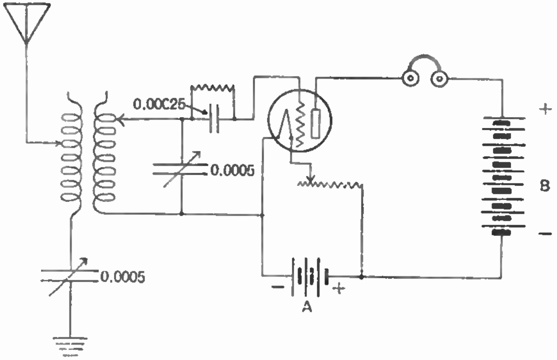


Fig. 13—Diagram of Two-Circuit Receiving Set using Electron Tube Detector.

The connections which are made from various parts of the circuit to the filament, grid and plate of the electron tube are made by means of a socket. The wire connections can be soldered to the terminals forming a part of this base or socket, and care should be taken to make these connections to the proper terminals. A tube is fastened into its socket by pushing it in as far as it will go and giving it a slight turn to the right. It is desirable to use an ammeter (not shown in the diagram) in series with the filament and the "A" battery, in order to tell the exact amount of current which is flowing through the filament and to secure again the best adjustment when this has once been found.

It is sometimes desirable to maintain the grid of an electron tube at a definite voltage above the negative terminal of the filament, so that the tube will operate with the maximum effectiveness as a detector or as an amplifier in a specific case. This may be done either by means of the "stabilizer" rheostat or by connecting a dry battery (called a "C" battery) of a few volts in series in the grid circuit. The voltage supplied is sometimes called a "biasing" voltage.

Regenerative Sets.—The diagrams shown in Figs. 14 and 15 are for one-tube circuits making use of the principle of regeneration. In such circuits the normal tube amplification is greatly increased (see explanation in chapter 5). The use of regeneration with a two-circuit

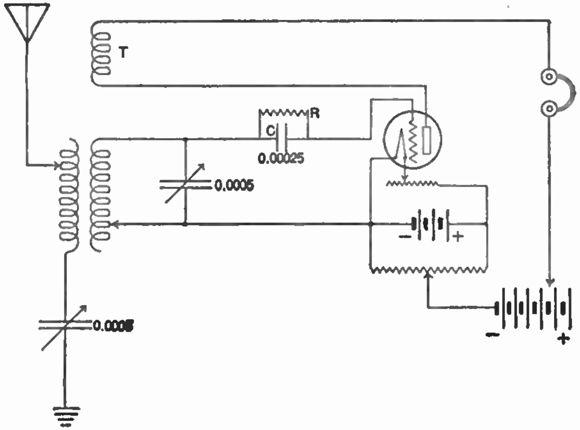


Fig. 14—Diagram of Two-Circuit Regenerative Receiving Set.

tuner is shown in Fig. 14. This circuit makes use of a tickler coil, T, which is placed close to the secondary inductance and which is effective in increasing the loudness of the received signals. The tickler coil may be the rotor of variocoupler, or may be wound on a cylinder and so arranged as to slide within or over the secondary coil. It is also satisfactory to use flat coils, such as the "honeycomb," so arranged that the tickler coil is placed alongside the secondary coil. A small condenser C and "grid leak" resistance R are connected between the tuned circuit and the grid of the tube. A grid leak resistance of 1 or 2 megohms shunted across a condenser having a capacity of 0.00025 microfarad is ordinarily satisfactory, though the best values depend upon the particular type of detector tube employed.

The resistance which is connected across the "A" battery in Fig. 14 is a potentiometer resistance or "stabilizer" of approximately 200 ohms. The sliding contact on this resistance makes it possible to obtain finer adjustment of the voltage in the plate circuit. In some circuits, as at R, in Fig. 26, a similar resistance is used to secure adjustment of the voltage between the grid and the filament. If the variations of voltage are obtained by direct connection to the individual cells of the battery it is impossible to adjust more closely than by steps of one or two volts. By using the potentiometer resistance, with its continuously variable contact, much finer variation is obtainable. This potentiometer resistance or stabilizer itself draws some current from the battery across which it is connected, but the amount is small if the resistance of the potentiometer is large. This follows from the principle stated in chapter 4, that the current is equal to the voltage divided by the resistance. It is well to entirely disconnect one end of the battery itself when the receiving set is not in use, in order to avoid unnecessary waste of current.

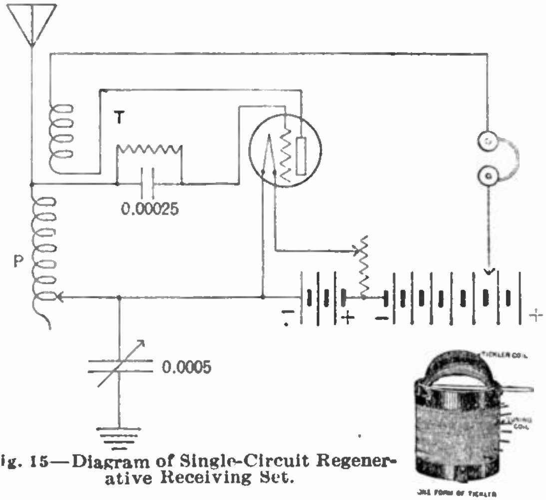


Fig. 15—Diagram of Single-Circuit Regenerative Receiving Set.

A somewhat simpler arrangement employing the principle of regeneration is shown in Fig. 15. In this circuit the inductance P and the tickler coil T are the two windings of a varioupler.

In all regenerative sets employing a tickler coil it is important to see that the connections to the tickler coil be so made that the coupling between it and the tuning inductance is in the proper direction. If, therefore, such a set fails to regenerate, try reversing the tickler coil leads.

Regenerative sets when adjusted to the generating (oscillating) condition often become very troublesome sources of interference to nearby receiving stations. The two-circuit set shown in Fig. 14 is less likely to produce such interference than the single-circuit set shown in Fig. 15.

A combination of a two-circuit regenerative set and an audio-frequency amplifier is shown in Fig. 16. This is a very satisfactory receiving set, distant stations being readily brought in on a loud speaker.

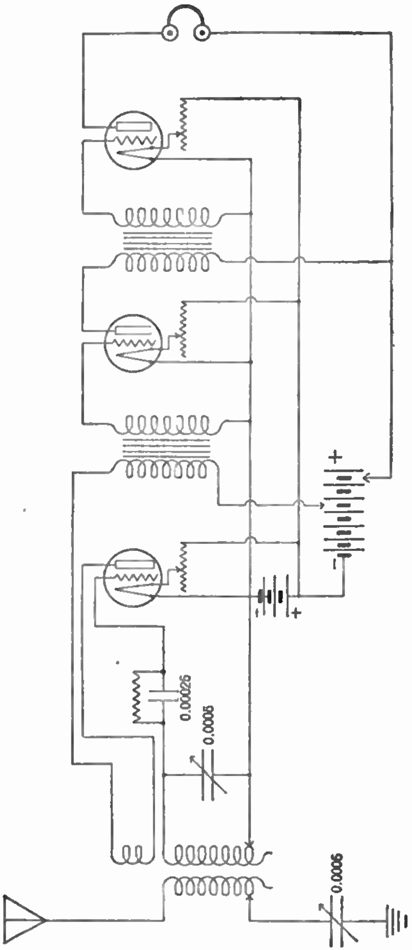


Fig. 16—Diagram of Regenerative Receiving Set and Two-Stage Audio-Frequency Amplifier.

Converting a Crystal Set Into a Regenerative Set.—The distance range of a crystal detector receiving set can of course be increased by connecting an amplifier between the crystal and the phones. A simpler, cheaper and better way, however, is to convert the set into a regenerative set, using a dry-cell electron tube. By adding such a tube to a crystal set and changing to a regenerative connection, stations at distances up to one hundred or two hundred miles can be heard, under good conditions. Exceptional transmission conditions make it possible to receive over distances up to about 1000 miles.

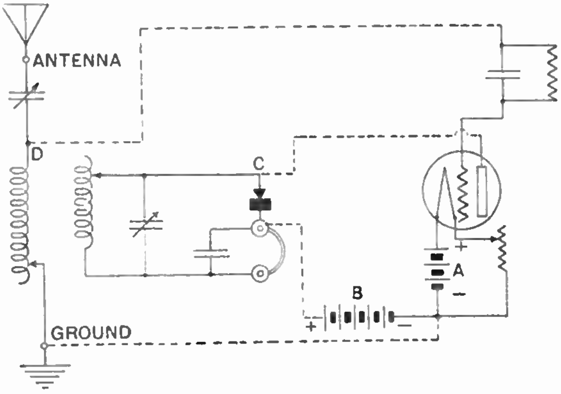


Fig. 17—Regenerative Connection of Electron Tube to a Two-Circuit Crystal Set.

No changes are necessary in the internal connections of the set when you start with a two-circuit crystal set. The ordinary connections of a two-circuit crystal set are shown at the left of Fig. 17. An electron tube with the associated batteries, etc., is shown at the right. The dotted lines between the two show how the connections are made to make the set regenerative. The

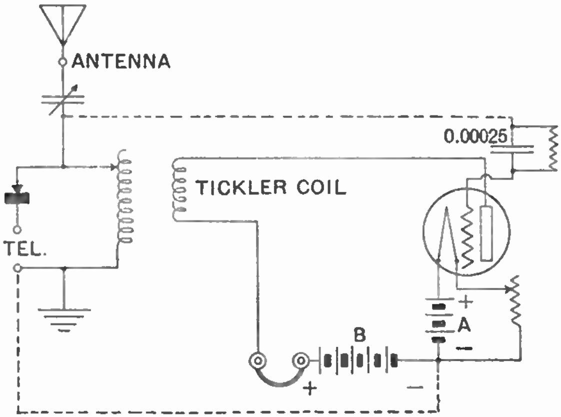


Fig. 17-A—Regenerative Connection of Electron Tube to a Single-Circuit Crystal Set.

crystal detector must be out of circuit by having its contact wire raised. If the set does not have a binding-post at points C or D, connection must be made to the proper switch arm or in some other manner. If the set does not regenerate, the connections to "D" and "Ground" should be reversed.

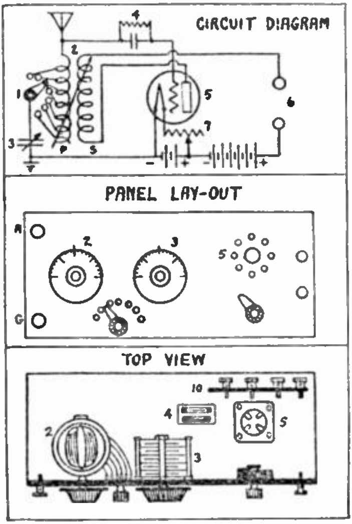
When starting with a single-circuit crystal set, one additional item must be provided—a tickler coil. This may be a simple cardboard tube about 2 inches long and 3 inches in diameter, with about 30 turns of No. 24 to 30 wire wound on it. This must be provided with a means of sliding either inside or over the inductance coil of the set, or else made to rotate within or near it. The ordinary connections of a single-circuit crystal set are shown at the left of Fig. 17-A. The dotted lines show how to make the connections to the electron tube and tickler coil.

Constructional Hints on Regenerative Sets.—For the benefit of those who have difficulty in visualizing, from circuit diagrams, what the panel layouts would be, several semi-constructional drawings are given below, the regenerative receiving circuit being taken as an example. No attempt is made at giving sizes and exact spacing of the holes that must be drilled, on account of the lack of uniformity in the radio parts obtainable on the market. Primarily, these drawings are intended to give readers an idea of the relative positions of the instruments and to show simple and practical arrangements. All instruments should be grouped so as to insure short leads in wiring and minimum mutual induction and stray capacity.

The single-circuit regenerative receiver shown in Fig. 17-B is characterized by its sensitivity and long-range receptive powers, although limited in selectivity. This is an excellent circuit to employ where there are not several local broadcasting stations operating at the same time. If greater selectivity is desired, the circuit shown in Fig. 17-E may be used. This coupled circuit also causes somewhat less radiation and interference to neighboring receiving sets when improperly operated.

Coils should be placed as far apart as conveniently possible, to minimize mutual induction. The audio-frequency transformers should be mounted at right angles to each other, for the same reason.

The following general rules in setting up any circuit should be carefully followed: Be sure to remove the greasy residue left after soldering connections. This is very often the cause of inoperative jacks, variocouplers, variometers, and any instrument on whose shaft or bearings this greasy material is left. It is inadvisable to solder connections to a fixed condenser unless it is so made as to withstand the soldering heat. See that all joints are tight, and use as short and as unparallel leads as possible in making connections between instruments. It is best to allow an average distance of about 4 inches between the centers of all parts.



1 = Switch knob.
2 = Variocoupler.
3 = .001 condenser.
4 = Grid leak and condenser.
5 = Detector.
6 = Phones.
7 = Rheostat.

A = Antenna.
G = Ground.
2 = Coupling control.
3 = Condenser control.
5 = Peep-holes, detector tube.

4 = Grid leak and condenser, .00025 mfd. and 2 megohms.
5 = Tube socket.
10 = Small upright panel for battery binding posts.

Fig. 17-B—Construction Plan for Single-Circuit Regenerative Receiver.

In laying out the panel of a set, the position of each instrument, with the necessary holes to be drilled, should be carefully diagrammed on a piece of paper; then, laying this template on the panel, it is comparatively easy to mark off the centers of the holes and to drill them accurately.

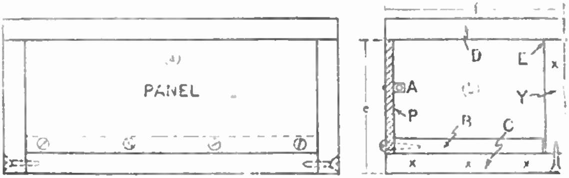


Fig. 17-C

Figure 17-C illustrates an easy way of building a cabinet to contain the panel and its base. The front view of the cabinet and panel is shown at (a). The end view at (b) shows how panel P is mounted on base B, the two forming a complete unit in themselves, which may be readily placed in or removed from the cabinet. The panel base B rests on the cabinet base C, and the panel with its base is prevented from sliding out by means of

the small angle bracket A fastened to the inside of the panel and which is flush with the end of the panel. This angle A is engaged by a stove bolt passing through the side of the cabinet. The cover of the cabinet is hinged at E, permitting easy access to the instruments within the case. The end of the cabinet, designated by (e f), should be fastened in place by screws at positions XXX in base C and XX in back Y. This arrangement provides a very rigid construction for the cabinet.

If the set-builder desires to use the baseboard of the cabinet as the base of the set itself, the panel may be readily mounted on the base by means of three angle-brackets, as shown in Fig. 17-D. This permits the full height of the panel to be used for mounting instruments, whereas in the plan used in Fig. 17-C about a half-inch of the height of the panel is used for screwing it to the base B.

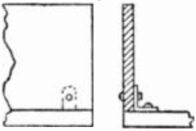


Fig. 17-D

Fig. 17-E is a diagram showing the use of three honeycomb coils in a regenerative circuit with two stages of audio-frequency amplification. The parts used in the construction of this set are as follows:

1.—Primary, 75-turn honeycomb coil.
2.—Secondary, 75-turn honeycomb coil.
3.—Tickler, 50-turn honeycomb coil.
4.—Double-pole, double-throw switch.
5.—43-plate variable condenser (.001).
6.—23-plate variable condenser (.0005).
7.—.00025 mfd. condenser and 2-megohm grid leak.
8.—Detector tube.
9, 10.—Amplifier tubes.
11.—A.F. transformer, about 5:1 ratio.
12.—A.F. transformer, about 3½:1 ratio.
13, 14, 15.—6-ohm rheostats.
16, 17.—Double-circuit jacks.
18.—Single-circuit jack.
19.—.001 fixed condenser.
20.—Battery switch.

The double-pole, double-throw switch enables condenser 5 to be thrown into the circuit either in parallel with the primary coil at position A or in series at position B, thereby adapting coil 1 to a wider range of wave lengths than would be possible if the condenser were connected in one fixed way.

A honeycomb coil has the advantage of possessing much lower distributed capacity than single-layer coils, in addition to being a very compact form of inductance. A set using these coils may be readily adapted to all wave lengths by inserting the proper coils in the "plug-in" mountings. An outfit of this type is characterized by its excellent selectivity, its long-distance receptive powers, and its comparative ease of construction.

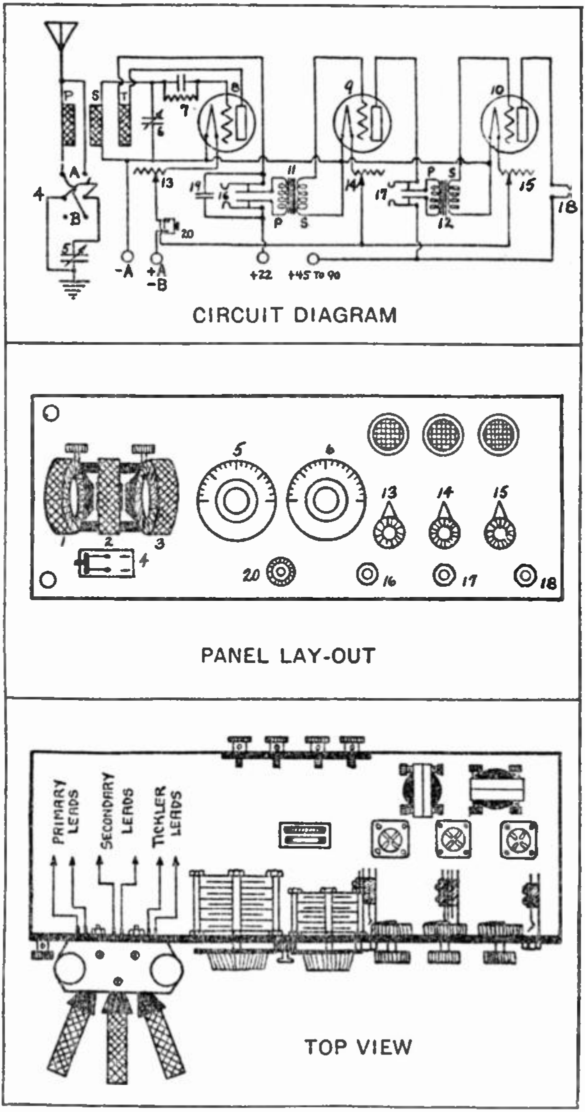


Fig. 17-E—Construction Plan for Two-Circuit Regenerative Receiver.

There is no fundamental difference between a 3-coil honeycomb set and a set using a variocoupler and tickler coil. The only difference lies in the fact that the honeycomb coils are interchangeable, and that instead of securing variation in coupling by means of *rotation*, the honeycomb coils move on hinged mountings through an arc of a circle.

It would be well if experimenters would become accustomed to thinking of inductance in microhenries instead of coils of certain size; then they could easily pick out the size required of any type they wish to use.

The honeycomb-coil circuit shown in Fig. 17-E is identical, except for the series-parallel switch and the jacks, to the variocoupler-tickler-coil circuit given in Fig. 16, The honeycomb coils are shown mounted in front of the panel, but by means of a special back-panel mounting, which can be procured at most dealers, the coils may be placed behind the panel, with only the two adjusting knobs projecting through to the front.

The wave-length range of this set is approximately 250 to 725 meters, using a 75-turn coil for the primary, a 75-turn for the secondary, and a 50-turn coil for the tickler. The .001 microfarad condenser is thrown into the circuit in series to receive the lower wave lengths up to 500 meters, and is used in shunt for higher values.

Three-Circuit Regenerative Set.—The connections used in a three-circuit regenerative receiving set are shown in Fig. 18. Here, in addition to the primary and secondary inductance coils forming the coupler, or variocoupler, it is necessary to use two additional variable inductance coil. swhich are usually of the form known as "variometers." These variometers are quite similar in appearance to the variocoupler, but the two windings are connected in series so that as the position of one of the coils is changed, the inductance is correspondingly varied.

This is a regenerative circuit in which, however, the feed-back action is accomplished by the capacity between grid and plate instead of by a tickler coil. Both the plate and the grid circuit are tuned by the combination of the tube capacity with the variometer in that circuit. The plate variometer really controls the regeneration rather than giving actual tuning. At a certain setting it gives maximum feed-back or reduction of effective resistance in the grid circuit. The condenser at the right is merely to give the radio-frequency current an easier path than it would have through the phones and battery. Since the amount of feed-back cannot be varied directly, as it can be in regenerative sets employing a tickler coil, this type of set is very difficult to adjust (see page 9). Any change of setting of the coupler coupling or of either variometer varies the adjustment of the others. It rewards patience by giving loud signals, but is troublesome to operate.

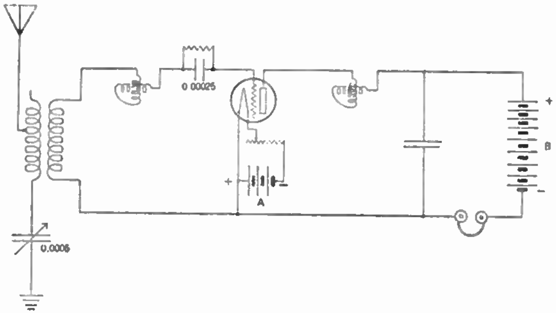


Fig. 18—Diagram of Three-Circuit Regenerative Receiving Set using Electron Tube Detector.

It is necessary to provide for fine adjustment of the antenna wave length, either by strictly continuous variations of the inductance in series with the antenna or by the series condenser. If the series condenser is not used, because of receiving longer waves, the condenser may be placed in parallel with the antenna inductance coil and serve as fine adjustment of it.

Special Types of Regenerative Sets.—The Reinartz receiving circuit is shown diagrammatically in Fig. 19, and in more detail in Fig. 20. This is a circuit in which the feed-back or tickler action is secured by connection to the coil which also forms part of the tuned circuit. A condenser is also connected between the plate of a detector tube and the antenna. The antenna circuit itself is not tuned. The antenna may therefore be much longer than is ordinarily possible when it must be tuned to the received signals. The tuning of the secondary circuit is relied upon to secure selectivity. The so-called "spider web winding" has been found by

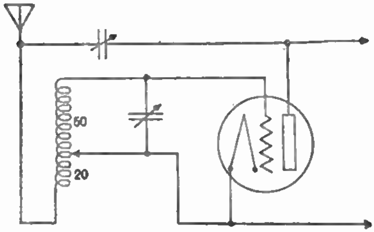


Fig. 19—Schematic Diagram of Reinartz Circuit.

many experimenters to be convenient, since the wires to the switch contacts can be brought out in a compact way. If this form of winding is used, eighty-five turns of No. 26 single cotton-covered wire should be wound on a nine-spoke wheel, thus forming a coil 5 inches in outside diameter and having an open center 2½ inches in diameter. A coil thus constructed will enable the receiving set to cover a range from 130 to 360 meters. The insertion of a radio-frequency choke coil at the point marked Ch. in the plate circuit of the detector tube will serve to increase the strength of the signals in case the distributed capacity of the primary winding of the amplifier transformer is large.

In actual use this circuit is quite similar to the ordinary single-circuit regenerative receiving set, regeneration being here controlled by means of a condenser connected to the antenna. It has the disadvantage of causing reradiation and thus interfering to some extent with the reception of signals at other receiving stations nearby.

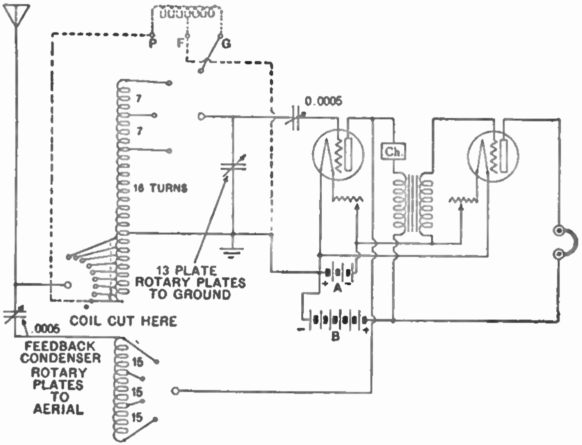


Fig. 20—Diagram of Reinartz Circuit.

The "four-circuit tuner" as described by L. M. Cockaday is shown in Fig. 21. The antenna circuit is tuned by means of the coil D. This coil is practically the same as the primary coil of any inductively coupled receiving set. This coil does not, however, provide the coupling with the secondary circuit. For this purpose a single turn of wire is connected in the antenna circuit as at A. Sharp tuning of the antenna circuit may be secured by the use of a variable condenser, though the selectivity of the other circuit is such that this additional adjustment is not necessary. The single-turn coil A is coupled to the two other coils B and C, which are also coupled to one another. These coils may be alike and may be wound as though they were to serve as secondary windings of the ordinary

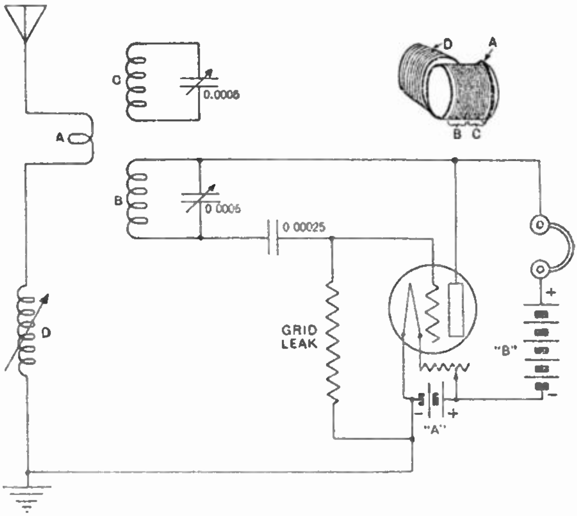


Fig. 21—Diagram of Four-Circuit Tuner

inductively coupled tuner. The coil C with its condenser is not connected conductively to any other part of the circuit.

Wire for coils B, C, and D can be 18 to 24 gage B. & S. For coils B and C use about 100 turns tapped at 20 turns and every 10 turns thereafter. For coil D use about 125 turns tapped at 25 turns and every 20 turns thereafter.

Radio-Frequency Amplification.—This is a scheme for increasing the received signal strength by amplifying the radio-frequency voltage produced in the receiving set tuner, this amplified voltage being then passed on to the detector. It is done by inserting one or more electron tubes between the tuner and the detector. It accomplishes the same thing as regeneration does in the sets described above, except that in those sets the amplification and detection take place in the same tube. The amount of amplification is more controllable in radio-frequency amplification, and the set is free from the objectionable oscillation or self-generation that occurs in a regenerative set when the regeneration is increased too much.

By using a tuned circuit connected in the output side of each tube (or "stage") of radio-frequency amplification, great selectivity can be obtained, so that interference from radio stations on other frequencies than that desired can be eliminated.

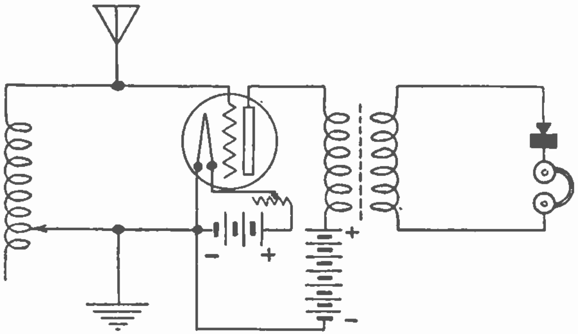


Fig. 22—Simplest Radio-Frequency Amplifier Receiving Set.

Information follows on the use of radio-frequency amplification with various types of set—one-circuit and two-circuit, crystal and tube detector, non-regenerative and regenerative. From one to three stages of radio-frequency amplification may be used. The simplest example is that of Fig. 22, which is the same as Fig. 9 except for the insertion of a stage of radio-frequency amplification between the single-circuit tuner and the crystal detector. The added apparatus is the tube with its associated batteries and rheostat and a radio-frequency transformer.

Radio-frequency transformers should be of proper design for the frequencies received. They may be purchased, or, with some experimenting, may be constructed by the user. They are of two types, "air core" (*i. e.*, no core at all) or "iron core." The air core transformers give greater amplification, but are limited to a narrower band of frequencies, while the iron-core transformers give less amplification, which is uniform over a wider frequency band. An ordinary vario-coupler may be used with some success as a radio-frequency transformer. A more standard form of air-core transformer is made of two similar coils, each consisting of about 300 turns of No. 38 B. & S. gage single silk-covered copper wire in a form having an inside diameter of 1¼ inches and a thickness of 3/32 inch. If this coil is wound in the so-called "basket" or "honeycomb" style, the distributed capacity of the coil will be kept low. This is an advantage. The two similar coils forming the two windings of the transformer should be mounted coaxial and parallel to each other and about half an inch apart. The wave length to which the transformer is tuned can be increased somewhat by moving the coils closer together. The wave length may be decreased by separating the coils slightly or by removing some of the turns of wire.

An iron-core radio-frequency transformer can be made by winding about 200 turns of No. 44 B. & S. gage enameled copper wire in a single layer over a core of thin laminated iron about ½ inch square and 3 or 4 inches long. A layer of some insulating material about 1/16 inch thick should be put around the iron core before the wire is wound on it. This winding can serve as the primary winding, the secondary being an identical one, wound on the same core. The inner ends of the two windings should be separated about ¼ inch from each other. In connecting these transformers to the electron tubes, the inside adjacent ends of the windings should be connected to the battery circuits, the extreme outer ends being connected to the grids and plates of the tubes. Varying the number of turns of wire and the distance between these windings changes the frequency or wave length at which the transformer is most effective. The exact values best for a certain wave length can be determined by trial.

Fig. 22 shows the radio-frequency amplifier connected to the tuner of an ordinary open antenna. It may be connected to a coil antenna, as shown in Fig. 23. The "radio-frequency amplifier" of this figure is simply the tube and radio-frequency transformer as shown in Fig. 22. The "detector" may be either a cyrstal or tube detector. Very distant stations would not be received unless several stages of amplification were used. It is usually desirable to use an audio-frequency amplifier to increase the signal produced in the detector. This is connected as shown in Fig. 24.

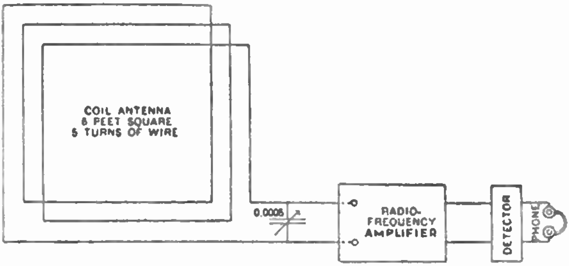


Fig. 23—Essential Connections of Radio-Frequency Amplifier Set Using Coil Antenna.

The stabilizer of Fig. 24 makes possible the adjustment of the voltage of the grid of the radio-frequency amplifier tube to give a minimum of distortion. Care must be taken to keep this adjustment below the point where the circuit "oscillates" or becomes a generator of radio-frequency current. In the latter case a hissing or a whistling sound is usually heard which seriously interferes with the received signals.

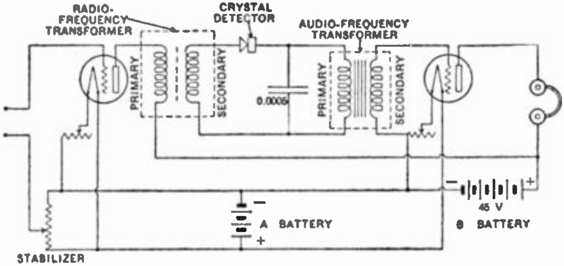


Fig. 24—Amplifier Consisting of One Stage of Radio-Frequency Amplification, a Crystal Detector, and One Stage of Audio-Frequency Amplification.

While this diagram shows only one stage of radio-frequency amplification and one stage of audio-frequency amplification, it is possible to use either two or three stages of either, employing connections similar to those in the other diagrams referred to above.

The use of an electron tube detector instead of a crystal is shown in Fig. 25, which includes two radio-frequency amplifier tubes and a detector tube. In place of the telephone receivers, connection may be made to an audio-frequency amplifier. In this figure the antenna is shown connected to a single-circuit tuner.

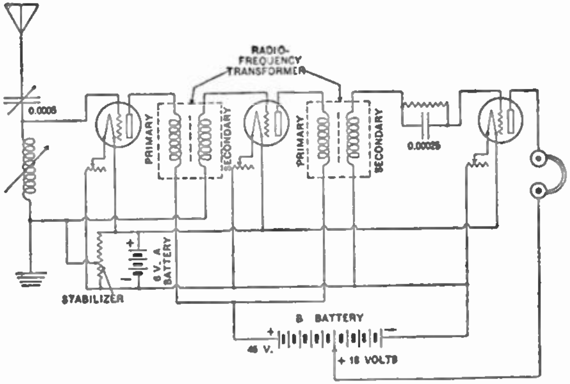


Fig. 25—Two-Stage Radio-Frequency Amplifier and Electron Tube Detector.

A very good set for receiving distant stations on a loud speaker is the two-circuit, 6-tube radio-audio amplifier set shown in Fig. 26. The first three tubes, with their radio-frequency transformers, act as radio-frequency amplifiers, the fourth tube as a detector, and the fifth and sixth as audio-frequency amplifiers. The

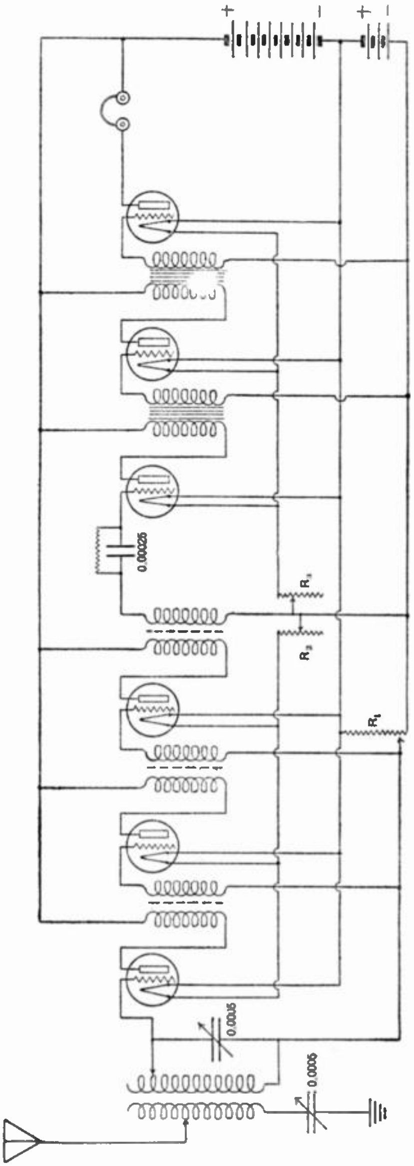


Fig. 26—Diagram of Receiving Set using Radio-Audio-Frequency Amplifier. (Using Amplifier Tubes throughout.)

rheostat R_2 adjusts the filament current in the radio-frequency tubes, and the rheostat R_3 adjusts that in the detector and audio-frequency tubes.

Combined Regeneration and Radio-Frequency Amplification.—Some further advantages are obtained by using a combination of regeneration with radio-frequency amplification. This permits very sharp tuning. It has the very great advantage over the ordinary regenerative set above that if self-generation or "oscillation" takes place in the regenerative tube it does not reradiate and cause interference, as regenerative sets do when (improperly) allowed to self-generate. The arrangement shown in Fig. 27 employs two tuned circuits, and in addition, has a feed-back or tickler coil which is used both to increase the strength of the received signals and to sharpen the tuning of the second tuned circuit. The first tube is used as a radio-frequency amplifier and the second tube as a regenerative detector. The detector circuit is almost identical with the single-circuit regenerative receiving set shown in Fig. 15. In fact, any single-circuit regenerative receiving set may be connected to the plate circuit of a radio-frequency amplifier tube and used in this way.

Fig. 28 differs from Fig. 27 by the substitution of a variometer for the tickler coil in the plate circuit of the detector tube and by the addition of one more stage of radio-frequency amplification (including a radio-frequency amplifier transformer) and one stage of audio-frequency amplification.

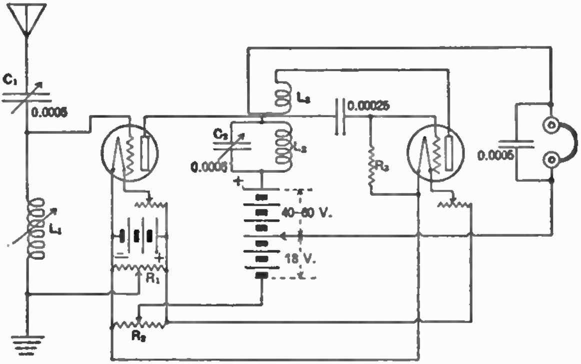


Fig. 27—One-Stage Radio-Frequency with Tickler Coil for Regeneration.

If a single-circuit tuner is used as L_2C_2 in either Figs. 27 or 28, it is necessary to make sure that the coil and condenser are in parallel with one another. A tuner having the coil and condenser connected in series can be used by connecting the antenna and ground terminals together for one terminal and bringing out a special connection from the mid-point between the coil and condenser for the other terminal.

In case it is desired to construct the coils for use in these circuits, the tuning coils L_1 and L_2 should be made like the tuning coil for a single-circuit tuner described in table on page 64. The construction of the tickler coil, L_3, Fig. 27, and the variometer for the plate circuit, L_3, Fig. 28, is also described in the same table. As much air and as little solid dielectric as possible should surround the coil winding. It is important to use a condenser, as shown, across the terminals of the telephone receiver or the primary winding of the audio-frequency amplifier in the plate circuit of the detector tube. A condenser across the terminals of the "A" battery also slightly increases the signal strength. The resistances R_1 and R_2 are "A" battery potentiometers of 200 or 300 ohms each, while R_3 is a grid leak resistance of approximately half a megohm. In case a hard or high-vacuum detector tube is used, a slightly higher voltage than the 18 volts shown will be required for its plate circuit.

In operating either of the circuits shown in Figs. 27 and 28 one should not move the sliding contact of the stabilizer or potentiometer, R_1, near enough to the negative "A" battery end to cause the generation of current in the antenna circuit. To do so causes interference with other receiving sets in the neighborhood. This condition can be recognized by the occurrence of a click or a hissing sound in the telephone receiver when this potentiometer is moved past a certain position.

The sensitiveness which accompanies the detector tube when it is nearly in this oscillating or generating condition, can, however, be obtained by the adjustment of the feed-back L_3, in Fig. 27, or the variometer L_3 in Fig. 28. The locally generated current is produced in the circuit L_2 C_2, and thus causes less interference than if it were produced directly in the antenna circuit.

In tuning to a desired station, both of the circuits L_1 C_1 and L_2 C_2 must be adjusted simultaneously. It is convenient to do the final tuning by means of the variable condensers. The signals can then be brought up to the maximum strength by adjusting the tickler coil or variometer. This sometimes changes the tuning of circuit L_2 C_2 slightly, and a final readjustment of this circuit is advisable. The use of the variometer causes less change in tuning than the tickler.

To tune the circuits of Figs. 27 and 28 to longer wave lengths loading coils can be connected in series with L_1 and L_2. If more than one stage of radio-frequency amplification is used one must be sure to employ radio-frequency transformers of the proper wave length.

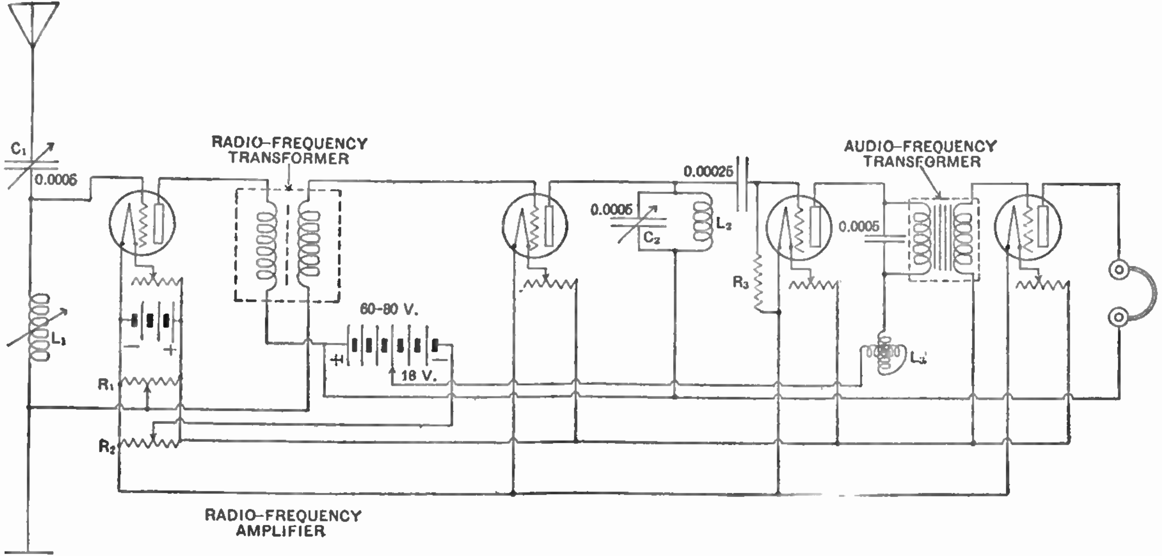


Fig. 28—Two-Stage Radio-Frequency andO ne-Stage Audio-Frequency with Variometer for Regeneration

Reflex Amplifier Circuits.—It is possible to make a tube serve both as a radio-frequency and audio-frequency amplifier simultaneously. This is done, for example, in Fig. 29, in which a crystal is used for detector. It will be seen that the radio-frequency current in the receiving antenna is amplified by the electron tube. The amplified radio-frequency current goes into the detector; then in place of telephone receivers or a connection to audio-frequency amplifier tubes, a return connection is made to the input terminals of the radio-frequency amplifier tube.

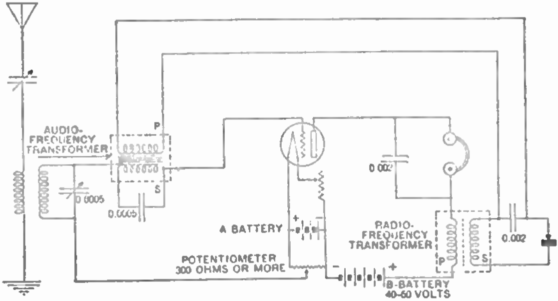


Fig. 29—One-Tube Reflex Circuit Using Crystal Detector.

The audio-frequency current from the detector tube is thus amplified by the tube which is simultaneously amplifying the original radio-frequency current. In the plate circuit of the tube is a connection to the telephone receivers. The telephones do not respond to the radio-frequency current originally passing through the tube, but are affected only by the audio-frequency current which has been brought back to the tube from the detector.

Fig. 30 is a similar circuit in which an electron tube instead of a crystal is used as detector.

The factors to consider in operating this type of circuit are the necessity of simple wiring and orderly arrangement of the circuit elements. The position of the sliding contact on the stabilizer rheostat is likely also to be important.

The tuning equipment is an ordinary variocoupler, specifications for which can be found on page 64. A 200-ohm potentiometer will be satisfactory if one of higher resistance cannot be procured.

If it is desired to have sufficient amplification to operate a loud speaker it is usually necessary to have two stages of audio-frequency amplification. With a reflex amplifier circuit this is accomplished by the use of a total of three tubes. The first two of these tubes serve as radio-frequency amplifiers and also as audio-frequency amplifiers. The third tube is the detector.

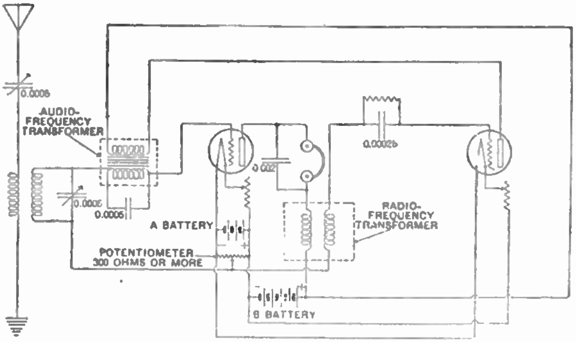


Fig. 30—Two-Tube Reflex Circuit.

A reflex circuit using three tubes in this way is shown in Fig. 31. If amplifier tubes are used in all three stages, the B battery voltage should be between forty and sixty volts. If a soft tube is used as a detector tube, the connection to its plate circuit should be made from the twenty-two volt tap on the B battery. The antenna and secondary inductance coils are the primary and secondary, respectively, of a variocoupler; or in place of a coupled circuit it is entirely feasible to use a single-circuit tuner. The details of the sizes of coils used in either case are given in table on page 64, of this chapter.

If the circuit tends to howl or "oscillate," this can sometimes be stopped by the insertion of a resistance, such as that of a potentiometer, 300 to 2000 ohms, in the plate circuits of the two amplifier tubes, as shown at R and R in Fig. 31.

For operation on a coil antenna or loop it is necessary to have additional stages of amplification. Two tubes, both operating simultaneously as radio-frequency and audio-frequency amplifiers, with a crystal for detector, are shown in Fig. 32. It should be noted that the audio-frequency current from the crystal detector is taken to the tube which acted as the second radio-frequency amplifier, and from there to the first radio-frequency tube, and thence to the phones. The order of passage of the radio-frequency and audio-frequency current through the two tubes is thus opposite. This feature, called the Grimes reflex or inverse duplex, has a number of advantages, the tubes being loaded uniformly and audio-frequency noises from the antenna being minimized. The same principles apply when a tube detector is used instead of a crystal. Such a circuit is given in Fig. 33.

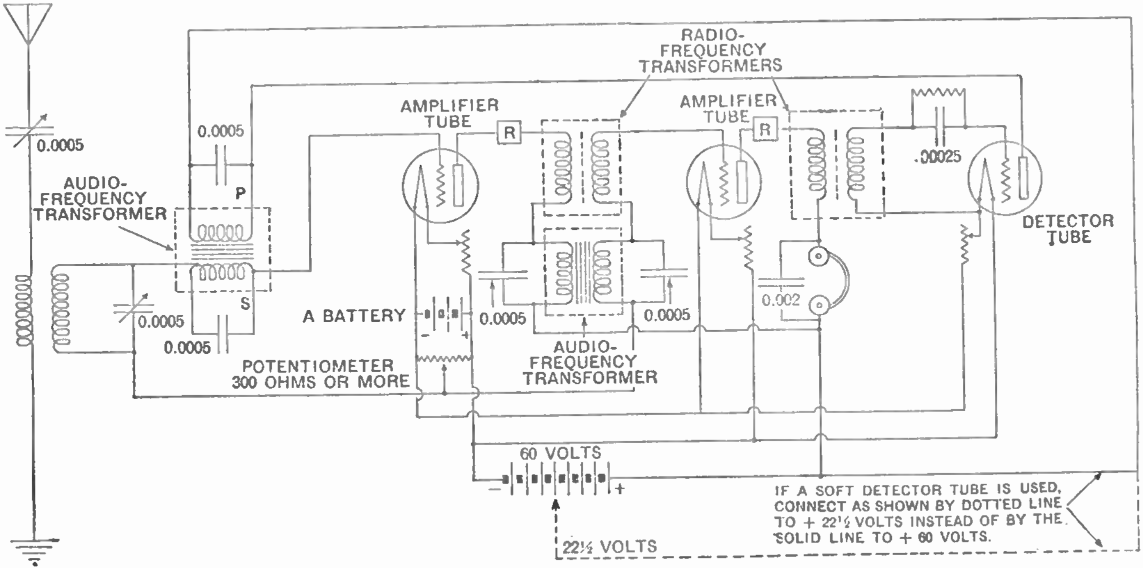


Fig. 31—Three-Tube Reflex Circuit.

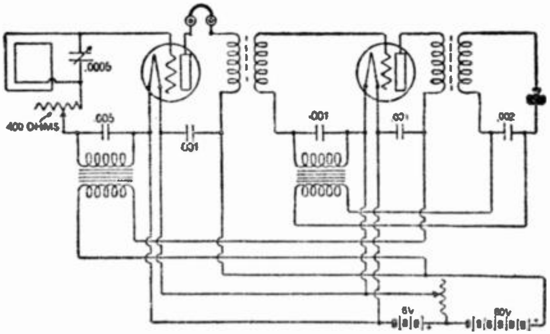


Fig. 32—Two-Tube Reflex with Crystal (Inverse).

An important factor to consider in duplex circuits is the perfect operation of the mica condensers used for by-passing the radio-frequency energies. The plate voltage is across them continuously, and should they happen to be leaky, a constant crackling is evident.

The set should be operated with as little radio-frequency power as possible. Just enough to operate the detector is sufficient, and this control is accomplished by the 400-ohm rheostat. In case a 400-ohm rheostat cannot be secured, a potentiometer of this value may be used as a rheostat, leaving one of the end terminals detached. If the radio-frequency currents are too high for a particular station, distortion follows; and upon excessively boosting these currents, powerful magnetic fields are set up around the radio-frequency transformers. It is these "cross-firing" magnetic fields that produce the well-known effect of "howling." Practically all the resistance of the 400-ohm rheostat will be out on distant reception, while on local reception most of it will be employed.

Considerable care must be exercised in connecting these reflex circuits, as in some cases all the tubes may not function. Sometimes the detector tube may be taken out of its socket and signals still be heard. This is because the amplifier tubes act as detectors, although their action as such is not very efficient. To eliminate this trouble it is necessary to obtain the correct voltage on the grids of the tubes, so it may be necessary to insert "C" batteries into the circuit. In this case the "C" batteries as well as the transformer windings should be by-passed by a condenser.

The output of any tube in this type of circuit which is to be "reflexed" sets up a difference of potential across the by-pass condenser, as, for instance, in the plate circuit of the tube adjacent the detector in Fig. 32. This difference of potential must be great enough to cause appreciable variations of potential on the grid of the first tube when passed through the transformer. This requires that the condensers in the plate circuits be as small as possible, since, for a given amount of

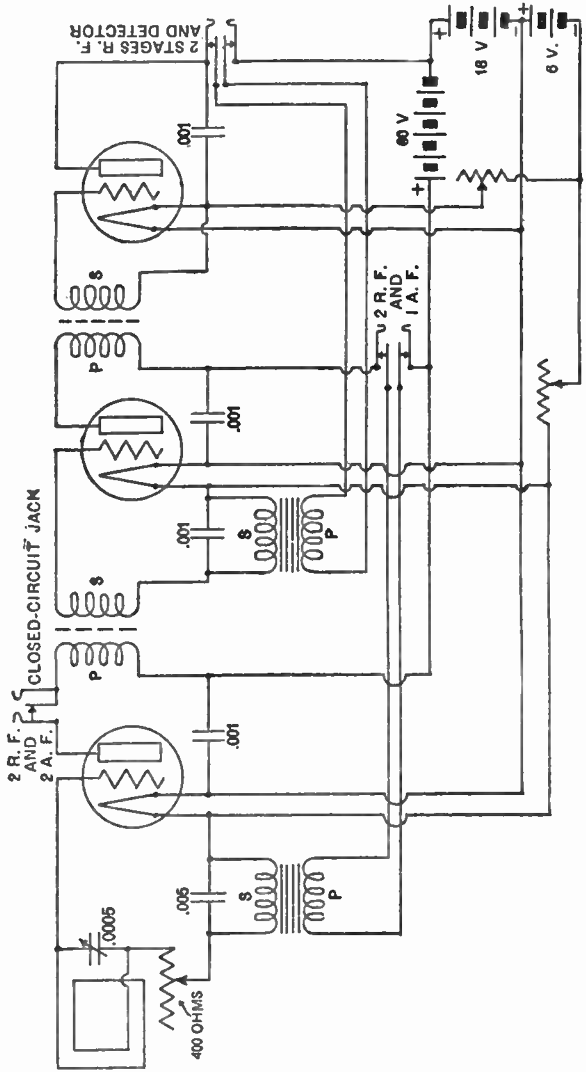


Fig. 33—Three-Tube Reflex Circuit (Inverse).

current flowing into a condenser, the potential difference across it becomes greater as the capacity is decreased. But by decreasing the size of the condenser the reactance of the circuit is increased. This limits the smallness of the condenser, since it is not well to introduce too much reactance into the plate circuits. The values given in the diagrams are recommended, but these may vary considerably with the conditions.

Neutrodyne Circuits.—Ideally, each stage of a radio-frequency amplifier is a one-way relay which passes the incoming power only in the one desired direction. However, on account of the proximity of the plate, grid, and filament of an electron tube to one another, there is always present a certain amount of coupling between the output and the input circuits of the amplifier. This coupling in effect causes a slight amount of regeneration or feed-back through the capacity between the tube elements, unless special devices are used to neutralize it. One way of neutralizing or balancing the capacity coupling through an electron tube is that of the Hazeltine Neutrodyne.

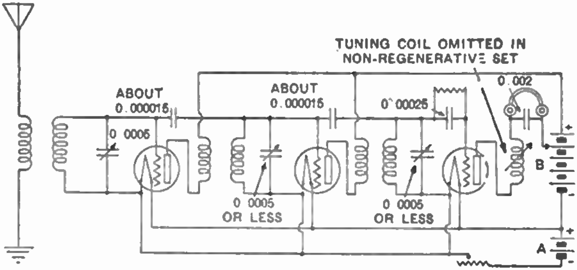


Fig. 34—Diagram of Neutrodyne.

In almost all radio-frequency amplifier circuits there is present some inherent regeneration, even though the circuits be designed as non-regenerative circuits. The tube capacities referred to above are perhaps the principal cause, though the fact that various parts of the circuit are placed near to one another in a receiving set results in capacity between input and output circuits in addition to this tube capacity.

The disadvantage of this capacity coupling or other stray feed-back is that its magnitude is different at different frequencies, and a receiving set which is not in the generating condition at one wave length may by the mere change in the tuning become unstable and generate local current which produces beat notes and whistling sounds. If this inherent regeneration is neutralized or balanced, the music or speech received is much clearer than otherwise, and the tuning adjustment is made entirely separate from the regeneration or feed-back adjustment, thus simplifying the operation of the circuit.

To reduce or balance this capacity feed back through the tube, a very small condenser is connected from the grid of one tube to one terminal of the secondary winding of the next tuned radio-frequency transformer. The circuit used in a neutrodyne receiving set is shown in Fig. 34. Fig. 35 shows a neutrodyne receiver in which a reflex connection is employed to utilize two of the tubes both as radio-frequency and as audio-frequency amplifiers. Each stage of a neutrodyne receiver should be shielded from the next adjacent stages by placing the transformers at proper angles or by means of partitions and metal linings in the amplifier cabinet. The terminal of the transformer secondary winding to which the neutralizing condenser is connected is dependent upon the direction of the windings. This can be determined by trial, the connections to the secondary terminals being interchanged or the direction of the winding reversed if necessary.

The proper capacity or size for this neutralizing condenser is dependent upon the capacity between the grid and plate of the amplifier tube and also upon the ratio of the number of turns in the amplifier transformer windings. The relation between these quantities is

$$\frac{N_1}{N_2} = \frac{C_2}{C_1}$$

where N_1/N_2 is the ratio of turns on the primary and secondary windings.

C_1 is the capacity between the grid and plate of the tube and C_2 is the capacity of the neutralizing condenser, sometimes called a "neutrodon." A ratio of transformation of 1 to 1 is found in many radio-frequency transformers. In this case the neutralizing condenser has the same capacity as that between the tube elements, which is usually about 10 or 15 micro-microfarads. This capacity can be secured by using two very small metal plates, or two very small cylinders about an inch long which slide within one another, though insulated from each other.

The adjustment of each neutralizing capacity is made experimentally by tuning in a very strong signal and then disconnecting the filament of the tube whose capacity is to be adjusted, but leaving the tube in its socket. If the neutralizing capacity is not correct, the circuits on each side of the tube will have capacity coupling which will transmit the signal. The neutralizing capacity is then adjusted until the signal disappears.

The neutrodyne circuit is most effective when care is taken to have sharply tuned radio-frequency transformers, though the adjustments required are more complicated if sharper tuning and greater selectivity are attained.

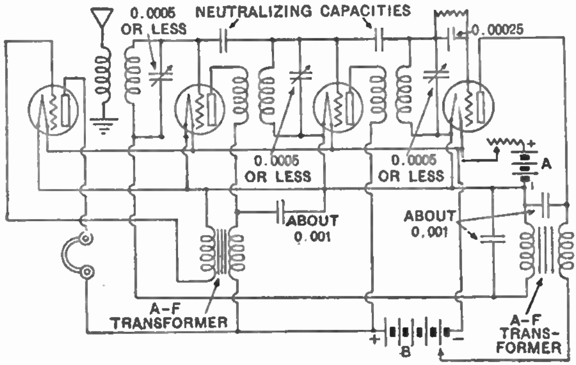


Fig. 35—Diagram of Reflex Neutrodyne.

There is no reradiation from the antenna of a neutrodyne receiver even when a regenerative circuit is used with the detector tube. Amplifier tubes may be used throughout, the choice of A and B batteries being determined by the type of tube employed as in any ordinary receiving set.

Super-Regeneration.—This is a method of reception by which regeneration can be carried much farther than in straight regeneration. This gives very loud signals, even when receiving on a small indoor antenna from distant stations. The method is not as free from circuit noises as some other methods.

In this method, the feed-back coupling is increased beyond the point where self-generation (oscillation) would take place in straight regeneration. This is done only momentarily, however, the feed-back being made to alternate repeatedly above and below the value required for self-generation. During the time that it is above this value the current in the tube builds up rapidly and to a much larger amount than with straight regeneration, and during the intervals when it is below this value, the current dies down.

Super-regeneration is accomplished by introducing in the ordinary regenerative circuits anything which periodically varies the feed-back above and below the point required for self-generation. The voltage which the tickler coil feeds back into the grid circuit depends upon the direct voltage existing in the plate circuit. Super-regeneration may therefore be brought about by introducing some form of alternating current generator (G, Fig. 36) in series with the B battery. When the voltage in this generator is in the same direction as the voltage from the battery, the feed-back increases beyond the point of self-generation and the current builds up to a very large value; when the voltage reverses the current dies out.

The same thing can be accomplished by varying the resistance in the tuned circuit (C L) connected to the grid. If the tickler coil is adjusted so as to be almost on the point for self-generation, a reduction of the resistance of the tuned circuit will start the current building up to a very large value. If the resistance is then increased again, the current will die out.

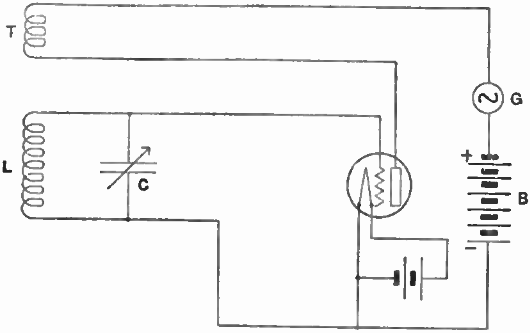


Fig. 36—Periodic Variation of Feed-Back Voltage.

The actual means that are used to produce super-regeneration consist of auxiliary electron tubes. For example, instead of using a rheostat with a contact sliding back and forth to produce a variable resistance, the grid and filament of the tube are shunted by a connection to the grid and filament of another tube (G, Fig. 23) which is generating current at some frequency

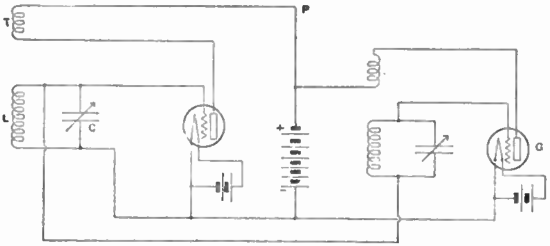


Fig. 37—Resistance Variation by Parallel Connection of Auxiliary Generating Tube.

lower than the received radio frequency. During one-half of the cycle of current generated by the auxiliary tube G it draws current from the tuned circuit C L, thus having the same effect as increasing the resistance of C L. The resistance thus rises and fa'ls periodically at the frequency of the current generated by the auxiliary tube G.

Signals may be received by inserting a phone at the point P in the plate circuit and something less than 5 volts negative on the grid. Still louder signals may be received by connecting an ordinary amplifier tube to the system. The way this is done is shown in Fig. 38. Tube 1 is the super-regenerative amplifier tube, tube 2 is the generator, and tube 3 is the audio-frequency amplifier. The generator tube (tube 2) employs capacitive coupling instead of inductive coupling as in Fig. 37, and the plate voltage is supplied to this tube through a filter to keep out the generated current. The amplifier tube (tube 3) is connected through any good audio-frequency transformer in the ordinary way. All three tubes may be Western Electric L tubes (VT 2). Other amplifier tubes, such as the UV 201-A, or small power tubes, may be used, with plate voltages as high as the tubes will stand. Power tubes are preferable. All tubes must be of the same type, but need not be matched. The various coils, condensers, batteries, and other parts are the standard types used in radio apparatus. The condensers marked 0.0025 and 0.005 are set once for all for a frequency of about 15,000 cycles per second.

Operation is as follows: Signals are tuned in by varying the 0.001 condenser in the tube 1 circuit. The 0.001 condenser in the tube 2 circuit is then adjusted for loudest signal. The 0.001 condenser in the tube 1 circuit is then adjusted once more for loudest signal. Both directions of the connection to the filament battery should be tried, as the signals will be much better with one connection than the opposite. The operator should not be discouraged if results are not obtained immediately.

The super-regenerative method may be used in a great variety of forms. The functions of super-regenerative amplification, generation, and detection may each be performed in separate tubes; they may be combined in various ways, or all functions may even be combined in a single tube. The three-tube arrangement is by far the easiest one to tune. In the other arrangements, the various tuning adjustments affect one another.

The frequency generated in the set for periodically varying the feed-back, called the "variation frequency," is 15,000, so as to be inaudible and not disturb the sounds received. It is best to keep the variation frequency as low as possible, because the lower this frequency the more time there is for the incoming current to build up. The sensitiveness of the method is proportional to the ratio of the wave frequency to the variation frequency. For this reason it is very well adapted to short waves.

It is highly desirable to use this circuit only on a coil antenna or loop. It generates and radiates sufficient

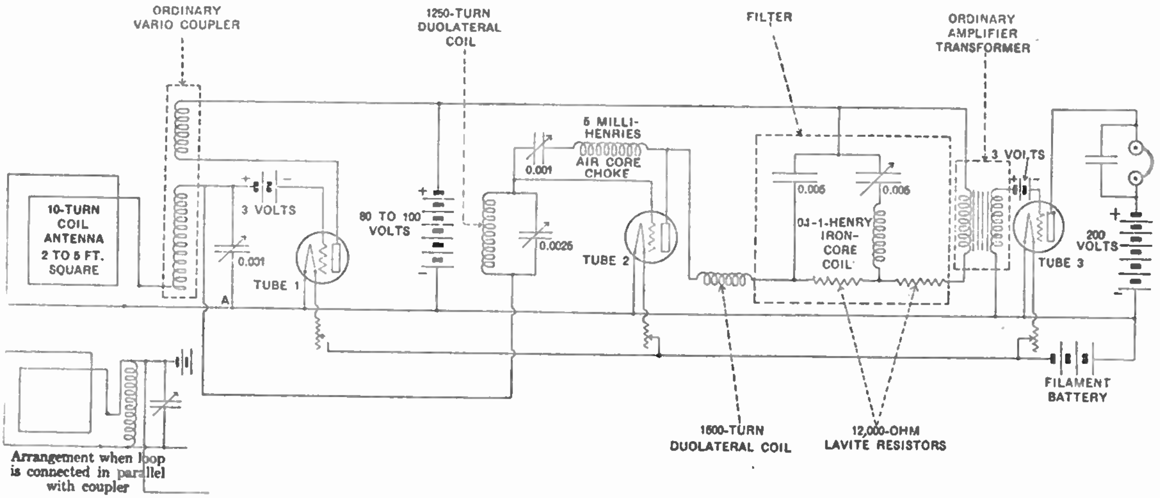


Fig. 38—Super-regenerative Circuits for Radiophone Receiving.

power to cause disturbance to radio reception by others. Fortunately, it produces signals of ample strength on a small coil antenna.

A one-tube circuit which appears to make use of super-regeneration is the Flewelling circuit, shown in Fig. 39. This circuit is very sensitive, but is extremely difficult to adjust properly, particularly the grid condenser C_2 and its grid leak resistance.

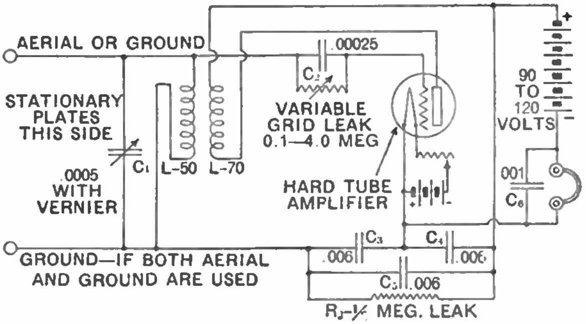


Fig. 39—Diagram of Flewelling Circuit.

The following notes apply to Fig. 38;

Variocoupler must have at least 50 turns on secondary.

Either honeycomb or duolateral coils may be used for the 1250 and 1500-turn coils. These coils should be kept well apart.

B battery of less than 200 volts may be used, but the results will not be as good.

The 80-100 volt battery need not be variable.

While a 200-volt battery is shown at the right of Fig. 24, this can utilize in part the "80 to 100-volt" battery to the left, so that only a 100-volt additional battery need be provided; this is done by breaking the connection shown at negative end of right-hand battery and running, instead, a connection from negative end of right-hand battery to positive end of "80 to 100-volt battery."

The 12,000 ohm resistors are non-inductive; this however, is not necessary. Grid leaks of proper value will function equally well. These resistors need not be variable and a tolerance of several thousand ohms is permissible.

The 5-millihenry air-core choke can be either closely wound or spread out, but is preferably of the former type.

The same number of turns are used for a 2-foot loop as for a 5-foot loop. Because of the variable value of inductance in standard variocouplers it is necessary to try connecting the loop both in series and in parallel with the primary of coupler, as shown in Fig. 24. Adopt the connection, which enables you to tune within the range of the variable condenser 0.001. If this is impossible with either connection, then reduce the number of turns on coil antenna until the desired result is obtained.

It is immaterial whether the grid tap "A" be as shown or tapped into the fi'ament rheostat.

Generally speaking, run plate voltage as high as tubes will allow.

Superheterodyne.—For very high radio frequencies it is difficult to get satisfactory results with radio-frequency amplification. The superheterodyne, devised by E. H. Armstrong, is a means of circumventing this difficulty, and is probably the most effective method now available for receiving very distant broadcasting stations. The incoming radio frequency is converted into a lower frequency by means of combining with it a signal from a local generating set (called a heterodyne) of very nearly the same frequency, with the resulting production of a "beat" frequency equal to the difference between the two. This "beat" frequency may be 100 kilocycles; it is amplified by a radio-frequency amplifier and then detected, etc., in the usual way. The circuit diagram is given in Fig. 40. The antenna and secondary tuned circuit are identical with those ordinarily used in radio reception.

The transformation of the high-frequency currents to a lower frequency is accomplished by means of a heterodyne, which for most satisfactory use should be kept separate from the receiving set proper. This separate heterodyne is only a continuous-wave generating set of low power which will generate current of a frequency nearly the same as that of the incoming signal. This separate heterodyne is coupled to the secondary circuit of the receiving set. For receiving 250-meter (1200 kilocycles) signals the separate heterodyne should be adjusted to generate a current of 1300 kilocycles (approximately 231 meters). A suitable circuit for this separate generating set is given in Fig. 41 and is described in more detail in chapter 5, in connection with Fig. 8. Any amplifier tube can be used in this circuit.

The first electron tube is a detector or rectifier tube which gives in its plate circuit a current having a D.C. component with the beat frequency component superimposed upon it. The tuned circuits in the plate circuit of the first tube and the grid circuit of the second tube are adjusted to resonance with the beats (for example, 100 kilocycles or 3000 meters) produced by the received signals and the superheterodyne. When once adjusted these two circuits can be left alone.

The next three tubes shown in the circuit, Fig. 46, are radio-frequency amplifier tubes with resistance coupling between the several stages. The next to last tube

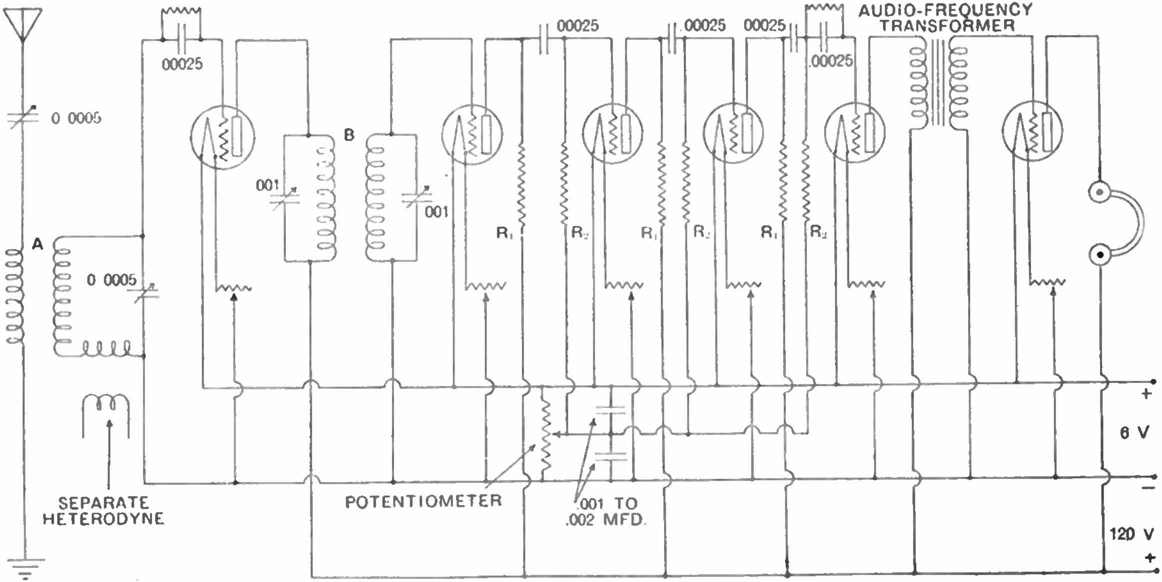


Fig. 40—Diagram of Superheterodyne.

is another detector tube. The last tube is an audio-frequency amplifier. By using hard or high vacuum tubes both as amplifiers and detectors, the connection to the batteries is simpler and the adjustments required are less complicated.

As a whole, the circuit is rather difficult to adjust when it is first being set up, but after this its use is simple, the adjustments required being the retuning of the antenna and secondary circuit to the frequency of the waves which it is desired to receive and adjusting the separate heterodyne to give the beat frequency for which the amplifier is originally tuned. The coupling between the separate heterodyne and the secondary and the strength of the current generated by the heterodyne set should be brought to the best value, though this condition is not at all critical. The greatest possibilities of this circuit are secured when four to eight tubes are used as radio-frequency amplifiers. It gives particularly good amplification of extremely weak signals and is very selective. If the coupling to the superheterodyne is kept small there is very little reradiation, and thus little interference is caused to nearby receiving stations. The use of radio-frequency amplification serves somewhat as a filter against stray noises. By transforming the incoming signals to the currents of a lower frequency it is possible to avoid the difficulty of radio-frequency amplification on short waves where the tube capacities cause trouble.

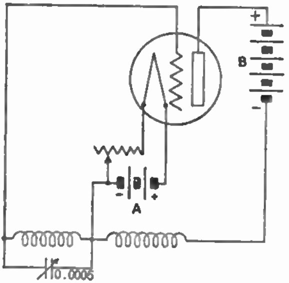


Fig. 41—Separate Heterodyne.

It is desirable to completely shield this receiving set, preferably by shielding separately the first detector tube, the radio-frequency amplifier and the last detector tube. This can be done by mounting these groups of tubes in boxes or in separate panels and lining these boxes with sheet copper. Care should be taken, of course, to avoid short circuits where the lead wires enter the boxes. In order to avoid back coupling from the current in the telephone cord it is desirable to cover it with woven copper braid, which is connected to the shield enclosing the last tube.

The following details apply to Fig. 40:

R_1 = 10,000 to 100,000 ohms.
R_2 = grid leak resistance, ½, 1 or 2 megohms.

The coupling between the separate heterodyne and the secondary of the variocoupler may be obtained by keeping the separate heterodyne on the same table or in the same room with the variocoupler. The two coils marked A are the primary and secondary of a variocoupler.

The coupling coils B must each have such value of inductance that they will, with the condenser, tune to the frequency to which it is desired to heterodyne the incoming signals. Honeycomb coils of 300 turns each are satisfactory if 3000 meters is used for the intermediate wave length.

The introduction of the beat frequency must originate in the tuning circuit of the receiver, and nowhere else. The separate heterodyne is coupled to this circuit. If coupled elsewhere in the outfit, other beat frequencies may be set up which would cause interference and distortion.

The heterodyne coupling must be very loose. It must be so loose that no special coupling coils are required. All that is necessary is to have the oscillator *near* the tuning circuit of the receiver. To prevent the introduction of beat frequencies in other parts of the receiver, all but the tuner should be carefully shielded.

In the separate heterodyne (Fig. 41) the inductance coil is one of about 60 turns of No. 18 or No. 20 wire, 3½ or 4 inches in diameter, tapped approximately at the middle. The part of this coil in the oscillator grid circuit should be coupled to the receiver tuner, although the coupling is so loose that both parts are about equally coupled. The condenser used in the heterodyne should have a maximum capacity of 0.0005 mf.

Since the output of the first tube will be in the neighborhood of 100 kilocycles (3000 meters), the values of the coils shown between the first and second tube on the diagram should be such that the circuits can be tuned to that frequency; 300-turn honeycomb coils will be satisfactory if their mounting is well designed, with fixed coupling about as close as can be secured.

The resistance R_1 is from 10,000 to 100,000 ohms, and R_2, the grid leak resistance, is from ½ to 2 megohms. The potentiometer may be about 300 to 400 ohms.

PART C

Accessories and Construction Details

Inductance Coils.—There are many styles of windings used in inductance coils for radio receiving circuits, and it is sometimes difficult to determine the relative advantage of one over another. The desirable features to secure in selecting inductance coils are (1) minimum resistance, and (2) minimum distributed capacity in the coil itself. This second feature is closely related to the first, since any capacity having solid insulation results in the addition of resistance to the circuit.

Where small inductances are employed and the use of coils which are somewhat bulky is not a disadvantage it is usually most satisfactory to use single-layer coils of cylindrical form. These have the advantage that taps can easily be brought out to contact points of a switch. Where compactness is desired it is convenient to use a short multi-layer coil instead of a long single-layer one. The capacity of such a coil is kept small by separating the adjacent turns of wire slightly from one another, and by separating the wires which lead to its terminals. Various manufacturers separate adjacent turns by a number of ingenious schemes of windings by which the layers of wire are made to cross each other at an angle, leaving air spaces between the adjacent turns of a given layer. Some of these winding methods also result in a self-supporting coil which avoids the presence of an undesirably large mass of insulating material in its field.

That the advantage of spaced winding and small coil capacity is not fully appreciated is indicated by the fact that some coils which are wound in this way are then mounted on blocks of solid insulating material through which the two terminal wires pass with very little spacing between them. These two terminal wires act like plates of a condenser, and the capacity between them has as its dielectric the solid insulating material of the mounting block. Thus the advantage gained by the spaced winding is at least partly lost by a poor method of mounting; therefore in selecting coils it is desirable to consider not only the method of winding but the method of mounting. Both should result in the use of as little solid insulating material as possible, and the turns of wire forming the coil, and especially the terminal wires, should be spaced from one another.

If this feature of design has been followed it is then worth while to investigate the resistance of the wire conductor itself, though ordinarily it is not essential to use large wire in an effort to keep the resistance low. A radio-frequency resistance of several ohms is usually unavoidable on account of the method of winding and mounting the coil; this makes it unimportant to go to the expense of the use of large wire, which would only decrease the resistance by a fraction of an ohm. No. 16 or No. 18 wire is as large as is desirable for receiving sets as ordinarily designed.

The various circuit diagrams given in this chapter show inductance coils either as single coils, couplers, or "variometers." The following table is given as a guide in the selection of coils for use in the several circuits. It is not necessary to conform to the exact sizes stated, some variations of tuning being made possible by means of the variometers or variable condensers as well as by the taps provided on the coils. These sizes will be found suitable for tuning to all radio-telephone stations which broadcast concerts, talks and market reports.

Table 2—Sizes of Inductance Coils for Tuning to Wave Lengths from 200 to 600 Meters.

Coil for single-circuit tuner:

Diameter of tube.....4 inches

Length of tube.......5½ inches.

Turns of wire.........85, tapped at 25 turns and every 20 turns thereafter.

Size of wire..........No. 18 to 24 B. & S. gage.

(If for non-regenerative circuit, use no smaller than No. 20 wire.)

Coupler:

Dimensions given apply to "loose-couplers."

(For variocoupler, see third table on page 65.)

Primary Tuning Coil

Diameter of tube ....4 inches

Length of tube.......5½ inches

Turns of wire.........85, tapped at 12 turns and every 6 turns thereafter.

Size of wire..........No. 18 to 24 B. & S. gage.

Secondary Tuning Coil

Diameter of tube.....3½ inches

Length of tube.......6 inches

Turns of wire.........80, tapped at 20 turns and every 10 turns thereafter.

Size of wire...........No. 18 to 24 B. & S. gage.

(If for non-regenerative circuit, use no smaller than No. 20 wire.)

The secondary coupling coil for a "3-circuit" receiving set should have about 30 turns of wire.

Variometer for antenna circuit of single-circuit receiving set:

Fixed Coil or "Stator"

Diameter of coil......4 inches
Turns of wire.........35
Size of wire..........No. 20 to 24 B. & S. gage.

Moving Coil or "Rotor"

Diameter of coil......3½ inches
Turns of wire.........30
Size of wire..........No. 20 to 24 B. & S. gage

Tickler coil:

Diameter of tube.....3 inches
Length of tube.......2 inches
Turns of wire.........30
Size of wire..........No. 24 to 30 B. & S. gage.

Variometer for grid and plate circuits of 3-circuit receiving set or Variocoupler for 2-circuit receiving set:

Fixed Coil or "Stator"

Diameter of coil......4½ inches
Turns of wire........65
Size of wire..........No. 20 to 24 B. & S. gage

Moving Coil or "Rotor"

Diameter of coil......3½ inches
Turns of wire........70
Size of wire..........No. 20 to 24 B. & S. gage.

There are a number of types of inductance coils sold for use in building up receiving sets. These differ chiefly in the details of construction or winding and are variously called "single-layer," "bank wound," "honeycomb," "spider web," "duolateral," etc., and are all of similar utility. Some coils are made so that the different sized ones are interchangeable on the set. They are frequently used as primary, secondary and tickler coils, the tuning adjustments being made by variable condensers.

Loading Coils.—To convert a receiving set designed for broadcast reception into one which will receive stations of lower frequency (longer waves), loading coils are used. In a single-cricuit set, the loading coil is connected in series with the antenna. In a coupled-circuit set, one loading coil is connected in the antenna circuit and another similar one is connected in series with the coil and condenser of the secondary circuit. The two circuits must be tuned to the same wave length. An example of a long-wave station to which it is sometimes interesting to tune is the Arlington station of the U. S. Navy Department. This station sends out time signals on a wave length of 2650 meters (113 kilocycles).

Loading coils for tuning a broadcast receiving set to this 2650-meter wave length may be made by winding about 300 turns of wire (Nos. 20 to 24) on a cylinder about 4½ inches in diameter and bringing out taps every 25 turns in order to make connections which will tune to various wave lengths. The loading coils should be entirely removed from the circuit when the set is used to tune to short wave lengths, since they greatly decrease the efficiency of the set by introducing capacities which result in power loss. Even when tuned to receive long-wave signals, a loaded set is not as efficient as one which is originally made according to the proper design for this use. Nevertheless, the use of a loading coil to extend the wave-length range of a short-wave set is thoroughly practicable; the long-wave stations which it is desired to hear are usually of higher power than the short-wave stations and can therefore be easily heard. It is not practicable to attempt to load a three-circuit tuner to receive signals of longer waves than those for which it is designed.

Series and Parallel Condensers.—The series condenser shown in the antenna circuit of diagrams given in Part B is not necessary if the antenna is short enough to enable one to tune to the desired wave length by the adjustment of the series inductance coil. The shorter the wave, the lower will be the setting of the series condenser. If the desired wave-length is longer than that to which the series inductance makes it possible to tune, the wave length of the antenna circuit may be increased somewhat by connecting the condenser across the terminals of the series inductance. This condenser can conveniently be a variable condenser having a maximum capacity of 0.0005 microfarad. Either the series or the parallel condenser serve the added purpose of enabling one to tune more closely to the wave length desired by making finer adjustment of the tuning of the circuit than may be obtained by varying the number of turns of the coil only.

Construction of a Wave Trap.—It is sometimes impossible to tune out a powerful nearby station when trying to receive a distant station on nearly the same frequency. The interfering station can be cut out by means of a wave trap. It is connected as shown in Fig. 42. The antenna is connected to the receiving set as shown, but the wave trap is inserted between the ground terminal of the set and the wire which leads to the actual ground. The wave trap is merely a coil connected in parallel with a condenser. The wave trap is most effective in cutting down the signals to which, as a series circuit, it is tuned. For example, if the coil and condenser are of a size suitable for use as the tuned secondary of a two-circuit receiving set, they will be effective in a bsorbing the current in the antenna of the frequency or wave length at which they would give loudest signals if used in the secondary. Therefore, the effective wave length of this wave trap can be changed by changing the number of turns on the coil or the setting of the variable condenser. For wave lengths in the broadcasting range, a coil having about 50 turns on a tube about 3 to 4 inches in diameter with a variable air condenser of 0.0005 microfarad capacity is suitable. By connecting the wave trap in the ground circuit as shown, it is possible to greatly decrease the strength of signals from the transmitting station to which the filter is tuned while maintaining at nearly the original intensity the signals from a station of a different wave length for which the regular antenna, tuning inductance and condenser are adjusted. If the two wave lengths in question are very close together, this separation is extremely difficult and in fact impossible with the coils and condensers which one can ordinarily buy. The effectiveness of the wave trap in stopping signals of a given wave length is greater if the resistance of the coil and condenser composing it are small.

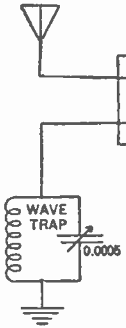


Fig. 42

Rheostats for Electron Tubes.—Since vacuum tubes operating on dry cells have appeared on the market, considerable confusion has existed among amateurs concerning the proper value of resistance to use in series with the filament when connected to various types of batteries.

The following table gives the values of resistance required. As an illustration of the use of the table we will consider the WD-11 tube. Normal current of 0.25 ampere flows through the filament when a voltage of 1.1 is impressed across the filament terminals. The resistance of the filament when hot is then, by Ohm's law, $1.1/0.25 = 4.4$ ohms. This value is given in the third column of the table. If a dry cell is used to light the tube, delivering a voltage of 1.5 volts, the total resistance which must be in the circuit to give the current a value of 0.25 ampere is $1.5/0.25 = 6$ ohms. Part of this resistance is in the filament itself, and the rest must be furnished by the rheostat. The rheostat must furnish $6 - 4.4 = 1.6$ ohms to allow the normal value of current to flow.

To be on the safe side, the resistance of the rheostat should be slightly higher than this value, say 2 ohms; but 2-ohm rheostats are not common on the market, so it is required that we use the next larger size. Too great a size must not be used, for although this will cut down the current to the proper value, the adjustment is not as critical. For instance, suppose we are using a 6-ohm rheostat. We require only 1.6 ohms, so that we shall be using only about one-quarter of the rheostat. It is obvious that slight changes in the rheostat setting will produce rather large changes in the resistance and in the filament current.

Tubes may be connected in series or parallel. The values in the table have been worked out for both cases, so that if the amateur happens to have on hand a storage battery and wishes to use it to light up tubes designed for lower voltages, he may do so by connecting the tubes in series. It is clear that the current in

	Rating		Fil. Re-sist.	Batt. Volts	No. of tubes	Total Cur-rent	No. Cells Required	Resist. Required	Size Rheostat	Tube Con-nec-tions
	Volts	Amps								
WD-11	1.1	0.25	4.4	1.5	1	0.25	2 (Parallel)	1.6	6	......
WD-12	.....	.....	.....	1.5	2	0.50	4	0.8	6	P
	.....	.....	.....	1.5	3	0.75	6	0.5	6	P
	.....	.....	.....	6.0	3	0.25	St. batt.	10.8	12	S
UV-199	3.0	0.06	50.0	4.5	1	0.06	3 (Series)	25.0	30	......
C-299	.....	.....	.....	4.5	2	0.12	3	12.5	20	P
	.....	.....	.....	4.5	3	0.18	3	8.3	12	P
	.....	.....	.....	6.0	1	0.06	St.batt.	50.0	60	P
	.....	.....	.....	6.0	2	0.12	"	25.0	30	P
	.....	.....	.....	6.0	3	0.18	"	16.7	20	P
	.....	.....	.....	6.0	2	0.06	"	0	6	S
UV-200	5.0	1.0	5.0	6.0	1	1	"	1.0	6	......
C-300	.....	.....	.....	6.0	2	2	"	0.5	6	P
	.....	.....	.....	6.0	3	3	"	0.3	6	P
UV-201	5.0	1.0	5.0	6.0	1	1	"	1.0	6	......
C-301	.....	.....	.....	6.0	2	2	"	0.5	6	P
	.....	.....	.....	6.0	3	3	"	0.3	6	P
UV-201A	5.0	0.25	20.0	6.0	1	0.25	"	4.0	10	......
C-301A	.....	.....	.....	6.0	2	0.50	"	2.0	6	P
	.....	.....	.....	6.0	3	0.75	"	1.0	6	P
215-A	1.1	0.25	4.4	1.5	1	0.25	2 (Parallel)	1.6	6	......
	.....	.....	.....	1.5	2	0.50	4	0.8	6	P
	.....	.....	.....	1.5	3	0.75	6	.5	6	P
	.....	.....	.....	6.0	3	0.25	St. batt.	10.8	12	S
216-A	6.0	1.1	5.5	6.0	1	1.1	"	0	6	......
	.....	.....	.....	6.0	2	2.2	"	0	6	P
	.....	.....	.....	6.0	3	3.3	"	0	6	P
VT-1	2.5	1.1	2.3	6.0	1	1.1	"	3.2	6	......
(203-B)	.....	.....	.....	6.0	2	2.2	"	1.6	6	P
(J)	.....	.....	.....	6.0	3	3.3	"	1.1	6	P
	.....	.....	.....	6.0	2	1.1	"	0.9	6	S
VT-2	6	1.35	4.5	6.0	1	1.35	"	0	6	......
(205-B)	.....	.....	.....	6.0	2	2.70	"	0	6	P
	.....	.....	.....	6.0	3	4.05	"	0	6	P

each tube when connected in series will be the same. The tubes in this case must have similar characteristics.

For tubes connected in parallel, the resistance required in the rheostat to give the normal value of current is given by $R = (V - E) \div (I\,n)$, in which R is the resistance in ohms required, V is the voltage of the battery in volts, E is the rated normal filament voltage, I is the rated normal filament current, and n is the number of tubes in parallel.

For tubes connected in series, the formula is $R = (V - nE) \div I$.

In using dry cells to light up WD tubes, greatest economy, that is, longest life, of the batteries is obtained when they deliver about 0.125 ampere each. Thus, for one WD tube, use 2 cells in parallel; for two tubes, 4 in parallel, etc.

To furnish 4.5 volts for the UV-199 tube, three 1.5-volt cells may be connected in series.

The rated normal current for these tubes is only 0.06 ampere, and three in parallel would take only 0.18 ampere. In this case it is not necessary to connect the cells in parallel to obtain good economy.

Potentiometers.—The diagram of Fig. 43 illustrates the principle of operation of potentiometers. A resistance AB is connected across the terminals of a battery, so that a current continually flows, producing a drop in potential along the resistance. The difference of potential between any two points on the resistor may be taken off as at A and a′ for any purpose which may require it, as will be explained below. In the example shown, the resistance is connected across a 6-volt battery, such as used for lighting the filaments of electron tubes. The total voltage drop across AB is equal to the voltage of the battery, i.e., 6 volts. This value is obtained when the movable contact has been moved to a_3. As the contact is moved in the direction from B to A, the voltage drop between A and the contact decreases from 6 volts to zero. For intermediate positions of the contact the voltage varies between 6 and zero volts. Thus, when the contact has moved over ⅓ of the resistance toward A, as at a_2, the voltage drop is 4 volts; when at a_1 it is 2 volts, and so on. In other words, the potential difference between A and the movable contact is proportional to the amount of resistance between them. When the contact has arrived at A, the voltage drop is zero, as there is no resistance between A and the contact at this setting. These are the principles involved in all potentiometers, but their applications are extremely varied.

Take the case of Fig. 44, which shows the application of potentiometer control to adjusting the grid potentials in electron tubes. AB is the resistor as before, and here the battery is also supplying the filament-heating

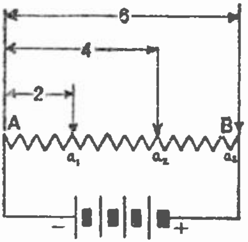


Fig. 43

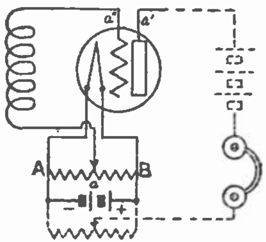


Fig. 44

current. This heating current is controlled by a rheostat in one of the leads to the filament, not shown. This rheostat does not affect the current through the potentiometer resistor, and is omitted for simplicity. When the moving contact a is midway between A and B, the potential of a is the same as that of the point a′ of the filament. The grid of the tube, shown at a″, has practically the same potential as a, neglecting the small resistance drop through the tuning inductance, so that for this setting of the contact, the potential of the grid is zero with respect to the filament. (We are not considering the potentials acquired by the grid in accumulating electrons emitted by the filament.) However, the point of zero grid voltage will not be exactly midway between A and B when some of the filament rheostat is in the circuit. This complicates matters and does not add to the explanation, so it is omitted.

Now as a is moved to the right, a″ will become positive with respect to a′; if to the left, it will become negative with respect to a′. The grid-filament voltage can thus be easily and accurately controlled by this method.

The same method can be used to control the voltage on the plate of the tube, as is indicated by the addition of another potentiometer, shown in broken lines in Fig. 44. As a rule, the tubes on the market do not require accurate adjustment of the plate voltages, and adjustment of this voltage is not vital to satisfactory operation of the set. However, if the experimenter wishes to have accurate control of both voltages, he may use this arrangement.

Fig. 45 shows another method of controlling the grid bias. This arrangement accomplishes not only the same effects as the usual "C" battery, but does it more accurately and effectively. The potentiometer may be placed in either of the two positions shown.

There are many makes of potentiometers on the market, and the amateur must be careful in picking out the one best suited to his purpose.

The resistance generally consists of a wire wound on a form. This wire must not be too fine, as continual rubbing of the moving contact will cut the wire. At

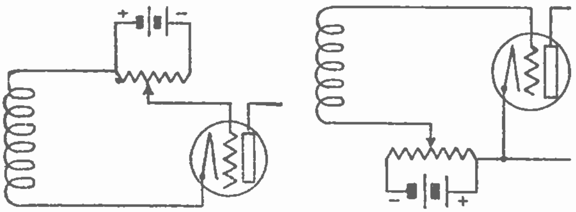


Fig. 45

the same time, the resistance must be sufficiently high to prevent an excessive drain of current from the battery. It will be noticed that there is a constant current from the battery flowing through the resistor. When the set is not in use, the battery should be disconnected from the potentiometer. The value of this current is obtained by dividing the resistance of the potentiometer into the voltage of the battery.

Use of Jacks in a Two-Stage Audio-Frequency Amplifier.—In the diagram shown in Fig. 46, X and Y are double-circuit jacks and Z is a single-circuit jack. The double circuit jack serves the purpose of facilitating the connection of head phones to the detector circuit and automatically connecting the detector circuit to the first stage of audio-frequency when the telephone plug is withdrawn. This action is accomplished at X. Double-circuit jack Y serves the purpose of enabling one to use the first stage of audio-frequency amplification and cutting out the following stages, and then automatically connecting the second stage to the rest of the circuit by simply removing the telephone plug. These jacks do not automatically control the lighting of filaments, this being done by means of individual rheostats on the tubes. A single-circuit jack is sufficient on the last stage.

It is highly important that the contact points in each of the jacks function properly. In Fig. 46 (b) is shown a double-circuit jack with the contact points touching at R and at S, as is the case when the telephone plug is withdrawn from the jack. When the contact points are touching, the circuit is as follows: From plate of detector into prong I, out of prong II to one primary terminal of the audio transformer, from the other primary terminal into prong III, out of prong IV to the positive terminal of the B battery. This arrangement throws the primary side of the transformer into the circuit, thereby linking the detector stage to the following stages of audio-frequency.

In Fig. 46 (c), the telephone plug is shown inserted, thereby spreading prongs I^1 and IV^1 apart and breaking the contact at R^1 and S^1. The circuit now is as follows: From detector plate into prong I^1, through tip of plug, P,

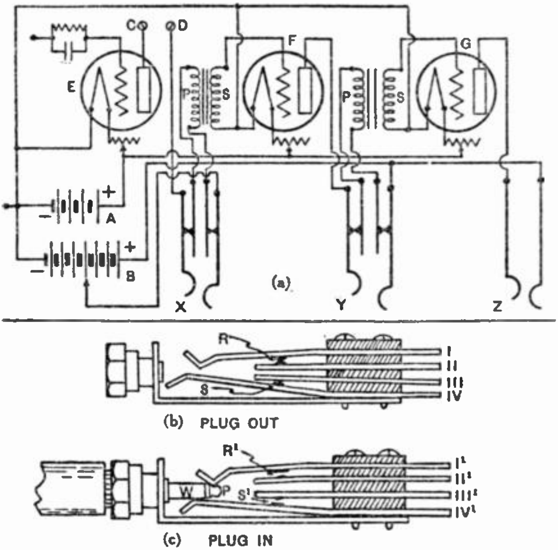


Fig. 46.—Use of Jacks in Detector and First and Second Stages.

to phones, back through collar of plug W, and out through prong IV^1 to the positive side of the B battery. This arrangement short-circuits the detector tube directly to the phones, cutting out the stages following.

To use the circuit shown in (a) as non-regenerative, connect terminals C and D together. If regeneration is to be used, connect terminal C to one terminal of a variometer (or tickler-coil), and terminal D to the other terminal of the variometer (or tickler-coil).

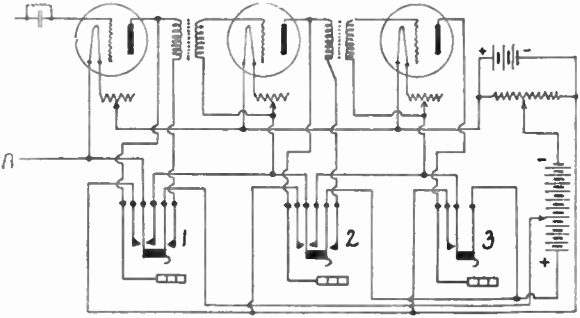


Fig. 47.—Connections to Jacks for Automatic Filiment Control of Detector and Two Stages of Audio-Frequency Amplification.

Automatic Filament Control.—Fig. 47 shows an arrangement by which the electron tubes are automatically lighted as needed. Insertion of the telephone receiver plug in any jack causes the needed tubes to light up, and the needed tubes only. That is, when the phone plug is inserted in jack 3 all three tubes light up; when in jack 2 only the detector tube and first audio-frequency amplifier tube light up; and when in jack 1 only the detector tube is lighted. Removing the phone plug automatically stops the drain on the filament battery. If radio-frequency stages (not shown in figure) are used, they will be lighted up by insertion of the phone plug in any jack, provided the filaments of the radio-frequency tubes are connected to the point A and to the positive end of the filament battery (either direct or through a potentiometer resistance).

Use of Ammeters and Voltmeters in Receiving Sets.—The use of measuring instruments to determine the condition of the batteries and to make it easy to re-establish a given adjustment of the filament circuit helps greatly to do away with much guess-work in the operation of radio receiving sets. The two batteries with which voltmeters or ammeters can be used in radio receiving sets are the "B" battery in the plate circuit and the "A" battery which furnishes power to the filament.

The exact voltage of the "B" battery is not ordinarily important, the signal intensity or the amplification secured remaining nearly the same, even though the battery decreases slightly in its voltage during the course of its use. However, when the battery is nearly discharged, the voltage drops rather rapidly and the signals then decrease noticeably in intensity. To determine whether the difficulty in the reception of signals is caused by a worn-out or discharged "B" battery, it is convenient to have a voltmeter with which the voltage of the "B" battery can be measured. Since the voltages used in ordinary receiving sets are of the order of 20 volts for the detector tube and 40 to 80 volts for the amplifier tube, a direct-current voltmeter having a maximum reading of about 100 volts is useful.

In the filament circuit either a voltmeter or an ammeter may be used. An ammeter connected in series with the filament of a tube reads the current flowing through it and through the filament from the "A" battery. When the filament rheostat has been adjusted so that the signals are received most satisfactorily, the reading of the ammeter is noted; then at a subsequent time when the receiving set is being used, the filament rheostat can be brought to the position corresponding to this same ammeter reading, and the operator can be quite certain that this adjustment is correct and thus give attention to the careful manipulation of tuning, coupling, and regenerative controls. It will be found, however, that as the tube is used, the condition of the filament changes, so that the current flowing through it when the best signals are received will become less and less. It is therefore necessary to make a redetermination of the best value of this current. This should be done perhaps once a week.

If a voltmeter is used to read the voltage across the terminals of the electron tube filament it will be found that this voltage reading for best signals does not change noticeably as the tube ages. A voltmeter is therefore somewhat preferable to an ammeter as an aid in reproducing the proper conditions in the filament circuit. The voltmeter should be connected across the terminals of the filament itself rather than across the battery to which the filament is connected; that is, the voltmeter readings should not include the voltage across both the filament and the filament rheostat, but should read the filament voltage alone. The maximum scale reading of the voltmeter should, however, be slightly greater than the normal voltage of the "A" battery when it is fully charged. This voltmeter will, then, be useful in determining whether this battery is becoming discharged, as will appear from a definite decrease in the voltage across its terminals.

In using direct-current voltmeters care should be taken to connect the plus terminal of the meter to the positive (plus) terminal of the battery. In many batteries the positive terminal is marked with red. In order to avoid the necessity of having separate voltmeters for each of the tubes used in a receiving set, one may provide jack and plug connections with which the voltmeter can be plugged into each of the filament circuits in turn. The jack used for a voltmeter connection must be an open-circuit jack; that is, the circuit must not be closed when the plug is removed. The jack used for making connection to an ammeter should on the contrary, be a closed circuit jack. That is, the circuit should close when the plug is removed, the insertion of the plug making a connection of the ammeter in series in the circuit.

Storage Battery.—When fully charged, the specific gravity of the electrolyte (as measured by a hydrometer) is between 1.210 and 1.300. The exact figure for a particular battery is given by the manufacturer.

To fully charge a battery after discharge, it is necessary to pass through the cells in the proper direction (opposite to that of discharge) an amount of current equal in ampere-hours to that taken out on discharge, plus some excess to make up for losses. If the charging rate is not too high, all the current is useful in charging the battery. If the rate is increased, a point is reached where gassing occurs, due to decomposition of the water in the electrolyte. Charging rates sufficiently high to produce gassing are not only wasteful of electric energy, but tend to dislodge the active material from the plates and produce excessive temperature rise.

In general, any charging rate is permissible which does not produce excessive gassing or a cell temperature exceeding 110° F. The value of the charging current at which gassing begins depends upon the factors mentioned above, but the principal factor is the state of charge of the battery. When a battery is fully charged, any rate, however small, will produce gassing, but this rate may be reduced so that the small amount of gassing that results is practically harmless. This safe rate is called the "finishing rate." The more completely the battery has been discharged, the greater may be the initial rate. The method of diminishing the rate toward the finish of the charge is called "tapering" the charge. A battery may be charged at any time when a charge will be useful; it is not necessary to wait until it has been completely discharged. A general rule for determining the maximum permissible rate of charging is: The charging rate in amperes must never exceed the ampere-hours out of the battery. Any method of charging that keeps the charging current within this limit will not overheat the battery or cause it to gas. If 34 ampere-hours have been removed from a battery, the charge may be started at 34 amperes. In a quarter of an hour the rate must be decreased $\frac{1}{4} \times 34$ or 8.5 amperes, giving a rate of 25.5 amperes, and so on. The intervals may be chosen to suit the convenience of the operator. Since the average output current of commercial battery charging devices rarely exceeds 6 amperes, there is little danger of harming a battery by an excess charging rate with such equipment. In addition, most chargers automatically give a tapering charge, so that when the battery is fully charged, the current output is reduced to a safe value.

The characteristics shown by this method will be approximated if the constant-voltage method is followed, provided the proper voltage can be chosen. A value of 2.3 volts per cell is usually considered as a good average value, although some adjustment may be necessary between summer and winter. This method requires a minimum amount of attention of the operator and lessens trouble that may follow from any excessive overcharge.

Bulb Rectifiers.—There are several types of bulb rectifiers on the market which operate on the same principle and have similar characteristics. When making a choice, the following things should be taken into consideration: First is the selection of the proper size of outfit. The choice of a 2-ampere or a 5-ampere rectifier is not, as it might at first appear to be, simply a question of the relative fatness or slimness of one's pocketbook. Each of these machines has its own field of usefulness.

In general, if the battery to be charged is of low capacity—as, for example, not over 40 ampere-hours—the 2-ampere size should be selected. For larger batteries the 5-ampere size is preferable, as it will charge the battery in a much shorter period of time.

Another point that should be considered is the load on the battery; that is, the extent to which it will be discharged when operating the receiving set. If only a single-tube outfit is used, the discharge rate may be about one ampere. Figuring roughly that the receiving outfit is in operation an average of three hours per day, then the total discharge would be three ampere-hours. In this case the 2-ampere size would be entirely large enough, regardless of the size of the battery. Operating the rectifier for one and one-half to two hours per day would keep the battery in a fully charged condition.

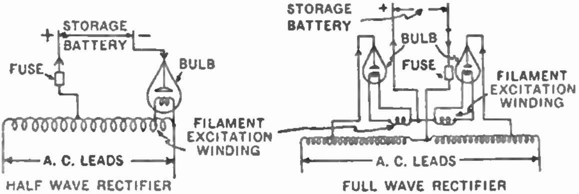


Fig. 48.—Bulb Rectifiers.

On the other hand, if a 3-tube receiving set is used, and each tube takes one ampere, the total discharge of the battery will be nine ampere-hours per day on the basis of operating the set three hours per day To keep the battery charged with a 2-ampere rectifier will require a charging period of five or six hours per day, whereas with the five-ampere size, a two-hour charge per day would be sufficient.

Mechanical Rectifiers.—These rectifiers employ a mechanism for interchanging the connections to the alternating current circuit at the end of every half-cycle and thereby deliver a pulsating direct current, the voltage of the supply being reduced to the proper value for battery charging by means of a transformer. The general principles of operation may be had from a study of Fig. 49, which is typical of all types. The rectifier shown is called a half-wave charger, only one-half of the alternating cycle being delivered to the battery. There is very little energy lost during the half-cycle that is not rectified, as no energy is taken from the line excepting that utilized in producing eddy-current losses, heating and hysteresis in the transformer. This is very small in the average well-designed transformer.

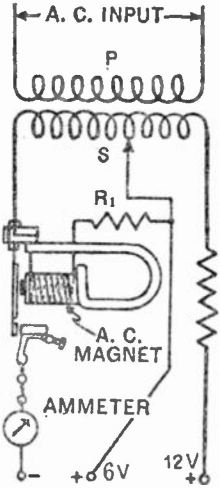


Fig. 49

The vibrating element, carrying one of the contacts, is attached to a spring in such a manner that its tension may be adjusted. The value of the current flowing through the a.c. magnet is adjusted by R_1 to such a value that when the magnetic field set up by this magnet is opposed in polarity to that of the permanent magnet it is also equal to it. There is, therefore, at this instant, no force in the direction which closes the contacts, and the spring opens them. When the current in the a.c. magnet reverses, the fields are in the same direction; the magnetic force overcomes the tension of the spring and the contacts close.

Special taps with suitable resistances may be taken from the secondary of the transformer, so that the charger may deliver direct pulsating current at various voltages.

Fig. 50 illustrates methods of connecting a charging outfit so that the operator may switch it on or off conveniently. Convenience of operation means a great deal, as the success obtained with any storage battery depends upon its condition, and this is maintained at its best when its charge is never left to run down. It is better to charge too much than not enough. No harm can come to the apparatus, as the charger is designed to furnish a voltage but slightly in excess of the full-charge voltage of the battery. The characteristics of the battery are such that it takes a tapering charge, i.e., as its voltage rises it takes a smaller and smaller current.

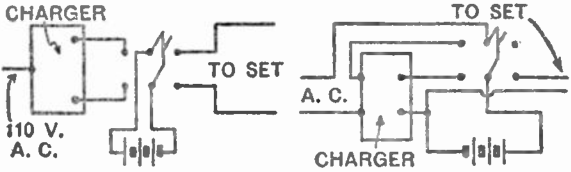


Fig. 50.—Wiring Diagram for Switch Control.

The terminals of the chargers are generally marked the same as the battery terminals to which they are to be connected; thus, + on charger to be connected to + on battery. In many cases no switch is needed for switching the battery over from the set to the charger, or vice versa, as when the a.c. supply is cut off, the charging circuit is automatically opened. In these cases the charger and battery may be connected permanently in parallel, at the same time maintaining the connections to the set. As a matter of protection, however, it is best to install a switch, to change over either one or both of the lines to the battery.

Motor-Generators.—The use of motor-generators for charging purposes is not very extensive, for as a rule the cost of these outfits is somewhat higher than the cost of a bulb or vibrating rectifier. They are used chiefly where several batteries are charged. They are more flexible in operation than bulb or vibrating rectifiers, and can be controlled at will without any trouble or inconvenience.

A motor-generator is simply a motor and a generator connected by a common shaft. The motor is driven by the 110 v.-a.c. supply and the generator delivers a d-c. voltage a little in excess of the voltage of the battery to be charged. The set operates at constant speed and the generator voltage can be varied by insertion of a rheostat in its field circuit.

Electrolytic Rectifiers.—The most common form of electrolytic cell consists of a plate of aluminum and a plate of lead or carbon immersed in a solution of ammonium phosphate or borate, dilute sulphuric acid or ordinary borax. Cells of this type are commonly used by radio amateurs for obtaining high voltage direct current for plate voltages in transmission. The rectification is not perfect, for as the voltage across the electrode is increased, leakage through the gas film on the surface of the aluminum takes place, until at a certain voltage the film breaks down completely and a large flow of current results. In the case of an aluminum cell using sulphuric acid as the electrolyte this critical voltage is about 25 volts. With ammonium borate it is about 500 volts; with ammonium phosphate it is 360 volts. In the case of a tantalum rectifier using sulphuric acid, the critical voltage is 430 volts. The tantalum rectifier uses electrodes of tantalum in place of aluminum.

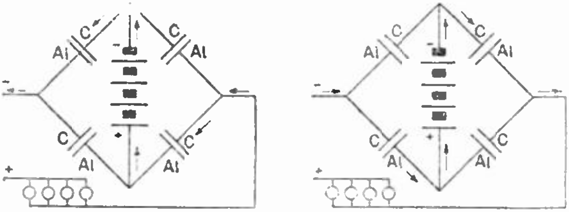


Fig. 51

Figure 51 shows the method of connecting four of these cells so as to rectify both half-waves of an alternating current. The direction of flow is indicated by the arrows, and is shown for both halves of the cycle. The current through the battery which is being charged is in the same direction in each case. The lamp bank indicated is for regulating the current through the cells, and hence regulating the charging rate of the battery.

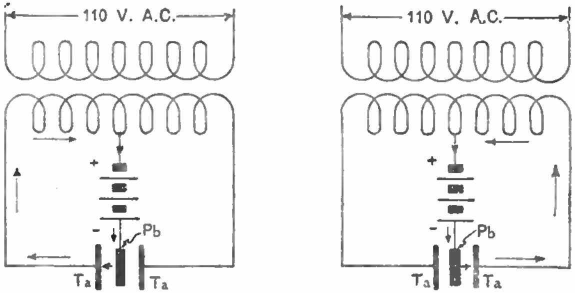


Fig. 52

Figure 52 shows the connection for rectifying both half-waves of the cycle, using a cell with two tantalum electrodes and one lead electrode. The voltage to be rectified is stepped down from the line voltage by means of a step-down transformer. Diagrams for both halves of the cycle are shown.

Electrolytic cells can cause little electrical disturbance in the line, since there are no circuits to be opened and closed or to oscillate. They require a minimum amount of attention on the part of the operator, requiring only water occasionally. They are able to handle currents large enough to charge small storage batteries satisfactorily, but attempts must not be made to use them to rectify heavy currents. The result would be excessive gassing, destruction of electrodes, and a high temeperature of the electrolyte. These failings are characteristic of the aluminum type, but have been partly overcome in the tantalum type using a special electrolyte of sulphuric acid and some other material.

A counter-emf. of about 3 volts is developed by the tantalum cell. There is a maximum voltage above which the cell will not operate, as mentioned before, due to breakdown of the film, and this voltage must be taken into consideration when determining how many cells to use in series in each arm of the bridge connection illustrated above.

It will charge 3 cells of storage battery at 3 amperes at a power input of 65 watts. When charging 2 cells at 1 ampere, the power input is about 18 watts, and when charging 1 cell at 2 amperes it is about 29 watts. The efficiencies of electrolytic cells are of the same order as those of other types of rectifiers.

Provisions for Improving the Sharpness of Tuning.—Use coils for tuned circuits and for feed-back in which the turns of wire are slightly separated from one another. Give preference to coils having as large air space as possible around the windings, rather than large masses of solid insulation. Keep the coils several inches from other parts of the receiving set, especially parts containing sheets of metal. In mounting coils, see that the end connections or terminal wires are separated several inches from one another. The advantage gained by spaced windings is often lost by using mounting blocks or blocks where the terminals come very close to one another through a good-sized piece of solid insulation.

Select variable air condensers in which the insulation of the movable from the fixed plates is accomplished with the use of a minimum number of supports. Often a metal shaft connected to one set of plates is brought through an insulating bushing in a metal end block connected to the other set of plates. The outside diameter of this bushing should be much greater than the inside diameter so that the metal parts connected to the two sets of plates will be as widely separated as possible at the place where this solid insulation intervenes. This keeps down the loss in the insulating material and reduces the resistance of the circuit, thus making the signal louder and the tuning sharper. It is not desirable, however, to secure this feature at the expense of rigid mechanical construction. The condenser must, first of all, be able to stand up in use without short circuiting or developing loose bearings.

Keep the antenna well clear of trees and buildings and separate the lead-in wire several inches from the wall of the house or the wall and ceiling of any room through which it passes.

An aid in precise adjustment of condensers is a very small variable condenser (sometimes incorrectly called a "vernier" condenser). This is a variable air condenser having two or three plates and is connected in parallel with the condenser used for the principal tuning of the circuit. Having set the small condenser at the middle of its scale the large condenser is used for the ordinary adjustment of tuning to the desired station. A slight turning of the small condenser enables the operator to secure the exact capacity value desired much more readily than when the large condenser is used alone.

Sometimes when a circuit is carefully tuned and the knobs are brought to their proper positions by the hand of the operator, the withdrawal of his hand changes the tuning so much that satisfactory signals are no longer secured. This difficulty is not so apparent in receiving sets which have metal sheets lining the front panel or surrounding the circuit elements. Without this shielding, however, it is possible to improve reception by using means for keeping the hand at a little distance from the knobs during the adjustment. One method is to attach a rod or flexible strip of insulating material to the knob and make the final slight adjustments of the position of the knob or dial by holding the end of the rod or strip. Another way is to use a long pencil, holding it near the point and pushing the condenser or inductor dial slightly with the eraser end.

Some filament rheostats making a sliding contact with successive turns of fine wire of high resistance are found to make such a large change in resistance from turn to turn that it is impossible to secure exactly the desired value of filament current. Rheostats are now on the market which have an additional means of fine variation of resistance. After securing approximately the desired value of the filament current by moving the slider in the ordinary way, the final careful adjustment is made by moving either the same or an additional slider over a short length of fine resistance wire. This wire is connected in series with the main winding of the rheostat and the value of resistance obtainable is therefore continuously variable.

Assembly and Details.—When a receiving set is assembled in a box it is desirable to use a sheet of metal as a lining of the front panel in order to reduce the effect of the hand of the operator on the capacity between the parts of the set. This shield should be connected to the negative terminal of the filament or "A" battery or else to the ground terminal of the receiving set.

In assembling a receiving set, all connecting wires should be as short as possible and should run in as nearly straight lines as is consistent with keeping them spaced well apart from one another. The size of the connecting wires is not especially important, though it should not be extremely small. Wire of any size between No. 26 and No. 14 B. & S. gage is satisfactory, though slight preference should be given to the heavier wire.

In theory it would be desirable in winding coils and in wiring up radio sets to use wire having many fine strands insulated from one another and woven together in the form of a cable. Such a conductor is called "litzendraht," or "litz," or "high-frequency cable," and would be expected to have a lower resistance to radio currents than solid wire of the same weight. Since the insulation cannot be infinitely thin, however, it turns out that for very short waves solid wire is better than any actual stranded wire. Practically, moreover, it is difficult to insure that the fine strands are continuous and not broken and that they are all completely insulated from one another. It is not easy to make a soldered connection to all of the strands forming such a cable. It is, therefore, usually not worth while to use other than solid copper wire in the construction and assembly of ordinary radio receiving apparatus.

Some of the variometers and variocouplers on the market employ the shaft as a connection to one side of the rotating bail or coil. If this type of variometer is purchased it should be seen that the shaft end which projects through the shielding panel is at the grounded end of the circuit. In the case of the variocoupler it is usually better not to use the shaft as a connection. Direct flexible connections should be made to the coils and the shaft should be grounded to the shield.

Sometimes inductance coils are used which have a very large number of turns, only a few of which are used for tuning to short wave signals. It is best in such a case to have a switch called a "dead-end" switch for entirely disconnecting the major part of the coil when not in use. This decreases the loss of power in the unused portion of the coil.

When a coil of many turns is wound in the ordinary way in several layers, the distributed capacity is made larger than if the same wire, were wound in a single layer. The objectionable length of a single-layer coil is avoided and the advantage of low distributed capacity is partly retained by coils wound with a basket form of winding. In such coils there is a considerable air space between the wires. This method of winding often makes the coils self-supporting.

It is desirable to have as little solid dielectric as possible in the region immediately surrounding the wires of an inductance coil. The existence of solid insulation results in the loss of power and the decrease of signal strength. Even the enamel or silk insulation on wire is a cause of loss of power, though of course the adjacent turns on a coil must be kept out of metallic contact with one another. Cotton insulation is better on this account and it is also less expensive. No shellac should be used for the coating or impregnation of coils, because it causes resistance and power loss.

On a variometer the dial should be fixed on the shaft in such a way that the zero is indicated when the coils are in such a position that the current flows in opposite directions in the two coils.

There should be a button or switch for disconnecting the "A" battery from the set when not in use.

A grid leak resistance can be made by drawing a heavy line with a soft pencil on a piece of cardboard, about one to two inches long, and connecting it to the terminals of the grid condenser. This resistance can be adjusted to the best value by trial, merely by lengthening, widening, or removing the pencil line.

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CHAPTER THREE

ANTENNAS

Size.—In radio communication it is necessary to have a device for radiating radio waves from the transmitting station and for receiving the radio waves from the air at the receiving station. Such devices are called antennas. Many types of antennas are in general use. The particular location in which the antenna is to be constructed usually goes far to determine its dimensions. The two general classes of antennas are, first, the ordinary elevated wire type, usually called simply an "antenna;" second, a "coil antenna" (sometimes called a "loop" or "frame aerial"), which is usually made by winding a number of turns of wire around a rectangular frame. This latter type is usable indoors. For receiving stations an antenna of the first type is usually the most satisfactory, a good form being a single wire about 75 or 100 feet long and raised 30 to 50 feet above the ground. The higher it is above the ground, the better. The natural wave length of such an antenna is about 200 meters, but the wave length to which the antenna circuit tunes is increased by inserting the inductance coil. The addition of more wires to such a single wire antenna is of but little advantage in securing louder signals. In case the antenna is necessarily shorter than about 75 feet, it is desirable to construct it of two wires placed parallel to one another and about 3 feet apart. The wires should be connected together at the distant end and also at the near end. From this latter, nearby end the "lead-in" wire is brought to the point marked "antenna" on the receiving set.

If necessary, the connection of the lead-in wire may be made to the center of the antenna wires instead of to the end. But this shortens the effective length of the antenna and makes it necessary to add to the series inductance in order to tune to a given wave length, thus somewhat decreasing the strength of the signals.

Figs. 1 to 7 show a number of suggested methods of installing simple antennas. The antenna wires may be strung inside the attic of a house, but care should be taken to locate them as free as possible from proximity to surrounding objects. It is especially desirable to keep the antenna wires some distance from wires used for electric light and power purposes. Antennas should not be run either under or over electric power lines.

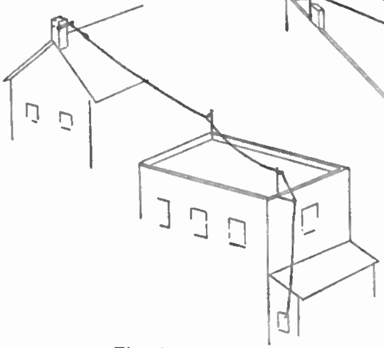


Fig. 1

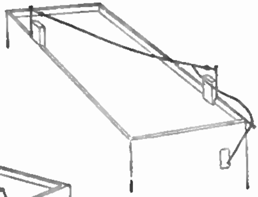


Fig. 2

Fig. 1—A single continuous wire antenna. Where wire passes over edge of roof it is prevented from coming in contact with the building by the insulators at the end of the wood poles.

Fig. 2—A single-wire antenna with lead-in held away from edge of building by insulator on end of pole.

For receiving purposes alone it is sometimes satisfactory to use a wire laid near or along the ground, though in this case, as in the case of the coil antenna, which is described in more detail below, it is necessary to have very sensitive amplifiers in order to receive loud signals from a distant station.

Material.—The usual material for constructing antennas is 7-strand No. 22 hard drawn copper or

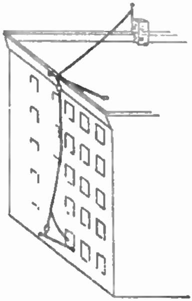


Fig. 3

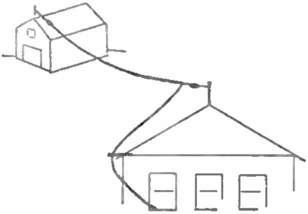


Fig. 4

Fig. 3—A single-wire antenna showing how advantage can be taken of the height of a building to get the necessary length. The horizontal length is very short compared to the vertical. The wire is held away from the building by running it through insulators on the end of poles.

Fig. 4—A single-wire antenna with lead-in held away from edge of roof.

phosphor-bronze wire, though No. 14 or larger bare, hard drawn copper is also quite satisfactory. If the antenna is used mainly for receiving signals from long-wave stations it is desirable to make it considerably longer than the 75 feet previously mentioned.

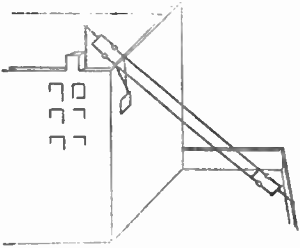


Fig. 5

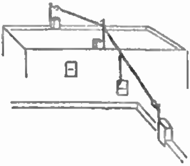


Fig. 6

Fig. 5—A two-wire antenna. The pole on the roof must be sufficiently high or so located that the antenna is held well away from the edge of the roof. This type is not as efficient as one where the entire antenna is above the building.

Fig. 6—A single-wire antenna with lead-in taken from the center.

Insulation.—Each end of the antenna should be insulated from its support by means of an insulator. Almost any insulator of glazed porcelain, glass, impregnated wood, or other material which will not absorb moisture and which has a length of several inches will be satisfactory for receiving antennas. Sometimes two or three porcelain cleats are used in series, the farther one being connected to a rope or heavy cord which is run through a pulley for convenience in raising or lowering the antenna. The lead-in wire should be held away from the building and should enter the room where the receiving apparatus is located through a lead-in bushing or insulator. A small hole may be made in a window pane or the wire may be mounted in any way which will insure its not becoming grounded during wet weather. Inside of the house the wiring should be as short and direct as possible and should not run close to the other wires or water pipes except where the ground connection is made. The receiving apparatus should be located as close as convenient to the entrance of the wire into the room.

Ground Connection.—A good ground connection is usually secured by connection to a water pipe or any thoroughly grounded metal structure. Sometimes louder signals may be secured by using several different ground connections together. If, however, one of the ground connections is poor and has a long connecting wire it may reduce the audibility of signals below that obtained with a single connection. It is usually

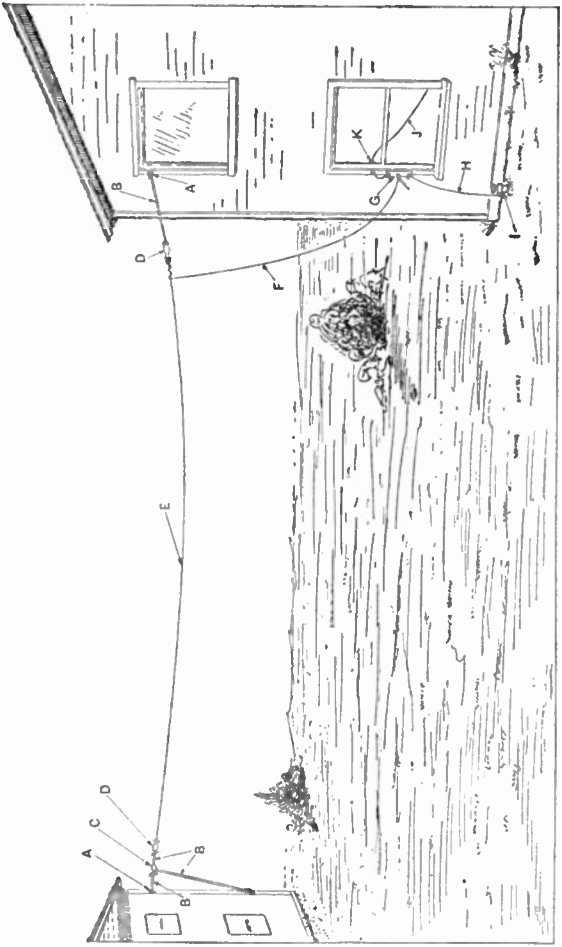


Fig. 7

Fig. 7—Complete detail of single-wire antenna and lead-in: A—screw eye, B—rope, C—pulley, D—insulator, E—antenna, F—lead-in wire, G—lightning switch, H—ground wire, I—ground pipe, J—lead to receiving set, K—insulating tube used where lead-in passes through window frame.

not as satisfactory to use a rod or pipe driven into the ground, since the soil surrounding the pipe may become dry and fail to make good connection. To insure good electrical contact with the grounding system, both the pipe and wire connecting to it should be well scraped and the connection made with an approved connecting clamp or else thoroughly soldered. It should be as short as possible.

Protection against Lightning.—The Fire Underwriters' Rules require the installation of an approved device for protection against lightning. The Underwriters' Rules regarding radio receiving antennas are given in the Appendix. This should be connected between the antenna lead-in wire and the ground wire at some point very close to the entrance of the antenna to the building. The protective device may be mounted on the receiving set itself if this is located close to the point where the antenna lead-in wire enters the building. While it is not required, it is desirable in receiving sets to employ in addition a single-pole double-throw knife switch to disconnect the antenna from the receiving set and connect the antenna directly to the ground. This does not obviate the requirement for the protective device, which must then be connected so that it will be short-circuited by the antenna switch as shown in Fig. 10. It is important that the wires used for the antenna lead-in and for the ground connection be large enough to withstand any danger of mechanical breakage to which they may be subject, while the lead-in wire should be kept from coming in contact with any conducting objects up to the point where it is connected to the receiving set. It is not necessary to insulate the ground wire unless it is an extremely long one. Protective devices, grounding clamps and antenna switches may be purchased from any dealer in radio receiving sets or parts.

Transmitting Antennas.—The most common form of antenna at a radio transmitting station consists of several long, parallel horizontal wires with a "lead-in" wire attached to the center or to one end of the horizontal portion. They are called "flat-top" antennas, of the "T" or the "inverted L" type. The "fan" or "harp" antenna consists of a number of wires extending upward and spreading somewhat from a common point. A good antenna where tall, supporting structures are available is the "cage" antenna, which consists of a number of parallel wires held in a vertical position and separated from one another by spreaders or a barrel hoop. This type can also be used horizontally. None of these forms are superior to the single wire for receiving.

The requirements as to the insulation of antennas used at transmitting stations are more severe on account of the high voltages which are created in the antenna by a transmitting set. The antenna and lead-in wire must

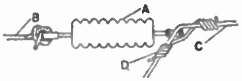


Fig. 8

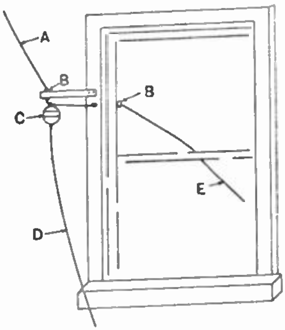


Fig. 9

Fig. 8—Detail at insulator, showing how antenna wire may be passed through the eye of the insulator and be secured by a tie wire. A—insulator, B—rope for raising and lowering the antenna, C—antenna wire, D—tie wire. This arrangement allows the use of a continuous wire forming both antenna and lead-in, thus eliminating the necessity for soldered joints.

Fig. 9—Detail showing arrangement of lightning arrester. A—lead-in from antenna, B—insulating tube through board used to hold lead-in away from building and where lead-in passes through window frame, C—lightning arrester, D—ground wire, E—wire to receiving instruments. Care must be taken that no appreciable strain is placed on the binding posts of the lightning arrester.

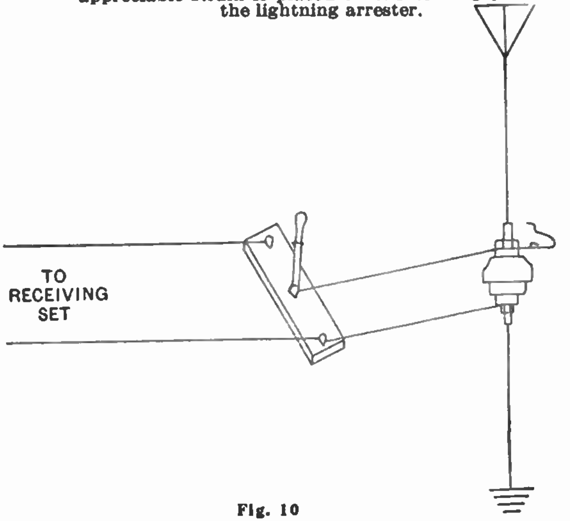


Fig. 10

Fig. 10—Wiring arrangement when using both a lightning switch and a lightning arrester. When lightning switch is thrown to the lower position, thus grounding the antenna, the arrester is short-circuited.

be supported at least five inches away from the building wall. The protective device referred to above is not required on transmitting sets, but instead it is necessary to install a grounding switch which will carry a current of 60 amperes and which has a spacing of at least 5 inches between the central contact and either end connection. The wire leading to the ground from this switch need not be insulated, but must, as in the case of receiving installations, be thoroughly strong mechanically.

Counterpoise.—Sometimes it is convenient, instead of making a connection through the receiving set to the ground, to replace the ground connection by a wire running to a set of wires, which approximately duplicates the antenna. Such an antenna system is, in reality, a two-plate condenser, the overhead wires forming one plate and the counterpoise the other. This set of wires is called a counterpoise. This is more commonly used at transmitting stations than at receiving stations. It is often convenient to run the counterpoise wires out in several directions from the radio set, supported a foot or so above the ground and insulated from it. The wires should cover an area at least as large as that covered by the antenna and should be placed below the antenna. Under some conditions of the surroundings of a radio station it is found to be an advantage to connect the transmitting set to both the ground and a counterpoise. When a counterpoise is used, both the antenna and counterpoise wires must be connected to the ground through the approved protective device as a protection against lightning. A counterpoise is especially useful where the ground is very dry or where the receiving set is located in one of the upper floors of a tall building where the distance to the ground is especially great.

Directional Properties.—A long, low antenna is somewhat directional in its action, that is, it will receive signals slightly better when the long, open end (the end opposite the lead-in connection) is pointed in a direction away from the transmitting station which it is desired to hear. For short antennas, however, this effect is not very noticeable and it makes little difference in which direction the antenna is strung. For further information regarding the directional and other properties of antennas, as well as suggestions for the construction of antennas and counterpoises of different types, the reader is referred to the book "The Principles Underlying Radio Communication."*

Coil Antennas.—A compact and sometimes very satisfactory type of antenna is the coil antenna, which

*The "Principles Underlying Radio Communication" is published as Signal Corps Radio Communication Pamphlet No 40, prepared by the U. S. Bureau of Standards. It may be purchased from the Supt. of Documents, Government Printing Office, Washington, D. C., for $1.00.

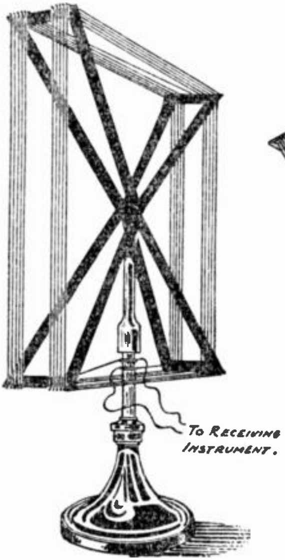


Fig. 11

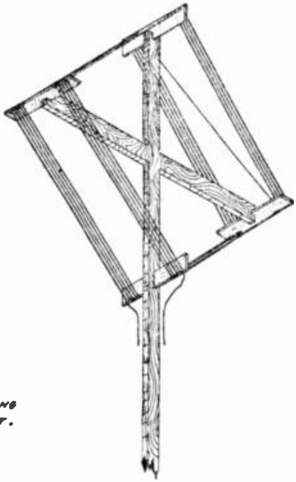


Fig. 12

Fig. 11—Coil antenna mounted on pedestal and arranged to allow revolving coil around its vertical axis.

Fig. 12—Coil antenna on wood frame fitted with end pieces of sheet insulation, such as bakelite or hard rubber. To be mounted so that coil can be revolved. The two ends of the coil shown hanging at side of support are to be connected to the receiving instruments.

consists of a few turns of wire wound on a wooden frame about four feet square. No ground connection is required on an antenna of this type. Arrangements of such an antenna are shown in Figs. 11, 12 and 13. On account of the small size of this antenna it cannot be used satisfactorily for receiving very distant stations unless sensitive amplifiers are employed with it. However, for nearby stations or where good amplification is available, the coil antenna has many advantages. One of the most important of these is its directional characteristic. When the coil is turned so that its plane is in the line of direction toward the transmitting station, the loudest signals are received. When the coil is turned at right angles to this direction, either no signals or only weak signals are received. This makes it possible to receive messages from some stations while avoiding the reception of messages from others, even though the stations are transmitting on the same wave length.

Circuits for Coil Antenna.—For receiving from nearby stations on a coil antenna it is desirable to have an electron-tube detector and two stages of audio-frequency amplification. For receiving from stations 50 or 100 miles away it is advisable to employ five or six stages of amplification. The above statements refer chiefly to the reception from transmitting stations, such as are ordinarily used for radio telephone broadcasting.

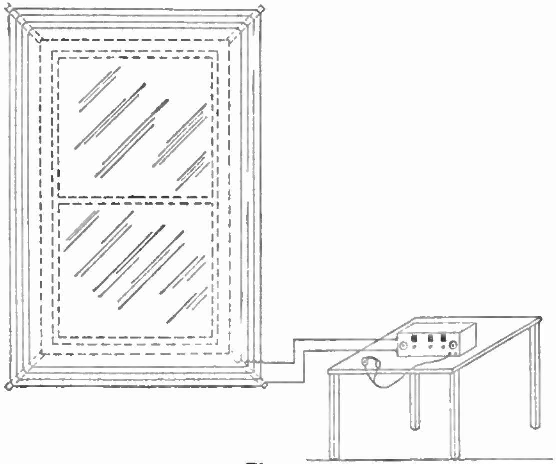


Fig. 13

Fig. 13—A coil antenna made by wrapping a length of wire around a window. The wire is held in place by being forced into saw kerfs in pieces of sheet insulation placed at each corner as shown. This type is of course fixed in position, and full advantage of the directional quality of coils cannot be obtained.

However, if coils are wound with a large number of turns of wire they can be used even with only moderate amplification to receive signals from European stations. A coil antenna may be connected to an ordinary receiving set. The actual connection which is used depends upon the wiring of the inside of the receiving set. If the receiving set or tuner has a series condenser, the coil antenna may simply have its two terminal wires connected to the antenna and ground binding posts of the receiving set, as shown in Fig. 14. If the receiving set or tuner does not have a series condenser it is necessary to connect a variable condenser in series with one side of the coil antenna, between it and the ground terminal of the tuner. The other terminal of the coil is connected to the antenna binding post of the tuner. This connection is shown in Fig. 15. It is very simple to use the coil antenna and an extra variable air condenser in place of the regular tuner. In this case the condenser is connected across the

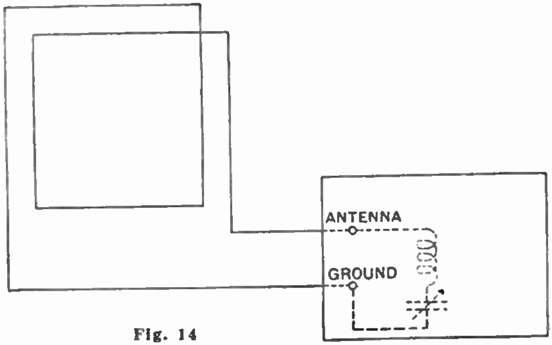


Fig. 14

Fig. 14—Coil antenna connected to receiving set having series coil and condenser.

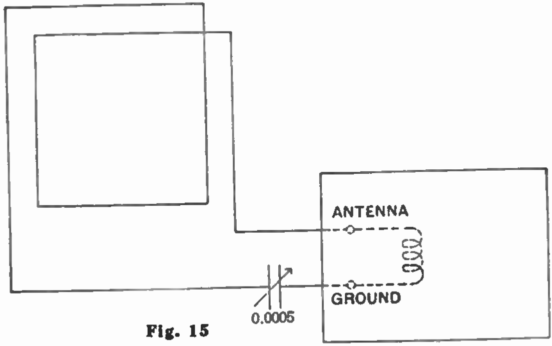


Fig. 15

Fig. 15—Coil antenna and tuning condenser connected to receiving set having series coil only.

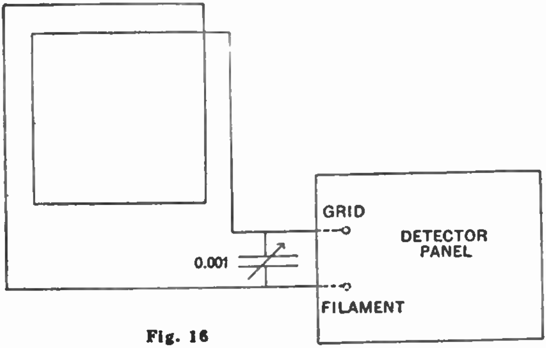


Fig. 16

Fig. 16—Coil antenna and variable condenser connected to detector panel.

terminals of the coil, and these two terminals are also connected to the grid and filament terminals of the detector or radio-frequency amplifier which is used. This circuit is very simple, as may be seen by reference to Fig. 16.

Construction of Coil Antennas.—In constructing a coil antenna for receiving, it is desirable to use as many turns of wire as possible without exceeding the wave length of the station to which it is desired to listen. This means that for short waves one can use only a few turns of wire, while for long waves a large number of turns may be wound on a frame. Square coils are usually found most convenient to construct. Figs. 14, 15 and 16 show a number of types of coil antennas. For receiving from the ordinary radio-telephone broadcasting stations it is convenient to use a coil about four feet square, wound with four turns of wire spaced ½ inch apart. The following table gives the wave-length range to which the coil antenna receiving set can be tuned, assuming several different numbers of turns of wire wound on a frame 5 feet square.

Using variable condenser having maximum capacity 0.00065 microfarad. Minimum capacity 0.00004 microfarad:

Four turns	200 to 400 meters
Eight turns	350 to 700 meters
Sixteen turns	500 to 1000 meters

Using variable condenser having maximum capacity 0.0014 microfarad. Minimum capacity 0.00004 microfarad:

Four turns	375 to 650 meters
Eight turns	400 to 950 meters
Sixteen turns	675 to 2300 meters

Direction Finding.—In chapter 2 it was explained that a coil antenna is directional; that is, it receives signals from stations which are in line with its plane and receives practically no signals from stations which are in a direction at right angles. This property of coil antennas is being used to an increasing extent as a method of eliminating the interference which is caused by the working of a number of broadcasting stations on practically the same wave lengths. In order to accomplish this, the coil should be turned about a vertical axis until its plane is at right angles to the station whose signals it is desired to eliminate. It will then be possible to hear stations which are in any direction within 30 or 40 degrees of the direction in which the plane of the coil lies, but nothing will be received from stations in a direction of 90°.

The coil antenna receives equally well from two opposite directions. Recent studies have indicated that it is possible to arrange a circuit which will receive from one direction to the exclusion of signals from the opposite direction. Fig. 17 shows a circuit

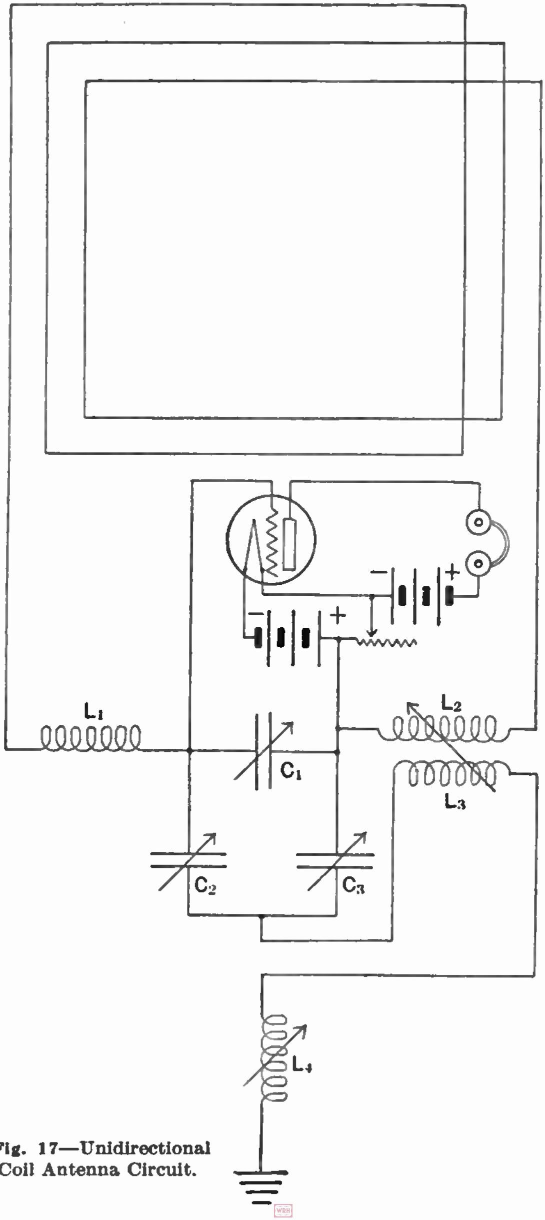


Fig. 17—Unidirectional Coil Antenna Circuit.

which may be used for this purpose. Other methods are possible. and it is to be expected that further experiments with combined coils and elevated antennas will greatly improve this unidirectional reception.

Sometimes it will be found that the minimum indication of a direction finder is not very sharp, but that weak signals can be heard, no matter in what position the coil is turned. One cause for this may be a lack of symmetry in the capacity of the two ends of the coil to ground or to the nearby metallic base. Remedies are being developed for such troubles. One remedy is to connect a "balancing condenser," as shown in Fig. 17. This is simply a variable condenser with two sets of fixed plates and one set of moving plates, the moving set of plates being connected to the ground or to one side of the filament ("A") battery. Sometimes even the adjustment of this condenser will not secure a sharp minimum. It is then likely that the waves in the immediate vicinity of the receiving station are bent from their normal position by the proximity of electric power wires, telephone wires, or metal structures. It is an interesting experiment to take a small coil antenna and rotate it in an effort to find the position in which it receives loud or weak signals.

The coil antenna shown in Fig. 17 and the tuning condenser C_1 are of ordinary design and construction, as described above. For example, the coil may consist of 6 turns of wire on a frame 5 feet square, and the condenser may be a variable air condenser having a maximum capacity of 0.001 microfarad. The three upper coils, L_1, L_2 and L_3, may have an inductance of the order of 100 to 1000 microhenries. The entire circuit, with the exception of the coupling of L_2 and L_3, should be arranged symmetrically. The lower coil, L_4, should have the proper inductance to tune the antenna to ground circuit to the wave length of the signals which it is desired to receive. An inductance of several millihenries is likely to be required, since the capacity to ground of the wire forming the coil antenna is ordinarily quite small. Instead of using the specially constructed balancing condenser, two variable air condensers may be used, as shown at C_2 and C_3. These may each have a maximum capacity of about 0.0002 microfarad.

Summer Antennas.—The principal difficulty with radio reception during the summer time is that caused by atmospheric disturbances or strays. If extremely sensitive receiving apparatus is used, the noises produced in the telephone receivers by the strays may be much louder than the signals which it is desired to hear. As the first principle in summer radio reception it may be stated that one should be content with weaker signals; that is, the receiving set and antenna used should not be as sensitive or susceptible to atmospheric interference. This means also that the signals received will not be as loud as might otherwise be secured. It is therefore desirable to use as small antennas as possible while still receiving the desired signals. Another principle to follow is that by increasing the sharpness of resonance or selectivity of the receiving set it can be made less susceptible to the kinds of waves which the atmospheric disturbances produce.

In order to increase the sharpness of tuning or selectivity of a receiving set, coupled circuits should be used. The use of radio-frequency amplifiers will also greatly assist in minimizing the effect of atmospheric disturbances.

Where the transmitting station is nearby, the antenna may be simply a single insulated wire laid along the ground. In case it is desired to tune the antenna circuit as in the case of ordinary elevated antennas, this ground wire should not be longer than 100 feet. There are some circuits, such as the Reinartz circuit, which employ untuned antennas. Even with the ordinary coupled-circuit receiving set it is possible to use an untuned antenna if one is fairly close to the broadcasting station. In this case the length of the antenna need not be as short as that required when tuning is u·ed. A much longer antenna (several hundred feet) may be used, with a probability that the signal strength will be somewhat increased. Long, low antennas of this sort should be placed in such a direction as to point from the receiving set away from the broadcasting station.

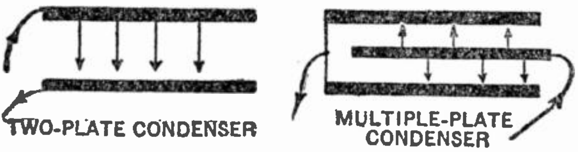
When fairly sensitive receiving sets are employed, that is, with one or more electron tubes, indoor antennas are sometimes found as satisfactory as outdoor antennas. An indoor antenna can be made by hanging a wire 50 to 100 feet long onto a picture moulding or other convenient support.

A coil antenna can be wound on blocks fastened to a door. The directional property of the coil can be utilized by swinging the door open and shut.

An antenna can be constructed on an automobile, in the form of a skeleton-like cap of wires over the top, a long piece of insulated wire being wound around the machine above the fenders and running boards as a counterpoise.

Condenser Antennas.—A "condenser antenna" is defined by the Institute of Radio Engineers as the same thing as an "open antenna," namely, an antenna consisting of two capacity areas. Such a definition is necessary to distinguish from the coil antenna or loop antenna, which is quite a different thing. The more common types of condenser antennas are the usual antennas having elevated wires for the upper capacity area and either a counterpoise or the ground for the lower capacity area. A special type, in which both capacity areas consist of wires or metal plates, both elevated well away from the ground, is sometimes meant when the term "condenser antenna" is used. This "plate condenser antenna" will be dealt with below after some general qualities of condenser antennas are mentioned.

A condenser antenna is primarily a condenser. It is simply the condenser of a radio circuit made large enough to have an appreciable power interchange with the ether, so that it either radiates or absorbs radio wave power. Any 2-plate condenser of large physical dimensions will do; this statement is quite important. In the first place, it must be large; hence the ordinary antenna wire is strung high above the ground. In the second place, it must be a 2-plate and not a multiple-plate condenser. The reason for this may readily be seen from the diagram. In the 2-plate condenser, the



instantaneous "displacement" current in the space between the plates has a certain direction. In a 3-plate condenser, as shown, the displacement current in one space is opposite in direction to that in the other space between plates. The effects at a distance neutralize each other. This is true, wholly or in part, for any condenser of more than two plates.

At least one of the two plates must be more or less parallel to the ground, or their principal effect will be to transmit the wave into the ground, or, in reception, to be unaffected by the incoming wave. The antenna's effectiveness in either transmitting or receiving depends on the vertical separation of the two plates. An effort is therefore made to raise the upper condenser plate to a considerable height. For reception, however, this is not so important, because a low and relatively ineffective antenna can be compensated by amplification. For this reason small antennas can be used for reception. The use of a wire hung up in the ordinary room is familiar, the lower condenser plate in that case being a mass of metal, such as the house piping.

A genuine "plate condenser antenna" has some advantages in those circumstances where a low or small antenna is possible. It may consist of two horizontal spreads of one or more square yards of galvanized or copper screening, netting, or sheet, with a vertical separation of 6 inches to 6 feet. Another form is simply two horizontal copper wires about 20 feet long, with a vertical separation of a few feet. No object should be allowed to be closer to the edges of the plate condenser antenna than the distance between the two "plates." One of the great advantages of such an antenna lies in this elimination of all objects from the space between the plates. Other forms of open antennas have a great variety of objects instead of merely the ideal (air) between the plates, and such objects are the cause of power loss that diminishes the signal strength. When used outdoors, the lower plate of the plate condenser antenna should have considerably more spread than the upper plate, so that the effect is confined to the air between the plates instead of spreading around the edges and possibly to ground.

An advantage of small antennas, such as the plate condenser antennas here described, is the relative freedom from atmospheric disturbances. As a rough rule, the troubles from atmospheric disturbances are proportional to the largest dimension of the antenna.

It should be borne in mind that what we here call a "plate condenser antenna" is a complete condenser consisting of two plates. Both of these plates are well away from the ground. In the more ordinary types of open antennas, the lower plate (counterpoise) may be close to or on the ground, or may even be the ground. As to the question how high above the ground a plate condenser should be placed, it is desirable to have the lower plate at a height above the ground greater than the distance between the plates. When used indoors, it is desirable to maintain the upper plate also at a distance from the ceiling or other objects greater than the distance between the plates.

As to the signal intensity obtainable with a small plate condenser antenna as described, for the broadcasting frequencies the received signals are of about the same loudness as with a coil antenna of the same general dimensions. It is better than the coil antenna for the higher broadcasting and the amateur frequencies.

FUNDAMENTAL PRINCIPLES

FUNDAMENTAL PRINCIPLES

CHAPTER FOUR

FUNDAMENTAL PRINCIPLES OF RADIO

It is a mistake to suppose that radio must remain a mystery because it operates through invisible electrical actions. It is easily possible to obtain an insight into the underlying processes. They are much less complicated than the mechanism of an automobile. The reader who is interested in the explanation of radio will be well repaid by perusing this chapter, especially because it gives him an introduction to electrical principles in general.

The thing about radio that seems mysterious and complicated is, of course, the lack of connecting wires between the place from which the message is transmitted and where it is received. This mystery begins to disappear when we think of some similar happenings. Sounding a certain note in a room will sometimes cause a string in a piano on the other side of the room to resound. Consider another case. Suppose you are watching a chip floating near the edge of a quiet pond. If someone drops a stone in the middle of the pond, the water ripples spread out in rings and soon the chip is bounding up and down. This is very much indeed like radio. The stone corresponds to the transmitting station, the chip is the receiving station, and the ripples correspond to the electric waves which constitute radio.

As will be explained later, the radio waves are produced by electric current in the transmitting station, and at the receiving station they are converted into electric current again. So, after all, we really have to deal with electric current, both at the transmitting and the receiving end. Understanding of radio and ability to work with it boils down to understanding of electric current.

Electric Current.—When a battery is connected to a metal wire, a something called an electric current flows in the wire. Like anything else, the electric current is useful because of the effect it produces. The two principal effects produced by electric current, through which it serves mankind, are (1) the heating effect and (2) the magnetic effect. Whenever current flows in a wire it heats it somewhat; this is the basis of electric heating devices and the incandescent lights in our homes. If a very small magnet is brought near a wire in which a current flows, the magnet will be deflected; that is, there is a magnetic effect produced near the wire. This is the basis of action of all dynamos and motors, of most electrical machinery, and (as we shall see later) of radio.

In order to have an electric current there must always be a closed "circuit," or path which returns into itself. A useful illustration of the electric circuit is a closed circuit of pipe (Fig. 1) completely filled with water, and provided with a pump to circulate the water. Electricity behaves in the electric circuit much like an incompressible liquid in a pipe line. We are very sure that electricity is not like any material substance which we know, but the common practice among students and shop men of calling it "juice" shows that they think of it as like a liquid. It is convenient to consider the electric current to be a stream of electricity flowing through the wires. Current is measured

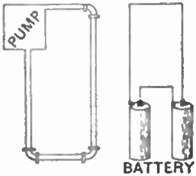


Fig. 1.—An electric circuit is like a pipe circuit full of water.

by an instrument called an ammeter, which shows at each moment just how strong the current is, in somewhat the same manner as we may estimate the swiftness of a stream by watching a chip on the surface. The ammeter measures the current in a unit called the ampere.

The water will not flow in the pipe line, Fig. 1, unless there is some force pushing it along, such as the pump, and it cannot be kept flowing without keeping up the pressure. Electricity will not flow in a circuit unless there is a battery or other source of electricity in the circuit. The battery is for the purpose of providing an electric pressure. This electric sort of pressure is called voltage. The larger the number of cells which are joined in the circuit the greater the electric pressure and the larger the current produced, just as the rapidity of flow of the water in the pipe line may be increased by increasing the pump pressure. The unit of voltage is the volt, and voltages are measured by an instrument called a voltmeter. The usual city lighting circuits have a voltage of 110 volts. One cell of a lead storage battery gives two volts and a dry cell about 1.5 volts.

There is always some friction or resistance in a pipe whatever its size or material, and this hinders the flow of the water to some extent. Similarly, there is something like friction in an electric circuit, which is called resistance. The greater the resistance the smaller the current which can be produced in the circuit by a given battery.

The unit of resistance is called the "ohm." The current in amperes is equal to the voltage in volts divided by the resistance in ohms.

Electric Energy and Power.—The flow of an electric current is accompanied by the flow of a certain amount of power. The capacity of anything to do work is called energy, and power is the rate at which energy is produced or the number of units of energy produced per second. The purpose of electrical apparatus is the transformation of the power of the current into other forms of power, heat, light and motion. The electric current is the means by which we transmit energy from the power-house to the consumer, and we are not, for practical purposes, concerned with the method of carrying the energy any more than we need to inquire into the nature of the belt by which mechanical energy is carried from one wheel to another, or into the chemical nature of the water which is furnishing the power in an hydraulic plant.

The electric current itself cannot be seen, felt, smelt, heard or tasted. Its presence can be detected only by its effects—that is, by what happens when it gives up some of its power, as, for example, causing a motor to turn. Electrical power is given up, and mechanical power takes its place. Similarly, electric power may be used up and heat or light may appear in its place. The electric lamp has an effect on the eye. We do not see the electric current in the lamp, but the effect on the eye is due to the light waves sent off by the hot filament. The power of the current has been changed over into heat in the lamp. When we hear a buzzing in the telephone, it is not the electric current we hear, but merely the vibration of the receiver diaphragm. The electric current has used some of the power in moving the diaphragm.

The power which is furnished by the electric current to any electrical apparatus depends both on the amount of the current and the voltage (electric pressure). The power is the product of the two. The product of current in amperes by voltage in volts gives power in watts. For example, an electric flatiron takes about 5 amperes at 110 volts, so the power which it uses is 550 watts. Another unit of power that is commonly used is the kilowatt, which is simply 1000 watts. Thus 750 watts is three-quarters of a kilowatt; that is, about one horsepower.

A little study of the following table may assist the reader to understand the units in which electric power and energy are expressed. The way electric current furnishes power is similar to the flow of water through a pipe system, at some point at which a water motor is placed. The power supplied to make this water motor turn and perform work would depend both on the flow of water through it and the pressure acting between the inlet and the outlet of the water motor.

	Water	Electricity
Rate of flow is measured in	Gallons per sec.	amperes
Pressure is measured in...	Lbs. per sq. in.	volts
Power is measured in....	Horsepower....	watts or kilowatts
Energy is measured in...	Horsepower-hrs.	kilowatt-hours

Batteries.—A battery consists of a number of units called voltaic cells, or simply cells. A cell is a combination of chemicals with two metal terminals. When the terminals are connected by a wire, a current flows in the wire, the electrical energy coming from the chemical energy inside the cell. Batteries are used to light the filaments of electron tubes and to supply plate voltage.

Among the most commonly used batteries are so-called dry batteries. These are not really dry, but are filled with a material which is moistened with the active solution and then sealed. One terminal is a carbon rod, while sheet zinc forms the containing vessel. This type of cell is made in a variety of shapes and sizes, and is now used in large quantities for use in flashlights, vehicles and all sorts of portable devices as well as radio receiving sets. Attempts are sometimes made to increase the life of dry cells by making a hole in the top and adding water, and also by recharging them electrically, like storage cells; but the gain is very slight and is seldom worth the trouble.

Dry batteries depend for their operation entirely upon the chemical energy contained in the materials of which they are constructed, and when the cells are exhausted, the materials have to be replenished or new cells purchased. In distinction from such cells are storage cells. These do not contain any available energy to start out with, but this energy is supplied by passing an electric current through them. This operation is called charging. After being so treated, current can be drawn from them. The process of drawing a current from the battery is called discharging.

The energy which is stored in the cell by the charging process is stated in watt-hours or kilowatt-hours, like any electrical energy. As already explained, electrical energy in watt-hours is the product of the voltage in volts, the current in amperes, and the time in hours. The last two of these factors taken together, *i. e.*, the current multiplied by the time, gives the quantity of electricity that is put into the cell in the process of charging or converting electrical energy into chemical energy in the cell. The quantity is expressed in ampere-hours. Battery manufacturers have gotten into the habit of rating storage batteries by the number of ampere-hours used in charging.

Only two types of storage cells have proved to be commercially successful. The more common type, called the "lead" storage cell, consists of lead plates, the surface of which have been specially treated with lead oxides, immersed in a dilute solution of sulphuric acid. It gives a voltage varying from 2.0 down to 1.75 when discharged. The Edison storage cell has nickel and nickel-iron for the plates, and the solution is an alkali. It gives a voltage varying from 1.4 down to 1.0 volt when discharged.

Direct and Alternating Current.—When a water pump keeps up a steady pressure, the water in the pipe line flows steadily and continuously in the same direction. Just so electric batteries and certain dynamo machines cause a current which flows always in the same direction around the circuit. This kind of current is called direct current. Certain other kinds of dynamo machines produce current which alternates in direction at some definite frequency; this is called alternating current. The usual frequency of lighting current is 60 per second; that is, the current flows first in one direction and then the other, repeating this 60 times each second. Radio makes use of currents alternating millions of times a second.

It is easy to tell whether an electric current is direct or alternating by using it to light a carbon-filament incandescent lamp and holding the lamp near a permanent magnet. If the hot filament is drawn to one side of the bulb and remains there, it is direct current. If the filament vibrates so that it seems to widen out into a bright band, the current is alternating.

Electric devices which depend for their operation on the heat produced by the electric current operate equally well on direct and alternating current. Devices, however, which make use of the magnetic effect of the current may behave very differently with direct and alternating current.

Magnetic Effect of Current.—One of the principal reasons why electricity has revolutionized the everyday life of mankind is that it may be utilized to produce motion. This simple principle makes possible the operation of telegraph and telephone, electric bells, electric motors, elevators and street-cars. The electric motor is also the backbone of many labor-saving devices used in the home, such as the vacuum cleaner, washing machine, electric fan, pump and sewing machine.

The reason that an electric current can cause motion is that every electric current is surrounded by a magnetic field. This is simply shown by the fact that any iron which is near an electric current becomes magnetized and tends to move. The motion of the iron may be back and forth, as in the telegraph, telephone, or electric bell, or it may be round and round as, in a motor.

In an electric bell, the electric current produces a magnetic action which causes motion of an iron piece; then the current is interrupted and the iron piece allowed to fall back to its former position, and then the whole process is repeated over and over.

Besides causing iron to move, the magnetic field which every electric current produces is responsible for many other important effects. Whenever a magnetic field changes, it tends to produce an electric current in any conductor nearby. Thus a changing electric current causes a changing magnetic field, and this in turn causes another electric current in a different conductor. The changing magnetic fields produced by varying electric currents are what make radio possible.

Production of Radio Waves.—Wherever there is an electric circuit in which alternating current is flowing, a magnetic field around the wire is constantly being produced and varied as the current in the wire varies. This magnetic field spreads farther and farther out, giving rise to an electric wave, just as a sound wave starts out from a vibrating bell or tuning fork. A powerful sound can be produced by using a very large tuning fork, and similarly a powerful electric wave is produced by making some part of the electric circuit large in dimensions. This enlarged part of the circuit is called the antenna. The antennas used in radio work, as is well known, often consist of long conductors supported on very high towers. The mechanism for producing a radio wave, therefore, is simply an enlarged or extended portion of an electric circuit in which an alternating current is made to flow. In the space near the antenna, alternations of electric pressure and of magnetic field are produced, just as alternations of air pressure are produced around a tuning fork. At any instant the electrical condition of the space around an antenna which is sending out radio waves could be shown by a diagram such as Fig. 2. The arrow on the line extending between the antenna and ground indicates that the electric pressure at a particular moment is in the direction indicated. When the current changes in direction, the direction of this electric pressure will be reversed and the electric pressure already mentioned will have handed on its effect to the surrounding space. Thus the effect of an electric pressure is handed on and spreads out through space, the direction of this pressure at any point is constantly alternating as the direction of the current in the antenna producing it alternates. The frequency of this alternation of the wave is the same as the frequency of alternation of the current in the antenna.

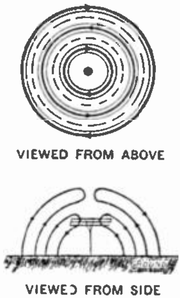


Fig. 2.—Production of Waves Around an Antenna.

Lines of electric pressure alternating in direction are thus constantly spreading out from the antenna just as the ripples spread out on a pond after a stone has been thrown into it. Something very similar to the ripples would be seen if, in some way, the alternations of electric pressure could be made visible and a person were to look down from above upon the antenna and the space around it. The waves of electric pressure spreading out and successively alternating in direction would look something like the lines shown in the upper part of Fig. 2. The waves spread out in all directions and go to great distances.

It at once suggests itself that the waves will produce an effect at a point far distant from the source if a means is provided at that point for converting the wave action into electric current in a circuit. In this way electric communication without connecting wires is established.

Nature of Radio Waves.—We cannot see electric waves as we see ripples or the waves on a pond, but there is nothing especially mysterious about them. We cannot see sound waves. If a tuning fork is struck, it gives off sound waves which, starting at the tuning fork, travel out into the air in all directions, like the ripples referred to. Sound waves are produced by the motion of the metal prong of the tuning fork. As the prong moves back and forth it causes the air next to it to move back and forth. This motion is handed on to the surrounding air and so moves out to a great distance in the air just as the ripple on the pond spreads out. The slight to-and-fro motion of the air spreading out in this manner is called a sound wave.

Electric waves also consist of a certain kind of to-and-fro motion. Just as the motion of the tuning fork causes alternating pressure in the surrounding air, similarly, whenever an alternating electric current flows in an electric circuit, the to-and-fro motion of the current causes alternating electric pressure in the space next to the wire. This to-and-fro or alternating electric pressure in the space surrounding the wire affects the surrounding space and spreads out in exactly the same way as a sound wave in air.

The electric waves are also called radio waves, and it is by means of them that radio communication is carried on. It is an interesting fact that radio waves are really of the same kind as light waves. We are all familiar with light waves, and it should help to make radio waves less mysterious to know that they are both electric waves. The difference between light and radio waves is the frequency of alternation. Thus electric waves are much more common things than is sometimes supposed. Electric waves are used for many purposes, their use depending on the frequency of the waves. This is shown by the following table.

Frequency and Wave Length.—Frequency is the number of cycles per second, or the number of to-and-fro alternations of the electric pressure as the wave travels out through space. Wave length is the distance from the crest of a wave to the crest of the next adjacent wave. Since all electric waves travel at the same velocity (186,000 miles per second, or 300,000,000 meters per second), the shorter the length of the waves the larger the number of them which will pass by a given point during a second. The length of the waves is numerically equal to their velocity divided by their frequency (number of cycles per second). That is,

$$\text{wave length in meters} = \frac{300,000,000}{\text{frequency}}$$

$$\text{or, more exactly,} = \frac{299\,820}{\text{frequency in kilocycles}}$$

For example, a radio wave 600 meters long is caused by a current in a transmitting antenna having a frequency of 500,000 cycles per second, or 500 kilocycles per second, the term "kilocycle" designating 1000 cycles

Waves Produced by	Cycles per Second
Commercial Alternating Currents	25 to 500
Ordinary Telephone Currents	16 to 3,000
Radio	10,000 to 30,000,000
Heat and Light	3,000,000,000,000 to 3,000,000 000,000,000
X-Rays	3,000,000,000,000,000,000

All of these waves travel at the same speed. These electric waves are of an entirely different nature from sound waves. Sound waves are not at all electrical; they consist of actual to-and-fro motions of the air particles and travel with a speed of about 1,000 feet per second. The speed at which electric waves travel is much greater than this; it is so great that the passage of any kind of electric wave is practically instantaneous. The various kinds of electric waves shown in the table are much alike in many ways, but they have some characteristic, differences. Thus, radio waves are different from light waves in that they go through ordinary walls of buildings and other obstacles which are opaque to light.

The waves are radiated and spread out more effectively the higher the frequency. The ordinary low frequencies used in the alternating, currents which light our houses alternate very slowly. Such waves travel readily along wires. In order to get a wave which will travel effectively through space, higher frequencies must be used; that is why the waves used in radio communication make a large number of vibrations per second.

It is to be noted that these frequencies are not, however, as high as the frequencies of light waves. Light waves travel in straight lines, which is one of their characteristic differences from low-frequency waves of alternating current power which follow along wires. Radio waves are intermediate in character between the two, and can travel in straight lines and also travel along conducting wires.

The fact that radio waves, which are able to travel out into space without conducting wires, are of high frequency, is one of the important characteristics of radio communication.

Wave Reception.—Now think of what is happening at a distance from an antenna which is sending out waves. As the wave passes any point there is an alternation of electric pressure going on continuously at that point. The alternating electric pressure or

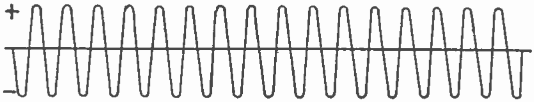


Fig. 3.—Continuous Wave.

wave action at that point could be illustrated by the wavy line of Fig. 6. The portions of the wave above the horizontal line correspond to the electric pressure in one direction, and the portions below correspond to the electric pressure in the other direction. This can be understood by thinking of a sound wave. As the sound wave passes out through the air, it will set in vibration any object which is capable of taking up the motion. Suppose, for instance, that a sound wave produced by a tuning fork passes a second tuning fork which is in tune with it, that is, having the same natural pitch or frequency of vibration as the first tuning fork. The to-and fro motion of the air will start the second tuning fork into motion. This can be readily shown with two tuning forks, striking one of the forks, thus producing a sound wave. It can be proved that the second tuning fork is set into vibration by grasping the first with the hand so as to prevent its further motion. A sound from the second one can then be heard.

A radio wave can produce an effect at a distance in just the same manner. In any electric circuit the moving wave of electric pressure produces an electric current alternating with the same frequency as the wave. The moving wave is accompanied by a magnetic field, just as a current is. This moving magnetic field produces an electromotive force in any conductor across which it cuts, just as an electromotove force is produced by any other relative motion between a conductor and a magnetic field. The electromotive force thus produced is what causes a current in the receiving antenna.

Transmission Formulas.—Formulas expressing the relation between the current received in an antenna expressed in terms of the current in the transmitting antenna and the constants of the two antennas and are presented below. The magnitude of the etheric disturbances depends upon the current in the transmitting antenna, and the magnitude of the current in the receiving antenna depends upon this disturbance. The effects are different for the different types of antennas, so the equations were worked out for different combinations of the two most used types.

Flat-top antenna to flat-top antenna

$$I_r = \frac{188}{\lambda d} (h_s) \; I_s \left(\frac{h_r}{R_r} \right)$$

Flat-top antenna to coil antenna

$$\frac{1184}{\lambda^2 d} (h_s) \; I_s \left(\frac{h_r l_r N_r}{R_r} \right)$$

Coil antenna to flat-top antenna

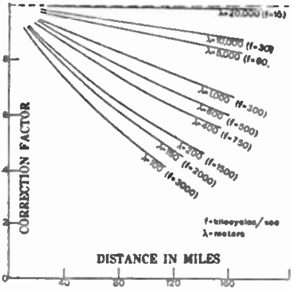
$$\frac{1184}{\lambda^2 d} (h_s l_s N_s) \; I_s \left(\frac{h_r}{R_r} \right)$$

Coil antenna to coil antenna

$$\frac{7458}{\lambda^3 d}(h_s l_s N_s)\, I_s \left(\frac{h_r l_r N_r}{R_r}\right)$$

As the waves travel through space they are subject to absorption of energy as the distance increases and various obstacles are presented in their path. Electric waves tend to follow conductors, but their energy is partly used up by poor conductors. Also obstacles, such as buildings, trees, etc., will cause a deflection of some of the energy from its original path of reflection and refraction, in a manner similar to these properties of light waves. By absorption of the waves we simply mean the diminishing of the wave through loss of energy in obstacles, etc.

This decrease in intensity, expressed in terms of the intensity at the transmitting antenna, is called the absorption or correction factor.



The figure shows how this varies with the wave length and the distance The chart is not meant for quantitative use, but rather to illustrate to what degree the intensity of received signals falls off as the distance or wave length are changed. This correction factor is of the form $2.718^{-0.076d}/\sqrt{\lambda}$ when the distance, d, is expressed in miles and the wave length in meters. To determine the value of the current received in an antenna, the proper formula must be used, and then multiplied by the correction factor to take into account the absorption. Here, I_r is the current received, I_s the current in the transmitting antenna, both in amperes; h_r, h_s are the heights of the two antennas in meters; R_r the resistance of the receiving antenna; d the distance in meters; λ the wave length in meters. In using the formulas remember that 1 meter = 3.281 feet, and 1 mile = 1609 meters, in case measurements are taken in these units.

The table on following page gives values of the correction factor when λ is in meters and d is in miles.

From the formulas certain general conclusions can be drawn. Thus, since λ appears in the denominator, it follows that, for given heights of antenna, sending current, receiver resistance, and distance apart, there will be more current in the receiver, the shorter the wave length used. On the other hand, there is more absorption of short waves than of long ones. This effect is taken account of in the correction factor to be used for long distances. In this factor, λ enters in such a way a as to make the received current less when the wave-length is short than when it is long. Hence, in general, we conclude that to get the greatest possible received current, we should use short waves for short distances and long waves for long distances.

ABSORPTION FACTORS

Values of $2.718^{-0.0015d/\sqrt{\lambda}}$		Frequency (kilocycles)						
		3000	2000	1500	1000	750	600	300
Distance		Wave-Length (Meters)						
Km.	Miles	100	150	200	300	400	500	1000
8.05	5	.962	.970	.973	.978	.982	.984	.988
16.1	10	.926	.938	.948	.957	.963	.967	.976
32.2	20	.858	.883	.897	.917	.928	.934	.942
64.4	40	.738	.780	.806	.840	.863	.872	.908
96.6	60	.633	.688	.725	.769	.803	.815	.866
128.8	80	.544	.608	.649	.705	.744	.762	.826
161	100	.467	.537	.583	.645	.692	.712	.887
322	200	.219	.288	.340	.417	.478	.506	.618
644	400	.048	.083	.116	.174	.229	.256	.384
966	600	.011	.024	.039	.072	.109	.132	.787
1288	800	.0023	.007	.013	.030	.052	.065	.147
1600	1000	.0005	.002	.0046	.013	.025	.033	.091

It may be seen from the formulas that, for simple antennas, the received current (for a given wave length, sending current, receiver resistance, and distance apart) is greater, the greater the heights of the antennas. In the case of coil antennas under the same conditions, the received current is greater, the larger the areas and the number of turns of the coils. For the dimensions actually used, antennas are much more effective radiators and receivers than closed coils. In order to secure the same radiation or received current with a closed coil as with an antenna, other conditions being the same, its dimensions must be nearly as great as the antenna height. However, it is often possible to put more current into a transmitting coil than into the corresponding antenna, and also the resistance of a receiving coil is usually smaller; hence the coil can be a smaller structure than the antenna.

The coil has some other advantages over the ordinary type. For a given power input in the transmitter a larger fraction of the radiation is sent out in the direction desired. As a receiver, the directional property is a great advantage.

Comparison of Radio with Ordinary Wire Telegraphy or Telephony.—In the preceding sections the mechanism by which an electrical action can be made to affect a distant point without wire connection has been explained. The ether which fills all space can be considered to replace the wire connection. Thus, in wire communication there is a system as represented in

Fig. 4, which shows a conducting wire line containing a source of varied current at one end and a detecting device (D) at the other end. In radio communication the wires are eliminated, so that the corresponding simplified system would be as represented in Fig. 5, which shows the similar source of varied current and detecting device (D), each of these, however, being placed in a simple electrical circuit and the conducting wires between being eliminated. Both of these diagrams have been so greatly simplified that neither of them is really just like an actual telegraph or telephone system. Certain additional features must be used beyond what is shown in either Fig. 4 or Fig. 5 to carry on telegraphy or telephony. A species of telegraphy is possible by merely adding a key in either Fig. 4 or Fig. 5. Wire communication of this kind

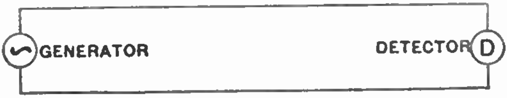


Fig. 4.—Wire Communication.

would thus be the use of an alternating-current generator as the cource of power and a telephone receiver as the detector (D). The corresponding radio system would be the use of an alternating-current generator of high but still audible frequency together with the use of a telephone receiver in place of detector D. As a

Fig. 5.—Radio Communication.

matter of fact, simple systems of just this kind are not used because great advantages are secured by the addition of certain features which will now be discussed. Furthermore, these additional features not only improve radio-telegraphy but are necessary for radio telephony.

Tuning.—The extremely simple system of radio communication indicated in Fig. 5 is not effective unless the alternating current used is of high frequency. Even then the current produced in the receiving circuit would be very small indeed unless the receiving circuit is in tune with the wave; that is, it must be arranged to respond to the frequency of alternation possessed by the first circuit and the wave which it sends out. This is just like what happens with the two tuning-forks and the sound wave. The second tuning-fork does not respond to the wave from the first unless the two are in tune. This can be shown by placing a bit of wax on one of the prongs of the second tuning-fork, changing the pitch of that fork. When the first tuning-fork is struck under these conditions it can readily be demonstrated that the second fork does not respond. In the same way the electrical arrangements in the receiving circuit which are used to receive radio waves must be such that the receiving circuit is electrically in tune with the radio wave. By this means the radio receiving circuit can pick out the particular wave which it is desired to receive and not be affected by other waves. This is fortunate, because otherwise the interference between different radio messages would be hopeless. It would be just as though every sound wave which passed through the air set absolutely everything which it touched into vibration.

Fig. 6.—Tuned Radio Circuits.

Just as the frequency to which a tuning fork responds depends upon its inertia or mass and its springiness or elasticity, the frequency to which the electrical circuit responds depends upon two corresponding electrical properties called inductance and capacity, respectively. The "inductance" is the electrical quality that corresponds to the inertia or mass of the tuning-fork, and the "capacity" corresponds to its elasticity.

A condenser may be thought of as similar to a gas tank used for the storage of gas. The amount of gas a tank will hold is not a constant fixed amount; it depends on the pressure. If the pressure is doubled, twice the amount of gas is forced into the tank. If the pressure is released and an opening is left in the tank, the gas rushes forth. Similarly, the amount of electricity that can be put into a condenser depends on the electrical pressure, called voltage. When the voltage is increased, more electricity flows into the condenser, and when the voltage is diminished, the electricity flows out again. By alternately increasing and diminishing the voltage, an alternating electric current flows in the condenser. Thus a condenser allows an alternating current to flow, although it contains an insulating partition which prevents the steady flow of direct current.

The greatest current is produced in a receiving circuit when both the transmitting and receiving circuits are tuned—that is, arranged so that the product of the capacity and inductance is the same in each. The elements of a typical radio circuit are thus rather more complicated than shown in Fig. 5, which should be replaced by Fig. 6. The symbols C and L indicate the conventional diagrams for capacity and inductance. The device used to introduce capacity into a circuit is called a condenser, this usually consists of a pair, or two sets, of metal plates separated by air or by some solid non-conductor. The device used to introduce inductance into a circuit is called an inductor, or an inductance coil, or simply a coil; it is a coil of wire, as suggested by the usual diagram for an inductance.

Modulation.—We come now to a feature of radio which is often not understood. Anyone who will take the trouble to read this section ought, however, to gain a clear comprehension of the important subject of "modulation." As just mentioned, the frequency of alternation of radio waves is very high. It is so high, in fact, that a sound wave of such frequency could not be heard. Suppose, for instance, that an ordinary telephone receiver is used as a detector (D) in the circuit which is receiving a radio wave. Electric currents produced in a receiving circuit are of the same frequency as the wave frequency and tend to cause motions of the telephone receiver diaphragm. These motions are, however, of such great frequency that the diaphragm produces no audible sound. In order to permit the radio wave to be received and transformed into a sound, it is therefore necessary to break up the radio wave in some manner. This is done in radio

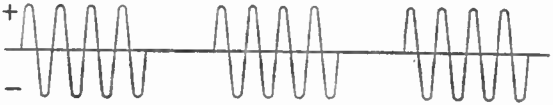


Fig. 7.—Interrupted Wave.

telegraphy by interrupting the wave completely, so that it consists not of a single regular series of alternations but of a succession of groups of such alternations; that is, instead of the continuous wave shown in Fig. 3, it consists of the interrupted wave or group of waves illustrated in Fig. 7. The frequency of the interruptions or of the groups of waves is a frequency which is low enough to be heard. One of the ways of breaking the waves up into groups is by use of a "chopper," which is simply a rapidly rotating disc with contacts on it so as to alternately open and close the circuit.

This process of varying the high-frequency wave so that it is no longer a single, regular series of alternations is called modulation.

Instead of breaking the wave up into simple groups of alternations, it is possible to modulate it (*i. e.*, cause it to vary) in a manner which follows the sound variations produced by the human voice. It is thus possible to make a radio wave carry a voice wave. This is the process of radio-telephony, and will be explained further in the next chapter.

Besides the reason given in a preceding section for the use of high frequency in radio, there is another very powerful reason, which is connected with modulation. When it is desired to carry on telephony, it is necessary that the alternating current which produces the waves be of a frequency to which the sense of hearing does not respond. This is necessary because if the waves were of an audible frequency, the current which they produce in the receiving circuit would produce a sound that would be heard and would interfere with the voice or other sound which it was desired to hear. The wave frequency must therefore be so high that a sound wave of such frequency could not be heard.

Summary.—The principles of radio have been briefly explained in this chapter. They are few and simple. An electric wave is sent out into the air by means of electric current flowing in the transmitting antenna, the current being an alternating current of very high frequency. The high-frequency current (and consequently the wave it produces) is varied in accordance with the sound variations of the speech or other sound

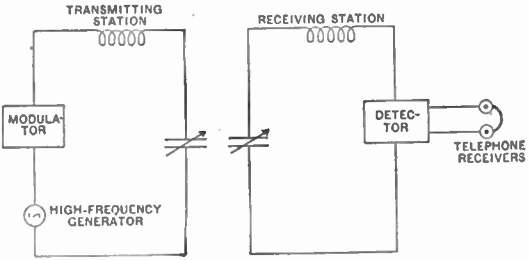


Fig. 8.—Complete Radio Transmitting and Receiving System.

or signal which is to be transmitted, this process being called modulation. The radio wave spreads out in all directions, and can produce electric current in any electric circuit that is tuned to respond to the radio wave frequency. The way in which the current thus produced in radio receiving apparatus is converted back into sound is explained in the next chapter. The essentials of a complete radio transmitting and receiving system are shown in Fig. 8.

RECEIVING &
TRANSMITTING

RECEIVING &
TRANSMITTING

CHAPTER FIVE

PRINCIPLES OF RECEIVING AND TRANSMITTING APPARATUS

In chapter 4 an explanation was given of the general processes by which radio is carried on. The present chapter explains the action of the various parts of the apparatus used. It gives the "how" or "why" of the devices whose operation was described in chapter 2. A few paragraphs are also devoted to transmitting apparatus, for the general information of the user of receiving apparatus. This book does not attempt a complete discussion of transmitting apparatus.

The Antenna.—The radio waves are produced by alternating current which flows in the circuits of the transmitting station, and these waves are converted back into alternating current in the circuits of the receiving station; that is, electrical vibrations produce electric waves which spread out in all directions and these waves are capable of producing electrical vibrations again in any circuit which they pass. The device which converts the electric vibrations (alternating current) into electric waves, or which converts the waves back into alternating current is the antenna. The antenna really has a large job to do, and for all that, it is nothing but a piece of wire.

The antenna is simply an enlarged portion of the circuit. As previously explained, radio circuits consist of two principal elements, called capacity and inductance. A circuit containing capacity and inductance naturally responds to some particular frequency of alternation of electric current, just as a vibrating bell or tuning-fork has some natural frequency of vibration. The "capacity" is the electrical quality that corresponds to the elasticity or springiness of the tuning-fork, and the "inductance" corresponds to its inertia or mass. Now the antenna can be either one of these two elements, the capacity or the inductance. In most radio stations it is the capacity. It consists essentially of two electrical conductors with air between. One of these conductors is an elevated wire, or set of wires, while the other conductor can be either a similar set of wires or else the ground. A typical circuit in which the antenna thus constitutes the capacity is shown in Fig 1. The other part of the circuit, the inductance coil, is connected between the elevated wires and the ground.

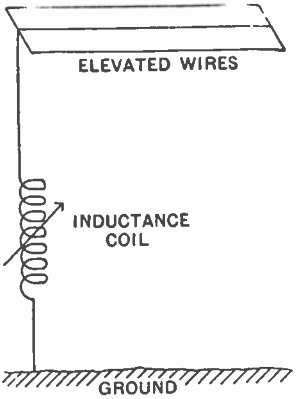


Fig. 1—Simple antenna circuit, with elevated wires and ground constituting a capacity.

Just the opposite arrangement is used with a "coil antenna." The inductance coil is made large and constitutes the antenna, and a device possessing capacity (called a condenser) is connected to the two ends of the inductance coil. The arrangement is shown in Fig. 2. The "condenser" consists of two metal plates, or sets of plates, with air or some other non-conductor between.

The simple antenna, consisting of elevated wires together with a ground connection, is much more commonly used than the coil antenna. The reason is that it gives more powerful signals. For special purposes, however, the coil antenna has advantages, especially in a receiving station. It can be very small, so that a complete radio receiving station can be within an ordinary room. Also, the strength of the signal received on it depends on the direction in which the coil is turned. By turning the coil, therefore, one can determine the direction from which the wave is transmitted. A coil antenna is thus a radio direction finder, it is useful in steering ships and airplanes, and also enables one to prevent interference by turning it so as not to receive the signals from a disturbing station.

Tuning and Coupling.—As explained in the last chapter, radio receiving apparatus must be so adjusted as to be in tune with the wave to be received. The alternating current produced in the receiving circuit will be greater the more nearly this circuit responds to the particular frequency of alternation that the wave has. The circuit is adjusted to respond best to the

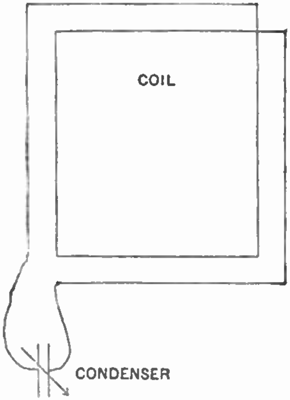


Fig. 2—Coil Antenna Circuit.

wave by varying either of the two elements, the capacity or the inductance. The process of adjusting the capacity or the inductance is called tuning. When the antenna constitutes the capacity, as in Fig. 1, the tuning is done by means of varying the inductance; and, *vice versa*, when the antenna is the inductance coil, as in Fig. 2, the tuning is done by varying the capacity of the condenser.

The diagrams shown in Figs. 1 and 2 are the foundations of all radio circuits and deserve careful study. Figure 1 in particular should be thoroughly understood, because most radio apparatus is designed for use with the elevated-wire antenna.

Tuning has another object besides getting the strongest possible response from the wave that it is desired to receive, and that is to avoid receiving any other waves of different frequency or wave lengths. It has been found that this is greatly helped by adding another circuit, which is also tuned in the same way as the first circuit. The additional circuit also consists of capacity and inductance, and is called the secondary circuit. The process by which it is connected to the antenna circuit is called "coupling." One method of coupling is shown by the diagram in Fig. 3. The inductance coil of the secondary circuit is simply placed close to the inductance coil of the antenna circuit. The magnetic effect of the latter coil gives rise to a current in the other coil. The condenser in the secondary circuit is varied until maximum current is produced. The amount of this current depends also on the position of the two coils with respect to each other.

The process of coupling may be considered as a sort of straining or filtering scheme to take in the wave

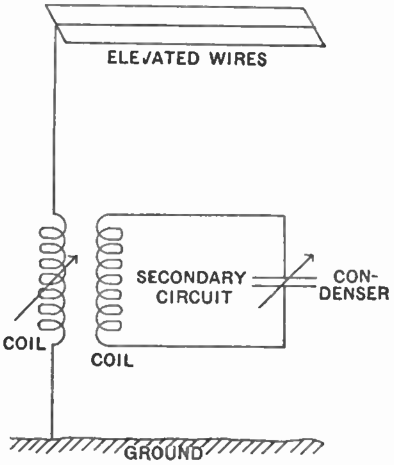


Fig. 3—Coupled Circuits to Improve Tuning.

desired and exclude others. The antenna circuit filters out the wave desired to a certain extent, by the process of tuning. This is passed on to the secondary circuit which filters once again, thus refining or purifying the received wave still further.

The Detector.—Besides receiving the radio current in an antenna and adjusting the circuits so that the current is as great as possible, there yet remains something to be done before it becomes possible to translate the received radio current into a sound that can be heard in the telephone receiver. When one of the groups of alternations shown in Fig. 10, chapter 4, acts on the telephone receiver it causes no motion of the diaphragm because each variation of the current in one direction is immediately followed by the current in the opposite direction so that the resulting effect of the group of waves upon the telephone receiver diaphragm, is no motion at all. It is therefore necessary, in order to convert the current into a sound, to use something else with the telephone receiver. This something else must be such as to make the current flow through the telephone receiver in only one direction. It must allow the electric current to flow through it in one direction and stop current which tries to flow through it in the opposite direction; that is, it must be some sort of electric valve. The effect of such an electric valve, may, perhaps be understood more clearly by taking a sheet of paper and placing it upon Fig. 10, chapter 4, so as to block out the lower half of the waves shown. This leaves only the upper halves of the little groups of waves and this is exactly what the electric valve does. The thing which acts as an electric valve is called the detector. Using it, successive impulses of current flow through the telephone receiver and all of these tiny impulses in any one group add their effects together and produce a motion of the telephone diaphragm.

Crystal Detector.—The simplest detector is a piece of crystal with a fine copper wire in light contact with it. (There are variations from this; sometimes two crystals in contact are used.) The crystal most commonly used is galena (lead sulphide). At the contact between the crystal and metal, current can flow in one direction but not in the other. When connected to a circuit, therefore, in which alternating current is flowing, it allows only the current impulses in one of the directions to flow through it. It thus has the electric valve action of which we have been speaking.

Electron Tube.—The most satisfactory and sensitive detector is the electron tube. This remarkable device, as will be shown, is not only useful as a detector but also as a high-frequency generator, as a modulator, and also as an amplifier by means of which the currents are more readily controlled and utilized. It is very satisfactory and stable in operation for all these various purposes. The basic principles of action of the electron tube are now discussed. For further study, the student is referred to "The Principles Underlying Radio Communication," Chapter 6. (See note, page 7, chapter 3).

The electron tube is a very simple device which looks more like an ordinary incandescent lamp bulb than anything else. While experimenting in the development of the incandescent lamp, Edison made the discovery that an electric current could be made to flow in the empty space inside the bulb near the hot filament. If a metal plate is placed inside of an incandescent lamp bulb near the filament (Fig. 4) and if by means of a wire through the glass this metal plate is connected by wire through a battery and an indicating instrument to the filament, a current will flow as indicated by the instrument. A current is flowing in the wire and also flowing across the empty space between the filament and the plate. By much patient scientific research, scientists have found that this current taking place in the lamp consists of the flow of a stream of very small electric particles, called electrons. These electrons are shot out into the surrounding space in all directions by the hot filament. The electrons may be said to fill the bulb like a vapor. They move at random in all directions unless there is an electric force to make them move in some particular direction. The battery connected in the circuit outside the bulb supplies an electric force which acts between the filament and plate and makes the electrons move from the filament to the plate. If the battery is disconnected, there is no current, and as many electrons as strike the plate fall off again into the bulb. The current depends on the number and speed of the electrons. The battery is what gives them their speed in the direction from filament to plate. The battery

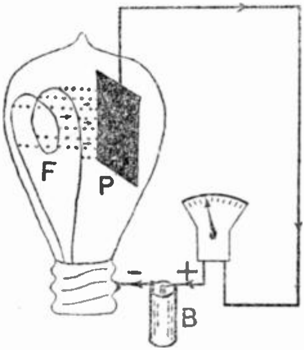


Fig. 4—Use of electron flow from hot filament (arrows show direction of electron flow, the reverse of the conventional direction of current).

performs much the same action as a pump would if the bulb were a tank into and out of which water pipes were connected. If the pump were disconnected, there would be no flow of water, and when the pump is connected, water is made to flow into and out of the tank and through the pipe.

The point of all this is that the electron flow in the bulb has a sort of valve action. The electrons are shot out from the very hot filament and can be made to flow toward the plate by connecting a battery in the proper direction. If the connections of the battery are reversed, however, no current will flow because there is no such emission of electrons from the plate, which is cold; the electric force produced by the battery in this case has nothing to work on and can do nothing except prevent the flow of electrons out of the filament to the plate. It should be clearly understood before going further that the action of the electron tube thus depends upon the fact that an electric force can be applied in one direction which causes an electric current from the filament to the plate, but that if this electric force is reversed, no current flows. The device gives exactly the rectifying action needed in order to make the received signals in radio produce sound in a telephone receiver. Suppose that the bulb shown in Fig. 4 is connected to a radio receiving circuit in place of the battery. Suppose also that the indicating instrument is replaced by a telephone receiver. This is shown in Fig. 5. The pulses of current in the receiving circuit similar to those of Fig. 10, chap. 4, produce electric force inside the bulb between the filament and plate which alternates in direction just as the pulses of current do. On account of the rectifying action, current can flow through the bulb only in one direction, and consequently

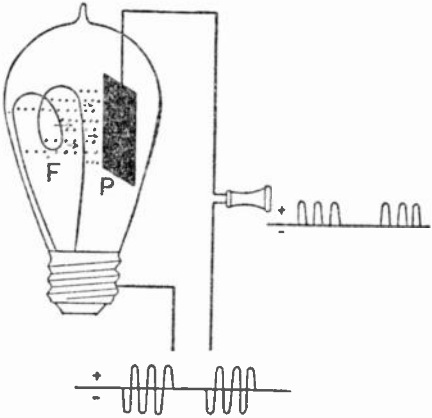


Fig. 5—Showing Principle of Detector Action.

the pulses of electric force in one direction only are effective. As a result, pulses of current flow through the telephone receiver in groups, the pulses being all in one direction. This causes a note in the telephone receiver, as already explained.

The Purpose of the Grid.—An improvement in the original electron device was made by L. De Forest, which very greatly extended its power and usefulness. As shown in Fig. 6, a grid of very fine wire is placed in the tube between the filament and the plate. The grid is placed closer to the filament than to the plate. The electrons which are emitted by the filament can move freely between the grid wires. If by means of a battery or something else an electric force is established between the filament and the grid, this electric force causes electrons to move away from the filament toward the plate, and since the grid is placed much closer to the filament. the electric force makes the electrons move much faster than would the same electric force between the filament and plate. Very few of the electrons are taken by the grid, and a very small current thus goes through the wire connected to the grid. Thus a very small current to the grid controls the flow of a much larger current to the plate. Hence a larger current can be taken out of the tube than is put into it. A small electric force acts between grid and filament, causing a large electron flow from filament to plate. There results a relatively large flow of current in the apparatus connected outside the tube between the plate and filament.

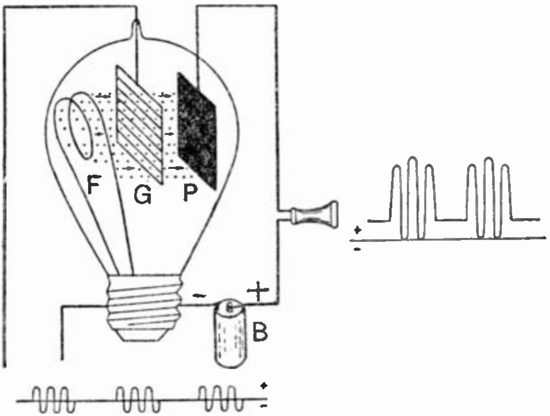


Fig. 6—Three-Electrode Tube as Detector.

This device is commonly called an electron tube. (It is also known by many other names, as vacuum tube, audion, triode, and radiotron.) It magnifies or amplifies electric currents. It accomplishes the control of a large amount of power by a small power. This is just the same thing that a gun does—pressing the trigger several times in a repeating pistol is like the action of the tube with successive pulses of electric force. The grid corresponds to the trigger, and the plate to the gun barrel.

Electron tubes which are used as detector tubes ordinarily have a slight amount of gas remaining inside. These are more sensitive than the highly evacuated tubes used as amplifier tubes, but they require more careful adjustment of the current which lights the filament and of the voltage of the battery connected to the plate circuit. On account of the fact that the adjustments are not so critical when amplifier tubes are used, many operators prefer to use them as detector tubes.

The electron tube detector has the advantage that it does not require special adjustment of a delicate contact to make it sensitive. Its sensitivity can be kept invariable, and it may also be much more sensitive than the ordinary crystal detector. The filament lighting battery or "A" battery, is usually a storage battery of about 6 volts or consists of one or more dry cells; though this depends upon the type of electron tube used. The other battery employed in connection with the electron tube, or "B" battery, usually consists of a number of small dry cells sealed in a block as a unit.

The frontispiece shows a number of electron tubes of various types designed for use as detectors, amplifiers and transmitters. The more recently developed tubes which operate on dry batteries are smaller than the others and are on this account often more convenient.

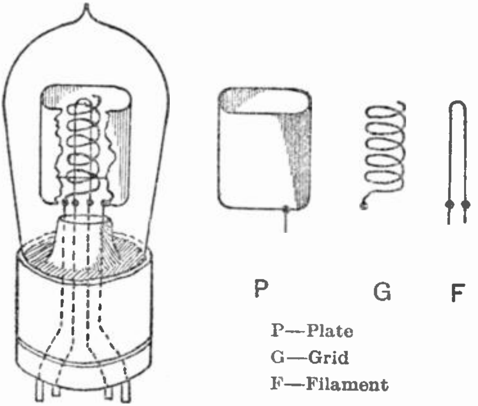


Fig. 7—Electron Tube.

In Fig. 7 there can be seen the several parts or elements of an electron tube. These are the filament, grid, and plate, mounted inside of the glass tube from which the air has been pumped. Each of these elements is separated from the other by a small space. There are two connections made to the filament, one at each of its ends. There is only one connection made to the grid and one connection to the plate. These four connections come to the four prongs on the base of the tube. The filament is surrounded by the grid, which is usually a spiral coil or lattice work. The plate is located outside of the grid and is usually cylindrical but is sometimes flat.

The construction features of tubes used as amplifiers are identical to those of the detector tubes. They differ in the degree of vacuum produced within the bulb. The amplifier tubes have a more nearly perfect vacuum than tubes suitable for detection only.

Amplifier.—On account of the control of the plate current by a smaller grid current, the electron tube makes possible some very wonderful things.

It is perfectly possible and quite easy to take the magnified output from an electron tube and pass it into a second electron tube, using that to make a still further amplification of the current. Using one tube after another in this way, we obtain what is called an amplifier. Two tubes joined together in this way are shown in Fig. 7-A and the process can be repeated several times, using a number of tubes. The current is increased by each tube and handed on to the next without any change or distortion of the current, even though it passes through several stages.

Fig. 7-A is only schematic. It is not possible, in actual practice, to run the connection directly from the plate of one tube to the grid of the next tube. The reason is that there must be a battery connected between plate and filament, and the battery must not be in the grid circuit. The battery is required to make the electrons flow to the plate, while the function of the grid is to introduce variations of the electron flow in its tube. Consequently there must be some device inserted between the two tubes which allows the battery to be inserted in the plate circuit of the first tube and passes on into the second tube only the altering or varying voltage which constitutes the signal which it is desired to amplify. This device may be a transformer or a resistance combination, as described in chapter 2, page 21.

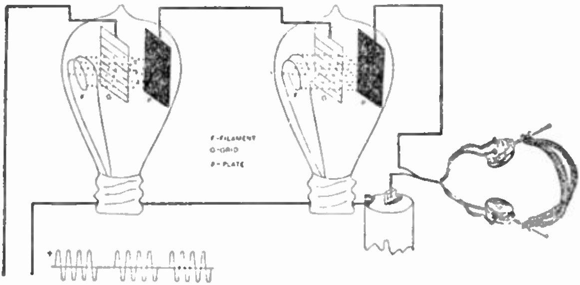
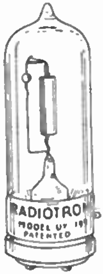


Fig. 7-A—Principle of the Amplifier.

The amplifier is of the greatest importance in radio and in long-distance wire telephony. It reduces the amount of power that must be used in a radio transmitting station, because when an amplifier is used in a receiving station, signals can be received which are far too feeble to be received without an amplifier. By means of amplifiers to which are connected loud-speaking telephones, speeches are made fully audible to all persons in a very large crowd. The large announcers used in railway stations now make use of amplifiers. By means of amplifiers, submarine vessels can receive radio messages when entirely submerged.

Tube Characteristics.—As an example for the explanation of tube characteristics we may consider the UV-199 Radiotron, a high-vacuum receiving tube. The filament operates normally at 3.0 volts and 60 milliamperes, and is designed for operation on three dry cells. Proper choice of rheostat resistance is necessary, for the life of the filament is greatly shortened by excessive voltage. When only one tube is used, the resistance of the rheostat should be about 30 ohms, and for three tubes in parallel operating on three dry cells it should be about 10 ohms.



UV-199

The life of the tube is usually ended by a decrease in electron emission. This is indicated by the necessity for increased filament voltage. The decrease is not gradual during life, but occurs over a period of a few hours at the end of the life of the filament. If by accident excessive filament or plate voltage is applied to the tube, the filament may lose its activity. Ordinarily, this activity may be restored by lighting the filament at rated voltage for twenty minutes or longer with the plate voltage off.

Van der Bijl has developed an empirical formula giving the plate current as a function of the various voltages in the tube. Thus:

$$I = \alpha(\gamma E_b + E_c + \epsilon)^2,$$

in which I is the thermionic current in milliamperes, E_b is the potential difference between the plate and filament, E_c is the voltage of the grid, and ϵ is a quantity which includes small differences of potential existing in the tube, due to surface conditions and other things; α is a structural constant.

The curve of plate current on page 13 is taken with the grid voltage zero. The curves of grid characteristics are taken for three different plate voltages. The quantity γ in the above equation has a meaning as given in the following statement taken from Phys. Rev., Vol. 47, 1918, p. 182, by Van der Bijl viz., "..from which it follows that for equivalent values of E_b and E_c, a change in the anode (plate) voltage E_b produces γ times as great a change in the current to the anode as an equal change in the grid voltage E_c." That is to say, a change on the plate would have to be γ times the voltage change on the grid that is required to produce a given change in the plate current. The voltage amplification factor is the reciprocal of this quantity; that is $\mu_o = 1 / \gamma$.

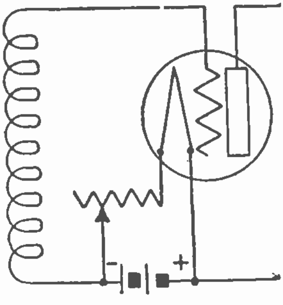
If the two sets of curves be plotted to the same scale, it will be noticed that the grid curves will be much steeper than the plate curve, indicating that a much smaller voltage change is required on the grid than on the plate to produce a given change in plate current. The ratio of the two voltages required to produce this given current variation is the voltage amplification factor; that is, the ratio of the slopes of the straight portions of these curves is the amplification factor.

The amplification factor of this tube varies from 6 to 6.25. Taking the average value, 6.12, we have $\gamma = 1/6.12 = 0.164$. The curves have been obtained experimentally. If we substitute the values of the co-ordinates of two points on the straight portion of the plate characteristic in the above equation, and solve simultaneously, putting E_c equal to zero, we obtain for the other constants $\epsilon = 3.28$ volts and $\alpha = 0.0134$. The resulting equation of the curve is, then,

$$I = 0.0134\,(0.164\,E_b + E_c + 3.28)^2.$$

The working portion of this curve is only from 40 to 100 volts; it must not be expected that the equation will hold over other portions of the curve. Over this part, then, the plate current may be calculated from this equation for various plate voltages.

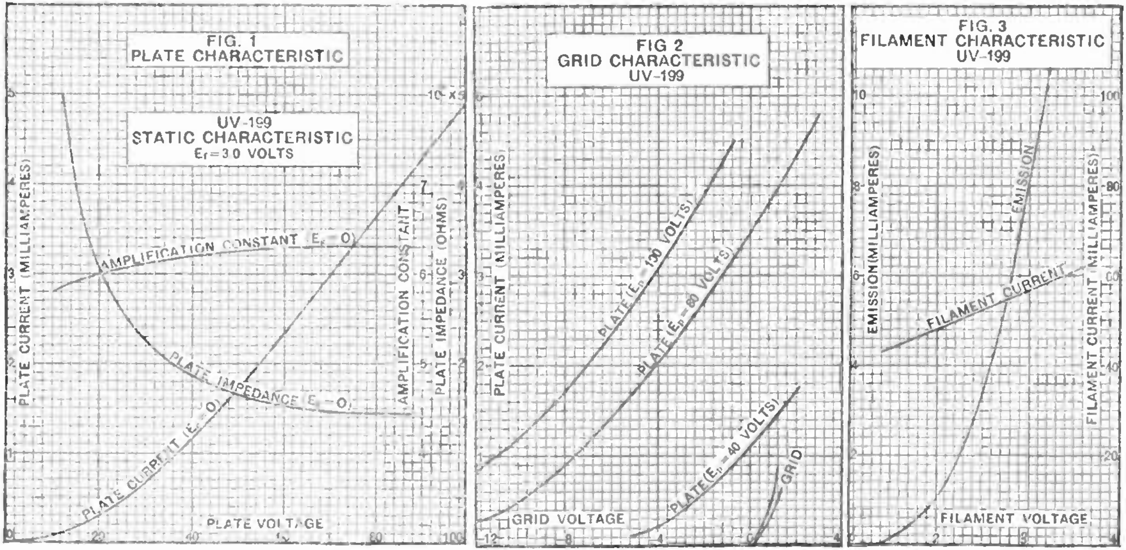
If any electrons are diverted in their motion away from the filament toward the grid, a grid current will result which will lower the amplification factor and cause losses of energy in the grid circuit. The tube will then not operate completely as a voltage-controlled device. This grid current can take place only when the grid is positive. It is necessary, therefore, to take care that the grid never becomes positive by subjecting it to a sufficiently great negative bias.



Reference to the grid curves will illustrate this point. Operating on a plate voltage of 40 volts, the curve intersects the zero axis of grid voltage at its lower bend, which means that we do not require a grid bias at that plate voltage. For voltages of 80 or 100 on the plate detector, action can be secured only by obtaining a grid bias of about 8 to 10 volts negative. It is not well to work with such high grid voltages, so for detector action it is best to use a plate voltage of about 40.

When the tube is to be used as an amplifier, plate voltages up to 100 may be used if a proper grid bias is provided. If the connection shown in the accompanying diagram is used, a bias will be furnished equal to the voltage drop in the filament. This amounts to from 0.5 to 1.0 volt, and is sufficient when the plate voltage is not greater than 40 and the signal voltage applied to the grid is relatively small.

In general, the grid bias required, or "C" battery voltage, should have a negative value which is in excess of the maximum instantaneous positive value of the oscillating potential placed on the grid in receiving



Characteristic Curves of UV-199

radio signals. As a consequence, the grid bias required rises from one stage to the succeeding ones. In the first stage, or in the detector, no special means of furnishing the bias may be required, a grid condenser furnishing sufficient bias, or the internal capacity between the grid and filament may be sufficient in many cases.

In general, the following negative grid bias voltages are suitable:

40 volts plate	0.5–1.0
60 volts plate	1.0–3.0
80 volts plate	3.0–4.5
100 volts plate	4.5–6.0

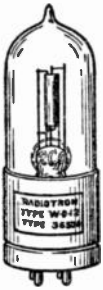
The filament curve shows the relation between the current through the filament and the voltage across the terminals of the filament, E_a. If the voltage of the "A" battery is V and the resistance of the rheostat is R, then $E_a = V - RI_a$, in which I_a is the current through the filament. This curve is a straight line, since it follows Ohm's law, viz., $I_a = E_a/R$.

The UV-201-A Radiotron is a high-vacuum tube for receiving, designed for use as a detector or amplifier. It may also serve as an oscillator for small outputs such as are used for heterodyne reception.

UV-201-A

For operation of the tube as a detector, the return lead from the grid should be connected to the positive side of the filament, and a grid condenser of 0.00025 microfarad and leak of from 2 to 10 megohms are recommended. A voltage of 40 is to be used on the plate. Slightly better detector action may be secured at higher voltages at the expense of higher plate current and consequent shortening of life.

When used as an amplifier, voltages up to 100 may be used if the proper grid bias is provided. The connections for the filament rheostat and battery and grid return should be as shown in the figures on page 17. The rheostat is placed in the negative battery lead and the grid return connected directly to the negative side of the battery. This furnishes a negative voltage on the grid equal to the drop in the filament. This amounts to 0.5 to 1.0 volt, and is sufficient when the plate voltage is not greater than 40 and the signal voltage applied to the grid is relatively small. For greater amplification and for strong signals, higher plate voltages should be used and negative bias provided by the use of one or more dry cel s in series with the grid. In general, the negative grid bias voltages given above for U.V. 199. are suitable:



Radiotrons WD-11 and WD-12 are designed to operate either as detectors or amplifiers. They are identical except for the base, the WD-11 having a special type, while WD-12 is equipped with the standard base.

When a WD tube is used as a detector, the grid return should be connected to the positive end of the filament. A grid condenser of 0.00025 microfarad and grid leak from 2 megohms up are necessary with this connection. Any plate voltage from about 16 to 50 volts may be used. The tendency to oscillate is greater at the higher voltages, so that a value about 22.5 volts is usually found best.

As an amplifier, WD tubes will operate through quite a wide range of plate voltage, but best results will be obtained with voltages between 45 and 120. It is possible to use higher plate voltages than this if care is taken to keep the grid sufficiently negative. When only 22.5 volts are used, no separate "C" battery is required. In general, the following negative grid bias voltages are suitable:

40 volts plate...1.0–1.5	80 volts plate...3.0–4.5
60 volts plate...1.5–3.0	100 volts plate...4.5–6.0

The UV-200 Radiotron was designed primarily as a detector.

When used as a detector, the filament of the UV-200 should be operated at constant voltage, because good detector action takes place only approximately at the correct value. Close variation of the plate potential is necessary for satisfactory performance. Since the tube was designed for a plate voltage of 18 to 23.5, a 22-volt block battery may be used to advantage. In some cases plate voltage steps of 1.5 volts (or the taps from consecutive dry cells) are sufficient, the adjustment being secured with the filament rheostat if it is continuously variable. A grid leak of approximately 0.5 megohm is recommended with a grid condenser of approximately 0.00025 μf., although results may be obtained without a grid leak and condenser. The grid return should always be to the negative filament lead.

These tubes when operated with —1.5 volts on the grid and 25 to 30 volts on the plate act as amplifiers. The plate voltage is not critical within 2 or 3 volts. The amplification with most tubes increases rapidly with plate voltage until a point is reached where there is a distinct maximum, this being at about 27 volts. Above this point, violent ionization occurs and the amplification decreases to a very low value.

The following table and the accompanying diagrams will be of use in the selection of electron tubes and in their proper connection in receiving circuits when used as detectors and when used as amplifiers. Data on the rheostats and batteries for the tubes are given in chapter 2, Part C.

The mutual conductance of an electron tube is the amplification factor divided by the output resistance. It is a better criterion of the effectiveness of the tube than either of its constituent factors alone.

Most of the receiving tubes now on the market may be used either as amplifiers or as detectors. The return connection from the grid circuit to the filament battery should be different in the two cases. When used as a detector, the grid circuit should be connected to the positive end of the filament, as shown in sketch. When used as an amplifier, the grid circuit should be connected to the negative terminal of the filament battery with the filament rheostat connected between this point and the negative terminal of the filament.

Receiving Tubes

Type	Filament		Plate		Amplification Factor	Output Resistance Ohms	Mutual Conductance Micromhos
	Volts "A"	Amperes	Volts "B"	Amperes			
*UV-199, C-299	3.0	0.06	40	0.0009	6.2	19,600	315
UV-200, C-300	5.0	1.0	20	0.0003	......	10,000	....
UV-201, C-301	5.0	1.0	40	0.0009	6.0	22,000	273
UV-201-A, C-301-A	5.0	0.25	40	0.0007	6.5	15,400	345
*WD-11, C-11	1.1	0.25	40	0.0012	5.2	17,500	290
WD-12, C-12	1.1	0.25	40	0.0012	5.2	17,500	290
*French	3.8	0.70	40	....	7	30,000	230
DV-6A	2.7	0.3	22–45	....	6.5	25,000	260
*215A, N, VT-5	1.1	0.25	40	0.0008	6.5	18,500	350
‡216A	6	1.0	125	0.011	6	4,400	1360
VT1, 203B	2.5	1.1	40	0.001	7.5	15,000	430
†VT2, 205B, E	7	1.35	350	0.055	7	2,800	2500

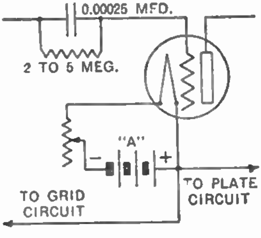
Power Tubes

Type	Filament		Plate		Amplification Factor	Output Watts
	Volts "A"	Amperes	Volts "B"	Amperes		
UV-202	7.5	2.35	350	0.050	7.5	5
UV-203	10.0	6.50	1000	0.150	15.0	50
UV-203A	10.0	3.25	1000	0.125	25.	50
UV-204	11.0	14.75	2000	0.250	20.	250
UV-204A	11.0	3.85	2000	0.200	25.	250
UV-206	11.0	14.75	10000	0.125	250.	1000
UV-207	22.0	52.00	15000	1.800	40.	20000
UV-208	22.0	24.50	15000	0.450	300.	5000

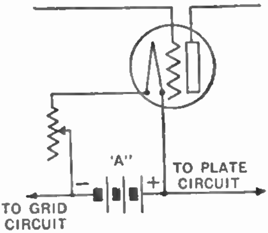
*Special base. All other receiving tubes in this list fit the standard base.
†May be used also as a transmitting tube.
‡Used as power amplifier.

Most of the information in the above table is taken from material supplied by the manufacturers of the tubes. While individual tubes differ somewhat in their characteristics, the figures here given are believed to be fairly typical of tubes of these types.

If a higher voltage is used in the plate circuit of an amplifier tube than that given in column 4 of the above table, it is desirable to use an additional voltage or "C" battery in the grid circuit. About one volt of "C" battery should be used for each ten or fifteen volts

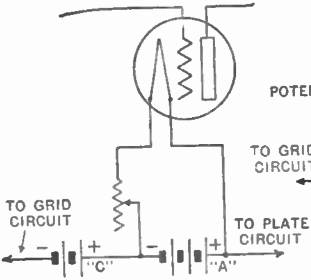


Detector Connection.

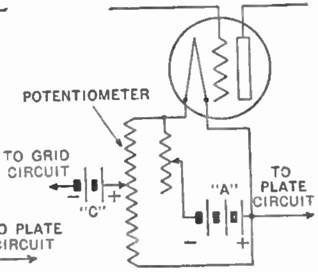


Amplifier Connection.

increase in "B" battery above that given. Not more than 100 volts "B" battery nor 6 volts "C" battery should ordinarily be used. The "C" battery (sometimes called the grid bias battery) should have its negative terminal connected to the grid circuit and its positive terminal connected to the negative terminal of the filament "A" battery, as shown in sketch. If a potentiometer is used as a method of controlling this grid voltage, the connections should be made as shown.



Grid Battery Connection. for Amplifiers.



Potentiometer Connection. for Grid Voltage Control.

In the case of a soft tube used with grid condenser, the presence of gas in the tube causes the input impedance to be considerably lower than that of the harder tubes. There is, therefore, the tendency for grid current to flow at much lower positive voltage. For this reason, best results are obtained by placing a negative bias on the grid, that is, by connecting the grid return to the negative side of the "A" battery instead of the positive side recommended above.

Sometimes the application of an excessive filament or plate voltage causes a tube to become inoperative without actually burning out the filament. It can in some cases be restored by lighting the filament at the rated voltage for ten to twenty minutes with the plate or "B" battery entirely disconnected.

Recent Developments in Receiving Tubes.—A receiving tube which dispenses with all batteries and operates with entire success on alternating current from the ordinary electric light socket has been developed by the General Electric Co; it is not yet on the market. This tube has the usual grid and plate, but the filament is replaced by a metal cylinder. This cylinder is the source of electrons for the regular functioning of the tube, and it is heated by radiation from an auxiliary filament inside it. The plate voltage is supplied by rectification of the alternating supply voltage connected between the auxiliary filament and the cylinder. The tube has higher amplification and detection constants than the ordinary receiving tubes. It is expected that receiving sets using these tubes for detector and several amplifier stages will become available.

Regeneration.—An electron tube may act as a detector and an amplifier simultaneously; that is, the output from the detector tube, instead of being connected to a second tube, may be connected back to the input of the detector tube itself. The current is then amplified in the tube and the process repeats itself. This results in enormous increase in the sensitiveness of the detector. The process of feeding back the output to the input circuit is called "feed-back" or "regeneration," and the principle is shown in Fig. 8. The radio-frequency input circuit consisting of the (coil of wire) inductance L_1 and the (condenser) capacity C is connected to the grid and filament of the electron tube. Between the plate and filament there is connected, besides the telephone receivers and battery, the inductance L_2. This is placed close to inductance L_1, and the magnetic field caused by the current in it reacts on L_1, increasing the current in it. This current in L_1 then flows to the grid and is amplified in the tube. The amplified current flowing in the inductance L_2 again reacts on L_1, and so the process is repeated over and over. These repetitions are simultaneous, and the net result is very greatly increased output current in the plate circuit and hence in the telephone receivers. There are other methods of connection, but the principle is the same.

Radiation from Regenerative Sets.—It is possible that some of the records of very long-distance reception (though quite certainly not all), when crystal detector receiving sets are used, have been made possible because of the reradiation of signals from regenerative

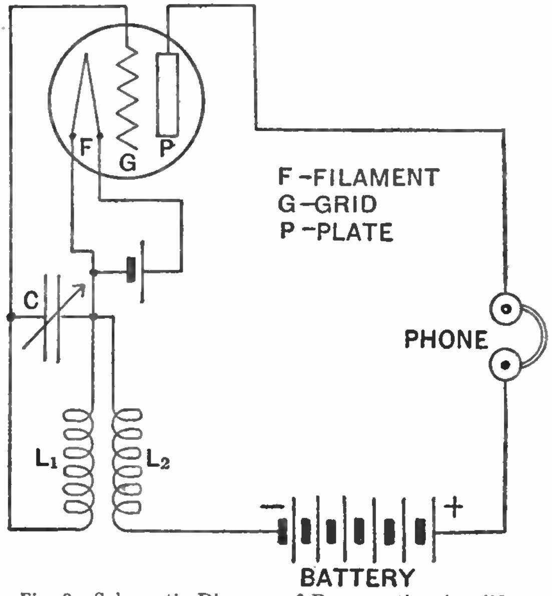


Fig. 8—Schematic Diagram of Regenerative Amplifier.

receiving sets. If a regenerative receiving set is adjusted to the condition where it is receiving signals from a distant station and is generating current in the antenna, signals are retransmitted from the antenna in the form of radio waves and may be received by comparatively insensitive receiving sets nearby. Thus, a person having a crystal detector set, located near to another receiving station which uses a regenerative set adjusted as described above, may receive broadcast service from distant stations to which the operator of the regenerative set may tune, but does not receive from other distant stations to which that set is not tuned.

While this is temporarily convenient for the operator of the simple set it does not make for satisfactory broadcast service, since the distant reception ceases for both as soon as the operator of the regenerative set readjusts or turns off his set, while the interference caused by the regenerative set may make it impossible for many persons to receive local broadcast service which they may desire to hear.

Resonance.—In any electric circuit, the value of the current flowing through the circuit depends upon the voltage impressed and the resistance of this circuit to the flow of current. In other words, the value of the current may be expressed as the voltage divided by the resistance. This relation holds true whether the current be direct or alternating, high frequency or low frequency. The difference in the several cases lies in the value of this resistance. For alternating currents it is known as the **impedance**, which includes the direct current resistance as well as the resistance offered by inductances and capacities. These latter are known as **inductive reactances** and **capacitive reactances.**

The formula for direct current is $I = E/R$; for alternating currents it is $I = E/Z$, in which I is the current in amperes, E the voltage in volts, R the resistance in ohms and Z the impedance in ohms. For resistance R, inductance L, and capacity C, in series,

$$Z = \sqrt{R^2 + (6.28\,fL - 1/6.28\,fC)^2}.$$

From a study of this formula it will be seen that I will be a maximum when Z is least. In other words, Z will be least when the term in the parenthesis equal zero. Using suitable units, and solving for f, we obtain:

$$f = \frac{159.3}{\sqrt{LC}}$$

when L (the inductance) is given in microhenries, C (the capacity) in microfarads and f in kilocycles per second.

The quantities $6.28\,fL$ and $1/6.28\,fC$ are the **inductive** and **capacitive reactances.** In the same units as above these may be written

$$X_c = -\frac{159.3}{fC} \qquad X_L = .00628\,fL,$$

where X_c = capacitive reactance and X_L = inductive reactance.

The condition for maximum current is that the impedance is least, or $X_L = X_c$, and is known as **resonance.**

The values of inductance and capacity, which, together, will give resonance with a given frequency or wave length are shown in Fig. 9 below. These curves have been constructed for the condensers available, viz., 0.001 and 0.0005 μf. It is noticed that the intersection of the broken lines drawn from the 800-meter division for the wave length and from the 415 μh division for the inductance, lies in the vicinity of the curve for the 0.0005 μf condenser.

Variable condensers all have minimum values of capacity; that is, the capacity is not zero when the reading on the condenser dial is zero. We have assumed in this case that the minimum capacity of the 0.0005 condenser is 0.00005 μf. The dotted line on the chart immediately shows that the lowest wave length this combination of variocoupler and condenser will tune to is 270 meters. This value can be arrived at by using the formula $\lambda = 1884\sqrt{LC}$, in which L is

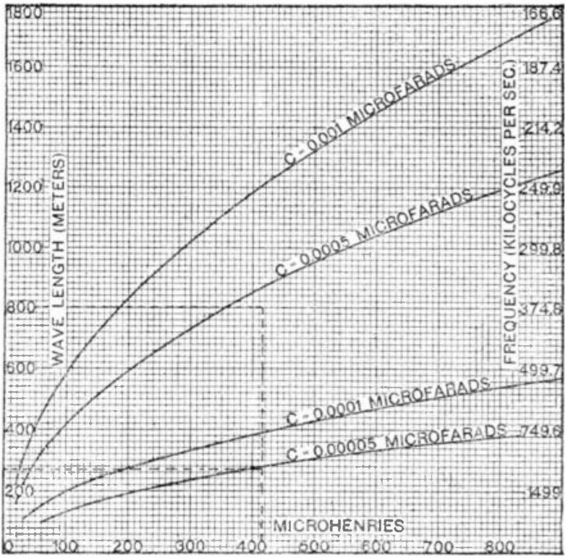


Fig. 9

415 μh and C is 0.00005 μf. Similar curves are drawn on the chart for the 0.001 μf condenser. These two condensers are generally known as the 23- and 43-plate condensers.

Calculation of Capacity.—For use in making computations there are given below a number of formulas for calculating the capacity of condensers of various forms. The formulas are given without any explanation as to their derivation. Where complicated factors occur, tables are given showing the values of these factors through ranges most suitable for amateur and broadcasting use.

All lengths are expressed in inches and feet, as specified, and the areas correspondingly. The capacities are given in microfarads.

Capacity of Parallel Plate Condenser.—S is the area of one plate; N, the number of plates; D, the distance between them; K, the dielectric constant of the material between the plates. S is in square inches and D in inches.

$$C = 2.246\ K \frac{S\,(N-1)}{D} \times 10^{-7}\ \mu f. \qquad (1)$$

Values of K (Dielectric Constant)

Air	1.0
Glass	4 to 10.
Mica	4 " 8
Hard rubber	2 " 4
Paraffine	2 " 3
Paper	1.5 " 3
Sulphur	3 " 4.2
Shellac	3 " 3.7
Wood, maple, dry	3 " 4.5
Wood, oak, dry	3 " 6
Molded insulating material, shellac base	4 " 7
Molded insulating material, phenolic base ("Bakelite")	5 " 7.5
Vulcanized fiber	5 " 8
Castor oil	4.7

Maximum Capacity of a Variable Condenser of Semi-Circular Plates:

$$C = 3.53K \frac{(N-1)\,(r_1^2 - r_2^2)}{D} \times 10^{-7}\ \mu f, \qquad (2)$$

in which r_1 is the outside radius and r_2 is the inner radius of the plates. The other symbols are as given above. (r_1, r_2 and D in inches.)

Capacity of Two Co-axial Cylinders.—This is included because of the newly aroused interest in Hazeltine's neutralizing capacity, which consists of two wires separated at their ends by a narrow space and having a co-axial cylinder around them. The combination of condensers in this arrangement may be considered as represented in Figure 10.

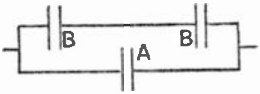


Fig. 10

The capacities represented as B are the co-axial capacities, and that represented as A is the capacity between the two end surfaces of the wires.

$$C = kl \times 10^{-6}\ \mu f, \qquad (3)$$

where l is the length and k is a constant as given in the following table. r_1 and r_2 are the radii of the outer and inner cylinders.

r_1/r_2	k	r_1/r_2	k	r_1/r_2	k
1.01	142.5	1.10	14.8	2	2.04
1.02	71.3	1.2	7.75	4	1.02
1.04	36.1	1.4	14.33	6	.79
1.06	24.2	1.6	13.00	8	.68
1.08	18.4	1.8	2.40	10	.61

The values of k in the table have been calculated from

$$k = \left[(0.2416 \div \left(\log_{10} \frac{r_1}{r_2} \right) \right] \times 2.54$$

Capacity of a Long Wire Parallel to the Ground.—For a length greater than four times the height,

$$C = \frac{0.614\,l}{(x_1 - k_1)} \times 10^{-6}\ \mu f. \qquad (4)$$

For a length less than four times the height,

$$C = \frac{0.614\,l}{x_2 - k_2} \times 10^{-6}\ \mu f. \qquad (4a)$$

Values of the constants are given in the following table; h/l, l/h, l/d, and h/d are ratios between the length of the wire, the height above the ground, and the diameter of the wire. The tables are good for lengths up to about 100 feet and for wire sizes Nos. 10, 12 and 14. The values in the table below for x_1, x_2, k_1, k_2, have been computed from the expressions

$$x_1 = \log_{10} \frac{4h}{d} \qquad k_1 = \log_{10}\left[\frac{1+\sqrt{1+\left(\frac{4h}{l}\right)^2}}{2}\right]$$

$$x_2 = \log_{10} \frac{2l}{d} \qquad k_2 = \log_{10}\left[\frac{l}{4h} + \sqrt{1+\left(\frac{l}{4h}\right)^2}\right]$$

h/l	k_1	h/d	x_1	h/l	k_2	l/d	x_2
0.9	.444	1,600	3.806	9	.673	12,000	4.380
.8	.453	1,400	3.748	8	.627	10,000	4.301
.7	.531	1,200	3.681	7	.576	8,000	4.204
.6	.620	1,000	3.602	6	.518	6,000	4.079
.5	.656	800	3.505	5	.455	4,000	3.903
.4	.740	600	3.380	4	.382	2,000	3.602
.3	.851	400	3.204	3	.301	1,000	3.301
.2	1.02	200	2.903	2	.209	800	3.204
.1	1.31	100	2.602	1	.107	600	3.079

All measurements should be made in inches.

Capacity of a Vertical Wire.—The formula given above for the capacity of a single horizontal wire whose length is less than four times its height, omitting the k_2 in the denominator, is sometimes used to calculate the capacity of a vertical wire. It applies accurately only when h is large compared with l, and gives very rough values for a vertical single-wire antenna, the lower end of which is connected to apparatus at least several yards above the ground.

Capacity of Various Types of Antennas.—The theoretical formulas that have been evolved for the capacity of types of antenna other than the single-wire are very involved and difficult to handle. A formula has recently been derived empirically which gives the capacity of antennas of all shapes not too elongated or having the wire too widely spaced.

$$C = \left[1.22\sqrt{a} + 0.27\frac{a}{h}\right] \times 10^{-5}\ \mu f, \qquad (5)$$

in which a is the area of the top of the antenna in sq. ft. and h is the actual mean height above the ground in ft.

For a very long antenna having a length greater than eight times its breadth, the above formula must be multiplied by the **elongation factor** $(1+0.01/b)$, (6) where b is the breadth of the antenna in feet. This equation is accurate to about 10% for antenna tops. The capacity of the lead-ins, etc., must be estimated. The poorest agreement between the calculated and experimental values is in the case of umbrella antennas. The quantity a is the area enclosed by the bounding wires of the antenna.

The estimation of the capacity of the lead-in wires from an antenna is a very difficult matter, due to the fact that very often we do not know the length and other characteristics of the ground lead. If the apparatus happens to be located in an upper story of a building or residence and the set grounded through the water system, it can be seen what an impossible problem we have at hand. Accurate calculation of the antenna constants is possible only when a special ground lead to a pipe or plate buried in the ground is used. In this case the capacities of the antenna top and lead-in wire are calculated separately and combined by the formula for condensers in parallel, viz.,

$$C = C_h + C_v,$$

in which C_h is the capacity of the horizontal or top portion and C_v is the capacity of the vertical portion or lead-in.

The **mutual capacity** of two parallel wires is the capacity of these two wires, regarded as a single system, with respect to the earth as the other plate of the condenser. The mutual capacity is not the same as the capacity of the two wires regarded as the two plates of a condenser, and the capacity of the two-wire system is not twice the capacity of each wire by itself with respect to the earth. As a matter of fact, it is less. The normal electric field of one of the wires overlaps the normal electric field of the other. The total capacity of these two wires to earth is diminished to some extent by this overlapping.

The capacity of a two-wire antenna with respect to the earth is twice the capacity to earth of one of the wires, less the mutual capacity of the two wires. In general, although each added wire adds something to the total capacity, it adds much less than the capacity it would have alone in the same position.

The use of all these formulas will give only an approximate idea of the capacity of an antenna, as, even in the simplest cases, the presence of houses, trees and other neighboring objects, and the difficulty of allowing for the lead-in wire, makes any precise calculation impossible.

Self-Inductance of Single-Layer Coils.—Nagaoka's formula for computing the self-inductance of single layer coils is:

$$L = 0.03948 \frac{n^2 r^2}{l} K.$$

Here n = total number of turns of wire; r = radius of the coil; l = length of the coil; K = elongation factor. If all the lengths are in centimeters, the self-inductance is given in microhenries. The nature of the elongation factor is explained as follows: Without this factor the equation is:

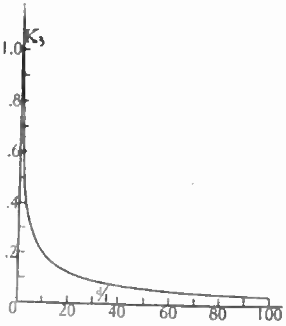
$$L = 0.03948 \frac{n^2 r^2}{l}$$

This formula assumes that when a current is passed through the coil and a magnetic field set up, all the magnetic lines of force pass through the coil from one end to the other without any of them escaping to the outside between the turns of the coil. This leakage causes a diminution of the inductance of the winding. which becomes quite appreciable as the diameter of the coil increases in proportion to the length.

Diam./Length	K	Diam./Length	K	Diam./Length	K	Diam./Length	K	Diam./Length	K
0.00	1.0000	2.00	0.5255	4.00	0.3654	8.00	0.2366	30.0	0.0910
0.10	0.9588	2.10	.5137	4.20	.3551	8.50	.2272	35.0	.0808
0.20	.9201	2.20	.5025	4.40	.3455	9.00	.2185	40.0	.0728
0.30	.8838	2.30	.4918	4.60	.3364	9.50	.2106	45.0	.0664
0.40	.8490	2.40	.4816	4.80	.3279	10.00	.2033	50.0	.0611
0.50	0.8181	2.50	0.4719	5.00	0.3198	10.0	0.2033	60.0	0.0528
0.60	.7885	2.60	.4626	5.20	.3122	11.0	.1903	70.0	.0467
0.70	.7609	2.70	.4537	5.40	.3050	12.0	.1790	80.0	.0419
0.80	.7351	2.80	.4452	5.60	.2981	13.0	.1692	90.0	.0381
0.90	.7110	2.90	.4370	5.80	.2916	14.0	.1605	100.0	.0350
1.00	0.6884	3.00	0.4292	0.00	0.2854	15.0	0.1527	......	......
1.10	.6673	3.10	.4217	6.20	.2795	16.0	.1457	......	......
1.20	.6475	3.20	.4145	6.40	.2739	17.0	.1394	......	......
1.30	.6290	3.30	.4075	6.60	.2685	18.0	.1336	......	......
1.40	.6115	3.40	.4008	6.80	.2633	19.0	.1284	......	......
1.50	0.5950	3.50	0.3944	7.00	0.2584	20.0	0.1236	......	......
1.60	.5795	3.60	.3882	7.20	.2537	22.0	.1151	......	......
1.70	.5649	3.70	.3822	7.40	.2491	24.0	.1078	......	......
1.80	.5511	3.80	.3764	7.60	.2448	26.0	.1015	......	......
1.90	.5379	3.90	.3708	7.80	.2406	28.0	.0959	......	......

To correct for this leakage, we resort to multiplication by the elongation factor, K, which is a function of the ratio d/l. Nagaoka has computed values of K, which are given in the preceding table.

The graph below has been plotted from this table, and shows how the correction factor itself varies with the length and diameter. The construction of alignment charts to determine graphically the values of the inductance requires that this curve when plotted on logarithmic paper be assumed an approximate straight line. Consequently the inductance as obtained therefrom is approximate.



The table of inductances is nothing more than the solution of this formula for a great number of coils of various diameters and lengths. No approximations have been made and the values given may be considered as correct within the limitations of the slide-rule.

The method of using the table is as follows: Let us assume that we have a coil 8 cms. in diameter, 12 cms. long, and wound with No. 24 enameled wire. The self-inductance is then, from the table, 1750 microhenries. Or, let us suppose that we wish to construct a coil of No. 22 single-covered cotton wire, 10 cms. in diameter, having an inductance of 750 microhenries. The table immediately gives a length between 8 and 10 cms. long. If it is desired, a closer approximation to the length may be obtained by interpolation. Thus, the difference between the values for 8 and 10 cms. length is $1035 - 722 = 313$. The difference between 722 and 750 is $750 - 722 = 28$. There is a difference of 2 between 8 and 10. The coil must be longer than 8 cms. by the amount $(28/313) \times 2 = 0.0179$, or the length is $8 + 0.0179 = 8.0179$ cms. To find the total number of turns required, multiply the length by the value given in the column headed "turns per cm." Thus there are required in the above case $8.0179 \times 12.36 = 99$ turns.

Although the inductance may be determined by an exact method, there are other factors entering which complicate matters considerably. These are the distributed capacity of the winding, and the resistance, which changes appreciably with the frequency.

The voltage drop between the terminals of the coil is the sum of all the drops of voltage between the turns. Any two turns of the coil have a difference of potential between them, and they act as the two plates of a condenser. This capacity is distributed in small bits throughout the length of the coil. When the frequency of the current is low, the reactance due to this capacity is large and decreases as the frequency is increased. This can be seen from the relation

$$X_c = \frac{159.3}{fC}$$

where X_c is the capacitive reactance in ohms, f is the frequency in kilocycles per second, and C is the capacity in microfarads.

These small capacities between the turns of a coil are of such importance in radio design and measurements that a coil can seldom be regarded as a pure inductance. The effect of this distributed capacity is ordinarily negligible at low frequencies, but it modifies greatly the behavior of a coil at radio frequencies. For most purposes a coil can be considered as an inductance with a small capacity in parallel with it. Investigations have shown that in ordinary coils the magnitude of this capacity does not vary with frequency. Thus a coil may in itself constitute a complete oscillating circuit even when the ends of the coil are open.

The variation of the resistance of a coil with frequency also becomes an important factor when dealing with such high frequencies, although its effect on the apparent inductance is such that it tends to neutralize the effect of distributed capacity of a coil. These points will be brought out below.

If such a coil be placed in a circuit with an e.m.f. in series, the case is one of parallel resonance, and the apparent inductance of the coil is given by

$$L_a = \frac{L(1-\omega^2 LC)}{(1-\omega^2 LC)^2 - \omega^2 R^2 C^2} - \frac{R^2 C}{(1-\omega^2 LC)^2 - \omega^2 R^2 C^2}$$

in which L is in henries, C in farads, and R in ohms; ω is equal to 6.28 times the frequency in cycles per second.

If the resistance is considered negligible, this may be written:

$$L_a = L(1 + 39.48\, f^2 C_0 L \times 10^{-6}) = L\left(1 + 3550000\, \frac{C_0 L}{\lambda^2}\right),$$

in which L_a is the apparent inductance in microhenries, L is the calculated (or measured by d-c. methods) inductance, f is the frequency in kilocycles per second, and C the capacity of the coil in microfarads.

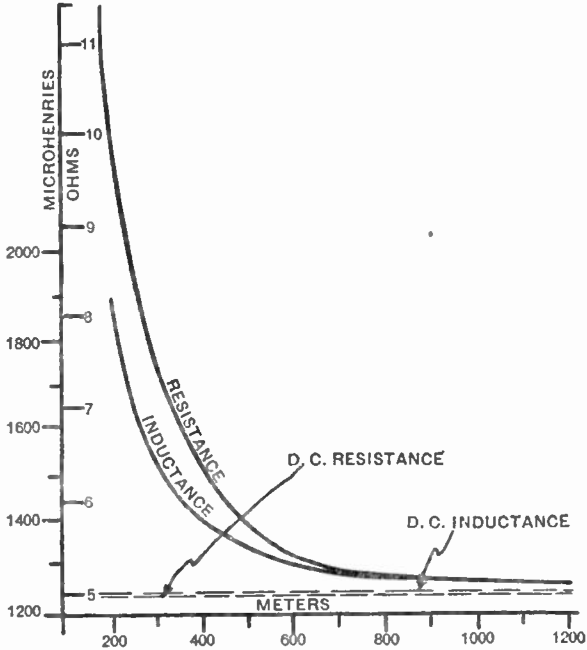
It is thus seen that the effect of distributed capacity is to cause an increase in the inductance of the coil. The capacity itself is not calculable directly, but its value may be determined by applying these formulas to resonance methods of measurement.

The formulas also show the variation in the resistance of the coil with changes of frequency. Increases in resistance or skin effect diminish the apparent inductance of the coil.

The inductance of a coil is decreased by skin effect and increased by capacity. The two tend to neutralize each other, and, in general, Nagaoka's formula, and the table, give as good values of self-inductance as can be obtained.

The chart on page 28 shows how the apparent inductance and resistance vary with the frequency or wave length. These curves are for a coil whose true d-c. inductance is 1250 microhenries, having a distributed capacity of 3.9×10^{-6} microfarads.

It will be noted that as the frequency is decreased, or the wave length increased, the apparent inductance decreases, having a limiting value at zero frequency equal to the true d-c. value of inductance. Likewise the effective resistance decreases as the frequency decreases, its limiting value being the value of the d-c. resistance.



An important state of affairs obtains when the frequency is the same as the natural frequency of the coil with its shunted distributed capacity. In the first equation for the apparent inductance, if the resistance is neglected, if $1/LC$ be substituted for its equal, ω^2, which is the case for resonant conditions, the apparent inductance becomes infinite. Consequently, the reactance of the coil would become infinite. This never happens in ordinary radio circuits, since the resistance of the coil at that frequency must become almost equal to zero for this to take place. The same reasoning, however, that applies to coils with distributed capacity applies to an inductance shunted by an actual condenser, as in the case of wave filters.

SELF-INDUCTANCE OF SINGLE-LAYER COILS (MICROHENRIES)

Wire Size and Insulation: Cotton, Double	Cotton, Single	Silk, Double	Silk, Single (enamel)	Diam. Mils	Turns per Inch	Turns per cm.	d=4 (cms.) Length (cms.) 4	6	8	10	12	14	d=6 (cms.) Length (cms.) 4	6	8	10	12	14	d=8 (cms.) Length (cms.) 4	6	8	10	12	14
20				42.161	23.72	9.33	38	63	90	117	149	174	73	127	185	244	304	364	115	206	302	403	507	607
	20			37.861	26.41	10.39	45	76	108	139	172	204	88	152	221	291	364	435	138	246	361	482	607	725
		20		36.161	27.66	10.89	50	88	123	159	196	234	100	174	253	333	415	497	157	281	413	552	695	830
22				35.547	28.13	11.08	53	90	127	165	203	241	104	181	262	342	428	514	163	291	427	570	717	857
			20	34.261	29.18	11.49	57	96	136	177	218	260	112	196	281	370	460	552	175	312	457	612	770	922
	22			31.247	31.40	12.36	66	111	157	205	251	300	129	224	325	427	531	637	202	381	529	707	890	1065
24				30.300	33.01	13.00	73	123	174	226	279	332	143	248	359	474	590	707	225	400	586	784	987	1180
		22		29.547	33.85	13.33	77	129	183	238	293	448	150	260	377	497	617	740	235	420	616	822	1032	1232
			22	27.647	36.16	14.24	88	148	209	272	334	399	172	298	431	569	705	847	269	480	702	941	1181	1415
26				26.140	38.25	15.05	98	165	234	304	374	446	192	332	483	636	790	950	301	535	787	1055	1320	1582
	24			26.000	38.46	15.12	99	166	235	305	376	447	193	335	486	644	796	952	302	545	792	1057	1332	1590
		24		24.300	41.15	16.17	114	191	271	351	431	500	221	384	559	735	912	1092	347	619	912	1215	1527	1822
28				22.841	43.78	17.23	129	217	306	399	489	582	250	435	632	832	1032	1245	392	701	1057	1377	1731	2071
			24	22.401	44.65	17.55	134	225	318	412	507	605	260	452	656	867	1071	1290	408	727	1100	1429	1750	2150
	26			21.840	45.78	18.01	140	236	334	434	535	636	273	475	690	907	1130	1355	429	765	1156	1504	1892	2257
30				20.225	49.45	19.48	165	277	392	510	627	747	321	557	810	1066	1325	1592	502	897	1356	1762	2225	2652
		26		20.140	49.66	19.52	166	279	394	512	631	751	323	560	812	1070	1331	1595	506	902	1362	1770	2231	2667
	28			18.541	53.94	21.25	196	329	467	601	742	885	380	661	935	1262	1570	1882	596	1066	1567	2087	2635	3137
			26	18.240	54.83	21.55	202	339	430	622	767	912	393	682	990	1305	1621	1944	615	1100	1659	2156	2715	3237
		28		16.841	59.37	23.40	237	398	564	731	900	1057	461	800	1162	1530	1900	1981	722	1287	1950	2530	3182	3805
	30			15.925	62.81	24.70	265	445	630	817	1006	1200	515	895	1272	1707	2127	2550	807	1442	2180	2830	3562	4257
			28	14.941	66.92	26.35	297	500	707	932	1130	1346	579	1006	1457	1947	2385	2865	907	1620	2445	3225	4000	4747
		30		14.225	70.33	27.70	334	560	792	1015	1265	1505	647	1125	1632	2125	2670	3200	1017	1812	2737	3555	4475	5337
			30	12.325	81.17	31.90	444	744	1052	1367	1680	2000	862	1495	2170	2857	3550	4250	1355	2410	3637	4725	4950	7100

SELF-INDUCTANCE OF SINGLE-LAYER COILS (MICROHENRIES)

Wire Size and Insulation				Diam. Mils	Turns per Inch	Turns per cm.	d=10 (cms.)						d=12 (cms.)						d=14 (cms.)					
Cotton		Silk					Length (cms.)						Length (cms.)						Length (cms.)					
Double	Single	Double	Single				4	6	8	10	12	14	4	6	8	10	12	14	4	6	8	10	12	14
20	......	......	......	42.161	23.72	9.33	162	273	412	590	750	910	212	389	587	800	1020	1250	266	494	750	1030	1319	1625
......	20	......	......	37.861	26.41	10.39	194	296	492	707	896	1087	254	465	702	956	1220	1492	318	589	899	1230	1580	1940
......	......	20	......	36.161	27.66	10.89	221	339	564	810	1025	1245	290	532	805	1095	1397	1707	362	673	1030	1407	1806	2220
22	......	......	......	35.547	28.13	11.08	228	351	587	837	1057	1284	300	551	831	1131	1442	1762	375	697	1067	1455	1865	2292
......	......	......	20	34.261	29.18	11.49	243	377	625	897	1137	1382	322	592	891	1215	1547	1897	401	750	1142	1560	2002	2467
......	22	......	......	31.247	31.40	12.36	284	435	722	1035	1312	1595	372	682	1031	1405	1790	2192	466	865	1319	1805	2312	2845
24	......	......	......	30.300	33.01	13.00	315	482	800	1150	1455	1770	413	757	1142	1555	1982	2430	516	960	1457	2000	2562	3162
......	......	22	......	29.547	33.85	13.33	330	506	842	1206	1527	1855	433	795	1200	1632	2082	2535	442	1006	1532	2100	2687	3305
......	......	......	22	27.647	36.16	11.21	378	579	960	1380	1742	2122	496	910	1370	1867	2375	2912	621	1155	1750	2400	3070	3787
26	......	......	......	26.140	38.25	15.05	422	646	1075	1545	1950	2377	555	1015	1532	2087	2660	3262	692	1285	1962	2682	3437	4237
......	24	......	......	26.000	38.46	15.12	425	651	1081	1550	1965	2382	557	1020	1542	2095	2680	3275	697	1295	1972	2695	3462	4250
......	......	24	......	24.300	41.15	16.17	489	745	1245	1782	2255	2732	640	1170	1775	2412	3070	3650	802	1482	2267	3100	3970	4750
28	......	......	......	22.841	43.78	17.23	551	845	1407	2020	2555	3107	722	1329	2007	2732	3480	4255	905	1681	2565	3512	4500	5525
......	......	......	24	22.401	44.65	17.55	572	879	1459	2095	2650	3227	762	1380	2082	2830	3612	4425	940	1746	2662	3645	4662	5750
......	26	......	......	21.840	45.78	18.01	602	922	1534	2205	2787	3387	790	1446	2187	2980	3800	4650	987	1835	2800	3832	4787	6050
30	......	......	......	20.225	49.45	19.48	707	1082	1804	2585	3275	3982	927	1700	2565	3500	4462	5462	1159	2155	3287	4500	5775	7100
......	......	26	......	20.140	49.66	19.52	711	1087	1812	2595	3287	4000	932	1707	2580	3525	4487	5475	1167	2165	3305	4520	5787	7125
......	28	......	......	18.541	53.94	21.25	837	1282	2082	3012	3875	4712	1097	2017	2962	4145	5225	6462	1375	2555	3900	5325	6825	8400
......	......	......	26	18.240	54.83	21.55	865	1325	2205	3162	4000	4862	1132	2081	3057	4275	5462	6675	1420	2637	4017	5500	7062	8675
......	......	28	......	16.841	59.37	23.40	1015	1555	2587	3707	4695	5712	1330	2440	3687	5012	6400	7825	1665	3090	4712	6450	8275	10175
......	30	......	......	15.925	62.81	24.70	1137	1737	2895	4150	5250	6637	1487	2657	4125	5612	7162	8762	1862	3462	5275	7225	9250	11412
......	......	......	28	14.041	66.92	26.35	1275	1955	3250	4725	5900	7175	1670	3067	4662	6400	8025	9850	2091	3887	5925	8225	10375	12800
......	......	30	......	14.225	70.33	27.70	1429	2187	3637	5212	6600	8125	1875	3430	5175	7062	9000	10225	2342	4350	6625	9075	11625	14300
......	......	......	30	12.325	81.17	31.90	1900	2905	4835	6925	8775	10662	2490	4562	6887	9375	11925	14600	3120	5775	8812	12062	15437	19000

Summary of Functions of the Various Parts of Typical Receiving Arrangements.—The functions of the several parts of the simple crystal detector set shown in Fig. 9, chapter 2, are summarized below:

Antenna: Converts radio wave into an alternating current of high frequency.

Inductance Coil: Forms, together with the antenna, a circuit which can be tuned to respond to the incoming radio wave. In this set it alone constitutes the "tuner."

Crystal Detector: Converts the alternating current in the antenna into a pulsating unidirectional current.

Telephone Receivers: Convert the pulsating unidirectional current into sound.

The functions of the parts of the two-circuit electron tube set as shown in Fig. 13, chapter 2, may be summarized as follows:

Antenna: Converts radio wave into an alternating current of high frequency.

Primary Inductance Coil: Forms, together with the antenna, a circuit which can be tuned approximately to respond to the incoming radio wave. In this set it is the primary coil of the "coupler."

Series Condenser: Shortens the wave length to which the antenna responds. It also gives fine adjustment of the tuning of the antenna circuit.

Secondary Circuit: Provides means of tuning more sharply to the desired wave than can be done by tuning in the antenna alone. It consists of the secondary inductance coil and the secondary condenser.

Secondary Inductance Coil: Couples the secondary circuit to the antenna circuit. It provides rough adjustment of tuning of secondary circuit.

Secondary Condenser: Provides fine adjustment of tuning of secondary circuit.

Electron Tube: Converts the alternating current in the secondary circuit into a pulsating unidirectional current and amplifies it.

Filament Battery (A): Supplies current to heat the filament of the electron tube.

Filament Battery Rheostat: Regulates current through the filament of the electron tube.

Plate Battery (B): Supplies current through the tube between plate and filament.

Telephone Receivers: Converts the pulsating unidirectional current from the electron tube into sound.

The functions of the several parts of the regenerative set shown in Fig. 14, chapter 2. may be summarized as follows: All parts are the same as in the two-circuit electron-tube set above except the following:

Tickler Coil: Feeds the effect of the current in the plate circuit back into the grid circuit so that the current is re-amplified.

Grid Condenser and Leak: Adjust voltage on the grid to a value giving sensitive action of electron tube as a detector.

Potentiometer Resistance: Provides fine adjustment of plate voltage.

Telephone Condenser: Provides path for radio-frequency current that is easier than through the telephone receivers.

The functions of the parts of the amplifier shown connected to a crystal detector set in Fig. 12, chapter 2, and to an electron-tube set in Fig. 16, chapter 2, as far as not already covered above, are as follows:

Electron Tubes: Convert the small voltage and power applied to the grid into larger voltage and power in the plate circuit.

Amplifier Transformers: Convert the small voltage applied to the input side into a larger voltage on the output side.

Generators of Radio-Frequency Current.—Turning now to radio transmitting apparatus, the principal apparatus which is required is a generator of alternating current of radio frequency. There are numerous kinds of generators, but the kind used in radio-telephony makes use of powerful electron tubes similar to those used in receiving sets, but larger.

The way in which electron tubes are used to generate current is a mere extension of their use in amplifiers. If, in Figure 8, the coils L_1 and L_2 are placed close together, the effect of L_2 on L_1 can become so great that the current continues to flow even if no signals are coming into the antenna to which the input circuit CL_1 is connected. The alternating current thus produced will have the frequency to which the circuit CL_1 is tuned. What happens might be expressed by saying that an amplifier can be made so powerful that no input current at all is required. This does not mean that it is a perpetual motion machine, because the power to operate it must be supplied by the battery that is connected in the plate circuit of the tubes. It does mean, however, that the electron tube can be used to generate alternating currents as well as to receive and to amplify them.

Apparatus for Transmitting Radio-Telegraph Signals.—The apparatus for transmitting radio-telegraphy and telephony differ mainly in the arrangement by which the continuous current produced by the generating circuits is modulated or changed in strength to follow the dots and dashes of the telegraph code or the variations of the voice. Radio-telegraph transmitting sets are the simpler. Means are provided to modulate the radio-frequency current at an unvarying audible frequency. To signal it is only necessary to stop and start the current suddenly by means of an ordinary telegraph key which opens and closes the circuit. The inductance coils and condensers are of somewhat different design than the coils and condensers used in receiving sets. In transmitting sets the various parts of the circuit must carry considerably larger currents. The filaments of the electron tubes are lighted from storage batteries, as in receiving sets, but the "B" battery (battery in plate circuit) is replaced by a dynamo which will supply

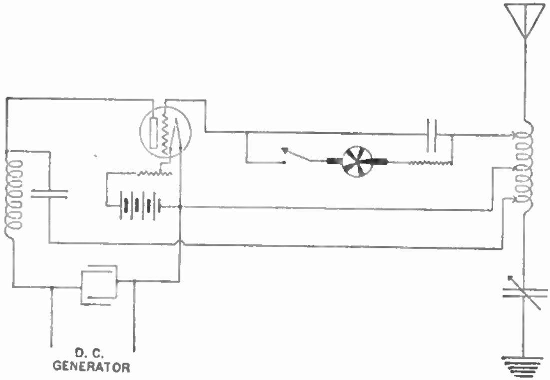


Fig. 11—Circuits of radio-telegraph transmitting set using chopper for securing modulated waves.

more power than is economically obtained from batteries. The voltage of this dynamo may be between 300 and 2000 volts. The power which it delivers depends upon

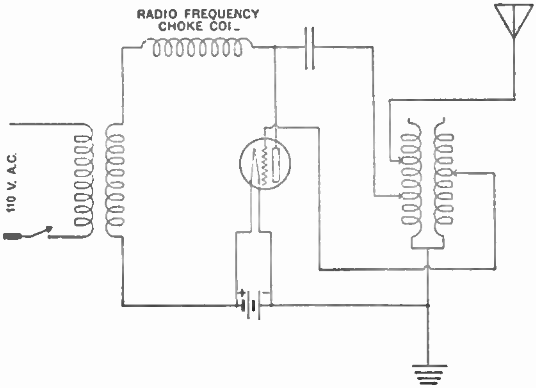


Fig. 12—Circuits of radio-telegraph transmitting set using alternating current for plate supply and modulation.

the type and number of electron tubes used in the transmitting set. The power of the set may be increased by using a larger electron tube or by connecting additional tubes to the circuit. In the latter case, the grids of all of the tubes are connected together and the plates of all of the tubes are likewise connected together. The filaments are all heated by current from the same storage battery.

One type of radio-telegraph transmitting circuit is that shown in Fig. 11. This shows one of various methods of connecting the key for use in signalling. It also shows how to connect a chopper (motor-driven interrupter) in order to modulate or break up the waves into groups at an audible frequency. Modulation of the waves may also be secured by using an alternating voltage to supply power to the plate circuit of the transmitting tubes. During the half of each cycle of this voltage, when it makes the plate negative, no current flows. It thus serves the purpose of a chopper. A circuit diagram for such a set is shown in Fig. 12.

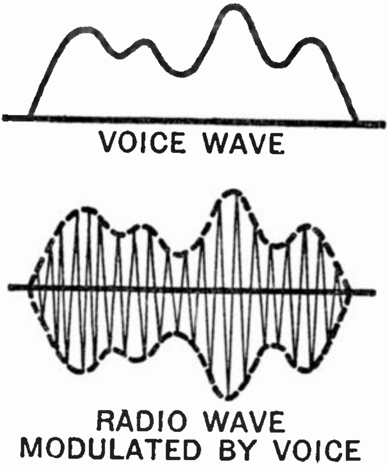


Fig. 13—Voice-modulated Radio Wave.

Modulation in Radio-Telephony.—The electron tube is the device used to modulate the radio-frequency current in radio-telephone transmitting apparatus. The general idea of modulation was explained in chapter 4. The human voice produces sound waves which cause air vibrations of an irregular character. Such a wave may be roughly illustrated as in Fig. 13. The variations in the voice wave are much slower than the alternations of current used in radio. It is possible to make a radio wave carry a voice wave, and when this voice-modulated wave is received it can be passed through a detector and telephone receiver and the voice heard just as radio-telegraph signals are heard. The way in which the voice wave is superimposed upon the radio wave is illustrated in Fig. 13. The alternations of the radio wave are shown by the full lines, and the dotted boundary lines show that the intensity of the wave has been made to vary in accordance with the sound wave produced by the voice. This wave can be received in exactly the same way as any wave in radio-telegraphy—no special apparatus is required for receiving radio-telephony. The voice at the transmitting station is heard very clearly. It can be made as loud as desired at the receiving station by the use of amplifiers.

The radio wave is really modulated or molded just as a phonograph record is molded by a sound wave. The means by which this modulation is accomplished is the electron tube. If in Fig. 6 the telephone receiver is replaced by any kind of generator of radio-frequency current, then if a person speaks into a telephone transmitter connected between the grid and filament of the tube, the variations caused by the sound of the person's voice cause the intensity of the radio-frequency current in the plate circuit to vary correspondingly with the voice sound wave. The radio-frequency current is thus not of constant amplitude but varies in amplitude in accordance with the voice. Thus a modulated radio wave as in Fig. 13 is produced.

Radio-Telephone Transmitting Apparatus. — The circuit of a radio-telephone transmitting set is similar to that of a radio-telegraph transmitting set except for

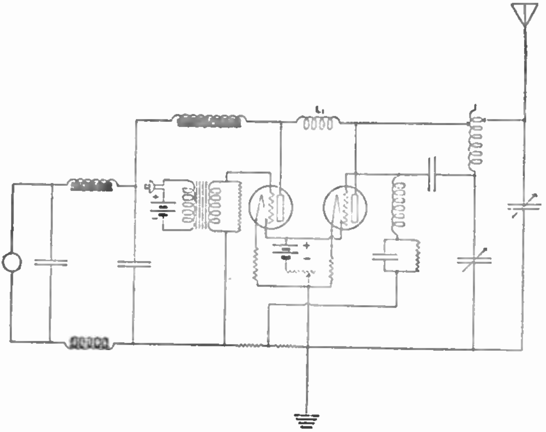


Fig. 14—Circuits of radio-telephone transmitting set using one generator tube and one modulator tube.

the modulating device. A diagram of a complete set is shown in Fig. 14. Here the microphone, into which the speaker talks, is connected through a suitable transformer to the grid and filament terminals of an electron tube. This tube, on account of this use, is called the modulator tube. The plate current from this tube varies according to the sound-wave variations of the voice. The plate current of the generator tube, which is to the right of the modulator tube, has variations corresponding to those of the modulator tube because there is a choke coil in the lead from the generator (at the left) which keeps the sum of the direct current supplied to the plate circuits of the two tubes constant. The arrangements of coils and condensers to the right

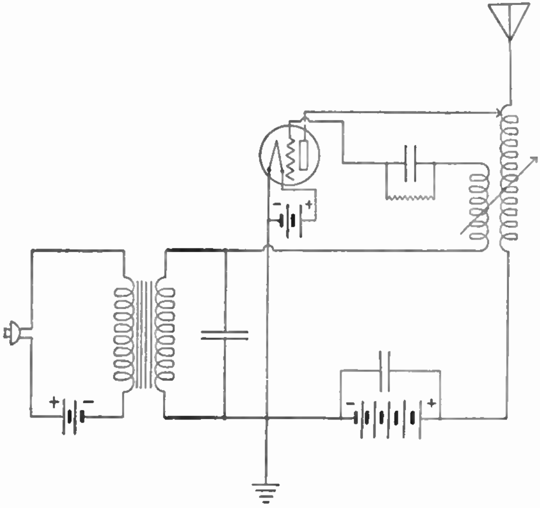


Fig. 15—Circuits of radio-telephone transmitting set using a single electron tube with grid modulation.

of the generator tube are for generating the radio frequency. The choke coil L_1 prevents any of the radio frequency from getting into the modulator tube. Thus the radio-frequency current is produced in the generator tube and has the voice variations impressed on it by the modulator tube. For further details, see "The Principles Underlying Radio Communication" pages 521 and 527 (see note, page 7, chapter 3.) The adjustments of the circuits associated with a modulator tube are usually very critical, and it is quite difficult to secure accurate production of current which varies in exactly the same way as the sound waves of the voice.

A somewhat simpler circuit arrangement, in which a single tube serves as both generator and as modulator, is that shown in Fig. 15. It is even more critical in adjustment but is sometimes used where a low-power transmitting set with a simple circuit arrangement is desired.

Continuous-Wave Radio-Telegraphy.—While considerable stress has been laid in all these explanations on the process known as modulation, the reader should know that there is a system of radio-telegraphy in which there is no modulation. This should be kept apart, however, in thinking on radio, as it is done by distinctly different processes. There being no modulation, the wave is simply an unvaried continuous wave of radio frequency. A circuit diagram of a continuous-wave transmitting station is given in Fig. 16. The bare essentials of this diagram are given in Fig. 8. For

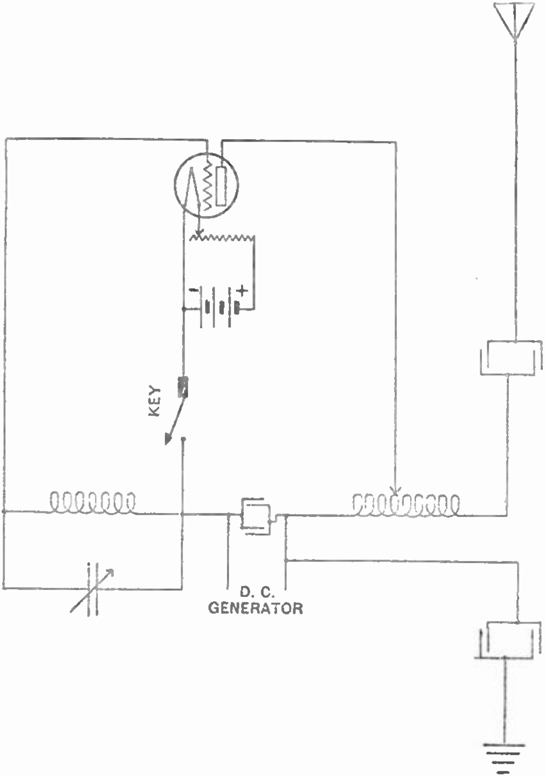


Fig. 16—Circuits of continuous-wave radio-telegraph transmitting set.

further explanation of the features of circuits like Fig. 14, see "The Principles Underlying Radio Communication," pages 491 to 498 (see note, page 7, chapter 3).

A "continuous wave" would not be heard in the ordinary receiving set because, as already explained, the frequency of radio waves is so high that the human ear does not react to a sound of such high frequency. These continuous waves are received by an ingenious scheme. In the ordinary regenerative receiving set, the coupling of the "feed-back" from the plate to grid is increased until the circuit begins to generate ("oscillate"), as explained on page 32 under "Generators of Radio-Frequency Current." The condenser is adjusted until the circuit is tuned to a frequency just a little different from that of the received continuous-wave current. There are thus present two high-frequency currents of slightly different frequency, the received current and the generated current. Beats are produced between the two, and these beats are heard in the telephone receivers. Thus if the continuous wave frequency is 200,000 and the generated current frequency is 201,000, a beat note of a frequency of 1000 is produced, and this is readily heard.

The signals from a nearby continuous-wave radio-telegraph transmitting station are heard in the ordinary receiving set (which is not oscillating) as a series of clicks, a click occurring at the beginning and end of each dot and each dash of the code signals. If the receiving set is, however, so adjusted as to be generating ("oscillating"), the signals from a continuous-wave radio-telegraph station are heard as long and short whistling sounds forming the dashes and dots. Sometimes signals are heard which cause the series of clicks referred to above, but also have a low-pitched, humming sound distinguishable as forming the telegraph code signals. Such signals are produced from a transmitting set which uses alternating current supply for the plate circuit of the transmitting tube.

Spark Radio-Telegraphy.—While the electron-tube transmitting sets for both radio-telegraphy and radio-telephony are being installed generally where new stations are being erected, there are a large number of old stations in operation which employ entirely different apparatus. Many of the commercial stations for radio-telegraphy between ships and shore and many amateur radio transmitting stations are of old types. These older transmitting sets are called spark sets because the high-frequency alternating current in the antenna is produced by the discharge of a condenser across a spark gap. Waves sent out from a spark station are able to create much more interference than waves from a well designed electron-tube transmitter.

ADVANCE

LINES OF ADVANCE

CHAPTER SIX

LINES OF ADVANCE IN RADIO

Elimination of Antenna and Battery.—The use of dry batteries in place of storage batteries for sets employing a small number of tubes and for portable sets has made radio apparatus acceptable where its use had previously been quite inconvenient. The further elimination of the battery altogether from radio receiving sets by the use of power drawn from the ordinary electric light socket is a development of the future which will appeal to most users of radio.

Strictly speaking, it will never be possible to eliminate the antenna. There must always be something to receive or catch the wave and convert it into a current. Nevertheless, the antenna can be made so small or in such a form that it will be as good as eliminated. As a general principle, when smaller forms of antenna are used it is necessary to have more sensitive amplifiers. One such small antenna is the coil antenna, which was explained in chapter 5. Another way out is to use a mass of metal within the house, such as a metal bed, as the antenna. The same effect is attained by a connection to the electric wiring in the house as an antenna. A special connecting plug is used, so as to avoid short-circuiting the wiring. All these schemes for eliminating the antenna will be more and more successful as receiving apparatus, already extraordinarily sensitive, is further improved and more widely used.

Line-Radio Communication.—It has been found that radio waves of the lower frequencies can be guided along wires between the transmitting and receiving stations instead of being radiated through space. The wires used in this way can be used simultaneously for ordinary telegraphic messages and telephone conversations, or for transmitting electric power. Various names have been applied to this method of communication, such as "wire-radio telephony," "carrier-frequency telephony," "guided-wave telephony," and "wired wireless." Line-radio telephony can be conducted by connecting a radio-telephone transmitting set to one end of a wire in the same way as it ordinarily is connected to an antenna. The receiving set should be connected to the other end of the wire in a similar manner. Distances of 10 or 20 times the radio transmission ranges can be obtained with the use of a given power by this method. In connecting transmitting or receiving sets to the wire lines in this way, care should be taken not to make any changes in the circuit which would affect other ordinary use. While the use of this method of communication is rapidly being extended, it is desirable that installations be made only by experts, on account of the danger of interrupting the normal service of the wire lines or making wrong connections which would cause serious injury or damage.

Line-radio telephony offers the additional advantage of carrying a number of messages over one pair of wires at the same time without interference. This is done by tuning arrangements at both the transmitting and receiving ends, which keep the different messages from interfering with one another. Waves guided along conductors seem bound to become more common, since trolley wires, power wires or any other sort of wires may be used to guide the waves. Thus a telephone becomes possible for every building into which electric light wires run. Furthermore, line-radio telephony may be linked with or connected to ordinary wire telephony. Thus it seems unquestionable that this method will more and more supplement the regular telephone system.

While this is not really radio communication, it presents a solution to some of the problems of radio. It is a secret method of communication, whereas radio is utterly public. It solves the question of communication in one direction to the exclusion of others wherever there is a guiding conductor in the direction desired.

Elimination of Strays.—Attention has been called in chapter 2 to the occurrence of noises in the receiving set which are caused by atmospheric electrical disturbances ordinarily called "strays" or "static." Strays are the most serious limitation on radio communication at the present time, and many methods have been devised for the purpose of minimizing their effect or increasing the strength of desired signals without increasing the strength of the undesired strays. So far, none of these methods have proven to be satisfactory in the elimination of strays. The most useful means which have been developed for approaching a satisfactory solution are the use of a low directional antenna and the use of loose coupling between several sharply tuned circuits of the receiving set. For receiving continuous waves, the use of the beat method of reception is also a great advantage, but this is not applicable to radio telephone reception. The elimination of the effect of strays on radio receiving apparatus is a very important problem; it is almost as difficult as devising a method which would keep a tuning-fork from vibrating when it is struck by a sledge hammer, while permitting it to vibrate when it is placed in the vicinity of another tuning-fork vibrating at the same pitch.

Elimination of Spark Sets.—It is desirable that the waves from a transmitting station be as nearly of a single frequency as possible. Most spark transmitting sets fall far from this requirement. As advances take place in radio and as new stations are installed, these old types of spark sets will doubtless go out of use. If all the spark sets now used by ships and commercial stations and by amateurs are some day replaced by transmitting sets which will send out continuous waves, the objectionable interference in the form of dots and dashes, which many receivers of broadcast service meet at the present time, will be eliminated.

Secrecy.—At present practically all radio transmission is of such a nature as to make it impossible to keep it from being received by anyone who so desires. The law forbids the disclosing of a message to other persons than those for whom it is intended. This of course does not cover the broadcast service, for the term is to signify transmission which is intended for an unlimited number of receiving sets, without charge at the receiving end. Technical methods are being developed which will make it impossible for persons to receive certain kinds of radio signals unless supplied with a special kind of receiving apparatus which is designed to match with the particular transmitting set employed. By the use of such methods unauthorized listening-in will become so difficult as to be accomplished only by persons who are experts. It is not likely, however, unless technical developments are carried very much farther than seems at all possible at the present time, that secrecy and selectivity will be obtained to such an extent as to make feasible the simultaneous secret communication between every pair of individuals who may desire to talk with one another.

Remote Control by Radio.—With the development of amplifiers there has come the increasing possibility of using radio to control the operation of any machinery or motion at a distance, by use of a relay or switch connected to special radio receiving apparatus. In order to accomplish this, signals are transmitted by radio and are received by a receiving station employing a very sensitive amplifier and a specially designed relay device. This relay is then connected to such mechanism as it is desired to operate at the receiving station. Such mechanism may be an electric light, an electric bell, the control lever of an airplane, the switch of an electric power line, or other mechanism. A disadvantage of radio control is that the receiving apparatus must be in continuous operation with consequent consumption of power from the batteries or generator which supplies current to the receiving set. For certain purposes, however, this is not too great an expense to keep the use of distant control by radio from being feasible. The use of radio in this way is being considered by a number of electric power companies for operating switches at distant power plants or stations.

Directive Radio Transmission.—As a means for minimizing interference in point-to-point radio services and in the development of radio beacons or "radio search-lights," experimental work has been done on the transmission of radio waves in a limited direction to the exclusion of transmission in other directions.

The most successful work along this line has been done with radio waves which are very short, for example about 10 meters. When these short waves are used it is possible to construct reflectors or electrical mirrors which can be placed partially around the small transmitting antenna and which will send most of the power out in a given general direction. However, the experiments which have been made up to the present time have been only partially successful, the transmitted power being limited to an angle of perhaps 30 degrees. On account of the small size of the antennas required for the short waves it is extremely difficult to radiate a large amount of power from a single antenna.

Another way in which the directive transmission of radio signals is approached is by the use of wires to guide the radio waves from one point to the other. The amount of power which has been transmitted by guided radio waves has so far been only a few watts. A more detailed discussion of this method of communication is given above under "Line Radio."

Another method of transmitting radio waves in a desired direction is by the use of a coil antenna in connection with the transmitting apparatus. Vertical single-turn coils of large dimensions have been employed in an experimental way; signals being transmitted to a greater distance in the general direction of the plane of the coil than in the direction at right angles to it. This method of transmitting will probably become important in the service of marine and aerial navigation.

Short Waves.—A few years ago, little or nothing was known of the properties or possibilities of using the very short radio waves produced by currents having frequencies of 2000 kilocycles or more. These are the waves which are shorter than 150 meters. These short waves are being used in experiments on directive transmission mentioned above, and have been used for experimental long-distance broadcasting and for transatlantic communication. They are well adapted for uses where the dimensions of the transmitting apparatus are limited, as on small boats. These high frequencies have the fortunate capability of carrying an extremely large number of communications simultaneously without mutual interference. Atmospheric disturbances are almost entirely absent.

Transmission of Pictures by Radio.—Several inventors have been working on the problem of transmitting photographs by radio, and very good results have been obtained. The picture to be transmitted is placed in the special transmitting apparatus, and through the medium of a radio wave of varying intensity, a duplicate of the picture is created on a film in the receiving apparatus. By increasing the speed so that sixteen or more successive pictures per second are produced on a screen at the receiving station, the transmission of moving pictures or pictures of moving objects becomes possible. This was, in fact, done in an elementary way in the summer of 1923. We may look for the continued improvement of such methods.

Extension of Use of Radio.—The growth of radio proceeding by leaps and bounds, obviously the perfection of devices that will increase its convenience will not be long delayed. The simplification of receiving sets and the organization of broadcasting are bound to lead to radio reception requiring as little effort as pressing a button. The receiving set of the near future may well look like Fig. 1. The large dial would be used to adjust the volume of sound to any desired amount.

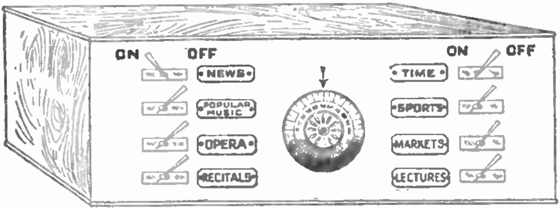


Fig. 2—Radio Broadcast Receiving Set of the Near Future.

It is not necessary to look to the future for extensive use of radio. It is used more extensively than most people realize for navigational aids, for communication with ships, aircraft, remote regions, and across the oceans. Its use on trains and all vehicles will come. Forests will be better protected by its use for instant reporting of fires. The broadcasting of news and important announcements will be accomplished and regulated with a perfection that would now seem startling. The problem in radio, will, indeed, be to restrict its uses enough to permit any messages to get through.

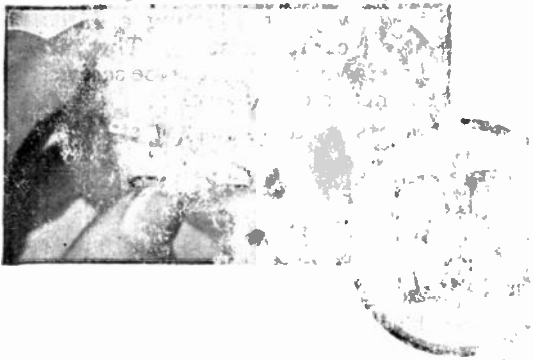
By inserting in this binder the additional sheets published in Radiofax, the holder will be kept fully advised of all advances of moment in the art of radio communication, and will thus be enabled to maintain his equipment at maximum efficiency.

The apparatus and materials described and illustrated in this section are, to the best of our knowledge, of high quality. We believe the statements made by the manufacturers thereof to be dependable. We have in most cases verified them by actual tests.

The authors, however, have been restrained by professional ethics from cooperating with us in our selection and can therefore not be held accountable for any unsubstantiated claims.

APPARA-
TUS

DUBILIER.



Dubilier Mica [illegible]
for any Circuit Requirement

DUBILIER Micadons are the [illegible] standard fixed [illegible] of [illegible] leading radio manufacturers [illegible] teurs. They are ma[illegible] capacities, so that they can [illegible] readily [illegible] corporated in any [illegible], [illegible] with grid-leaks, or connected wi[illegible] and other terminals.

Guaranteed permanence of capacity makes Dubilier M[illegible] what they [illegible]. Hence tube [illegible] capacity are [illegible]

Dubilier Condenser and Radio Corp.

Dept. LF 48-50 W [illegible]

DEVICES

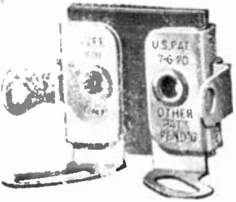
facilitate soldering without affecting Micadon's electrical characteristics. The tabs ... on Micadons are ... screwed together ...

Price ... up, ... style and ...

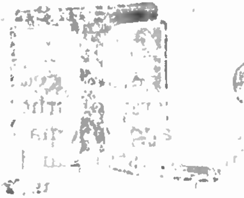
... for bulletin showing uses of mic... ... clips.

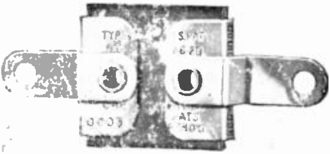
... grid ... adjust ... clips ... over binding posts.

Micadon Type 601 ... le clips ... transformer ... binding posts.



Micadon Type 601 G-T





Micadon Type 601 L

Micadon Type 601 L has ... tabs which slip over the terminals of a ... grid leak.

Micadon Type 601 G has clips ... hold fixed grid ... grid leaks not supplied with Micadons).

DUBILIER

THE DUBILIER DUCON T[illegible] PLACE OF THE ANTE[illegible]

Price
$1.50

The Dubilier Ducon d[illegible] away with the antenna. Simply screw it into any lamp socket and connect it with the set. Near and distant broadcasting stations come in with the utmost sharpness. Tuning is m[illegible]ch more selective than with an antenna.

The Dubilier Ducon makes it possible to use the set in any room. It is useful in apartment houses and residences where the erection of an antenna is impossible or forbidden.

The Ducon does away with lightning arresters and the usual safety-switches. It is approved by the Laboratories of the National Board of Fire Underwriters (Test No. 5865).

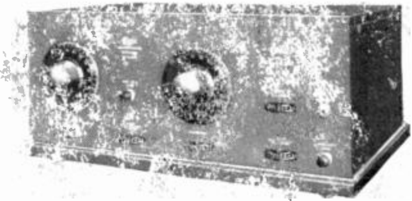
Money refunded if found unsatisfactory after five days' trial.

Dubilier Condenser and Radio Corporation
Dept. [illegible] 48-50 W. 4[illegible] St. New York

DEVICES

The Grebe CR-14 Broadcast Receiver

Wave-length Range: 290-300 M.



Licensed under Armstrong U.S. Pat. No. 1,113,149

The CR-14 Broadcast Receiver is an Instrument that anyone can operate. Embodying the Armstrong Regenerative Circuit, it will bring in distant as well as local stations with loud-speaker volume, using an outdoor antenna of moderate size.

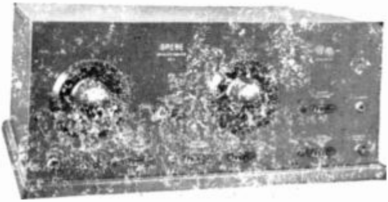
The use of three UV-199 or C-299 tubes without adapters, three dry cells, and three B batteries of the vertical type insures the utmost economy in upkeep.

A 2-stage audio-frequency amplifier is included for loud-speaker operation. The controls for each of the three rheostats are calibrated direct in ohms: 0-50.

The standards of excellence in craftsmanship, developed by this Company during more than ten years of experience, are well maintained in this instrument.

The Grebe CR-12 Broadcast Receiver

Wave-length Range: 200-600 M.



Licensed under Armstrong U.S. Pat. No. 1,113,149

Seven Points of Satisfaction

1. No outdoor antenna—or loop.
2. Uses all kinds of tubes (4 of them) in any desired combination.
3. Employs the perfect combination of Regeneration and Tuned Radio-Frequency Amplification with only 2 tuning adjustments.
4. Receives on all broadcast wave-lengths.
5. Tuning Dial graduated in wave-lengths.
6. May be set up immediately and successfully operated—anywhere—by anyone.
7. Complete, self-contained Receiver, in attractively finished walnut cabinet, with compartments for A and B batteries.

Ask Your Dealer

A. H. GREBE & CO., INC.

Richmond Hill, N. Y.

Brandes

The Table-Talker—the loud-speaking device that has achieved nation-wide popularity because of its high standard of performance and remarkably low price. Clear of tone—mellow, harmoniously true. Always ready to reproduce the *whole* program with every shade of expression that makes the voice or the music *real.*

Good-looking, too. Simple of line, graceful, and finished in a neutral shade of brown.

Worth comparison with any loud-speaking device on the market. And sure to be chosen at its phenomenally low price.

Table-Talker, $10.00

50¢ additional, west of the Rockies

In Canada, $14.00

(See next page)

Table-Talker

TRADE MARK REG. U.S. PAT. OFF.

Brandes

... the Brandes ... has ... identified ... construction ... of ... T ... y there are more ... Brandes Heads... ing ... ever ... pick s ...

The ... Type

has the ... the radio ... cord, which ... metal parts of the ... eliminating body capacity ins... terminals. It ... the inv... choice of ... *must* have ... keenest sensitivity ... accurate reproducing quality. Impedance at 800 cycles approximately 20,000 ohms.

The Superior is —

a headset with a matched tone quality that makes it a universal favorite. Clear reception — every time — whether the program be instrumental or vocal. And the Superior is ple... light in weight comfortable, easily adjust. Impedance at 800 cycles ... proximately 25,000 ...

... Type ... Canada $1?.00

Superior Headset, $6.00
Canada, $7.00

Matched Tone
Radio Headsets

Formica Radi 'anels and Insulating T

... prod-
... Corps,
... independ-
... sets. Grade
... grade is manufactured from a
fibre ... per cent of Bakelite

... has a dielectric strength approximately
... to the best performance of any other
material in that respect, and in addition it has
... tensile strength, and is unaffected by heat
up to ... degrees Fahrenheit. It will not sag or
cold flow, or soften at any ordinary temperature.
It does not change color under the influence of
sunlight.

The moisture absorption of the material is so low
that no degree of humidity will affect its insulating ability, and ... immune to extremes of
weather conditions.

Grade ... characteristics that
are ... strength,
19,000 ... at
50 degrees ... at 50
degrees ... 1.36;
moisture absorption per cent ... at 50

(over)

degrees Centigrade, 0.29; dielectric strength, puncture voltage, volts per mil., 1/32-inch samples, 7,300. Phase difference, 1½ to 2 degrees; dielectric constant, 5; surface resistivity, 10 inches.

Mahogany finish panels are black on one side and mahogany on the other. Formica plate for panel purposes is made in three finishes. Black, mahogany and natural brown. Tubes winding coils are made in black and nat[illegible] brown. The black tubes have a high gloss similar to that of the panels.

Formica is supplied in standard sheets 36 inches to radio manufacturers and dealers and [illegible] tributors. It is also cut into standard panels of the following sizes and supplied [illegible] distributor and dealers [illegible] 6x7, 7x8, [illegible] 7x18, 9x14, 12x14, 9[illegible] 8, 7x14, 7[illegible] and 7x26. These standard panels are [illegible] individual craft paper envelopes to protect [illegible] in shipment and while they are in the d[illegible] stock.

Other sizes may be provided if ordered in quantity, but will not be packed in envelopes.

Many washers, strips and bushings of various kinds made from Formica are used by radio manufacturers who cut them from Formica sheets, tubes or rods. The material works well with tools—usually the tools that are used with metal.

THE FORMICA INSULATION CO.

4632 Spring Grove Ave.,

Cincinnati, O.

INSTRUMENTS USED BY

The Bureau of Standards and Other Leading Laboratories

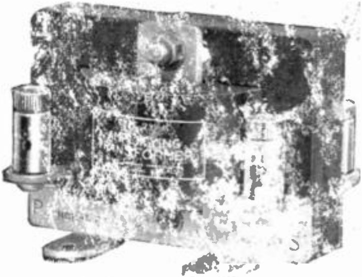
For nearly a decade the General Radio Company has been manufacturing radio measuring instruments and standard radio parts that are used extensively in the laboratories of the Bureau of Standards, Signal Corps, … as well as in … nationally … Electric Co., Westinghouse Electric … Western Electric … Radio Corp. … and many others. … in particular … used extensively in the laboratories of the country's leading … institutions, such as Harvard, Yale, Massachusetts Institute of Technology, Princeton and over one hundred other colleges.

… two main groups, namely measuring instruments … radio parts. Because of the research work required … of the measuring instruments, we have much … that … been used in the … development of our standard parts, which have made them far superior … the usual parts on the market. It is not possible to list all of these … here and it is, accordingly, … that you send for … BULLETIN 914LA.

… which have become … standard of quality in-

GENERAL RADIO

AMPLIFYING TRANSFORMER



The GENERAL RADIO COMPANY was the first company to have available for the experimenter a closed core audio-frequency amplifying transformer. This was before the United States entered the war. Many of these transformers were supplied to the army and navy during the war and with the return of amateur radio after the war thousands have been sold for use in this country and abroad.

The subject of amplification has received much attention in our research laboratory. Improvements have been made from time to time until now our model, the Type 231 A, represents the best in amplifying design.

The Type 231 A Amplifying Transformer is designed to give maximum of amplification possible without distortion. It is the careful engineering design.

The electrical characteristics of the windings are as follows:

	Primary
Direct current resistance, ohms	1,100
A.C. resistance at 1000 cycles, ohms	11,000
Reactance at 1000 cycles, ohms	66,800

Price, Completely mounted, $5.

GENERAL

LOW L

The careful design Type 247 Condenser vides not only for tric losses, but mechanical

MOON C-2-A RECEIVER

"It gets them all"

THE MOON RECEIVING SET

prime requisite in the development of any radio ving set is a fundamental and thorough knowledge of frequency electrical waves, the manner of transmission and ways of receiving them. In the Moon set this has been most scientifically realized. It is ination of twenty-six years of research work in menon of the invisible part of the spectrum.

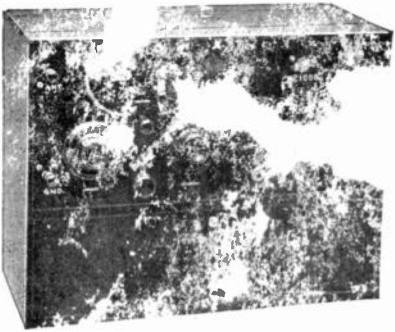
Before the broadcasting era was ushered in, Dr. F. Merlee, the renowned X-ray specialist, had ed in high-frequency electrical transmission. from the fundamental laws that radio (infra- form part of the spectrum, d that largely the laws that rays insofar as the wave-length w permit. It is well known, of course, -ray and light rays travel in straight lines from their origin and that they are an electronic discharge. These discharged electrons pass along their energy through the potential electrons that make up the composition of the atoms of the media through which they pass.

To illustrate: Place half a dozen coins in a row on a table. Give the coin nearest you a sharp rap with the finger, and you will find that only the coin on the extreme end will move away from the rest, all the others remaining where they originally were. Like the electrons passing along their energy, the coins pass the energy of the finger along so that at the extreme end of the row it performs useful work.

The more homogeneous and stable the medium through which these high-frequency waves are to be conveyed, the better that medium will be for transmission purposes; therefore, earth reception should be better than antenna reception except when governed by factors such as ore deposits in the earth, steel structures, underground wires, etc., all of which tend to neutralize or absorb the transient energy or possibly deflect it from its course. And in actual practice it is found better, with the exception of water, which, owing to the uniform homogeneous make-up of that medium, is perhaps best of all.

As is well known, the high-frequency radio waves are discharged in all directions from the transmitting station, both from the sending aerial and the sending ground connection, the actual transfer of energy taking place as alternate charges of positive and negative electricity, which, added to the normal potential charge, cause the electrons of the media to pass the excess of electrons on to their neighbors. This electronic transfer, of course takes place at the same speed of light—186,000 miles per second—and, similar to light, does not require a return circuit in order to actuate a sensitive radio receiver.

Inasmuch as radio waves, light waves (as well as the ultra-violet or X-ray) belong to the same family, it is of course apparent that radio waves may be reflected and refracted by properly arranged units in the manner that light waves may be controlled by mirrors, prisms and lenses. In this connection it will be recalled that C. S. Franklin, in England, and Marconi, while in America two years ago, demonstrated control of radio waves in this manner, but Dr. Satterlee has devised a method for controlling and directing the waves within a radio receiving set.



In this method, the designer has employed two primary inductance coils of his own design, which are so mounted as to be movable in a way [illegible] to two [illegible] coils on a honeycomb mounting. [illegible] construction of the Satterlee coils and mounting [illegible] is far superior to anything known [illegible] the coils [illegible] are made in the form of flat spirals on [illegible] rubber frames, somewhat after [illegible] for aircraft work. The [illegible] structed, which ac[illegible] the [illegible] variable condenser [illegible] upon a shaft so that its position with relation to the two primary coils—one located on either side—may be varied. In this manner, therefore, much on the order of movable mirrors, the high-frequency "message-bearing" radio waves may be focused [illegible] inductance within the set, resulting in increased distance, very sharp and selective tuning.

The Moon model C-2-A is a non-regenerative and therefore non-reradiating receiver. It embodies the tuning circuits, one step of radio-frequency amplification, a detector and two steps of audio-frequency. It is the last word in radio receiver construction. Bakelite knobs, dials and panel are used, thus insuring minimum dielectric loss. There is not a soldered joint in the whole circuit, but, on the contrary, every joint is made absolutely tight by lock washers and burrs. The condensers were chosen only after the most exhaustive and painstaking laboratory tests, thus insuring uniform capacity, and proper modulation over all voice frequencies and tonal quality without distortion are made possible by specially constructed transformers. Each and every unit comprising this set is housed in a kiln dried solid mahogany cabinet with "B" battery compartment, over-all dimensions being 14x18½x8¾ inches.

Thus with the introduction of these "Moon" [illegible] coils and the employment of one wire which is used as a counterpoise and connected to the ground post of the circuit, it is no longer necessary to string an [illegible] to get volume and distance. The Moon model [illegible] A Receiver brings "everywhere" right to your home, [illegible] mobile, camp or [illegible] alizes [illegible] the factors of distance [illegible] onious niche in the most [illegible] Moon [illegible] modernity to the evolution [illegible]

[illegible] twenty-four wire employed as a [illegible] thrown over the roof-beams of a coal mine [illegible] hundred feet below the surface of the earth, loud and clear reception was had with one of these sets. Indeed, signals came in as clearly as if the set were being operated in a choice location above ground, proving conclusively that the earth will transmit high-frequency electrical waves with the maximum of efficiency.

—EBY—

QUALITY BINDING POSTS

Ensign Engraved Posts

The Tops Can't Come Off

Manufacturers, jobbers, and dealers everywhere insist upon EBY BINDING POSTS. Every radio enthusiast knows them.

Sergeant

The *Sergeant* is an EBY METAL POST, possessing an [illegible] construction that finds instant favor. The square slot, large enough to accommodate several terminal wires, is milled the entire width of the main body and forms the lower contact surface. The sliding shoe forms the other contact surface, assuring a positive grip even on a fine wire. The knurled cap is spun on and cannot be lost. The base is heavily knurled to prevent the post from turning when mounted. Furnished in eight sizes, many styles.

The beautiful finish of EBY INSULATED POSTS and the fact that the tops don't come off have won for them world-wide recognition. The popular *Ensign Post* is furnished plain or in all desired markings—ANT, GND, PHONE, etc. This eliminates danger of making wrong connections and saves expense of engraving panel. Made in two sizes, fifteen styles.

Valuable binding post data mailed on request.

Ensign

THE H. H. EBY MFG. COMPANY

Philadelphia, Pa.

MAGNAVOX Radio Products

THE name "Magnavox" is identified with the oldest and largest line of Radio reproducing and amplifying equipment. Every requirement in the art of radio reproduction can be most successfully met by Magnavox instruments, as listed below.

Reproducers

R3 Electro-dynamic—new model with Volume Control **$35.00**

R2 Electro-dynamic—with Volume Control; new model at reduced price **$50.00**

M1 Semi-dynamic—requires no battery for its operation **$35.00**

Combination Sets

A1-R—the only instrument combining a Reproducer and Power Amplifier in one unit...... **$59.00**

A2-R—same, with 2-stage Amplifier............ **$85.00**

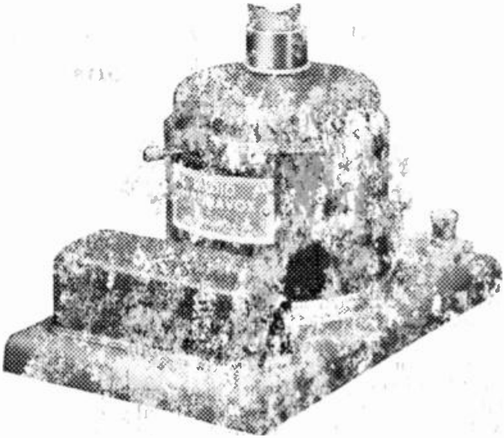
Power Amplifiers

A1 the most efficient instrument ever designed for audio-frequency amplification. One-stage, metal case **$27.50**

AC-2-C—two-stage, hardwood case.............. **$50.00**

AC-3-C—three-stage, hardwood case............. **$60.00**

The results obtained by the use of Magnavox Products cannot be equalled through apparatus of any other type.



The Base of the new model Magnavox Reproducer R3, showing Tone Control.

THE Magnavox electro-dynamic principle obviates the need of any mechanical adjustment to regulate the air-gap or change the position of moving parts. This famous principle of operation permits the use of an electrical volume control.

This control directly affects the [illegible] of the electrical circuit which creates the sound [illegible]ing the sensitivity of the instrument and also [illegible] of reproduction.

Moreover, this electrical control produces a great saving of current (already reduced in the new R3 and R2 to a maximum of .6 ampere), for, by its action, the current line can be reduced to a minimum of .1 ampere. The new Magnavox electro-dynamic Radio Reproducers R3 and R2, in fact, are equipped with the first true sound-controlling device ever designed. See them at your dealer's and write us for catalog.

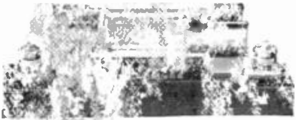
THE MAGNAVOX COMPANY

Oakland, Calif.

New York Office: 370 Seventh Ave.

Perkins Electric Limited
Toronto, Montreal, Winnipeg,
Canadian Distributors

Vacuum Tube Lightning Arrester For Receiving Stations



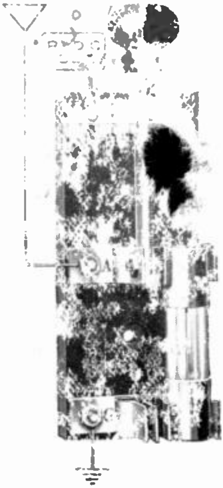
Catalog No. 6 Price $2.00

A simple Lightning Arrester of the Vacuum Tube type, employing our Standard No. Vacuum Tube.

The ... heavy and rugged, along ... our long experience with similar devices has ...

... must be distinguished from the air gap arrester, where it is difficult to maintain ... of approximately .004", due to dirt deposited at each discharge.

The ... edition of the National Electric Code requires ... Lightning Arrester on the outdoor antenna of every Receiving Station.



Catalog No. 602
Price $3.50

This Arrester is approved and ... by the Underwriters' Laboratories.

... mounting is recommended. This is approved by the Code, and is in accordance with long standing telephone practice ... the Lightning Arrester is mounted inside.

One tube is furnished with each arrester.

Length, $5\frac{1}{8}$"; width, $1\frac{1}{8}$"; depth, $1\frac{1}{2}$".

Individual Box:
1 Arrester.............. 1 Lb.
Carton Quantity:
10 Arresters........... 7 Lbs.
Standard Package:
50 Arresters ....30 Lbs.

Lightning Arrester Switch
(Patents Pending)
For Receiving Stations

A combination, on ... base, of a Radio Ground Switch and a Vacuum Tube Lightning Arrester, retaining the merits of both and eliminating the faults of each.

THE ... ELECTRIC MFG. CO.

This Arrester is a distinctive device for those who know and demand the best in Lightning Protection.

The Vacuum Tube Arrester is permanently in the circuit from antenna to ground, ready to "spill" any overcharge.

With the switch blade, the antenna may be disconnected from the radio set and thrown directly to ground.

It meets not only the requirements but also the additional recommendations of the latest edition of the National Electric Code.

It is approved by the Underwriters' Laboratories.

It may be installed either inside or outside, but for convenience in operation we recommend inside mounting.

One tube is furnished with each switch.

Length, 8"; width, 2½"; depth, 2½".

Individual Box	1 Switch	2 Lbs.
Carton Quantity	10 Switches	17 Lbs.
Standard Package	Switches	60 Lbs.

FOUR-PHONE PLUG
SERIES CONNECTED

Catalog No. 616

This Improved Four-Phone Plug with insulated case connects one to four Head Sets, and all in series, to any Radio Set employing standard telephone jacks.

It is small, simple, of sturdy build and adds to the appearance of any set.

The phone tips enter from the front and therefore do not increase the diameter, which with all the tips adjusted is but 1¼ inches.

Phone tips show considerable variations, but large and small make excellent contact with our improved spring grip.

Individual Box	1 Plug	3 Ozs.
Carton Quantity	10 Plugs	2 Lbs.
Standard Package	100 Plugs	15 Lbs.